1 • XXXIII • 2022, p-ISSN 1024-0845, e-ISSN 2228-4893

Kaastööde esitamiseks ja lugemiseks külastage: https://agrt.emu.ee
For online submission and open access visit: https://agrt.emu.ee/en

AGRAARTEADUS

JOURNAL OF AGRICULTURAL SCIENCE

Akadeemilise Põllumajanduse Seltsi väljaanne
Estonian Academic Agricultural Society publication
Tartu 2022

Agraarteadus
Journal of Agricultural Science

Vol. **33** No. **1**
June 2022

Abstracted / indexed: AGRICOLA, AGRIS, CABI, CABI Full Text, DOAJ, EBSCO, SCOPUS, etc

p-ISSN: 1024-0845, **e-ISSN:** 2228-4893

Väljaandmist toetavad Eesti Maaülikool ja Eesti Taimekasvatuse Instituut
Supported by Estonian University of Life Sciences and Estonian Crop Research Institute

Trükk / Print: Eesti Ülikoolide Kirjastus OÜ. Kaanepilt / Cover image by LesenFox / Freepik

AGRAARTEADUS
JOURNAL OF AGRICULTURAL SCIENCE

1 ◆ XXXIII ◆ 2022

Väljaandja:	Akadeemiline Põllumajanduse Selts
Peatoimetaja:	pm-dr Alo Tänavots
Aadress:	Fr. R. Kreutzwaldi 1, 51006 Tartu
e-post:	jas@emu.ee
www:	https://aps.emu.ee, https://agrt.emu.ee

Agraarteaduses avaldatud teaduspublikatsioonid on retsenseeritud

SISUKORD

TEADUSARTIKLID

AGRAARTEADUS
JOURNAL OF AGRICULTURAL SCIENCE

1 ◆ XXXIII ◆ 2022

Published by:	Estonian Academic Agricultural Society
Editor in Chief:	Alo Tänavots DSc (agriculture)
Address:	Fr. R. Kreutzwaldi 1, 51006 Tartu, Estonia
e-mail:	jas@emu.ee
www:	https://aps.emu.ee, https://agrt.emu.ee

Research articles published in Agraarteadus are peer-reviewed

CONTENTS

RESEARCH ARTICLES

Agraarteadus
1 • XXXIII • 2022 1–10

Journal of Agricultural Science
1 • XXXIII • 2022 1–10

CARCASS CHARACTERISTICS AND MEAT QUALITY OF BROILER CHICKENS FED DIETARY WHITE AND CAYENNE PEPPER POWDERS AS ADDITIVES

Adeola Adegoke, Kehinde Sanwo, Lawrence Egbeyale, Munirat Abatan, Modupe Oluwasinmi, Oluwaseun Adebesin, Oluwaseun Williams

Department of Animal Production and Health, Federal University of Agriculture, P.M.B. 2240 Abeokuta, Nigeria

Saabunud: Received: 01.03.2022

Aktsepteeritud: Accepted: 10.06.2022

Avaldatud veebis: Published online: 10.06.2022

Vastutav autor: Corresponding author: Adeola Adegoke

E-mail: adegokeav@funaab.edu.ng

ORCID:
0000-0002-5973-3175 (AA)
0000-0002-2760-2453 (KS)
0000-0002-6908-4754 (LE)
0000-0001-8338-6237 (MA)
0000-0001-9029-3879 (MO)
0000-0003-3701-3262 (OA)
0000-0002-2293-7377 (OW)

Keywords: white pepper powder, cayenne pepper powder, carcass characteristics, lipid profile, enzymatic antioxidants, oxidative spoilage.

DOI: 10.15159/jas.22.18

ABSTRACT. A study was conducted to investigate the influence of dietary white pepper (wp) and cayenne pepper (cp) powders fed as additives on carcass characteristics and meat quality of broiler chickens. Fifty-six broiler chickens (two per replicate) were slaughtered (each close to average weight per replicate) from a total of 336 randomly allotted chickens given seven diets each apportioned to four replicates. Data obtained were subjected to a One-way Analysis of Variance with significant means separated at P <0.05. Results obtained reveal larger dressed and breast weights, as well as meat + skin:bone ratio was recorded among chickens fed addition of 200 g of cayenne pepper to the Control diet (C) (C+200cp). Notably, only chickens fed C+200wp and C+125wp+125cp diets had meat containing palmitoleic fatty acid; though the latter (1.28) had higher (P <0.05) linoleic than C+100wp+100cp (0.67). On the contrary, feeding C+125wp+125cp diet resulted in numerically least meat Index of Atherogenicity (IA) (0.49). Meat lipid cholesterol profile was preferred (P <0.05) in the meat of chickens fed C+200wp diet, though identical (P <0.05) to C+250wp diet. Feeding C+125wp+125cp diet resulted in a low (P <0.05) meat superoxide dismutase value (89.23). This study has shown that to gain a larger yield, C+200cp diet should be fed to chickens. Palmitoleic acid – a rare fatty acid occasionally consumed in Western diets was found only in the meat of chickens fed C+200wp and C+125wp+125cp diets, but for an overall balanced fatty acid profile - hazily depicted by Index of Atherogenicity, C+125wp+125cp diet is suggested as it indicates the impact of stress was minimized. Meat endogenous antioxidant profile reveals stress imposed on chickens in C+125wp+125cp group was lowered by antioxidant fed – a significance to poultry farmers.

Introduction

Encouraged by the rapid conversion of feed to meat coupled with short rearing cycles, rearing meat-type chickens is the trend in commercial poultry with special emphasis on carcass yield and quality meat. Marangoni *et al.* (2015) class poultry meat to be comparable to other meats in cholesterol content but offer superior nutrients when the protein, total fat and calorie content are compared with meat from other sources. Nutritional compositions have been adjusted with a significant impact on yield and quality of the product as findings abound on the application of additives such as probiotics, vitamins and mineral mixture mix on carcass characteristics of broiler chicken in tandem with production economics (Singh *et al*., 2018).

Meat quality is a critical field of study, especially considering meat is a common component of the diet of man. Limited advancement in technology can have negative effect on the quality of meat and meat products supplied to consumers. Animal products are traditionally preserved in a variety of ways but nutrients obtained post-slaughter and subsequent storage employed may result in depleted nutrients that are inadequate to sustain healthy living – especially in countries with developing economies. A positive, however is that meat can be enriched and the desired goal is to increase the profile of essential but limited nutrients as well as minimize product spoilage. Lopez-Ferrer *et al.* (1999) posited that enrichment of poultry meat with health-promoting substances should be explored as modification of muscle tissue composition can be achieved via increased dietary polyunsaturated fatty acid profile (PUFA) content (Lopez-Ferrer *et al*., 2001) in tandem with its nutritional profile and characteristics (Galli *et al*., 2019).

Additives have been incorporated into poultry diets to elicit special effects desired by producers and consumers. Mondal *et al.* (2015) referred to feed additives as all products excluding commonly known feedstuffs that are incorporated into rations to obtain desired outcomes. Pepper powders have been added as addit–ives in broiler rations with contrasting outcomes on performance (Galib *et al*., 2011; El Tazi *et al*., 2014), though a dearth of information exists on carcass yield and quality of meat produced afterwards. One of such few was conducted by Adegoke *et al*. (2016), who reported that cayenne pepper significantly affected carcass weight at lower levels of incorporation. Cayen–ne pepper (*Capsicum frutescens*) is a phytogenic sub–stance that can stimulate endogenous enzymes that promote growth. Capsaicin, the principal antioxidant principle in cayenne and red peppers suppresses fat accumulation, oxidation and triglyceride levels as well as regulates the inflammatory process (Kang *et al*., 2011). On the other hand, Olalere *et al*. (2018) declared that *Piper nigrum* (white pepper) contains beneficial functional compounds as shown by the optimized oleoresin yield of 8.72 w/w %, while its analyzed compositional output of 31 bioactive compounds attests to its radical scavenging activity. A study on piperine showed that it possesses potential fat reducing and lipid-lowering effects, without any change in food appetite at a small dose (Shah *et al.*, 2011), but at a high dosage, fat content in animal products may be affected. On this premise, this study was designed to assess the impact of dietary white and cayenne pepper powders fed as additives on carcass characteristics and meat quality (lipid, antioxidant and storage potential) of broiler chickens.

Materials and Methods

Experimental site

Slaughtering of chickens and subsequent extraction of breast muscles from the carcass was carried out at the Animal Product and Processing Laboratory of the Department of Animal Production and Health. Meat quality assessment was performed at the College of Veterinary Medicine within the same Institution.

Feed offered before the experiment

Dietary layout chickens were subjected to prior to experiment comprised:

- Control diet (C) (No pepper added)
- T2 – Control diet + 200 g White Pepper (wp) (C+200wp)
- T3 – Control diet + 250 g White Pepper (C+250wp)
- T4 – Control diet + 200 g Cayenne Pepper (cp) (C+200cp)
- T5 - Control diet + 250 g Cayenne Pepper (C+250cp)
- T6 – Control diet + 100 g White Pepper +100 g Cayenne Pepper (C+100wp+100cp)
- T7– Control diet + 125 g White Pepper + 125 g Cayenne Pepper (C+125wp+125cp)

Proximate analysis of the seven diets fed before the experiment was determined according to AOAC (2005) and the values obtained are documented in Table 1.

Table 1. Composition of diets fed chickens prior to experiment

Ingredients, kg	Control	C+200wp	C+250wp	C+200cp	C+250cp	C+100wp +100cp	C+125wp+125cp
Maize	54.00	54.00	54.00	54.00	54.00	54.00	54.00
Wheat offal	10.50	10.30	10.25	10.30	10.25	10.30	10.25
Soybean meal	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Groundnut cake	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Bonemeal	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Limestone	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Mineral and vitamin premix*	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Methionine	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Lysine	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Cayenne pepper	0.00	0.00	0.00	0.20	0.25	0.10	0.13
White pepper	0.00	0.20	0.25	0.00	0.00	0.10	0.13
Total	100.00	100.20	100.25	100.20	100.25	100.20	100.25
Determined analysis, **%**							
Crude protein	20.53	20.54	20.54	20.52	20.53	20.53	20.53
Metabolizable energy, Kcal	2 851.33	2 851.33	2 851.36	2 851.40	2 851.46	2 852.39	2 851.42
Ether extract	3.94	3.95	3.96	3.95	3.95	3.95	3.95
Crude fibre	3.68	3.74	3.76	3.73	3.74	3.73	3.74
Calcium	1.26	1.26	1.26	1.27	1.27	1.26	1.26
Phosphorus	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Lysine	1.55	1.55	1.55	1.55	1.55	1.55	1.55
Methionine	0.47	0.47	0.47	0.47	0.47	0.47	0.47

*Premix composition per kg diet – Vit A – 400 000.00 IU; Vit D3 – 800 000.00 IU; Vit E – 20 000 IU; Vit k – 800.00 mg; Vit B1 – 1 000.00 mg; Vit B6 – 500.00 mg; Vit B12 – 25.00 mg; Niacin – 6 000.00 mg; Pantothenic acid – 7 500.00 mg; Folic acid – 200.00 mg; Biotin – 8 mg; Mn – 300 000.00 g; Zn – 20 000.00 g; Cobalt – 80.00 mg; I – 40.00 mg; Choline – 80 000.00 g; Antioxidants – 125.00 mg

Management of chickens before the experiment

A total of fifty-six chickens were selected from three hundred and thirty-six (2-weeks old) collectively floor brooded Cobb-500 broiler chicks randomly distributed into groups (each comprising forty-eight chickens per treatment and twelve chickens per replicate) fed seven diets (laid out above) for 32 days. Chickens were raised under an intensive system and reared on deep litter using wood shavings up to a depth of 3 inches as bedding material. Post-brooding, chickens were distributed into replicates setup using 1 sq ft per spacing. Feed and water were provided *ad libitum*.

Experimental procedure

Upon expiration of feeding, a total of fifty-six (two per replicate) chickens, each with a weight close to the average of a replicate were selected for carcass evaluation. Chickens selected weighed between 2 003.75 and 2 087.75 grams. Afterwards, breast muscles were extracted from twenty-eight carcasses for meat quality assessment.

Data collection

Carcass analysis

Each selected bird was weighed, tagged, separated and fed-fasted overnight. After 12 hours, chickens were slaughtered with carcasses cleaned and drained post-slaughter. The plucked, eviscerated and dressed weights were taken using a Hana kitchen scale (Model J1109130189, China, Calibration – 20 kg x 50 g) and then the head, shank and viscera were removed before the documentation of the dressed weight. Thereafter, the weight of cut-up parts and organs was recorded with an Electronic Compact Scale (Model – SF- 400C, Venezia, Calibration – 500 g x 0.01 g), then expressed as a percentage of the live weight. Internal organs (heart, liver, kidney and gizzard) were harvested, weighed and expressed as a percentage of the live weight, while the whole intestinal weight was likewise recorded.

Meat and bone from the right drumstick of each carcass were separately weighed to obtain a meat + skin to bone ratio. Fat around the cloaca, bursa of *Fabricius*, proventriculus, and muscles adjacent to the abdomen were harvested as abdominal fat deposits were weighed and recorded.

Meat lipid profile assessment

Fifteen grams of meat from the breast muscles of each replicate was apportioned for lipid profile analysis. Apportioned meat was ground and formed into a compound paste by the addition of a known amount of chloroform and methanol mixture 1:1 (v/v). Thereafter, extract from meat was formed into a final volume by chloroform addition, followed by decantation, before meat cholesterol, triacylglycerol and high and low-density lipoprotein determination (Folch *et al*., 1957). Fatty acid methyl esters were obtained via acid catalysis as described by Hartman and Lago (1973). Thirty grams of meat from the breast muscle of each sample was injected (1 μL) in split mode (20:1) into a Varian 3400CX gas chromatography (USA), equipped with a flame ionization detector (GC-FID) and the GC column was an HP-88 (Agilent Technologies, USA) (100 m x 0.25 mm x 0.20 µm). The column temperature was held at 50 °C for 1 min. Afterwards, the temperature was increased to 185 ºC, at the rate of 15º C min^{-1}, followed by an increase at 0.5 ºC min^{-1} to 190 ºC, and increased at 15 ºC min^{-1}, to 230 ºC, hand-held for 5 min. The injector and detector temperature was set at 250 ºC. The absorbance of concentration of different standard solutions of each specific fatty acid and sample benzene extracts were taken on a spectrophotometer at a wavelength defined for each fatty acid. Fatty acid was identified via normalization of each peak area to the total peak area based on AOCS (1998) Ce1f-96. To obtain the Index of Atherogenicity of chicken meat, the connection between the sum of the proatherogenic and antiatherogenic fatty acids was calculated using a formula designed by Ulbricht and Southgate (1991):

$$IA = \frac{(4 \times C14:0 + C16:0)}{\sum MUFA + \sum(n-6) + \sum(n-3)} \qquad (1)$$

Twenty grams of meat from the thigh muscles were cut out for oxidative analysis. Samples were placed in test tubes in homogenized Tris-HCL (Sigma Chemical Co. USA) for superoxide dismutase (SOD) and glutathione peroxidase activity. These were measured spectrophotometrically at 480 nm for SOD, and 340 nm for GPx respectively (Galli *et al*., 2019) respectively. Values were expressed as U mg^{-1} protein. To determine the malondialdehyde count in chicken meat, ten grams of meat from the breast muscles of each replicate was homogenized in 30 ml of distilled water to obtain meat malondialdehyde (MDA) count. Lipid oxidation was measured and recorded as a 2-thiobarbituric acid-reactive substance (TBARS) value according to the method described by Ahn *et al.* (1998). Lipid oxidization was reported as milligrams of MDA per gram of meat.

Statistical analysis

Data obtained were subjected to One-Way Analysis of Variance using Statistical Package for Social Sciences (SPSS) version 21 (SPSS, 2012). Significantly different means at P <0.05 were compared and separated using the Duncan Multiple Range Test (DMRT) of the same statistical package.

Results

Carcass yield of broiler chickens fed dietary peppers as additives were documented (Table 2). Carcass yield was not significant (P >0.05) except for dressed percentage. Highest (P <0.05) dress percentage was recorded for groups fed C+200cp diet though a similar value was obtained when C+250wp (72.69%) C+250cp and C+ 100cp+100wp diets were fed. The head, neck, back and breast were influenced (P <0.05) by the integration of peppers as additives in poultry feed. Head (2.69%) and neck parts for chickens fed no additive were highest (P <0.05), though statistically identical to the neck weight of the group offered C+200cp diet. Back weight ranged between 14.54 – 16.98%. Breast portions of groups that offered C+200cp and C+250cp diets were higher (P <0.05) than in the Control. Meat + skin:bone ratio was greater among groups given C+200cp diet than C+250cp, but similar (P <0.05) in weights to the other groups. Internal organs (heart, kidney, gizzard, spleen and liver), abdominal fat and intestine + ceca weights were not influenced (P >0.05) by dietary pepper powders offered.

Table 2. Carcass yield of broiler chickens fed dietary peppers (*Capsicum frutescens and Piper nigrum*) as additives

Parameters	Control	C+200wp	C+250wp	C+200cp	C+250cp	C+100wp+100cp	C+125wp+125cp	SEM
Initial weight, g	318.63	323.42	323.56	323.69	323.29	322.40	318.10	1.01
Feed intake, g	3 858.04	3 861.88	3 692.42	3 729.46	3 818.85	3 767.66	3 630.13	17.81
Live weight (LW), g	2 041.50	2 003.75	2 022.50	2 026.25	2 087.75	2 024.00	2 066.25	11.08
Carcass yield								
Eviscerated weight, g	1 671.25	1 660.25	1 695.50	1 719.75	1 730.75	1 691.00	1 675.50	10.91
Dressed weight, g	1 437.50	1 445.75	1 470.00	1 530.50	1 517.50	1 490.25	1 470.00	11.83
Dressed, % LW	70.43[c]	72.13[bc]	72.69[abc]	75.52[a]	72.66[abc]	73.62[ab]	71.15[bc]	0.43
Cut-up parts, % LW								
Head	2.69[a]	2.36[ab]	2.30[ab]	2.06[b]	2.47[ab]	2.41[ab]	2.28[ab]	0.06
Shank	3.95	3.77	4.03	3.49	3.71	3.67	3.88	0.06
Neck	4.62[a]	4.15[abc]	4.27[ab]	4.68[a]	3.34[c]	3.64[bc]	4.38[ab]	0.13
Wings	8.13	8.18	8.12	8.11	7.50	7.77	7.31	0.16
Back	14.57[b]	14.89[ab]	16.52[ab]	14.54[b]	14.87[ab]	16.98[a]	16.06[ab]	0.30
Breast	23.53[b]	25.16[ab]	24.09[ab]	26.81[a]	26.70[a]	25.71[ab]	24.45[ab]	0.38
Thigh	10.90	11.71	11.71	11.91	11.20	11.03	10.75	0.19
Drumstick	11.65	11.50	11.69	11.39	11.08	11.36	10.94	0.15
Meat + skin:bone ratio	4.96[ab]	4.56[ab]	5.08[ab]	5.71[a]	4.21[b]	5.10[ab]	5.47[ab]	0.17
Internal organs, % LW								
Heart	0.42	0.35	0.47	0.41	0.48	0.41	0.41	0.03
Kidney	0.27	0.36	0.41	0.35	0.36	0.35	0.41	0.02
Gizzard	1.72	1.65	1.69	1.53	1.47	1.66	1.63	0.04
Spleen	0.05	0.04	0.04	0.04	0.03	0.03	0.04	0.00
Liver	1.38	1.46	1.46	1.38	1.40	1.46	1.45	0.04
Intestine + caeca	3.12	2.65	2.92	2.99	2.71	2.89	3.15	0.07
Abdominal fat	0.81	0.69	1.10	0.70	0.67	0.77	0.85	0.07

[a, b] – Means on the same row with different superscripts differ significantly (P <0.05).
cp – cayenne pepper powder; wp – white pepper powder

Saturated and unsaturated fatty acid (SFA and UFA), Index of Atherogenicity (IA) and n-3:n-6 ratio in the meat of chickens fed dietary additives are represented in Table 3. Monounsaturated fatty acids (MUFA) found in meat are palmitoleic and oleic fatty acids with the former significant (P <0.05). Lauric acid was higher (P <0.05) among groups fed the Control and C+200wp diets but lower (P <0.05) in meat of chickens fed C+100wp+100cp and C+125wp+125cp diets, while groups between the extremes exhibited similar (P >0.05) value. Myristic fatty acid count in the meat of chickens fed C+200wp diet was increased than in the Control, C+200cp, C+250cp and C+125wp+125cp groups, though similar as meat from groups given C+100wp+100cp diet. Groups given the Control, C+200cp and C+250wp diets had higher (P <0.05) palmitic fatty acid values than chickens fed C+125wp+125cp diets. The margaric fatty acid content in meat of chickens fed C+200wp diet was higher (P <0.05) than C+125wp+125cp diet, though the amount in the latter (C+ 125wp+125cp) was similar (P <0.05) as groups that had no margaric fatty acid. Meat MUFA values ranged from 0.000 to 0.310% for palmitoleic fatty acid. C+200wp diet-fed resulted in elevated (P <0.05) meat palmitoleic fatty acid count for C+200wp group than C+125wp+125cp group, though absent when other diets were fed. No effect (P >0.05) of dietary peppers was observed for PUFA except for linoleic fatty acid. Chickens given C+200wp diet had increased (P <0.05) meat linoleic acid than chickens offered C+100wp+100cp diet. Meat n-3:n-6 was significant (P <0.05) with values ranging between 1.560–3.372, with least (P <0.05) value recorded among C+125wp+125cp and C+200wp groups, compared to C+100wp+100cp group that higher value..

The meat lipid profile of chickens fed additives is shown in Table 4. Meat cholesterol and triglyceride were not influenced (P >0.05) by dietary additives. At 200 g wp addition with the Contol diet, meat HDL was highest (P <0.05). Meat from chickens on 0% pepper additive, C+250cp and C+125wp+125cp groups had lowest (P <0.05) HDL values though identical as C+100wp+100cp diet. The least LDL value was recorded in groups fed the Control diet, though statistically similar to chickens on C+250cp diet. Highest (P <0.05) meat LDL was recorded for groups on C+200cp diet. Enzymatic antioxidant profile in the meat of chickens given dietary *Capsicum frutescens* and *Piper nigrum* powders as additives is documented in Table 5. Meat superoxide dismutase for the Control and C+125wp+125cp groups were significantly (P <0.05) highest and lowest respectively, while other groups had similar (P >0.05) values. Glutathione peroxidase content in meat was not significantly (P >0.05) influenced by dietary additives fed.

Meat malondialdehyde (MDA) count from chickens offered dietary pepper (white and cayenne) powders was significantly influenced by the diet as presented in Table 4. Meat MDA count was least in meat from chickens fed C+250wp diet, followed by the Control group. All other groups had statistically higher (P <0.05) MDA count.

Table 3. Fatty acid profile of meat from broiler chickens offered dietary pepper powders as additives

Parameters (%)	Control (C)	C+200wp	C+250wp	C+200cp	C+250cp	C+100wp+100cp	C+125wp+125cp	SEM
Lauric (12:0)	1.230[a]	1.140[a]	0.920[ab]	1.080[ab]	1.080[ab]	0.770[b]	1.020[b]	0.045
Myristic (14:0)	0.180[c]	0.390[a]	0.210[bc]	0.130[c]	0.130[c]	0.330[ab]	0.160[c]	0.025
Palmitic (16:0)	8.790[a]	6.890[ab]	7.850[ab]	8.810[a]	8.760[a]	7.150[ab]	5.110[b]	0.405
Margaric (17:0)	0.040[bc]	0.250[a]	0.000[c]	0.000[c]	0.000[c]	0.000[c]	0.060[b]	0.198
Stearic (18:0)	21.050	23.040	19.780	24.330	21.890	21.670	18.770	1.158
SFA	31.290	31.710	28.760	34.350	31.860	29.920	25.120	1.233
Palmitoleic (16:1; ω-7)	0.000[c]	0.310[a]	0.000[c]	0.000[c]	0.000[c]	0.000[c]	0.140[b]	0.026
Oleic (18:1 ω-9)	11.030	8.260	9.890	11.040	12.050	8.260	8.050	0.550
MUFA	11.030	8.570	9.890	11.040	12.050	8.260	8.190	0.540
Linoleic (18:2; ω-6)	1.080[ab]	1.280[a]	1.030[ab]	1.080[ab]	0.910[ab]	0.670[b]	1.18[ab]	0.065
Linolenic (18:3; ω-3)	2.950	2.330	2.970	2.790	2.980	2.810	2.090	0.147
Arachidonic (20:4; ω-6)	0.310	0.230	0.280	0.253	0.290	0.180	0.180	0.165
PUFA	4.340	3.840	4.280	4.123	4.180	3.66	3.450	0.155
IA	0.621	0.681	0.613	0.615	0.572	0.710	0.494	0.052
n-3:n-6	2.222[ab]	1.570[b]	2.324[ab]	2.272[ab]	2.482[ab]	3.372[a]	1.560[b]	0.183

[a, b, c] – Means on the same row with different superscripts differ significantly (P <0.05)
cp – Cayenne pepper powder; wp – white pepper powder; SFA – saturated fatty acid; MUFA – mono-unsaturated fatty acid; PUFA – poly-unsaturated fatty acid; IA – Index of Atherogenicity

Table 4. Effect of dietary white and cayenne pepper powders on lipid profile of broiler chicken meat

Parameters	Control (C)	C+200wp	C+250wp	C+200cp	C+250cp	C+100wp+100cp	C+125wp+125cp	SEM
Cholesterol, mg dL^{-1}	47.30	43.70	41.50	40.20	37.10	32.60	40.20	2.59
Triglyceride, mg dL^{-1}	170.90	165.50	163.10	189.30	152.30	143.40	112.90	9.12
HDL, mg dL^{-1}	10.10[c]	18.30[a]	16.10[ab]	15.70[ab]	10.40[c]	13.10[bc]	11.30[c]	0.77
LDL, mg dL^{-1}	3.02[d]	7.70[b]	7.20[b]	13.40[a]	3.80[cd]	9.20[b]	6.30[bc]	0.79
Antioxidant status								
SOD, U mg^{-1}	124.62[a]	112.31[ab]	112.31[ab]	113.85[b]	101.54[ab]	102.95[ab]	89.23[b]	3.54
GP_x, U mg^{-1}	0.75	0.69	0.70	0.58	0.62	0.60	0.56	0.02
TBARs MDA g^{-1} tissue	0.15[b]	0.20[a]	0.10[c]	0.15[b]	0.20[a]	0.21[a]	0.20[a]	0.12

[a, b, c, d] – Means on the same row with different superscripts differ significantly (P <0.05)
cp – cayenne pepper powder; wp – white pepper powder; HDL – high-density lipoprotein; LDL – low-density lipoprotein; SOD – superoxide dismutase; GP_x – glutathione peroxidase; TBARs – 2-thiobarbituric acid reactive substances; MDA – malondialdehyde

Discussion

The positive influence of pepper powders on carcass yield was observed in this study. Chickens fed a single dosage of dietary cayenne pepper had improved breast muscles per weight basis. Pepper according to Puvaca *et al.* (2015) plays an important role in regulating cholesterol and fat deposition by influencing triglycerides distribution to tissues. Carcass weight is consequently improved together with vascular system health via facilitation as tissue aggregation is enhanced with limited space for deposition of fat within the adipose layer for a fat deposition that translates into a higher dressed percentage. Ogbuewu *et al.* (2018) referred to concentrations of active ingredients and their interactions with other active components in feed as potent. Additives exert influence on energy and fat levels, affecting increased intestinal movements, turnover and yield. Notable high breast meat and meat + skin: bone ratio yield conforms to the group that had a greater dressing percentage. Though Puvaca *et al.* (2019) reported a significant impact of dietary additives on carcass yield of chickens fed 1.0 g 100 g^{-1} of additives in feed containing garlic, black pepper and hot red pepper, this study reveals an increased dressed percentage at 0.2 g kg^{-1} inclusion of cayenne pepper powder, corroborating outcome reported (Adegoke *et al.*, 2016). Better Meat + skin: bone ratio signifies efficient muscle deposition as a result of increased absorption and utilization of feed consumed optimally among chickens fed C+200cp diet. A consequence, however, is that high meat + skin: bone among groups given C+200wp diet reveal a possibility of lameness if rearing and feeding progresses beyond 32 days, along with a suppressed ability to withstand heat stress. On the contrary, low meat + skin: bone ratio when C+250cp diet was fed indicate higher bone strength, supported by the increased calcium and phosphorus proportion in cayenne pepper.

Dietary lipid sources have a direct and generally predictable effect on the fatty acid composition of livestock products as the total fatty acid in meat of chickens offered the Control diet correspond with the total combination of saturated fatty acid (SFA) and unsaturated fatty acid (UFA). Cayenne Pepper increases the production of certain receptors (lipase and connexin-4) that modify fat and fatty acid composition in tissues (Wood *et al.*, 2008). The report of the feeding trial by Milićević *et al.* (2014) indicates that the presence of saturated fatty acids in poultry meat is greatly dependent on their presence in the diet and/or synthesis in the liver. Galli *et al.* (2019) declared a reduction in saturated fatty acids in the meat of chickens fed the combination of herbal phytogenic and curcumin, while Toomer *et al.* (2020) elaborated on ways high-oleic peanut diet-fed chickens altered meat fatty acid composition which agrees in part with the outcome of SFA in this study. Lipid digestion occurs in the small intestine, as the pancreatic lipase breaks triacylglycerols down to mainly 2-monoacylglycerols and free fatty acids. Subsequent formation of micelles enhances absorption via lipid uptake mediated by the lipoprotein lipase enzyme that is dispersed throughout the body with a notable deduction that additives included modified liver synthesis that altered SFA produced and subsequent deposition in tissue. The least SFA produced in the meat of groups supplied C+125wp+125cp diet was documented, however, SFA production by the body renders dietary SFA unessential to the body. High SFA yield is associated with increased serum cholesterol production. A report by Zong *et al.* (2016) associates increased dietary intakes of SFA with an increased risk of coronary heart disease. The presence of palmitoleic fatty acid in the meat of groups fed C+200wp and C+125wp+125cp diets but not C+250wp and C+100wp+100cp suggest a range that stimulates its production. Palmitoleic acid (16:1n-7) is a product of stearoyl-CoA desaturase (SCD-1), an enzyme produced in the liver that changes palmitic acid into palmitoleic acid. Possibly, addition at 125 g served as a minimum for the conversion of palmitic acid that was optimal at 200 g per 100 kg of the Control diet, but not C+250wp diet. Palmitoleic acid is a rare fatty acid consumed in Western diets as its primary dietary sources are occasionally consumed in food, such as macadamia and codfish liver oil. (Hodson, Karpe 2013; Norde *et al.*, 2019). High monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) documented for chickens offered C+200wp diet implies intake of white pepper in minimal quantity resulted in significantly higher palmitoleic and linoleic fatty acid deposition in muscle tissue. Linoleic acid is obtained principally from the diet and in this study, it can be inferred that the oxidative protection conveyed by the incorporation of white pepper with the Control diet at the stated level above translates into the transfer of unsaturated fatty acid from the feed to the diet with modification by the liver. Findings by Galli *et al.* (2019) that the widely accepted opinion that unsaturated fatty acids pass through the small intestine unchanged to be absorbed into the bloodstream and deposited in the tissues is not universally substantiated as modification in the liver determines refined obtainable fatty acid deposited in tissues. Additionally, an inference depicted by the overall picture of the susceptible relationship that exists between the balance between SFA and UFA when consumed on the cardiovascular health of human health is observed in the numerical values documented for the Index of Atherogenicity though not significant in this study. Conscious present-day consumers tend towards selective acceptance of meat and meat products, with special emphasis on decreased levels of fat, salt, cholesterol and caloric content enriched with dietary fibre for healthy living (Cherian, 2015; Nayeem *et al.,* 2017). Fatty acids, especially essential fatty acids, are gaining importance in poultry feeding systems not only for improving the health and productivity of chickens but also because health-conscious societies prefer properly balanced diets to minimize adverse health issues (Lee *et al.,* 2019). Novel studies today target the manipulation of diet composition to increase n-3 PUFA content and decrease n-3:n-6 ratio in poultry meat since n-6 PUFA act as a pro-inflammatory factor but n-3 PUFA – is an anti-inflammatory factor (Rahimi *et al*., 2011). With n-3:n-6 having a notable influence on immune functions and inflammatory processes in animals and humans, meat from chickens fed C+100wp+100cp appears to exhibits a better cardiovascular balance due to its high n-3:n-6 value. This however contradicts the Index of Atherogenicity value, which was numerically least in C+125wp+125cp group. A clarity can be derived from explanation of Wijendran and Hayes (2004), who declared that the absolute mass of essential fatty acid profile (MUFA and PUFA) in product should be considered foremost when considering implications of n-3:n-6 on human health. Hence, dietary n-3:n-6 is neither the sole nor foremost factor to be considered for assessment of cardiovascular balance for cardiovascular health.

The outcome of this experiment indicates both groups offered solely dietary white pepper and C+200cp diet had higher meat High-density lipoprotein (HDL) in comparison with the Control group. Puvaca *et al.* (2015) explained that significant lowering of plasma cholesterol, triglycerides, LDL and increased HDL production by *Piper nigrum* incorporation signifies effective regulation of lipid metabolism favourably for the prevention of atherosclerosis or coronary heart diseases. This indicates that phytochemicals in the diets of chickens offered dietary white pepper solely triggered increased transport of HDL-cholesterol which is associated with the removal of fat molecules from cells that are subsequently exported as lipids such as cholesterol, phospholipids, and triglycerides in variable quantities. HDL cannot be discussed in isolation but with LDL with cholesterol transport to the liver. Plasma LDL levels are determined by the rate of LDL production and clearance, both of which are regulated by the number of LDL receptors in the liver (Feingold, Grunfield 2018). The plasma LDL in turn define the quantity to be deposited or evacuated from tissues. Across the experimental groups, white pepper offered chickens as an additive resulted in a balanced lipid profile but the best lipid profile (HDL: LDL) was obtained in meat from groups given 200 g 100 kg^{-1} white pepper additive and it agrees with the study by Cardoso *et al.* (2012) whose study showed that the supplementation of piperine is toxic to liver tissue at a higher dosage which was observed from the reduced absorption surface of the jejunum; but lower inclusion dosage had piperine to be secure. Piperine is shown to be an effective antioxidant that offers protection against the oxidation of human low-density lipoprotein (LDL) (Naidu, Thippeswamy 2002). Palmitoleic acid functions as an adipose tissue-derived lipid hormone that triggers muscle insulin action, suppresses hepatosteatosis, has an antithrombotic effect, can prevent stroke, and lower LDL cholesterol but effect higher HDL production (Mozaffarian *et al.,* 2010; Yang *et al.,* 2011). An abundance of small dense LDL particles is associated with hypertriglyceridemia, low HDL levels, obesity, type 2 diabetes and infectious and inflammatory outcomes.

Superoxide dismutase (SOD) in meat was significantly influenced by the diet. Meat from chickens supplied with the Control diet (0% additive) showed increased SOD distribution within the tissue. Minimal or absence of external supplementary radical scavenging substances (additives) resulted in adaptative response at a cellular level to oxidative stress via increased SOD production to overcome homeostatic imbalance or a disturbance in the pro-oxidant – antioxidant balance. Oxidative stress results from imbalance and overload of stressors such as Reactive Nitrogen or Oxygen species (RNS/ROS) with potentially hazardous substances produced along with several biological and pathological processes (Trachootham *et al.*, 2008) that ultimately determine the fate of the stressed cell. The mechanism by which a cell dies (*i.e.*, apoptosis, necrosis, pyroptosis, or autophagic cell death) depends on various exogenous factors as well as the management/coping mechanism adopted by the cell to stress it is exposed (Fulda *et al.,* 2010). Though SOD is one of the cell's natural defences against oxidative imbalance, uncontrolled perturbation of this balance may result in either apoptosis or necrotic cell death (Orrenius *et al.*, 2007). Scavenging free radicals (piperine and capsaicin); detoxification/decomposition of the free radicals and non-radical toxic products (SOD, GPx *etc.*) are important steps in the antioxidant defence mechanism (Surai *et al*., 2019). The intake of C+125wp+125cp diet yielded the best complimentary activity to minimize overload in SOD production. The observed decrease in SOD expression as additive incorporation increased in this study contradicts the report of Surai *et al.* (2019) who declared that nutritional antioxidant (phytochemicals) in the feed increases SOD count but supports research published by Roehrs *et al.* (2011) that increased endogenous antioxidants increase oxidative damage, quality of lipids and possible effects associated with cardiovascular risk linked to atherogenic and haemodialysis (HD) patients.

Quality deterioration indicators such as colour changes, off-flavour and odours are outcomes of oxidative spoilage that results from the oxidation of susceptible PUFAs in chicken meat. Subsequent development of lipid oxidation products (LOPs), such as malondialdehyde (MDA) and 4-hydroxy-2-nonenal (4-HNE) can be detrimental post-consumption (Van Hecke *et al.*, 2017). The lowest malondialdehyde count for groups offered C+250wp additive was observed. While this does not signify that meat from C+250wp group had the overall best oxidative profile, the potency of white pepper (*Piper nigrum*) in limiting lipid oxidation or spoilage associated with rancidity is shown. For C+200wp diet, the meat lipid peroxidation product was highest, and it suggests polyunsaturated fatty acid formed with the inclusion of white pepper at 200 g 100 kg^{-1} of the Control diet was not sufficiently protected by antioxidants present. Morel *et al.* (2006) reported that lipid oxidation was significantly greater in tissues and processed products from PUFA-fed pigs supporting the outcome of this research. High PUFA levels may result in alterations in meat flavour due to their susceptibility to oxidation and the production of unpleasant volatile compounds (Jaworska *et al.*, 2016). An investigation by Martinez *et al.* (2006) points to *Piper nigrum* as best suited for shelf-life extension of fresh sausages because it effectively delayed off-odour formation owing to its richness in flavonoids, vitamin C and vitamin A. In addition, piperine – a bioactive alkaloid in white pepper has been demonstrated in in-vitro studies to protect against oxidative damage by inhibiting or quenching reactive oxygen species. Piperine treatment likewise alters (lowers) lipid peroxidation in vivo and beneficially influences the antioxidant status of cells.

Findings from this study likewise reveal all dietary pepper powders fed contributed to suppressed production and activity of endogenous antioxidants – a pointer to poultry farmers. Though C+125wp+125cp diet had a highly potent influence on endogenous enzymes, the radical scavenging activity post-slaughter was least effective in meat obtained from this group. Post slaughter, meat from chickens offered C+250wp diet strongly repressed the translation of primary radicals into secondary products of spoilage such as malondialdehydes. The meat of chickens fed C+250wp had the least MDA count. According to Olalere *et al.* (2018), bioactive compounds extracted from oleoresin extract of white pepper contribute to its peroxidation potency. Vasavirama and Upender (2014) similarly reported that white pepper is made up of piperine and pungent resins which possibly limited the translation of radicals produced post slaughter that could have been oxidized into aldehydes.

Conclusion

Feeding C+200cp diet resulted in heavier dressed and breast weights as well as meat + skin: bone ratio – a significant gain to poultry farmers and meat processors that sell meat according to its weight. Palmitoleic acid – a rare fatty acid consumed in Western diets occasionally found in foods such as macadamia and codfish liver oil was present in the meat of chickens fed C+200wp and C+125wp+125cp diets. Meat linolenic and palmitoleic fatty acid were increased and present respectively by the addition of 250 g of white pepper per 100 kg of the Control diet (C+250wp), however, the overall profile promoting healthier cardiovascular function appear obtainable by feeding chickens C+125wp+125cp diet (depicted by the IA and n-3:n-6 values) – contributing to consumer welfare. Meat endogenous antioxidant profile reveals stress imposed on chickens was lowered by feeding C+125wp+125cp diet. Poultry farmers can take advantage of this level of pepper combination, especially in tropical climates loaded with environmental stressors. White pepper offered at 2.5 g kg^{-1} of the Control diet (C+250wp) suppressed spoilage from rancidity post-slaughter as refrigeration storage progressed, therefore, indicating white pepper possesses bioactive compounds that can function as preservatives.

Acknowledgements

I would like to appreciate the laboratory staffs of the Department of Animal Production and Health, College of Animal Science and Livestock Production, Federal University of Agriculture, Abeokuta for the assistance rendered throughout the experiment.

Conflict of interest

The authors declare no conflict of interest exists.

Ethical statement

Approval for this research was obtained from the Departmental Ethical Committee (FUNAAB-APH20-03) of the College of Animal Science and Livestock Production Animal welfare board.

Author contributions

AA – design/sampling/analysis/writing;
KS, LE – design of experiment;
MA – editing and approving the final manuscript;
MO, OA, OW – sampling.

References

Adegoke, A.V., Abanikanda, I.A., Sanwo, K.A., Egbeyale, L.T., Abiona, J.A. 2016. Dietary addition of turmeric (*Curcuma long*a) rhizome powder and cayenne pepper (*Capsicum frutescens*) powder as antioxidants on carcass traits of broiler chickens. – In New Technology for Enhanced Animal Production in Nigeria. Proceedings of the 41st Annual Conference of the Nigerian Society for Animal Production (NSAP), pp. 371–374.

Ahn, D.U., Olson, D.G., Jo, C., Chen, X., Wu, C., Lee, J.I. 1998. Effect of muscle type, packaging, and irradiation on lipid oxidation, volatile production and color in raw pork patties. – Meat Science, 49:27–39. DOI: 10.1016/s0309-1740(97)00101-0

AOAC, 2005. 4. Animal Feed. – In Official Methods of Analysis. (18th ed.). Horwitz, W., Latimer, G.W. (Eds.) – AOAC International (Association of Official Analytical Chemists), Maryland, USA, 68 p.

AOCS. 1998. Official Methods and Recommended Practices of the AOCS. (5th ed.). Firestone, D. (Ed.). – American Oil Chemists' Society. Press, Champaign, USA, 1200 p.

Cardoso, V.S., Ribeiro de Lima, C.A., Freire de Lima, M.E., Dorneles, L.E.D., Danelli, M.G.M. 2012. Piperine as a phytogenic additive in broiler diets. – Pesquisa Agropecuária Brasileira, 47(4):489–496. DOI: 10.1590/S0100-204X2012000400003

Cherian, G. 2015. Nutrition and metabolism in poultry: Role of lipids in early diet. – Journal of Animal Science Biotechnology, 6(1):28. DOI: 10.1186/s40104-015-0029-9

El Tazi, S.M.A., Mukhtar A.M., Mohamed, K.A., Tabidi, M.H. 2014. Effect of using black pepper as natural feed additive on performance and carcass quality of broiler chickens. – International Journal of Pharmaceutical Research and Analysis, 4(2):108–113.

Feingold, K.R., Grunfeld, C. 2018. Introduction to Lipids and Lipoproteins. – In Endotext. Feingold, K.R., Anawalt, B., Boyce, A., Chrousos, G., Dungan, K., Grossman, A., Hershman, J.M., Kaltsas, G., Koch, C., Kopp, P., Korbonits, M., McLachlan, R., Morley, J.E., New, M., Perreault, L., Purnell, J., Rebar, R., Singer, F., Trence, D.L., Vinik, A., Wilson, D.P. (Eds.) – South Dartmouth MA, USA. MDText.com, Inc.; 2000–. PMID: 26247089.

Folch, J., Lees, M., Sloane-Stanley, G.H.A. 1957. A simple method for the isolation and purification of total lipids from animal tissues. – Journal of Biology Chemistry, 266(1):497–509.

Fulda, S., Gorman, A. M., Hori, O., Samali, A. 2010. Cellular stress responses: Cell stress and cell death. – International Journal of Cell Biology, 2010(214074):23. DOI: 10.1155/2010/214074

Galib, A., Al-Kassie, M., Mamdooh, A., Al-Nasrawi, M., Saba, J.A. 2011. The effects of using hot red pepper as a diet supplement on some performance traits in broiler. – Pakistan Journal of Nutrition, 10 (9):842–845.

Galli, G.M., Roger, B.F., Dos Reis J.H., Gebert, R.R., Barreta, M., Griss, L.G., Casagrande, R.A., De Cristo, T. G., Santiani, F., Campigotto, G., Rampazzo, L., Stefani, L.M., Boiago, M.M., Lopes, L.Q., Santos, R.C.V., Baldissera, M. D., Zanette, R. A., Tomasi, T., Da Silva, A. S. 2019. Glycerol monolaurate in the diet of broiler chickens replacing conventional antimicrobials: Impact on health, performance and meat quality. – Microbial Pathology, 129:161–167. DOI: 10.1016/j.micpath.2019.02.005

Hartman, L.R., Lago, C. 1973. Rapid preparation of fatty acid methyl esters from lipids. – Lab Practice, 22(6):475–476.

Hodson, L., Karpe, F. 2013. Is there something special about palmitoleate? – Current Opinion Clinical Nutrition and Metabolic Care, 16(2):225–231. DOI: 10.1097/MCO.0b013e32835d2edf

Jaworska, D., Czauderna, M., Przybylski, W., Rozbicka-Wieczorek, Agnieszka, J. 2016. Sensory quality and chemical composition of meat from lambs fed diets enriched with fish and rapeseed oils, carnosic acid and seleno-compounds. – Meat Science, 119:185–192. DOI: 10.1016/j.meatsci.2016.05.003

Kang, J.H., Tsuyoshi, G., Le-Ngoc, H., Kim, H.M., Tu, T.H., Noh, H.J., Kim, C.S., Choe, S., Kawada, T., Yoo, H, Yu, R. 2011. Dietary capsaicin attenuates metabolic dysregulation in genetically obese diabetic mice. – Journal of Medicinal Food, 14(3):310–15. DOI: 10.1089/jmf.2010.1367

Lee, S.A., Whenham N., Bedford, M.R. 2019. Review on docosahexaenoic acid in poultry and swine nutrition: Consequence of enriched animal products on performance and health characteristics. – Journal of Animal Nutrition, 5(1):11–21.

Lopez-Ferrer, S., Baucells, M.D. Barroeta, A.C. Grashorn. M.A. 1999. Influence of vegetable oil sources on quality parameters of broiler meat. – Archiv für Geflügelkunde, 63:29–35.

Lopez-Ferrer, S., Baucells, M.D., Barroeta, A.C., Grashorn, M.A. 2001. n-3 enrichment of chicken meat. 1. Use of very long-chain fatty acids in chicken diets and their influence on meat quality: Fish oil. – Poultry Science, 80(6):741–752. DOI: 10.1093/ps/80.6.741

Marangoni, F., Corsello, G., Cricelli, C., Ferrara, N., Ghiselli, A., Lucchin, L., Poli, A. 2015. Role of poultry meat in a balanced diet aimed at maintaining health and wellbeing: An Italian consensus document. – Food Nutrition Research, 59:27606. DOI: 10.3402/fnr.v59.27606

Martinez, L., Cilla, I., Beltran, J.A., Roncales, P. 2006. Effect of *capsicum* (Red Sweet and Cayenne) and *Piper nigrum* (Black and White) pepper powders on the shelf life of fresh pork sausages packaged in modified atmosphere. – Journal of Food Science, 71(1):S48–S53. DOI: 10.1111/j.1365-2621.2006.tb12405.x

Milićević, D., Vranić, D., Mašić, Z., Parunović,, N., Trbović, D., Nedeljković-Trailović, T., Petrović, Z. 2014. The role of total fats, saturated/unsaturated fatty acids and cholesterol content in chicken meat as cardiovascular risk factors. – Lipids in Health and Diseases, 13:42. DOI: 10.1186/1476-511X-13-42

Mondal, M.A., Yeasmin, T., Karim, R., Nurealam Siddiqui, M., Raihanum-Nabi S.M., Sayed. M. 2015. Powder on growth performance and carcass traits of broiler chicks. – South Asian Association for Regional Cooperation Journal of Agriculture, 13(1): 188–199. DOI: 10.3329/sja.v13i1.24191

Morel, P.C., McIntosh, J.C., Janz, J.A.M. 2006. Alteration of the fatty acid profile of pork by dietary manipulation. – Asian-Australian Journal of Animal Science, 19(3):431–437. DOI: 10.5713/ajas.2006.431

Mozaffarian, D., Cao, H., King, I., Lemaitre, R., Song, X., Siscovick, D., Hotamisligil, G. 2010. Trans-palmitoleic acid, metabolic risk factors, and new-onset diabetes in U.S. adults: a cohort study. – Annals of internal medicine. 153(12):790–799. DOI: 10.7326/0003-4819-153-12-201012210-00005

Naidu, K.A., Thippeswamy N.B. 2002. Inhibition of human low-density lipoprotein oxidation by active principles from spices. – Molecular Cellular Biochemistry, 229(1-2):19–23. DOI: 10.1023/a:1017930708099

Nayeem, N., Chauhan, K., Khan, M. A., Siddiqui, M., Sidduqui, H. 2017. Development and shelf-life studies of buffalo meat sausages incorporated with foxtail millet (*Setaria italica*). – International Journal of chemical Studies, 5(3):648–654.

Norde, M.M., Oki, E., Rogero, M.M. 2019. C-reactive protein and fatty acids: public health concerns and implications. – In The molecular nutrition of fats (1st edition). Patel, V. (Ed.) – Academic Press, pp. 117–133. DOI: 10.1016/B978-0-12-811297-7.00009-3

Ogbuewu, I.P., Okoro, V.M., Mbajiorgu, E.F., Mbajiorgu, C.A. 2018. Beneficial effects of garlic in livestock and poultry nutrition: A Review. – Agricultural Research, 8:411–426, DOI: 10.1007/s40003-018-0390-y

Olalere, A.O., Hamid, N.A., Rosli, M.Y., Oluwaseun, R.A., Malam, M.A., Yasmeen, H.Z., Hybat, Salih, M.A. 2018. Parameter study, antioxidant activities, morphological and functional characteristics in microwave extraction of medicinal oleoresins from black and white pepper. – Journal of Taibah University for Science, 12(6):730–737. DOI: 10.1080/16583655.2018.1515323

Orrenius, S., Gogvadze, V., Zhivotovsky, B. 2007. Mitochondrial oxidative stress: implications for cell death. – Annual Review of Pharmacology and Toxicology, 47:143–183. DOI: 10.1146/annurev.pharmtox.47.120505.105122

Puvaca, N., Kostadinovic, L., Ljubojevic, D., Lukac, D., Levic, J., Popovic, S., Novak, V.N., Vidovic, B., Duragic, O. 2015. Effect of garlic, black pepper and hot red pepper on productive performances and blood lipid profile of broilers chickens. – European Poultry Science, 79:1–13. DOI: 10.1399/eps.2015.73

Puvaca, N., Pelic, D. L., Cabarkapa, I., Popovic, S., Tomicic, Z., Nikolova, N., Levic, I. 2019. Quality of broiler chicken carcass fed dietary addition of garlic, black pepper and hot red pepper. – Journal of Agronomy, Technology and Engineering Management, 2(1): 218–227

Rahimi, S., Kamran, Azad S., Karimi, Torshizi M. A. 2011. Omega-3 Enrichment of Broiler Meat by Using Two Oil Seeds. Journal of Animal Science and Technology, 13 (3): 353-365

Roehrs, M., Valentini, J., Paniz, C., Moro, A., Charão, M., Freitas, F., Brucker, N., Duarte, M., Leal, M., Burg, G., Bulcão, R., Grune, T., Garcia, C.S. 2011. The relationships between exogenous and endogenous antioxidants with the lipid profile and oxidative damage in hemodialysis patients. – BMC Nephrology, 12:59. DOI: 10.1186/1471-2369-12-59

Shah, S.S., Shah, G.B., Singh, S.D., Gohil, P.V., Chauhan, K., Shah, K.A., Chorawala, M., 2011. Effect of piperine in the regulation of obesity-induced dyslipidemia in high-fat diet rats. – Indian Journal of Pharmacology, 43(3),296–299. DOI: 10.4103/0253-7613.81516

Singh, S.K., Sahu, S.P., Kumar P. 2018. Influence of supplementation of feed additives on carcass characteristics, mortality and economics of broiler production. – International Journal of Current Microbiological Applied Science, Special Issue-7:4810–4817

SPSS. 2012. Statistical package for social sciences. – IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.

Surai, P.F. 2016. Antioxidant systems in poultry biology: Superoxide dismutase. – Journal of Animal Research and Nutrition, 1(1:8):1–17. DOI: 10.21767/2572-5459.100008

Surai, P.F., Kochish, II, Fisinin, V.I., Kidd, M.T. 2019. Antioxidant defence systems and oxidative stress in poultry biology: An update. – Antioxidants (Basel), 8(7):235. DOI: 10.3390/antiox8070235

Trachootham, D., Lu, W., Ogasawara, M.A., Valle, N.R. Huan, P. 2008. Redox regulation of cell survival. – Antioxidants & Redox Signaling, 10(8): 1343–1374. DOI: 10.1089/ars.2007.1957

Toomer, O., Livingston, M., Wall, B., Sanders, E., Vu, T., Malheiros, R., Livingston, K., Carvalho, L., Ferket, P., Dean, L. 2020. Feeding high-oleic peanuts to meat-type broiler chickens enhances the fatty acid profile of the meat produced. – Poultry Science, 99(4):2236–2245. DOI: 10.1016/j.psj.2019.11.015

Ulbricht, T.L.V., Southgate D.A.T. 1991. Coronary heart disease: seven dietary factors. – The Lancet, 338(8773):985–992. DOI: 10.1016/0140-6736(91) 91846-M

Van Hecke, T., Ho, L-P., Goethals, S., De Smet, S. 2017. The potential of herbs and spices to reduce lipid oxidation during heating and gastrointestinal digestion of a beef product. – Food Research International, 102:785–792. DOI: 10.1016/j.foodres. 2017.09.090

Vasavirama, K., Upender, M. 2014. Piperine: a valuable alkaloid from piper species. – International Journal of Pharmaceutical and Pharmacological Science, 6(4):34–38.

Wijendran, V., Hayes, K.C. 2004. Dietary n-6 and n-3 fatty acid balance and cardiovascular health. – Annual Review of Nutrition. 24:597–615. DOI: 10.1146/annurev.nutr.24.012003.132106

Wood, J.D., Enser, M., Fisher, A.V. 2008. Fat deposition, fatty acid composition and meat quality: A review. – Meat Science, 78 (4):343–358. DOI: 10.1016/j.meatsci.2007.07.019

Yang, Z.-H., Miyahara, H., Hatanaka, A. 2011. Chronic administration of palmitoleic acid reduces insulin resistance and hepatic lipid accumulation in KK-Ay mice with genetic type-2 diabetes. – Lipids in Health and Disease, 10:120. DOI: 10.1186/s12944-021-01513-w

Zong, G., Li, Y., Wanders, A.J., Alssema, M., Zock, P.L., Willett, W.C., Hu, F.B., Sun, Q. 2016. Intake of individual saturated fatty acids and risk of coronary heart disease in US men and women: two prospective longitudinal cohort studies. – British Medical Journal, 355:i5796. DOI: 10.1136/bmj.i5796

Agraarteadus
1 • XXXIII • 2022 11–20

Journal of Agricultural Science
1• XXXIII • 2022 11–20

EFFECT OF HUMIC ACIDS AND THE AMOUNT OF MINERAL FERTILIZER ON SOME CHARACTERISTICS OF SALINE SOIL, GROWTH AND YIELD OF BROCCOLI PLANT UNDER SALT STRESS CONDITIONS

Muneer N. A. Al-Falahi[1], Kamal H. Al-Dulaimi[2], Emad Telfah Abdel Ghani[3], Duraid K. A. Al-Taey[4], Khaleel J. Farhan[2]

[1]*University of Anbar, Upper Euphrates Basin Developing Center, 31001, Al-Ramadi, Iraq*
[2]*University of Anbar, College of Agriculture, Department Soil Science and Water Resources, 31001, Anbar, Iraq*
[3]*University of Anbar, Upper Euphrates Basin Development Centre, Planning and Database Department, 31001, Anbar, Iraq*
[4]*AL-Qasim Green University, College of Agriculture, Department of Horticulture, 00964, Iraq*

Saabunud: Received: 09.04.2022

Aktsepteeritud: Accepted: 19.06.2022

Avaldatud veebis: Published online: 19.06.2022

Vastutav autor: Corresponding author: Duraid K. A. Al-Taey

E-mail:
duraidaltaey@gmail.com (DKAA-T)
muneer84@yahoo.com (MNAA-F)
kmhm81@uoanbar.edu.iq (KHA-D)
emadabdulghani@uoanbar.edu.iq (ETAG)

ORCID:
0000-0003-3045-8381 (MNAA-F)
0000-0001-5652-7635 (KHA-D)
0000-0001-2345-6789 (ETAG)
0000-0003-3601-5573 (DKAA-T)

Keywords: humic acids, saline irrigation water, broccoli, saline soil.

DOI: 10.15159/jas.22.24

ABSTRACT. A pots experiment was undertaken to determine the combined effect of humic acids and mineral fertilizer on some characteristics of saline soil, growth, and yield components of broccoli. The experiment was conducted in a randomized complete block design with three replications. The first factor consists of two levels of humic acids, namely without humic acid (H0 = 0.00 g L^{-1}) and humic acid application (H1 = 0.35 g L^{-1}), while the second factor included nine fertilizer (92 kg N ha^{-1}, 200 kg P_2O_5 ha^{-1}, 150 kg K_2O ha^{-1}) application rates that were (100, 100, 100%), (120, 120, 120%), (120, 120, 100%), (80, 120, 120%), (100, 100, 120%), (80.100, 100%), (120, 80, 80%), (100, 80, 80%), (80, 80, 80%) which added as a percentage of original fertilizer recommendation taking the symbols of R1 to R9 respectively. The treatment R1 was designated as a control treatment. The results indicated that humic acid application (H1) and increasing the amount of applied mineral fertilizer (R2) reduced the hydraulic conductivity of the soil for different soil depths. Humic acid addition (H1) increased concentrations of calcium and magnesium while reducing sodium concentration compared to control (H0). Contrary to humic acid, increasing the supplied mineral fertilizer led to a reduction in concentrations of calcium and magnesium while increasing sodium concentration in the soil. The sodium adsorption in soil particles in the ground was decreased due to humic acid application while improving the mineral fertilizer. Humic acid (H1) combined with increasing the amount of chemical fertilizer (R2) gave the desirable results in decreasing the sulphate, chloride and bicarbonate in the soil profile. The addition of humic acid (H1) and increasing mineral fertilizer application (R2) led to a significant increase in plant height, leaf area and head weight of broccoli per plant. Similarly, the interaction between humic acids and chemical fertilizers (H1R2) led to a significant increase in plant height, leaf area and head weight of broccoli per plant.

Introduction

Soil salinization is one of the most global challenges in the arid and semi-arid areas that strongly affect the sustainability of agricultural production (El Azzouzi, 2019). Consequently, encouraging long-term sustainable water management is required to achieve a sustainable water supply. Therefore, in regions facing water deficiency, it is common practice to exploit the saline water in irrigated agriculture (Pereira *et al.*, 2009); however, when saline water is used, the annual production is possibly subject to yield damage due to salt uptake by the plant, which causes a high risk to plant growth and a limiting factor for the productivity of most major crops (Sahi *et al.*, 2006), especially in the arid and semi-arid regions of the world (Munns, 2002), owing to the high salinity result in osmotic stresses, osmotic ions, disruption of the nutritional balance (Ashraf, 2004; Al-Khafajy *et al.*, 2020). Although difficult to accurately estimate the area of the salinized soil, it continues to expand, and this phenomenon is particularly acute in irrigated soils (Machado, Serralheiro, 2017). Worldwide, over 930 million hectares have been estimated to be salt-affected (Bacilio *et al.*, 2016; AL-Azawi, 2015). Therefore, for sustainable agriculture under saline irrigation water, the suggested strategies should focus on improving the soil's physical and chemical properties (Singh, 2014; Mahmood *et al.*, 2020). Many different practical methods have been suggested involving selecting suitable irrigation systems, salt-tolerant crops and proper field drainage (Kiremit, Arslan 2016; Redeef *et al.*, 2021). Humic acid (HA) is one of the considered methods. It is a fundamental component of humic substances, which form more than 60% of the soil's organic matter (Sani, 2014; Canellas *et al.*, 2015). It can amend the soil properties and improve plant metabolic processes (Bacilio *et al.*, 2016).

Moreover, it induces plant tolerance to various environmental stressors (Hatami *et al.*, 2018). Currently, humic acids are becoming obtainable as a commercial supplement for plant melioration (Rose *et al.*, 2014; Ali *et al.*, 2021). It is the critical component of organic fertilizers and contains a considerable amount of nutrients (Canellas *et al.*, 2015). Humic substances have antioxidant activity, which is assumed to prevent ROS production and protect cells from oxidative damage (Khan *et al.*, 2010; Hussain *et al.*, 2021). It does not merely assist in reducing the negative impacts of salinity but may also contribute to preserving sustainable cultivation in an adverse environment (AL-Taey, Burhan, 2021).

Moreover, it could help increase the yield per unit area, counterbalancing any needed increase in the cultivated area, and protecting the environment from additional negative impacts. Broccoli (*Brassica oleracea*) was considered one of the important vegetable cancer because it comprises considerable amounts of antioxidants and fibre. It can be cultivated worldwide (Sotelo *et al.*, 2014). Besides being a good source of minerals, vitamins and phenolics, several studies have recommended broccoli for cataract prevention. This research was conducted to investigate the combined effect of humic acid, and the amount of mineral fertilizer on some characteristics of saline soil, growth and yield components of broccoli.

Materials and Methods

A pots experiment was conducted from October to February in the agricultural season 2020–2021. A two-factor experiment was performed as a randomized complete block design with three replications. The first factor consists of two levels of humic acids (consist of humic and fulvic acid), namely without humic acids (H0 = 0.00 g. L^{-1}) and humic acids application (H1 = 0.35 g. L^{-1}). In contrast, the second factor consisted of nine treatments with different doses of fertilizer combinations. The nine treatments of mineral fertilizer were added as a percentage of the original fertilizer recommendation of broccoli (92 kg N h^{-1}, 200 kg P_2O_5 ha^{-1}, 150 kg K_2O ha^{-1}) according to El Magd *et al.* (2005). The details of applied treatments were (100, 100, 100%), (120, 120, 120%), (120, 120, 100%), (80, 120, 120%), (100, 100, 120%), (80, 100, 100%), (120, 80, 80%), (100, 80, 80%), (80, 80, 80%) taking the symbols of R1 to R9 respectively. The treatment R1 (100, 100, 100%) was designated as a control treatment. Before fieldwork commenced, six disturbed samples were randomly taken from the plough layer (0–30 cm depth) from a private farm and comprehensively mixed to form one representative composite sample. The representative sample was air-dried and preserved in a sealed polythene bag. Subsequently, it was transferred to the laboratory, crushed and passed across a 2 mm sieve to determine the principal selected soil chemical and physical properties Table 1. Soil from the study field was passed through a 4 mm sieve and packed in 30 kg plastic pots. The humic acids were obtained from the local markets in a powder with dark brown colour (country of origin: Spain). The humic acids understudy is 100% soluble in water and composed of 68% humic acid, 17% fulvic acid (humic acids of 85%) and 12% K_2O. The humic acids (humic and fulvic acid) were applied by mixing with irrigation water. Urea fertilizer was applied as a nitrogen source in two equal splits; the first dose was applied at planting, and the second dose was applied after two months of planting. Triple superphosphate (44% P_2O_5) and potassium sulfate fertilizer (50% K_2O) was applied to the soil as a source of phosphorous and potassium once at planting. Broccoli seedlings were planted with one seedling per pot, and irrigation water with an electrical conductivity (EC) of 4.2 dS m^{-1} was used for plant watering. Some chemical properties of irrigation water are listed in Table 1. The gravimetric method was adopted for irrigation to bring soil moisture to the limits of field capacity. Throughout the experiment, all treatments were irrigated when 35% of available water was consumed. Leaching requirements of 13% were added according to Ayers and Westcot (1985). Agricultural practices such as weeding were adopted when required. Crops were harvested on 05/02/2021. Data concerning plant height (cm), leaf area (cm^2) and yield per plant (g $plant^{-1}$) were taken.

The obtained data were statistically analyzed using analysis of variance (ANOVA) with SPSS 20. Mean data were compared using the least significant difference (LSD) at a 0.05% probability level. To measure the electrical conductivity, of cations and anions, soil samples were taken from three depths, namely 0–10, 10–20 and 20–30 cm. The pH and EC for the soil under study were estimated from the 1:5 soil-water suspensions using a pH and EC meter. The soil organic matter was determined according to the acid extraction method (Jackson, 1967). While the total nitrogen was determined using the Kjeldahl method as described by (Mulvaney *et al.,* 1982). Olsen and Sommers method was used to determine the available P (Olsen, Sommers, 1982). Titrations measured chloride with silver nitrate (Richards, 1954), while the bicarbonate was estimated by titration according to the sodium adsorption ratio (SAR) using the concentration values of the sodium, calcium and magnesium (mmol L^{-1}) according to the Equation 1. Regarding the sulphates, it was estimated by the turbidity method. Atomic absorption spectrophotometry was used to measure Ca and Mg, while flame photometers used for Na and K (Polemio, Rhoades, 1977).

$$Sodium\ Adsorption\ Ratio\ (SAR) = \frac{Na}{\sqrt{Ca + Mg}} \qquad (1)$$

Table 1. Some properties of soil and irrigation water before planting

Parameter		In soil	In irrigation water	Unit
pH		7.40	7.60	
SAR		4.42	3.83	
EC		7.30	4.20	dS m^{-1}
Organic matter		8.72		mg kg^{-1}
Ca^{+2}		16.55	5.35	mmol L^{-1}
Mg^{+2}		15.80	8.00	
Na^{+1}		25.15	14.00	
K^{+}		0.62	0.15	
SO_4^{-2}		16.50	3.10	
HCO_3^{-}		1.10	0.10	
Cl^{-}		37.80	12.20	
N		100.50		mg kg^{-1}
P		52.00		
Na		139.50		
Bulk density		1.34		mg $m^{3\ -1}$
Soil particles	sand	650.00		g kg^{-1}
	silt	100.00		
	clay	250.00		
Texture	Sandy clay loam			

SAR – sodium adsorption ratio

Results and Discussion

Effect of humic acids and the amount of mineral fertilizer on soil electrical conductivity

The effect of humic acids mixed with irrigation water and the amount of mineral fertilizer led to a decrease in the soil electrical conductivity values with depth (0–10, 10–20 and 20–30 cm) Table 2. Where the electrical conductivity values (ECe) decreased with depth when the humic acids have been used (H1) compared to without humic acids (H0 = 0.00 g L^{-1}). The ECe were 4.71, 4.71 and 4.82 dSm^{-1} for the soil depths of 0–10, 10–20 and 20–30 cm respectively when adding humic acids at the level of H1 (0.35 g L^{-1}), while the average of electrical conductivity values ascending order 5.10, 5.26, 5.47 dS m^{-1} for the same depths respectively when humic acids (H0) were not added with a decrease of 7.64, 10.45 and 11.88% compared to without humic acids. Soil electrical conductivity decreased for the depths of 0–10, 10–20 and 20–30 cm with increasing the application of mineral fertilizer, where the lowest obtained values of soil electrical conductivity were 4.61, 4.75 and 4.95 dS m^{-1} for the aforementioned depths respectively at the R2 treatment. On the contrary, the treatment R9 gave the highest values of soil electrical conductivity reaching 5.11, 5.25 and 5.32 dS m^{-1} for the same previous mentioned depths respectively, with decreasing rate of 9.78, 9.52 and 6.95% respectively for the same depths. Whereas the interaction (between humic acids and mineral fertilizers) led to a decrease in the electrical conductivity values for the three different soil depths. The lowest average of the electrical conductivity values were 4.26, 4.40 and 4.50 dS m^{-1} for the three different soil depths respectively, at the combination of H1R2, while the highest values of the electrical conductivity were 5.29, 5.56 and 5.68 dS m^{-1} for the three different soil depths respectively at the combination of H0R9.

The reason for the reduction of ECe in the aforementioned depths of the soil could be due to the application of humic acids and its role in improving the soil chemical properties because humic acids are relatively complex molecules containing a wide range of effective groups. Such as carboxyl and hydroxyl that work on chelating, complicating and adsorption of salt ions, and changing the ionic composition of the soil solution, through leaching out the sodium salts out of the soil profile, thereby reduces their effect on the soil (Tchiadje, 2007). In addition, to the ability of humic acids to improve the physical properties of soil such as structure and bulk density, increasing permeability and speed of salt leaching out (Nan *et al.,* 2016). The findings of this research are consistent with (Khattak, Dost, 2014). Decreasing the soil electrical conductivity with increasing the levels of chemical fertilizers application probably due to the role of humic acids in improving plant growth which in turn absorbs considerable amount of dissolved ions from the soil solution, consequently reduces the soil electrical conductivity, in addition, urea is a non-ionic mineral fertilizer. Borzouei *et al.,* (2014) found that the use of urea led to a decrease in the electrical conductivity of the soil, as well as the effect of the added fertilizer on the plant, where it compensates for the deficiency in the availability of elements, including potassium and phosphorous, which plays significant regulatory roles in plant vital activities and its relationship to an increase in vegetative growth and absorption essential and non-essential elements for the plant due to the nutritional imbalance resulted from salinity where the excessive dissolved salts accumulated in the plant salt glands or into salt bladders for temporary storage and then the salt will scatter from salt bladders when it encounters strong winds moreover old leaves fall is one of the means of protecting the plant from salinity (Chen *et al.,* 2018).

Effect of humic acids and the amount of mineral fertilizer on the concentration of Ca, Mg and Na in the soil

The results listed in Table 3 show an increase in dissolved calcium, and magnesium and a decrease the sodium for three different soil depths with the application of humic acids H1 compare to H0. Where the dissolved calcium, magnesium and sodium values reached 13.05, 20.66 and 15.33 mmol L^{-1} and 6.95, 12.17 and 17.81 mmol L^{-1} for the depth of 0–10 cm respectively for H1 and H0 respectively, with an increasing rate of 87.76 and 69.76% for calcium and magnesium while sodium decreased 13.92% for the same depth. The next two depths (10–20 and 20–30 cm) show similar trends to the depth of 0–10 cm, in terms of increasing calcium, magnesium and decreasing sodium. Where under the effect of humic acids, the average values of dissolved calcium, magnesium and sodium were 18.15, 22.83 and 16.28 mmol L^{-1} respectively compared to 8.87, 13.77 and 18.66 mmol L^{-1} in the absence of humic acids for the depth of 10–20 cm with an increase of 104.62 and 65.79% for calcium and magnesium and with a decrease of 12.75% for sodium.

Table2. Effect of humic acids and the amount of mineral fertilizer on the soil electrical conductivity for the three different soil depths (0–10, 10–20 and 20–30cm) after planting

Soil depth, cm	Levels of humic acids, g L^{-1}	Supplied mineral fertilizer. %									
		R1	R2	R3	R4	R5	R6	R7	R8	R9	Average of
		Electrical conductivity values, dS m^{-1}									humic acids
0–10	H0 (0.00)	4.98	4.97	5.12	5.15	5.10	5.10	4.98	5.26	5.29	5.10
20–10		5.12	5.10	5.43	5.40	5.10	5.10	5.15	5.45	5.56	5.26
20–30		5.44	5.40	5.50	5.43	5.43	5.34	5.42	5.62	5.68	5.47
0–10	H1 (0.35)	4.36	4.26	4.68	4.66	4.65	4.50	4.48	4.88	4.93	4.71
10–20		4.48	4.40	4.87	4.83	4.76	4.60	4.58	4.93	4.95	4.71
20–30		4.60	4.50	4.94	4.94	4.93	4.82	4.76	4.98	4.97	4.82
											mineral fertilizer
0–10	Average of mineral fertilizer	4.67	4.61	5.40	4.90	4.87	4.80	4.73	5.07	5.11	4.90
10–20		4.80	4.75	5.15	5.11	4.93	4.85	4.86	5.19	5.25	4.98
20–30		5.02	4.95	5.32	5.18	5.18	5.08	5.09	5.30	5.32	5.15

R1 to R9 – fertilizer (92 kg N ha^{-1}, 200 kg P_2O_5 ha^{-1}, 150 kg K_2O ha^{-1}) application rates (100, 100, 100%), (120, 120, 120%), (120, 120, 100%), (80, 120, 120%), (100, 100, 120%), (80.100, 100%), (120, 80, 80%), (100, 80, 80%), (80, 80, 80%), respectively.

Table 3. Effect of humic acids and the amount of mineral fertilizer on the concentration of Ca, Mg and Na mmol L^{-1} for the three different soil depths (0–10, 10–20 and 20–30cm) after planting

Soil depth, cm	Levels of humic acids, g L^{-1}	Supplied mineral fertilizer, %									Average of
		R1	R2	R3	R4	R5	R6	R7	R8	R9	
						Ca, mmol L^{-1}					humic acids
0–10	H0 (0.00)	7.5	6.0	7.5	7.5	7.5	7.0	5.5	6.8	7.3	6.95
10–20		8.5	8.0	9.0	10.0	8.5	10.0	8.5	8.0	9.4	8.87
20–30		9.5	9.0	10.0	10.2	10.5	10.3	9.4	9.0	12.0	9.98
0–10	H1 (0.35)	17.5	10.0	12.5	15.0	12.0	9.5	16.0	10.0	15.0	13.05
10–20		19.0	17.5	17.5	17.5	17.5	20.5	17.9	18.5	17.5	18.15
20–30		21.5	19.0	19.0	20.0	20.0	21.0	22.5	23.0	22.5	20.94
											mineral fertilizer
0–10	Average of mineral fertilizer	12.5	8.0	10.0	11.3	9.8	8.3	10.8	8.4	11.2	10.00
10–20		13.8	12.8	13.3	13.8	13.0	15.3	13.2	13.3	13.5	13.51
20–30		15.5	14.0	14.5	15.1	15.3	15.7	16.0	16.0	17.3	15.46
						Mg, mmol L^{-1}					humic acids
0–10	H0 (0.00)	10.5	11.0	12.5	13.0	12.6	13.0	12.5	12.5	12.0	12.17
10–20		13.0	13.0	14.0	14.0	14.50	14.0	13.5	14.0	14.0	13.77
20–30		13.5	13.5	14.5	14.5	15.0	15.0	14.5	15.5	14.5	14.50
0–10	H1 (0.35)	21.0	20.5	20.0	19.5	20.0	20.0	22.5	22.5	20.0	20.66
10–20		22.5	22.0	22.5	23.0	22.5	23.0	24.0	22.5	23.5	22.83
20–30		27.0	22.5	25.5	25.5	25.0	26.0	26.5	24.6	28.0	25.62
											mineral fertilizer
0–10	Average of mineral fertilizer	15.75	15.75	16.25	16.25	16.3	16.5	17.5	17.5	16.00	16.41
10–20		17.75	17.5	18.25	18.5	18.5	18.5	18.75	18.25	18.75	18.30
20–30		20.25	18	20.00	20.00	20.00	20.5	20.5	20.05	21.25	20.06
						Na, mmol L^{-1}					humic acids
0–10	H0 (0.00)	17.61	17.50	17.38	17.60	16.90	18.40	18.20	18.00	18.70	17.81
10–20		18.34	18.10	18.29	18.16	17.20	19.37	18.96	20.46	19.10	18.66
20–30		19.50	18.90	19.40	19.72	18.60	20.30	19.84	20.61	21.00	19.76
0–10	H1 (0.35)	14.41	15.27	15.05	14.73	14.61	14.72	16.40	15.95	16.83	15.33
10–20		16.03	15.96	15.53	15.81	14.73	15.46	18.17	17.31	17.60	16.28
20–30		17.17	16.64	16.28	16.60	17.84	16.72	18.73	18.33	18.50	17.42
											mineral fertilizer
0–10	Average of mineral fertilizer	16.01	16.38	16.21	16.16	15.75	16.56	17.30	16.97	17.76	16.57
10–20		17.18	17.03	16.91	16.98	15.96	17.41	18.56	18.88	18.35	17.47
20–30		18.33	17.77	17.84	18.16	18.22	18.51	19.28	19.47	19.75	18.59

R1 to R9 – fertilizer (92 kg N ha^{-1}, 200 kg P_2O_5 ha^{-1}, 150 kg K_2O ha^{-1}) application rates (100, 100, 100%), (120, 120, 120%), (120, 120, 100%), (80, 120, 120%), (100, 100, 120%), (80.100, 100%), (120, 80, 80%), (100, 80, 80%), (80, 80, 80%), respectively.

Likewise, at the depth of 20–30 cm, the average values of dissolved calcium, magnesium and sodium were 20.94, 25.62 and 17.42 mmol L^{-1} respectively compared to 9.98, 14.50, and 19.76 mmol L^{-1} in the absence of humic acids with an increase of 109.81 and 76.68% for calcium and magnesium, respectively, and a decrease of 11.84% for sodium. The research results show that increasing the chemical fertilizers application led to a decrease in the values of calcium, magnesium and sodium for soil depths 0–10, 10–20 and 20–30 cm. where the lowest value of calcium and magnesium obtained from the treatments R2 while the lowest value of sodium obtained from the treatments R5. Increasing the concentration of calcium and magnesium while decreasing the concentration of sodium in the soil under the effect of humic acids may be attributed to the role of humic acids on the chelation of the dissolved ions from the soil solution and humic acids may also induce the formation of organic complexes because it contains functional groups such as carboxyl (COOH-) and phenol (OH-), which was one of the main reasons for the large reactions of adsorption, cation exchange, complex and chelation, in addition, the complexes formed with calcium and magnesium have less mobility compared to the movement of complexes formed with sodium (Zhang *et al.*, 2013). While decreasing the values of calcium, magnesium and sodium under the effect of mineral fertilizer application probably due to the increase in the growth rate of the plant (Table 6), consequently increased the absorption of nutrients due to the role of potassium in inducing the plant to absorb the dissolved nutrients from the soil, including sodium, which thereafter the plants get rid of or sequestering the harmful ion by different means (Munns 2002), or probably due to the levels of applied potassium to the soil contributed to release the sulfur that can be grouped with calcium to precipitate in the form of calcium sulfate, which characterized as scarcely soluble salt (Rahmati *et al.*, 2019).

Effect of humic acids and the amount of mineral fertilizer on the sodium adsorption ratio (SAR)

Table 4 presents the effect of mixing humic acids with irrigation water and the amount of mineral fertilizer on the values of SAR for the three different soil depths (0–10, 10–20 and 20–30 cm). The results indicated that there was a decrease in the values of SAR for the three different soil depths with the addition of humic acids (H1) compared to the treatment without humic acids (H0). The obtained values of the sodium adsorption ratio were 2.64, 2.54 and 2.55 for the three successive soil depths (0–10, 10–20 and 20–30 cm) respectively under the effect of humic acids (H1), with a decrease of 35.13, 35.03 and 36.09% compared to without humic acids application treatment that gave 4.07, 3.91 and 3.99 for the same previous mentioned depths respectively. The research results show that increasing the chemical fertilizers application led to an increase in the values of the sodium adsorption ratio for the three different soil depths (0–10, 10–20 and 20–30 cm), especially those containing a high percentage of nitrogen, where the highest value of the sodium adsorption ratio reached 3.50 for a depth of 0–10 cm at the treatment R2, while the lowest value was 3.17 for the same depth at the treatment R5. The highest value of the sodium adsorption ratio was 3.53 and 3.40 for the depths of 10–20 and 20–30 cm respectively at the treatment R9, while the lowest values of sodium adsorption ratio were 2.95 and 3.16 respectively, for the same depths at the treatment R5. The general decline in the sodium adsorption ratio is probably due to those humic acids containing functional groups such as the carboxylic and hydroxyl groups that work on chelating, complex and adsorption of sodium ions and forming soluble and movement organic complexes thus increasing the possibility of its leaching out. The functional groups in humic acids also chelate and complex the calcium and magnesium ions to form organic complexes that are less mobile than sodium ions in the soil, which reduces the process of their leaching out (Zhang *et al.*, 2013), and these findings are consistent with (Nan *et al.*, 2016). On contrary with humic acids, the amount of mineral fertilizer increases the values of the sodium adsorption ratio in the soil by increasing the rate of mineral fertilizers application. possibly due to the increase of plant growth rate, which increased the nutrients uptake by the plant such as calcium and magnesium, or the competition between sodium and ammonium on the absorption sites on the surface of the roots, which reduced the absorption of sodium by the plant (Pardo, Rubio 2011) and thus increased the sodium adsorption ratio values. This is consistent with the findings of (Tester, Davenport 2003).

Table 4. Effect of humic acids and the amount of mineral fertilizer on the sodium adsorption ratio for the three different soil depths (0–10, 10–20 and 20–30cm) after planting

Soil depth, cm	Levels of humic acids, g L^{-1}	Supplied mineral fertilizer (%)									Average of
		R1	R2	R3	R4	R5	R6	R7	R8	R9	
		Sodium adsorption ratio									humic acids
0–10	H0 (0.00)	4.15	4.24	3.88	3.88	3.76	4.11	4.28	4.09	4.25	4.07
10–20		3.95	3.94	3.81	3.70	3.58	3.95	4.04	4.36	3.94	3.91
20–30		4.06	3.98	3.91	3.96	3.68	4.03	4.05	4.16	4.07	3.99
0–10	H1 (0.35)	2.32	2.76	2.63	2.50	2.58	2.71	2.64	2.79	2.84	2.64
10–20		2.48	2.53	2.45	2.48	2.32	2.34	2.80	2.70	2.74	2.54
20–30		2.46	2.58	2.44	2.46	2.65	2.43	2.67	2.65	2.60	2.55
											mineral fertilizer
0–10	Average of mineral fertilizer	3.23	3.5	3.25	3.19	3.17	3.41	3.46	3.46	3.44	3.35
10–20		3.21	3.23	3.13	3.09	2.95	3.14	3.42	3.42	3.53	3.22
20–30		3.26	3.28	3.17	3.21	3.16	3.23	3.36	3.36	3.40	3.27

R1 to R9 – fertilizer (92 kg N ha^{-1}, 200 kg P_2O_5 ha^{-1}, 150 kg K_2O ha^{-1}) application rates (100, 100, 100%), (120, 120, 120%), (120, 120, 100%), (80, 120, 120%), (100, 100, 120%), (80.100, 100%), (120, 80, 80%), (100, 80, 80%), (80, 80, 80%), respectively.

Effect of humic acids and the amount of mineral fertilizer on the concentration of dissolved ions SO_4, Cl, and HCO_3 in the soil

The results listed in Table 5 present the effect of mixing humic acids with irrigation water and the amount of mineral fertilizer on the dissolved values of sulphate, chloride and bicarbonate for the three different soil depths (0–10, 10–20 and 20–30 cm). The observed trend in dissolved values of former salts is a decrease for different depths under the effect of humic acids (H1 = 0.35 g L^{-1}) compared to the treatments without humic acids addition (H0) for the three different soil depths. Where the average values of dissolved sulphate, chloride and bicarbonate were 3.73, 14.83 and 0.13 mmol L^{-1} respectively for depth 0–10 cm with the addition of humic acids (H1), while the average values of dissolved sulphate, chloride and bicarbonate for the treatments without humic acids were 4.31, 25.50, and 0.39 mmol L^{-1} for the same depth, respectively, with a decrease of 13.45, 41.84, and 66.66% for sulphate, chloride and bicarbonate, respectively. For the depth of 10–20 cm, the average values of the dissolved sulphate, chloride and bicarbonate were 4.33, 23.15 and 0.19 mmol L^{-1} respectively, with the addition of humic acids (H1). While the average values of dissolved sulphate, chloride and bicarbonate for the treatments without humic acids were 5.17, 30.86, and 0.64 mmol L^{-1}, respectively, for the same depth, with a decrease of 16.24, 24.98 and 70.31%, respectively. Similarly, the effect of humic acids continues to decrease the values of dissolved sulphate, chloride and bicarbonate in the depth of 20–30 cm. Where the dissolved former mentioned salts were 5.35, 30.68 and 0.27 mmol L^{-1} respectively. Contrastingly, the average values of dissolved sulphate, chloride and bicarbonate in the absence of humic acids were 5.51, 34.62 and 0.86 mmol L^{-1}, respectively, for the same depth, with a decrease of 2.90, 11.38, and 68.60%, respectively. Regarding the effect of mineral fertilizer application, mineral fertilizers led to a decrease in the values of chloride and bicarbonate for the three soil depths, where the lowest values resulted from the treatment R2, while the highest resulted from the treatment R9. Concerning the sulphate, its values were varied because the potassium fertilizer contains sulphate, thus it increased with the increase in the levels of potassium sulphate fertilizer addition. Decreasing the concentration of dissolved sulphates, chlorides and bicarbonates in the soil under the effect of humic acids may be attributed to the role of humic acids in improving the soil's physical properties such as soil structure, bulk density and porosity, increasing permeability and increasing the rate of leaching in the soil (Paksoy *et al.*, 2010; Turan *et al.*, 2011). The research findings are in agreement with Aydin *et al.* (2012) and Khattak and Dost (2014).

Table 5. Effect of humic acids and the amount of mineral fertilizer on dissolved SO_4, Cl, and HCO_3 for the three different soil depths (0–10, 10–20 and 20–30 cm) after planting

Soil depth, cm	Levels of humic acids. g L^{-1}	Supplied mineral fertilizer (%) R1	R2	R3	R4	R5	R6	R7	R8	R9	Average of
						SO_4, mmol L^{-1}					humic acids
0–10	H0 (0.00)	4.00	4.70	4.41	4.61	4.19	4.55	4.22	4.00	4.14	4.31
10–20		5.00	5.00	5.25	5.22	5.62	5.11	5.13	5.00	5.25	5.17
20–30		5.30	5.32	5.86	6.00	5.9	5.56	5.23	5.14	5.31	5.51
0–10	H1 (0.35)	3.22	3.37	3.8	4.06	4.10	4.00	3.72	3.66	3.67	3.73
10–20		4.00	3.43	4.00	5.11	4.32	4.19	4.40	4.53	5.00	4.33
20–30		5.35	5.73	5.46	5.80	5.11	5.22	5.11	5.26	5.13	5.35
											mineral fertilizer
0–10	Average of mineral fertilizer	3.61	4.03	4.10	4.33	4.14	4.27	3.97	3.83	3.90	4.02
10–20		4.50	4.21	4.62	5.16	4.97	4.65	4.76	4.76	5.12	4.75
20–30		5.32	5.52	5.66	5.90	5.50	5.39	5.17	5.20	5.22	5.43
						Cl, mmol L^{-1}					humic acids
0–10	H0 (0.00)	25.22	16.75	20.08	24.75	24.41	26.66	26.15	33.43	32.08	25.50
10–20		30.41	26.75	30.18	29.75	30.90	30.22	31.11	34.32	34.11	30.86
20–30		33.45	30.18	33.41	34.12	35.45	35.55	36.31	36.43	36.75	34.62
0–10	H1 (0.35)	13.47	13.41	13.43	13.41	13.41	17.46	16.75	14.75	17.44	14.83
10–20		27.75	22.06	26.45	25.55	25.41	20.44	20.45	19.75	20.50	23.15
20–30		31.19	29.42	29.34	30.27	29.22	31.67	31.98	31.42	31.65	30.68
											mineral fertilizer
0–10	Average of mineral fertilizer	19.34	15.08	16.75	19.08	18.91	22.06	21.45	24.09	24.76	20.16
10–20		29.08	24.40	28.31	27.65	28.15	25.33	25.78	27.03	27.30	27.00
20–30		32.32	29.80	31.37	32.19	32.33	33.61	34.14	33.92	34.20	32.65
						HCO_3, mmol L^{-1}					humic acids
0–10	H0 (0.00)	0.54	0.50	0.50	0.52	0.52	0.56	0.58	0.61	0.59	0.54
10–20		0.62	0.60	0.61	0.62	0.63	0.72	0.67	0.67	0.66	0.64
20–30		0.86	0.80	0.82	0.85	0.84	0.88	0.9	0.89	0.90	0.86
0–10	H1 (0.35)	0.11	0.10	0.10	0.11	0.11	0.13	0.19	0.18	0.19	0.13
10–20		0.17	0.16	0.16	0.16	0.17	0.21	0.22	0.25	0.25	0.19
20–30		0.21	0.20	0.21	0.21	0.20	0.34	0.35	0.35	0.39	0.27
											mineral fertilizer
0–10	Average of mineral fertilizer	0.32	0.30	0.30	0.31	0.31	0.34	0.38	0.39	0.39	0.33
10–20		0.39	0.38	0.38	0.39	0.4	0.46	0.46	0.46	0.45	0.41
20–30		0.53	0.50	0.51	0.53	0.52	0.61	0.62	0.62	0.64	0.56

R1 to R9 – fertilizer (92 kg N ha^{-1}, 200 kg P_2O_5 ha^{-1}, 150 kg K_2O ha^{-1}) application rates (100, 100, 100%), (120, 120, 120%), (120, 120, 100%), (80, 120, 120%), (100, 100, 120%), (80.100, 100%), (120, 80, 80%), (100, 80, 80%), (80, 80, 80%), respectively.

While decreasing the concentration of chloride and bicarbonate in the soil by increasing the application of mineral fertilizers could attribute to the increase in plant growth and consequently uptake of relatively larger amounts of these ions, which is reflected in decreasing their concentration in the soil solution with depth (Sayyad-Amin *et al.,* 2018) .while increasing the sulfate concentration, probably due to release the sulfur from the applied fertilizer, which causes an increase in the dissolved amount in the soil (Klikocka, Marks 2018).

Effect of humic acids and the amount of mineral fertilizer on some growth and yield components of broccoli

Table 6 presents the effect of mixing humic acids with irrigation water and the fertilizer recommendation on growth and some yield components of broccoli (plant height, leaf area, head weight per plant). The results show a significant increase in the aforementioned traits under the effect of humic acids, where the average plant height reached 35.75 cm for the H1 level of humic acids and 25.29 cm in the absence of humic acids (H0), with an increase of 41.36% compared to without humic acids treatment. Likewise, the average leaf area increased under the effect of humic acids achieving 215.52 cm^2 for treatment H1, while the treatment H0 gave 138.40 cm^2 with an increase of 55.72%. Similarly, humic acids led to an increase in the head weight per plant. Where the highest head weight resulted from the treatment H1 by achieving 246.46, g plant^{-1} while the lowest weight was obtained from the treatment H0 by achieving 117.73 g plant^{-1}, with an increase of 109.34%. In the same way, the mineral fertilizer led to a significant increase in the plant height reaching 36.17 cm at the treatment R2, while the lowest value of plant height was 27.03 cm at the treatment R9 with an increase of 33.81%, the highest average in leaf area was 211.82 cm^2 at the treatment R2, and the lowest average in leaf area was 135.28 cm2 at the treatment R9 with an increase of 56.57%, while the highest head weight per plant was 271.74 g and lowest head weight per plant was 120.50 g plant^{-1}, with an increase of 125.51%.

The interaction effect of humic acids, and the amount of mineral fertilizer, show significant differences in the traits of plant height, leaf area, and head weight per plant. The highest value of the plant height trait was 41.75 cm at the combination of H1R2. While the lowest was 23.13 cm at the combination of H0R9. Regarding the leaf area, the highest value of the leaf area has resulted from the combination H1R2 reaching 244.22 cm^2. While the lowest value of the leaf area trait was 85.39 cm^2 obtained from the combination H0R9. Concerning head weight per plant, the highest and lowest head weight per plant was 368.60 and 74.82 g plant^{-1} attained from the combination of H1R2 and H0R9 respectively. The study revealed that the main reason for the increase in the plant height, leaf area, and head weight per plant was probably because humic acids change the pattern of carbohydrate metabolism, leading to the accumulation of soluble sugars that increase the osmotic pressure inside the cell walls thus make the plant more resistant to osmotic stresses moreover, humic acids increase the availability of crucial nutrients in the vegetative growth of plants such as nitrogen, phosphorous and potassium (Suh *et al.,* 2014) also the absorption of humic acids increase the division and elongation of cells, which is positively reflected in increased growth and leads to an increase in the level of protein representation and synthesis of DNA and RNA within the plant Pettit, 2004). Furthermore, humic acids enhanced the soil's chemical, physical and biological properties (Chen, Aviad, 1990), consequently reducing the effect of toxic elements and improving the plant's resistance to saline stresses, so, which affected the aforementioned traits. These results are in agreement with the findings of Asik *et al.* (2009).

Table 6. Effect of humic acids applied and saline irrigation water and the amount of mineral fertilizer on plant height (cm), leaf area (cm^2), head weight (g) per plant of broccoli

Levels of mineral fertilizer	Plant height, cm			Leaf area, cm^2			Head weight, g plant^{-1}		
	Levels of humic acids, g L^{-1}		Average of fertilizer	Levels of humic acids, g L^{-1}		Average of fertilizer	Levels of humic acids, g L^{-1}		Average of fertilizer
	H0	H1		H0	H1		H0	H1	
R1	24.80	34.18	29.49	136.26	220.45	178.35	125.32	234.90	180.11
R2	30.60	41.75	36.17	179.43	244.22	211.82	174.88	368.60	271.74
R3	27.40	40.67	34.03	170.37	231.47	200.92	159.89	349.67	254.78
R4	25.60	38.90	32.25	160.73	227.84	194.28	136.43	309.39	222.91
R5	25.04	35.55	30.29	148.97	225.69	187.33	131.68	244.22	187.95
R6	23.83	33.58	28.70	131.04	210.74	170.89	94.55	194.85	144.70
R7	23.67	33.25	28.46	119.98	200.30	160.14	86.67	185.77	136.22
R8	23.55	32.94	28.24	113.43	193.82	153.62	75.35	177.68	126.51
R9	23.13	30.94	27.03	85.39	185.18	135.28	74.82	166.19	120.50
Average of humic acids	25.29	35.75		138.4	215.52		117.73	247.91	
$LSD_{0.05}$									
H		0.392			2.034			6.55	
R		0.913			4.315			13.62	
R*H		1.167			6.103			19.59	

R1 to R9 – fertilizer (92 kg N ha^{-1}, 200 kg P_2O_5 ha^{-1}, 150 kg K_2O ha^{-1}) application rates (100, 100, 100%), (120, 120, 120%), (120, 120, 100%), (80, 120, 120%), (100, 100, 120%), (80.100, 100%), (120, 80, 80%), (100, 80, 80%), (80, 80, 80%), respectively.
H0 and H1 – with and without humic acid (H0 = 0.00 g L^{-1} and H1 = 0.35 g L^{-1})

While increasing the plant height in response to the mineral fertilizer, probably due to the increase of fertilizer application that increased the availability of nitrogen, phosphorous and potassium ions in the soil solution consequently the plant will uptake an adequate amount of limiting nutrients such as nitrogen, phosphorous and potassium. which increases plant growth as a result of the vital role of these elements in vegetative growth, division and elongation of the meristematic cells by achieving a perfect swelling of the cell wall, the accumulation of carbohydrates in the stem and an increase in the number of nodes, thickness and elongation of the stem, which positively affected the increase of these traits.

Conclusion

The present study indicated that using the humic acids and chemical fertilizers reduced soil salinity and the concentration of harmful ions in the soil solution on plant growth, consequently reducing the effect of salt stress in saline soil which positively reflected in the increase of the growth and production of broccoli. Also, the combination of d the humic acids with mineral fertilizers reduced the electrical conductivity and SAR, sulfate ions, chloride, bicarbonate and sodium, and increased the concentration of calcium and magnesium in the soil. Additionally, led to an increase in the growth and yield components of broccoli.

Acknowledgements

This study was supported by the Upper Euphrates basin Developing Centre, the University of Anbar. The authors also appreciate the efforts of the academic and supporting staff of the Upper Euphrates basin Developing Centre, for providing all the required assistance and materials in conducting this research.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Funding statement

This research did not receive any specific grants from funding agencies in the public, commercial, or not-for-profit sectors.

Author contributions

MNAA-F – designed the experimental setup;
KHA-D – analysed the data and results, and wrote the manuscript;
ETAG, KJF – performed biochemical analyses;
DKAA-T – editing the manuscript.

References

Abou El Magd, M.M., Hoda M.A. 2005. Relationships, growth, yield of broccoli with increasing N, P or K ratio in a mixture of NPK fertilizers. – Annals of Agricultural Science Moshtohor, 43(2):791–805.

AL-Azawi, S.S.M. 2015. Effect of water quality and kinetin treatment on growth and catalase activity of maize seedlings (*Zea mays* L.). – Journal of Babylon University : Journal of Applied and Pure Sciences, 23(4):1676–1685

Ali, N.M., Altaey, D.K.A., Altaee, N.H. 2021. The impact of selenium, nano (SiO_2) and organic fertilization on growth and yield of potato *Solanum tuberosum* L. under salt stress conditions. – IOP Conference Series: Earth and Environmental Science. 2nd Virtual International Scintific Agrticultural Conference 21-22 January 2021, Iraq, 735, 012042, 6 p. DOI:10.1088/1755-1315/735/1/012042

Al-Khafajy R.A., AL-Taey D.K.A., AL-Mohammed, M.H.S. 2020. The impact of water quality, bio fertilizers and selenium spraying on some vegetative and flowering growth parameters of *Calendula officinalis* L. under salinity stress. – International Journal of Agricultural and Statistical sciences, 16(Supp.1:1175–1180.

AL-Taey, D.K.A., Burhan, A.K. 2021. The effect of water quality, cultivar, and organic fertilizer on growth and yield of volatile oil carvone and limonene in Dill. – International Journal of Vegetable Science, 27(5)1–7. DOI: 10.1080/19315260.2021.1970075

Ashraf, M. 2004. Some important physiological selection criteria for salt tolerance in plants. – Flora-Morphology, Distribution, Functional Ecology of Plants, 199(5):361–376.

Asik, B.B., Turan, M.A. Celik, H., Vahap Katkat, A.V. 2009. Effects of humic substances on plant growth and mineral nutrients uptake of wheat (*Triticum durum* cv. Salihli) under conditions of salinity. – Asian Journal of Crop Science, 1:87–95. DOI: 10.3923/ajcs.2009.87.95

Aydin, A., Kant, C. and Turan, M. 2012. Humic acid application alleviate salinity stress of bean (*Phaseolus vulgaris* L.) plants decreasing membrane leakage. – African Journal of Agricultural Research, 7(7):1073–1086.

Ayers, R.S., Westcot, D.W.1985. Water quality for agriculture. – FAO Irrigation and drainage paper 29, Rev. 1. Food and Agricultural Organization, Rome, 1, 74 p.

Bacilio, M., Moreno, M., Bashan, Y. 2016. Mitigation of negative effects of progressive soil salinity gradients by application of humic acids and inoculation with *Pseudomonas stutzeri* in a salt-tolerant and a salt-susceptible pepper. Applied Soil Ecology, 107:394–404.

Borzouei, A. Eskandari, A., Kafi, M., Mousavishalmani, A., Khorasani, A. 2014. Wheat yield, some physiological traits and nitrogen use efficiency response to nitrogen fertilization under salinity stress. – Indian Journal of Plant Physiology, 19(1):21–27. DOI: 10.1007/s40502-014-0064-0

Bremner, J.M., Mulvaney, C.S. 1982. Nitrogen-Total. – In: Methods of soil analysis. Part 2. Chemical and microbiological properties, Page, A.L., Miller, R.H. and Keeney, D.R. (Eds.). – American Society of Agronomy, Soil Science Society of America, Madison, Wisconsin, pp. 595–624.

Canellas, L.P. Olivares, F.L., Aguiar, N.O. Jonesb D.L., Nebbioso, A., Mazzei, M., Piccolo, A. 2015. Humic and fulvic acids as biostimulants in horticulture. – Scientia Horticulturae, 196:15–27. DOI: 10.1016/j.scienta.2015.09.013

Chen, M., Yang, Z., Liu, J., Zhu, T., Wei, X., Fan, H., Wang, B. 2018. Adaptation mechanism of salt excluders under saline conditions and its applications. – International Journal of Molecular Sciences, 19(11):3668. DOI: 10.3390/ijms19113668

Chen, Y., Aviad, T. 1990. Effects of humic substances on plant growth. – In Humic substances in soil and crop sciences: Selected readings. MacCarthy, P., Clapp, C.E., Malcolm, R.L., Bloompp, P.R (Eds.). – American Society of Agronomy, Inc. Soil Science Society of America, Inc., pp. 161–186. DOI: 10.2136/1990.humicsubstances.c7

Idrissi, Y.E., Baghdad, B., Saufi, H., El Azzouzi, M., Benchrif, A., El Hasini S., El Mekkaoui, A., El Azzouzi, E. 2019. Assessment of trace metal contamination in peri-urban soils in the region of Kenitra-Morocco. – Mediterranean Journal of Chemistry, 8(2):108–114. DOI: 10.13171/mjc8219042505mea

Hatami, E. 2018. Alleviating salt stress in almond rootstocks using of humic acid. – Scientia Horticulturae, 237:296–302. DOI: 10.1016/j.scienta. 2018.03.034

Hussain, I., Ali, I., Ullah, S., Iqbal, A., Al Tawaha, A.R., Al-Tawaha,A.RA., Thangadurai, D., Sangeetha, J., Rauf, A., Saranraj, P., Al Sultan, W., AL-Taey, D.K.A., Youssef, R.A. Sirajuddin, S.N. 2021. Agricultural soil reclamation and restoration of soil organic matter and nutrients via application of organic, inorganic and bio fertilization. – IOP Conference Series: Earth and Environmental Science. The 3rd International Conference of Animal Science and Technology 3-4 November 2020, Makassar, Indonesia, 788, 012165. DOI: 10.1088/1755-1315/788/1/012165

Jackson, M.L. 1967. Soil Chemical Analysis. – Prentice Hall Inc. Englewood cliffs, NJ, USA, 498 p.

Khan, M.A.M., Ulrichs, C., Mewis, I. 2010. Influence of water stress on the glucosinolate profile of *Brassica oleracea* var. Italica and the performance of *Brevicoryne brassicae* and *Myzus persicae*. – Entomologia Experimentalis et Applicata, 137(3):229–236. DOI: 10.1111/j.1570-7458.2010.01059.x

Khattak, A.M.R.A., Dost, M. 2014. Humic acid and micronutrient effects on wheat yield and nutrients uptake in salt affected soils. – International Journal of Agriculture and Biology, 16(5):991–995.

Kiremit, M.S., Arslan, H. 2016. Effects of irrigation water salinity on drainage water salinity, evapotranspiration and other leek (*Allium porrum* L.) plant parameters. – Scientia Horticulturae, 201:211–217. DOI: 10.1016/j.scienta.2016.02.001

Klikocka, H., Marks, M. 2018. Sulphur and nitrogen fertilization as a potential means of agronomic biofortification to improve the content and uptake of microelements in spring wheat grain DM. – Journal of Chemistry, 2018:9326820. DOI: 10.1155/2018/ 9326820.

Machado, R.M.A., Serralheiro, R.P. 2017. Soil salinity: effect on vegetable crop growth. Management practices to prevent and mitigate soil salinization. – Horticulturae, 3(2):30. DOI: 10.3390/horticulturae 3020030

Mahmood S.S., Taha, S.M.,Taha, A. M. AL-Taey, D. K. A. 2020. Integrated agricultural management of saline soils of sowaira, wasit governorate. – International Journal of Agricultural and Statistical Sciences, 16(1):113–119.

Munns, R., 2002. Comparative physiology of salt and water stress. – Plant, Cell and Environment, 25(2):239–250. DOI: 10.1046/j.0016-8025.2001.00808.x

Nan, J., Chen, X., Wang, X., Lashari, M.S., Wang, Guo, Y.W., Du, Z. 2016. Effects of applying flue gas desulfurization gypsum and humic acid on soil physicochemical properties and rapeseed yield of a saline-sodic cropland in the eastern coastal area of China. – Journal of Soils Sediments, 16:38–50. DOI: 10.1007/s11368-015-1186-3

Olsen, S.R., Sommers, L.E. 1982. Phosphorus. – In Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties, 9.2.2, 2nd Edition. Page, A.L. (Eds.). – The American Society of Agronomy, Inc., Soil Science Society of America, Inc, pp. 403–430. DOI: 10.2134/agronmonogr9.2.2ed.c24

Paksoy, M., Türkmen, Ö., Dursun, A. 2010. Effects of potassium and humic acid on emergence, growth and nutrient contents of okra (*Abelmoschus esculentus* L.) seedling under saline soil conditions. – African Journal of Biotechnology, 9(33):5343–5346.

Pardo, J.M., Rubio, F. 2011. Na+ and K+ transporters in plant signaling. – In Transporters and Pumps in Plant Signalling. Geisler, M., Venema, K. (Eds.). – Springer Berlin, Heidelberg, Germany, pp. 65–98. DOI: 10.1007/978-3-642-14369-4_3

Pettit, R.E. 2004. Organic matter, humus, humate, humic acid, fulvic acid and humin: their importance in soil fertility and plant health. – CTI Research, 15 p.

Pereira, L.S., Cordery, I., Iacovides, I. 2009. Coping with water scarcity: Addressing the challenges, – Springer Science and Business Media, 382 p. DOI: 10.1007/978-1-4020-9579-5

Polemio, M., Rhoades, J.D. 1977. Determining cation exchange capacity: A new procedure for calcareous and gypsiferous soils. – Soil Science Society of America Journal, 41(3):524–528. DOI: 10.2136/sssaj1977.03615995004100030018x

Rahmati, A., Gholamianb, M., Rostamic, S., Amirpourd, M., Safarie H., Mohammadifg A.H. 2019. An efficient model for estimation of gypsum (calcium sulfate di-hydrate) solubility in aqueous electrolyte solutions over wide temperature ranges. – Journal of Molecular Liquids, 281:655–670. DOI: 10.1016/j.molliq.2019.02.077

Redeef, M.A., AL-Taey, D.K.A., AL-Attabi, B.R.H. 2021. Effect of salt stress and nano SiO_2 on growth, flowering and active components in *Tagete erecta* L. – Plant Cell Biotechnology and Molecular Biology, 22(1–2):152–158.

Richards, L.A. 1954. Diagnosis and improvement of saline and alkali soils. – Agriculture Handbook No. 60. – US Department of Agriculture, Washington, DC, USA, 159 p.

Rose, M.T. Patti, A.F., Little, K.R., Brown, K.L., Jackson, W.R., Cavagnaro, T.R. 2014. A meta-analysis and review of plant-growth response to humic substances: practical implications for agriculture. – Advances in Agronomy, 124:37–89. DOI: 10.1016/B978-0-12-800138-7.00002-4

Sahi, C., Singh, A., Blumwald, E., Grover A. 2006. Beyond osmolytes and transporters: novel plant salt-stress tolerance-related genes from transcriptional profiling data. – Physiologia Plantarum, 127(1):1–9. DOI: 10.1111/j.1399-3054.2005.00610.x

Sani, B. 2014. Foliar application of humic acid on plant height in canola. – APCBEE Procedia, 8:82–86. DOI: 10.1016/j.apcbee.2014.03.005

Sayyad-Amin, P., Borzouei, A., Jahansooz, M., Ajili F. 2018. The response of wild type and mutant cultivars of soybean to salt stress-comparing vegetative and reproductive phases on the basis of leaf biochemical contents, RWC, and stomatal conductance. – Archives of Agronomy and Soil Science, 64(1):58–69. DOI: 10.1080/03650340.2017.1328733

Singh, A., 2014. Conjunctive use of water resources for sustainable irrigated agriculture. – Journal of Hydrology, 519(B):1688–1697. DOI: 10.1016/j.jhydrol.2014.09.049

Sotelo, T., Soengas, P., Velasco, P., Rodríguez, V.M., Cartea, M.E. 2014. Identification of metabolic QTLs and candidate genes for glucosinolate synthesis in *Brassica oleracea* leaves, seeds and flower buds. – PLoS ONE, 9(3):e91428. DOI: 10.1371/journal.pone.0091428

Suh, H.Y., Yoo, K.S., Suh, S.G., 2014. Tuber growth and quality of potato (*Solanum tuberosum* L.) as affected by foliar or soil application of fulvic and humic acids. – Horticulture, Environment, and Biotechnology, 55(3):183–189. DOI: 10.1007/s13580-014-0005-x

Tchiadje, N.F.T. 2007. Strategies to reduce the impact of salt on crops (rice, cotton and chili) production: A case study of the tsunami-affected area of India. – Desalination, 206(1–3):524–530. DOI: 10.1016/j.desal.2006.03.579

Tester, M., Davenport, R., 2003. Na+ tolerance and Na+ transport in higher plants. – Annals of Botany, 91(5):503–527. DOI: 10.1093/aob/mcg058

Turan, M.A. Aşik, B.B., Katkat, A.V., Çelik, H. 2011. The effects of soil-applied humic substances to the dry weight and mineral nutrient uptake of maize plants under soil-salinity conditions. – Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 39(1):171–177. DOI: 10.15835/nbha3915812

Zhang, W.-Z. Chen, X.-Q., Zhou, J-M., Liu, D.-H., Wang, H.-Y., Du, C.-W. 2013. Influence of humic acid on interaction of ammonium and potassium ions on clay minerals. – Pedosphere, 23(4):493–502. DOI: 10.1016/S1002-0160(13)60042-9

Agraarteadus
1 • XXXIII • 2022 21–32

Journal of Agricultural Science
1 • XXXIII • 2022 21–32

RESEARCH OF MECHANIZED PROCESS OF ORGANIC WASTE COMPOSTING

Elchyn Aliiev[1], Sergey Pavlenko[2], Gennadii Golub[2], Olena Bielka[1]

[1]*Institute of Oilseed Crops of the National Academy of Agrarian Sciences of Ukraine, 1 Instituts'ka St, v. Sonyachne, Zaporizhzhya region, 69093, Ukraine*
[2]*National University of Life and Environmental Sciences of Ukraine, 11 Heroyiv Oborony St, Kyiv, 03041, Ukraine*

Saabunud: Received:	04.03.2022
Aktsepteeritud: Accepted:	22.03.2022
Avaldatud veebis: Published online:	22.03.2022
Vastutav autor: Corresponding author:	Elchyn Aliiev

E-mail: aliev@meta.ua

ORCID:
0000-0003-4006-8803 (EA)
0000-0003-3352-5797 (SP)
0000-0002-2388-0405 (GG)
0000-0002-7243-5404 (OB)

Keywords: mechanized composting, aerator-mixer, modelling, experiments, parameters, dependencies.

DOI: 10.15159/jas.22.04

ABSTRACT. The article is devoted to mechanising composting based on energy-saving technical systems. The goal of the research is to determine the patterns that describe the impact of different drum-blade working bodies' design and technological parameters on their work energy performance, the homogeneity of the mixture components distribution and their structure in the formed composting pad of a certain height. The physical-mathematical model of the mechanized composting process of organic raw materials from agroecosystems by technical equipment with drum-blade working bodies has been theoretically substantiated and experimentally investigated. There has been developed the mathematical model that correlates the value of the mixing quality variation coefficient with the load factor and the kinematic indicator of the operating mode. It has been established that, if provided the composting pad layer height is the same, the use of a double-drum working body is more rational in terms of power loss in comparison with a single-drum one.

Introduction

Mechanized composting based on energy-intensive technical systems was economically feasible due to additional crop production (Center for Clean Air Policy, 2019; Modupe *et al.*, 2020; Kiyonori, 2021). In modern conditions of the financial, material and raw material resources shortage usage of these technologies and technical equipment leads to increased production costs and economic inexpediency of controlled composting in many cases as production costs are not covered by increased yields from their use. (Baba *et al.*, 2018; Pergolaa *et al.*, 2018a; Pergolaa *et al.*, 2018b; Singh *et al.*, 2020). As a result, there is a problematic situation: on the one hand, there is a need to increase the application of organic fertilizers to restore soil fertility, provided the actual significant reduction in manure. On the other hand, there is an inconsistency of existing technologies and technical equipment with social requirements and economic feasibility.

It's not the first time the topic of mechanized livestock waste composting being researched (Nelson, 2002; Golub, 2007; Golub *et al.*, 2017a; Golub *et al.*, 2017b; Nghi *et al.*, 2020; Aliiev *et al.*, 2021). Modern technological equipment for mechanized composting technologies today can be divided into three basic groups of machines: usage of modernized and adapted to economic conditions trailers-spreaders for organic fertilizers, loaders, road-building machines; usage of aerators-mixers – trailed, mounted, self-propelled, tunnel, aerator-mixer loaders with the intermittent operation; usage of aerator-mixer loaders with the continuous operation – self-propelled or trailed.

Monitoring of constructive solutions of the technological equipment models for mechanized compost production technologies has shown that manufacturers offer technical tools that provide different economic and technological conditions. Therefore, the variety of technical solutions is quite large. The following leading companies and corporations that develop and manufacture aerators-mixers and other composting equipment can be listed: Sittler MFG, Brown Bear (Australia), TAGR (China), BACKHUS, Menart, Compost systems GMBH, Gujer Landmaschinen (Germany), ALLU Group, Sandberger (Finland), Frontier, HCL Machine, Wildcat, SCARAB (USA), ABONO (Turkey), Caravaggi, PEZZOLATO (Italy), KOMPTECH, Morawetz (Austria), *etc*.

The only common thing between aerators-mixers is the performance of the working bodies (Fig. 1). The main structural elements that the drum-blade working bodies consist of are the drum, inclined blades, straight blades, or screws. Straight blades are located radially in the centre of the drum. Inclined blades are installed symmetrically from the drum centre (respectively symmetrical to the straight blades) and fixed along the helical winding lines. The inclined blades' attack angle differs from the angle of the helix. When running, the drum-blade working body performs both translational and rotational movements and, as a result, interacts with the compacted compost material. While cutting into the structure of the compost material, inclined blades or a screw, separate a certain part of the compost material and at the same time separate the portion (chips), mix, loosen, move and throw it behind the drum, forming a new composting pad as a result. Straight blades that work in the area of the greatest height of the composting pad, separate the material from the pad's mass, overturn it with a one-time formation of a new pad. The presence of a technologically free zone behind the working body, which limits the possibility of re-transfer of the compost mass, is an important parameter. During the operation of both straight and inclined blades (screw), the mixture in the separated particles flight zone becomes saturated with oxygen and weathering of carbon dioxide is formed because of microbiological processes. Reforming of the composting pads is also followed by a decrease in mass temperature, weathering of moisture and other gaseous substances.

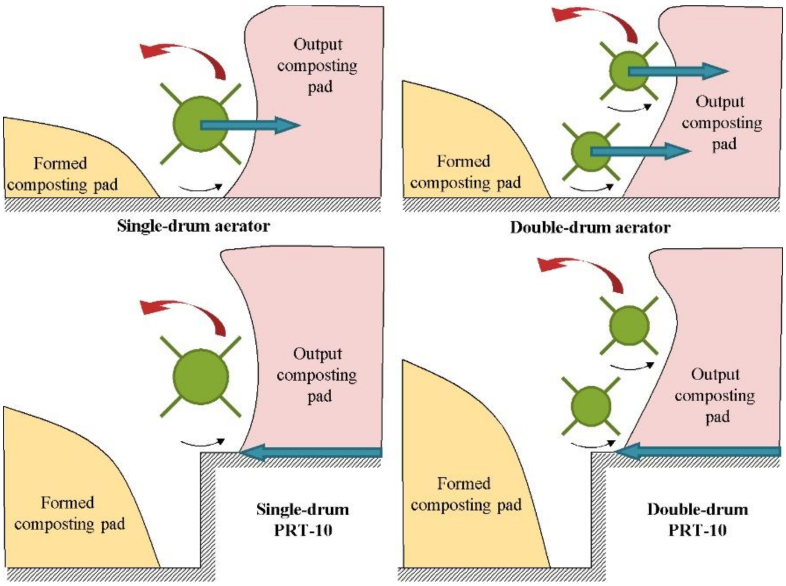
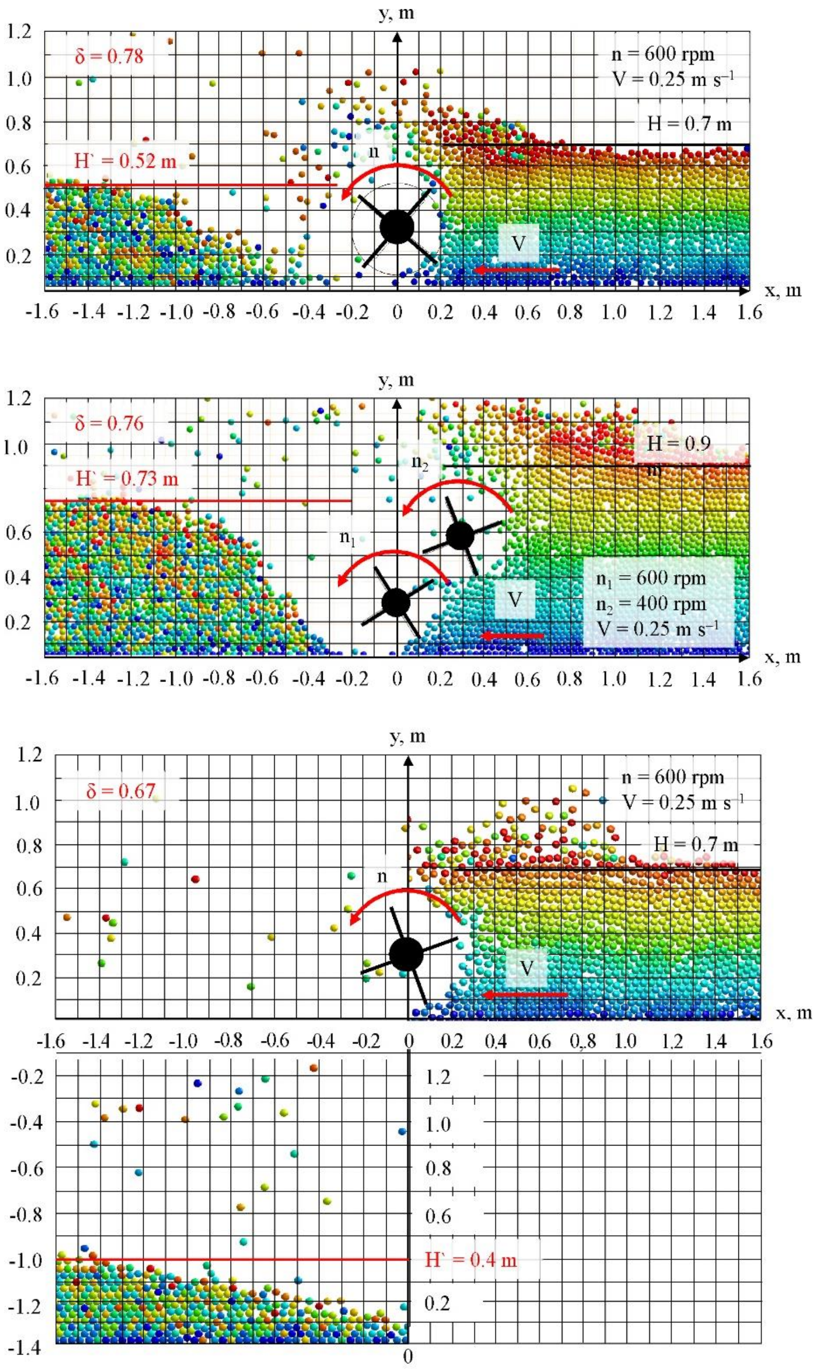


Figure 1. Rotary drum-blade grinding, mixing and formatting machines operation schemes

Many researchers (Mironov, 2006; Golub, 2007; Petunov, 2007; Kudrya, 2015; Golub *et al.*, 2017a; Shevchenko, Aliiev, 2021) are devoted to studying the process of interaction of certain types of working bodies with the manure-compost mixture, which is formed into composting pads. However, it is very difficult to compare the results of these studies due to different conditions. Therefore, the goal of the research is to determine the laws that describe the influence of design and technological parameters of different drum-blade working bodies on the energy performance of their work, the homogeneity of the mixture components and their structure in the formed composting pad with a certain height.

Numerical Simulation Results

To implement numerical simulation in the software package Simcenter Star CCM+ (Siemens Digital Industries Software, Germany) we have made the calculation scheme of the manure-compost mixture mixing process by a single-drum blade working body in two versions (Fig. 2a,b) and a double-drum blade working body in one embodiment (Fig. 2c). Simcenter Star-CCM + software uses numerical simulation methods based on models of k-ε turbulence of split flow, gravitational field, real Van der Waals gas, discrete elements, multiphase interaction to solve this issue (Shevchenko, Aliiev, 2021).



a

b

c

a– single-drum blade working body at the level of the original composting pad;
b – single-drum blade working body at the level higher than original composting pad;
c – double-drum blade working body at the level of the original composting pad

Figure 2. Calculated scheme of the manure-compost mixture mixing process

To model the manure-compost mixture mixing process with a single-drum blade working body, the following design and technological parameters have been adopted: outer radius R = 0.2 m; shaft radius r = 0.05 m; blade thickness $\delta = 0.004$ m; the height of the option "a" location (Fig. 2) h = 0.22 m; the height of the option "b" location (Fig. 2) h = 1.42 m. The following design and technological parameters have been used as modelling factors: speed n (200–600 rpm, step – 200 rpm), the linear speed of movement of the working body (or manure-compost mixture) V (0.05–0.25 m s^{-1}, step – 0.1 m s^{-1}) and the height of the output composting pad H (0.3–0.7 m, step – 0.2 m).

The following design and technological parameters have been used to model the manure-compost mixture mixing process with a double-drum blade working body: outer radii of the first and second drum $R_1 = R_2 = 0.2$ m; the radius of the first and second drums shaft $r_1 = r_2 = 0.05$ m; blade thickness $\delta = 0.004$ m; the height of the first drum location $h_1 = 0.22$ m; the height of the second drum location $h_2 = 0.41$ m. The following design and technological parameters have been used as modelling factors: speed of the first drum rotation n1 (200–600 rpm, step – 200 rpm), frequency of the second drum rotation n_2 (200–600 rpm, step – 200 rpm), the linear velocity of the working body (or manure-compost mixture) V (0.05–0.25 m s^{-1}, step – 0.1 m s^{-1}).

The simulation has been performed on a full factorial experiment with a total number of experiments – $3^3 = 27$. To summarize the data, we introduce the kinematic index of the operating mode λ and the load factor of the working body κ that are determined by the formulas:

$$\lambda = \frac{\omega R}{V}, \tag{1}$$

$$\kappa = \frac{H}{2R}. \tag{2}$$

The height of the obtained manure-compost mixture and the quality of its mixing, which has been determined by the coefficient of variation, have been determined as a modelling criterion

$$s\delta = 1 - \frac{1}{\overline{C}}\sqrt{\frac{\sum_{i=1}^{n}(C_i - \overline{C})^2}{n-1}}, \tag{3}$$

where $\overline{C}$ – the average concentration of material in the composting pad; C_i – material concentration in the i-th zone of the composting pad; n is the number of zones in the composting pad.

As a result of the compost mixture mixing process simulation and approximating the obtained data using the Mathematica software package (Wolfram Research, USA), the dependencies between the formed composting pad height H` and the coefficient of variation of mixing quality δ on rotational speeds n (n_1, n_2), the linear velocity of the working body movement (or compost mixture) V and the height of the output pad H:

– single-drum blade working body at the level of the original composting pad:

$$H` = 0.268866 + 0.296528\,H + 0.319444\,H^2 - 0.00103403\,n - 0.000208333\,H\,n + 9.02778\cdot10^{-7}\,n^2 - 1.05417\,V + 2.54167\,H\,V + 0.000125\,n\,V + 0.944444\,V^2; \tag{4}$$

$$\delta = 1.0964 + 0.413927\,H - 0.569826\,H^2 - 0.00161823\,n - 0.00023426\,H\,n + 1.44573\cdot10^{-6}\,n^2 - 1.94199\,V + 2.33282\,H\,V + 0.00149216\,n\,V + 1.84121\,V^2; \tag{5}$$

$$\delta = 0.667428 + 0.298578\,\kappa - 0.0911722\,\kappa^2 - 0.00112821\,\lambda - 0.000888689\,\kappa\,\lambda + 4.88711\cdot10^{-6}\,\lambda^2; \tag{6}$$

– single-drum blade working body higher than original composting pad:

$$H` = 0.186875 + 1.34236\,H + 1.5\,H^2 - 0.0016798\,n - 0.00129167\,H\,n + 2.08333\cdot10^{-6}\,n^2 + 1.70972\,V - 6.20833\,H\,V + 0.00120833\,n\,V - 3.33333\,V^2; \tag{7}$$

$$\delta = 1.16933 - 0.199309\,H - 0.184407\,H^2 - 0.000914836\,n + 0.000523364\,H\,n + 6.78265\cdot10^{-7}\,n^2 - 1.11349\,V + 1.03217\,H\,V - 0.000416279\,n\,V + 0.017169\,V^2; \tag{8}$$

$$\delta = 0.684991 + 0.0632616\,\kappa - 0.0295052\,\kappa^2 + 0.000994089\,\lambda - 0.000140935\,\kappa\,\lambda - 1.35072\cdot10^{-6}\,\lambda^2; \tag{9}$$

– double-drum blade working body at the level of the original composting pad:

$$H` = 0.97787 + 0.977778\,V - 2.11111\,V^2 - 0.000499306\,n_1 + 0.000291667\,V\,n_1 + 4.3055\cdot10^{-7}\,n_1^2 - 0.001878\,n_2 + 0.002708\,V\,n_2 - 2.29167\cdot10^{-7}\,n_1\,n_2 + 1.4305\cdot10^{-6}\,n_2^2; \tag{10}$$

$$\delta = 0.630425 - 0.357841\,V + 0.926431\,V^2 - 0.000119875\,n_1 - 0.000149469\,V\,n_1 + 2.50835\cdot10^{-7}\,n_1^2 + 0.00094284\,n_2 + 0.000114028\,V\,n_2 - 1.10538\cdot10^{-7}\,n_1\,n_2 - 1.04456\cdot10^{-6}\,n_2^2; \tag{11}$$

$$\delta = 0.721983 - 0.000132435\,\lambda_1 - 8.24555\cdot10^{-7}\,\lambda_1^2 + 0.00110122\,\lambda_2 + 2.33733\cdot10^{-6}\,\lambda_1\lambda_2 - 4.359\cdot10^{-6}\,\lambda_2^2. \tag{12}$$

Material and Methods

The program of experimental research includes:

– research of the universal device for grinding and mixing of solid organic fertilizers;
– research of the trailed fertilizer spreader PRT-10 with the double-drum hinged device for the firm organic fertilizers grinding;
– research of the aerator of manure-compost mixes with a double-drum working body.

Experimental studies of the grinding and mixing process of solid organic fertilizers have been carried out with the creation of the universal experimental installation, which consists of a plant, double-drum working bodies and an electric drive. The created device for solid organic fertilizers grinding and mixing can be placed on the trailed fertilizer spreader like PRT-10 (Fig. 3a) or on tracks that are placed on the ground (Fig. 3b). In the first case, the flow of solid organic fertilizers on the drum working bodies is carried out by a conveyor, and in the second case, it is performed by the movement mechanism of the device (Fig. 3c). It is also possible to install single or double-drum working bodies of a different configuration on the device (Fig. 3d,e).

The following factors were selected as factors of experimental research: manure type (factor A) – litter cow manure (density γ = 680–750 kg m$^{3\,-1}$; humidity W = 42–66%), bedding litter (density γ = 360–460 kg m$^{3\,-1}$; humidity W = 32–44%); location (factor B) – on a trailed spreader (type PRT-10), on tracks (aerator type); type of drum working body (factor C) – auger-blade type D = 350 mm (W-shaped), blade type D = 540 mm (V-shaped); number of drum working bodies (factor D) – 1, 2; rotation frequency of the drum working body, n (factor E) – 180, 320, 460 rpm. The frequencies of the lower and upper working bodies' rotation have been set via the transmission mechanisms. Experimental studies have been conducted according to the plan with a total of 36 experiments. We have used the coordinate plane with a unit size of 100 mm as a background to determine the trajectories of the compost particles. This process has been recorded on a video camera. Based on the obtained photographs, we have determined values of the greatest particle velocity V_p, the greatest particle flight altitude h_p, the greatest particle flight range, l_p. We have chosen the following values as criteria of experimental research: homogeneity of components distribution of the output compost mix δ, consumed power P, composting pad's structural indicator θ.

The calculated homogeneity of the distribution of the manure-compost mixture components of the pre-formed composting pad has been determined by the discrete feature method – humidity. Homogeneity in humidity is determined by the coefficient of variation

$$\delta_i = 1 - \upsilon_i = 1 - \frac{\sigma_i}{W_i}\,, \tag{13}$$

where υ_i is the coefficient of variation of the manure-compost mixture humidity in the experiment; σ_i is the standard deviation of humidity in a series of manure-compost mixture portions in the experiment; w_i is the arithmetic mean value of the moisture content in a series of manure-compost mixture portions in the experiment. For raw materials, the homogeneity in terms of humidity was 0.33–0.47. We have adopted repetition ten times to determine the manure-compost mixture homogeneity in terms of humidity.

a – location on a trailed fertilizer spreader PRT-10;
b – the location on tracks;
c – device moving mechanism;
d – V-shaped double-drum working body;
e – W-shaped single-drum working body

Figure 3. The general look of a universal experimental plant for grinding and mixing solid organic fertilizers

The composting pad's structural indicator θ has been defined as the total percentage of the most valuable fractions up to 5 mm:

$$\theta = \frac{m_{<5}}{M} 100\,\%, \qquad (14)$$

where $m_{<5}$ is the mass of the most valuable fractions up to 5 mm, g; M is the mass of the original sample, g. The mass of the original sample M is selected in the range of 200 to 300 g. Each measurement has been repeated 10 times.

The average value of power consumption P has been used as the energy criterion for evaluating the process of grinding and mixing solid organic fertilizers. The dynamics of changes in power consumption P has been determined by the frequency converter VLT Micro Drive (Danfoss, Denmark).

We have created an experimental plant based on the trailed fertilizer spreader PRT-10 with a two-drum mounted device for grinding solid organic fertilizers to carry out experimental studies of the compost mixture mechanical aeration and mixing process (Fig. 3a). The following constructive-technological parameters have been set as experimental researches factors: rotation frequency of the lower working body n_1 (170–490 rpm, step – 160 rpm), the rotation frequency of the upper working body n_2 (170–490 rpm, step – 160 rpm), linear movement velocity of the compost mixture (PRT-10 spreader's velocity) V (0.05–0.25 m s^{-1}, step – 0.1 m s^{-1}), location of the upper working body with the lower one L (–0.4...+0.4 m, step – 0.4 m). The simulation has been performed according to the Box-Benkin plan with a total of 27 experiments. On the second stage of the experiment, we have performed the calculation of research results with the following factors: kinematic index of the lower working body λ_1, kinematic index of the upper working body of the drum λ_2, location of the upper working body with the lower one L. Fresh litter based on sunflower husk (unloaded from the premises) with an average volume weight of γ = 480 kg $m^{3\,-1}$ and average humidity of W = 32.2% has been used as raw material for experimental research. Technological criteria for assessing the formation of the composting pad is its height H, which should be 1.5 m. This value is achieved by periodically moving the unit MTZ-80+PRT-10.

We have created an experimental plant based on the compost mixtures aerator with a double-drum working body (Fig. 3b) to carry out experimental studies of the compost mixture mechanical aeration and mixing process. The following constructive-technological parameters have been established as factors of experimental research: rotation frequency of the lower drum n_1 (180–460 rpm), the rotation frequency of the upper drum n_2 (180–460 rpm, step – 140 rpm), linear movement velocity of the working body V (0.05–0.15 m s^{-1}, step – 0.05 m s^{-1}), output composting pad's height H (0.5–1.1 m, step – 0.3 m). Rotation frequencies of the lower and upper working bodies have been set by changing the sprockets and chains on the transition mechanisms. The linear speed of the compost mixture movement has been set by changing the sprockets on the movement mechanism of the device. The height of the original composting pad has been formed by a fertilizer spreader PRT-10 conveyor. The simulation has been performed according to the Box-Benkin plan with a total of 27 experiments. The second stage is to obtain the results of studies with the following factors: the kinematic index of the lower working body λ_1, the kinematic index of the upper drum λ_2, the height of the output-composting pad H. We have set homogeneity in humidity as qualitative criteria for evaluating the process of mechanical aeration and the compost mixture mixing. Quantitative criteria for performance evaluation is capacity Q (m^3 h^{-1}). Energy criterion is the average value of power consumption P (kW). The criterion for evaluating the research is the specific energy consumption of the process, which has been determined by the expression $E = P/Q_p$ (kWh $m^{3\,-1}$).

We have used the method of mathematical planning of multifactor experiment, which allows obtaining mathematical models of work processes in the form of regression equations (polynomial) of the second-order to study the influence of each factor on the criterion of process optimization and determination of technical equipment's rational parameters. Processing of the experimental research results have been conducted by the method of mathematical factor planning of experiments and performed using the Mathematica software package. The mathematical model is determined by one optimization criterion. The regression coefficients of the mathematical model are calculated by formulas for D-optimal experimental plans. The confidence limits of the random error of the measurement results are calculated according to the Student's test. The adequacy of the model is checked using a correlation coefficient. The adequacy of the model is checked using Fisher's test.

Results

We have obtained the rational design variant of the developed universal device for cow manure grinding and mixing (single blade W-shaped drum working body mounted on a trailed spreader PRT-10 type, rotating at 460 rpm) using analysis of variance, this provides the greatest observed distribution homogeneity of the obtained compost mixture components $\delta = 0.98 \pm 0.1$ and the greatest composting pad's structural indicator $\theta = 90.4 \pm 0.2$ at the smallest average value of the consumed power – $P = 8.7 \pm 0.2$ kW. Thereafter, the rational design version of the developed universal device for manure grinding and mixing is the following: single-drum W-shaped working body, which is installed on the tracks (aerator) and rotates at a frequency of 460 rpm. With these parameters, the greatest distribution homogeneity of the obtained compost mixture components $\delta = 0.95 \pm 0.1$ is observed and the composting pad's structural indicator equals $\theta = 90.1 \pm 0.2$ at the smallest average value of the consumed power $P = 8.4 \pm 0.2$ kW.

The trajectories of the mixture particles have been experimentally determined for each experiment. Visualization of one of the experiments is shown in Figure 4 on which the trajectory of the particles of the compost mixture is visible and it is possible to determine for the particles the largest values of velocity V_p, flight altitude h_p and flight range l_p. Analysis of the obtained data shows that the highest velocity of compost mixture particles V_p = 13.1–13.4 m s^{-1} is observed for the variant of the universal device with a single-drum working body, which is installed on a trailed spreader PRT-10 type at the highest speed. In this case, for particles, the largest values are their flight altitude h_p = 6.2–6.5 m and flight range l_p = 18.9–19.8 m. Comparison of real trajectories of particles with theoretical shows that the correlation coefficient is R = 0.82–0.93 which allow us to state that the theoretical physical and mechanical models are adequate.

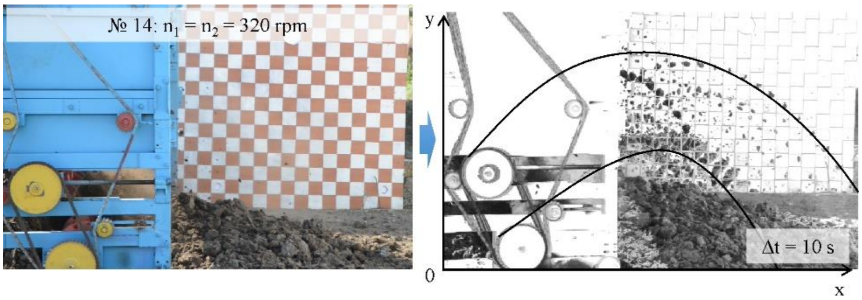


Figure 4. Visualization of the compost mixture particles movement process under the impact from the working bodies of the universal experimental installation

The following dependencies have been established because of experimental research of the trailed fertilizers spreader PRT-10 with the double-drum hinged device for the solid organic fertilizers grinding:

– average power consumption value P

$$P = 3.88672 + 0.764405\,L + 0.922574\,L^2 - 0.00828371\,n_1 + 0.000198171\,L\,n_1 + 0.0000146636\,n_1^2 - 0.0021879\,n_2 - 3.0726\cdot10^{-7}\,n_1 n_2 + 6.46516\cdot10^{-6}\,n_2^2 - 1.4447\,V - 0.641768\,L\,V + 0.000320122\,n_1 V - 0.000301067\,n_2 V + 15.313\,V^2; \quad (15)$$

– compost mixture homogeneity δ_W

$$\delta = 0.542498 - 0.330861\,L + 0.0013886\,n_1 - 1.69596Ч10^{-6}\,n_1^2 - 0.000102664\,n_2 + 0.000398441\,L\,n_2 - 1.04511\,V + 0.3625\,L\,V + 0.00153125\,n_1 V + 0.0025\,n_2 V - 2.7604\,V^2. \quad (16)$$

We have established rational constructive-technological parameters of the developed hinged device for solid organic fertilizers grinding as a result of solving the compromise problem, in particular: ensuring the greatest homogeneity of the compost mixture with low energy losses: n_1 = 320 rpm, n_2 = 170 rpm, V = 0.05 m s^{-1}, L = –0.4 m. The homogeneity of the compost mixture is δ = 0.88, and power consumption is P = 3.34 kW.

Because of experimental research of the trailed fertilizers spreader PRT-10 with the double-drum hinged device for firm organic fertilizers grinding we have found dependencies for determination (Figs. 5–6):

– average compost mixture homogeneity value δ_W

$$\delta = 0.349092 - 0.116667\,L + 0.00555772\,\lambda_1 - 0.0000233032\,\lambda_1^2 + 0.00174708\,\lambda_2 - 0.0000104244\,\lambda_2^2; \quad (17)$$

– specific energy consumption E

$$E = 0.0025768 + 0.0125862\,L + 0.00748881\,L^2 + 0.000198874\,\lambda_1 + 0.00000239753\,\lambda_1^2 + 0.000306521\,\lambda_2 - 0.00000512468\,\lambda_1\lambda_2 + 0.00000201042\,\lambda_2^2. \quad (18)$$

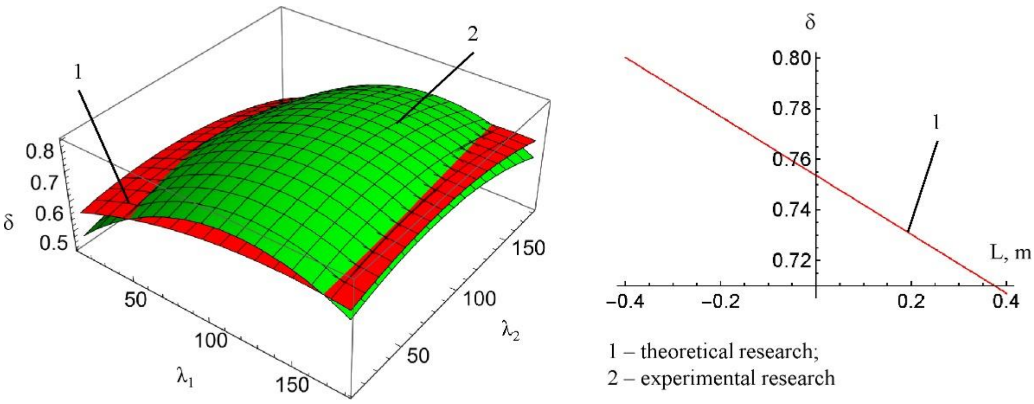


Figure 5. Dependence between the compost mixture homogeneity during its mechanical aeration mixing and research factors

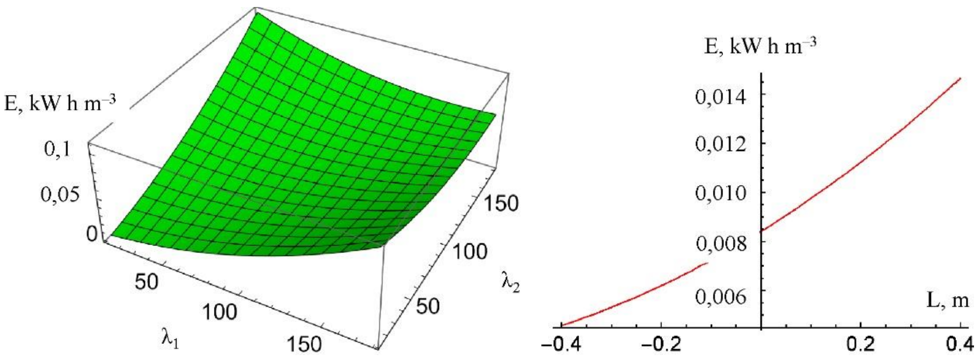


Figure 6. Dependence between the specific energy consumption of mechanical aeration mixing process and research factors

Comparison of theoretical and experimental (at L = –0.4 m) dependencies has been performed using a correlation coefficient of R = 0.78.

Analysis of the obtained data shows that for the kinematic coefficients $\lambda_1 = 119.2$ and $\lambda_2 = 83.8$ the maximum value of the compost mixture homogeneity is $\delta = 0.80$. Rational values of research factors are determined under the condition of ensuring the minimum specific energy intensity of the process: E ($\lambda_1 = 12.4$, $\lambda_2 = 12.4$, L = –0.4 m) = 0.0046 kWh $m^{3\,-1}$.

Because of experimental research of the aerator with the double-drum hinged device for solid organic fertilizers grinding we have obtained the dependencies for the definition of the following (Figs. 7–8):

– formed composting pad's height H`

$$\begin{gathered} H` = 0.61079 + 0.55894\,H - 0.001214\,n_1 + 1.1735 \cdot 10^{-6}\,n_1^2 - 0.001204\,n_2 - 0.0005868 H n_2 + \\ + 1.20822 \cdot 10^{-6}\,n_2^2 - 2.10133\,V + 2.01556\,H\,V + 0.00166191\,n_1\,V + 0.00323809\,n_2\,V; \end{gathered} \tag{19}$$

– homogeneity δ_W

$$\begin{gathered} \delta = 0.465213 + 0.0833333\,H + 0.0000381031\,n_1 + 3.57128 \cdot 10^{-7}\,n_1^2 + 0.00137346\,n_2 - \\ - 8.33327 \cdot 10^{-7}\,n_1\,n_2 - 1.3847 \cdot 10^{-6}\,n_2^2 + 0.438326\,V - 0.833333\,H\,V; \end{gathered} \tag{20}$$

– structural indicator θ of the compost mixture

$$\begin{gathered} \theta = 70.0153 - 55.0926\,H - 2.70062\,H^2 + 0.125581\,n_1 + 0.00992063\,H\,n_1 - 0.00014384\,n_1^2 + \\ + 0.0358717\,n_2 + 0.0248016\,H\,n_2 - 0.000106293\,n_1\,n_2 - 0.0000549178\,n_2^2 - 81.5785\,V - \\ - 125.\,H\,V + 0.35119\,n_1\,V + 0.505952\,n_2\,V - 850.689\,V^2; \end{gathered} \tag{21}$$

– average power consumption value P

$$\begin{gathered} P = 7.10504 + 1.12952\,H - 0.0130359\,n_1 + 0.0000171157\,n_1^2 - 0.0102114\,n_2 - \\ - 0.00357143\,H\,n_2 + 0.000014824\,n_1\,n_2 + 0.000018041\,n_2^2 - 18.5434\,V + 18 H\,V + 63.5024\,V^2. \end{gathered} \tag{22}$$

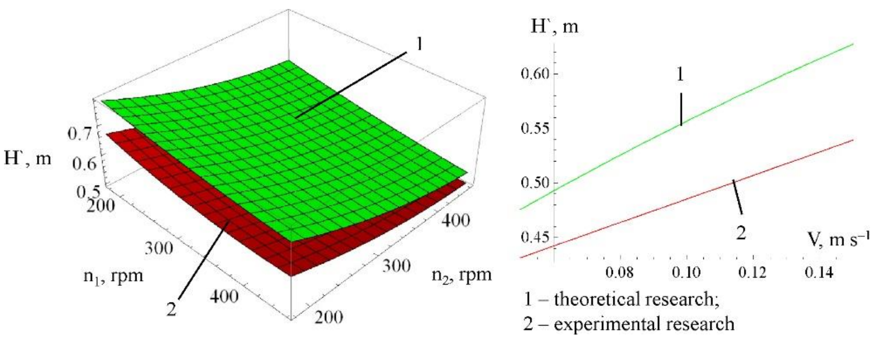


Figure 7. Dependence of the formed compost mixture height from the research factors

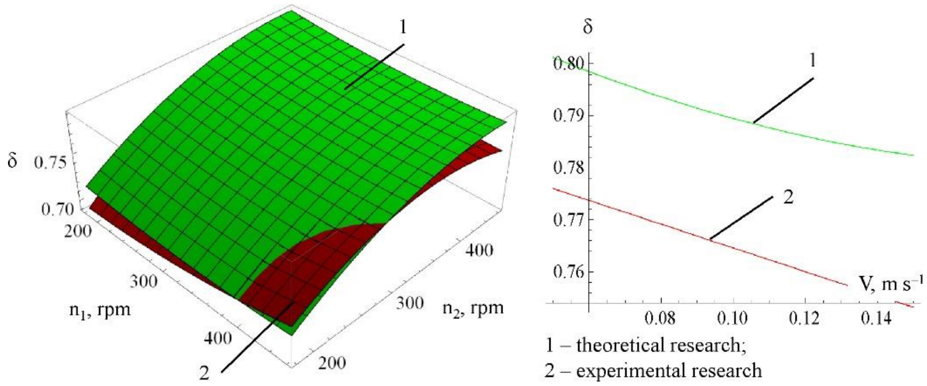


Figure 8. Dependence of the compost mixture homogeneity per humidity from research factors

The following rational design and technological parameters of the developed attachment device for solid organic fertilizers grinding have been developed as a result of solving the compromise problem, in particular, ensuring the greatest homogeneity, structure and height of the compost mixture with low energy losses: n_1 = 293 rpm, n_2 =180 rpm, V = 0.05 m s^{-1}, H = 0.62 m. The homogeneity of the compost mixture is $\delta = 0.71$, the composting pad's structural indicator is θ = 62.4%, the height of the formed composting pad is H` = 0.47 m, and the power consumption is P = 4.37 kW.

Comparison of theoretical and experimental (at H = 0.8 m) dependence has been performed using a correlation coefficient of R = 0.96.

The following dependencies have been determined because of experimental studies of the aerator with a double-drum mounted device for solid organic fertilizers grinding:

– average homogeneity value δ_W

$$\delta = 0.717503 - 0.0000510901\,Q - 0.00152583\,\lambda_1 + 2.05241\cdot10^{-6}\,Q\,\lambda_1 + 4.70363\cdot10^{-6}\,\lambda_1^2 + \\ +0.00250197\,\lambda_2 - 9.8496\cdot10^{-7}\,Q\,\lambda_2 - 8.82403\text{Ч}10^{-6}\,\lambda_2^2; \quad (23)$$

– compost mixture composting pad's structural indicator θ

$$\theta = 98.1988 - 0.21856\,Q + 0.0001382\,Q^2 + 0.109371\,\lambda_1 + 0.0000199\,Q\,\lambda_1 - 0.00304718\,\lambda_1^2 - \\ - 0.116435\,\lambda_2 + 0.000494316\,Q\,\lambda_2 + 0.00436899\,\lambda_1\,\lambda_2 - 0.00246702\,\lambda_2^2; \quad (24)$$

– specific energy consumption E (Fig. 9)

$$E = 0.0564278 - 0.00008622\,Q + 1.32731\cdot10^{-7}\,Q^2 + 0.000223716\,\lambda_1 - 4.76335\cdot10^{-7}\,Q\,\lambda_1 - \\ - 8.873\cdot10^{-7}\,\lambda_1^2 + 0.000259487\,\lambda_2 - 5.367\cdot10^{-7}\,Q\,\lambda_2 + 6.64573\cdot10^{-7}\,\lambda_1\,\lambda_2 - 9.54008\cdot10^{-7}\,\lambda_2^2. \quad (25)$$

The following rational values of research factors on the condition of ensuring the minimum specific energy consumption of the process have been determined: E (λ_1= 168, λ_2 = 168, Q = 535 m^3 h^{-1}) = 0.0052 kWh m$^{3-1}$.

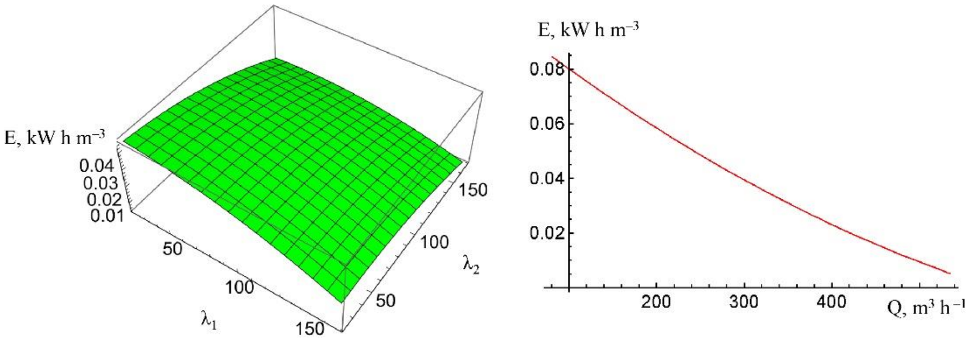


Figure 9. Dependence of the aerator's specific energy consumption from research factors

Comparisons of research results for single and double working bodies that are placed on PRT-10 for cow manure are presented in Figure 10. Comparisons of the research results for single and double working bodies that are placed on the aerator for the bedding and cow manure mixture are presented in Figure 11. The analysis has shown that the quality of mixing (homogeneity in humidity δ) and the quality of grinding (composting pad's structural indicator θ) is better in the double-drum working body. However, this causes greater consumption of energy.

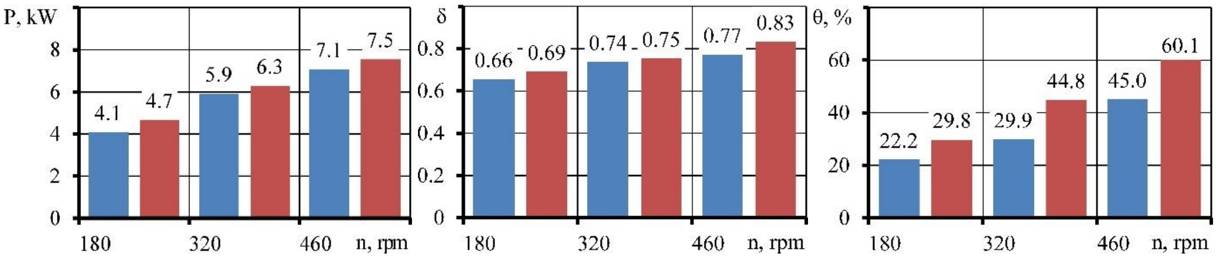


Figure 10. Comparisons of research results for single (blue) and double (red) working bodies that are placed on PRT-10 for cow manure

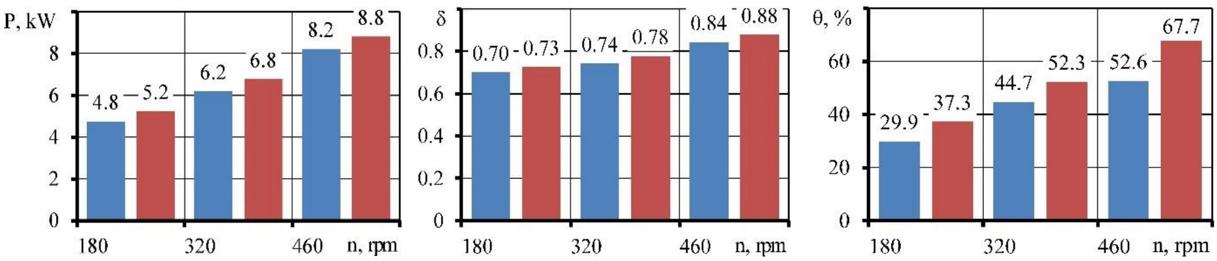


Figure 11. Comparisons of research results for single (blue) and double (red) working bodies that are placed on an aerator

Discussion

Unlike the research Mironov (2006), which examines the analytical process of a cascade drum machine interaction with a particle of manure-compost mixture in the form of a material point, our research is aimed at numerical modelling by discrete elements. Thus, we have determined the dependencies of the formed composting pad's height H` V and the original pad's height H as a result of the discrete element method modelling of the manure-compost mixture mixing process via single-drum and double-drum blade working body in two variants of placement on the formed pad.

Because of the obtained data analysis, we have acquired the mathematical expression, which connects coefficient of mixing quality variation δ with loading factor κ and operating mode kinematic index λ and specifies the obtained mathematical models of research (Golub, 2007; Golub *et al.*, 2017b). Similar methods as in our research have been considered in the article (Shevchenko, Aliiev, 2021), which presents the results of modelling the flow mixing process of bulk materials.

We have determined the rational design variant of the developed universal device for grinding and mixing of cow manure (single-blade W-shaped drum working body, which is mounted on a trailed spreader PRT-10 and rotates at a frequency of 460 rpm), as a result of experimental research, using analysis of variance, the greatest homogeneity of components distribution of the obtained manure-compost mix δ = 0.98 is observed at the specified parameters and the composting pad's structural indicator θ = 90.4 at the lowest average value of power consumption P = 8.7 kW. In turn, a rational design variant of the developed universal device for grinding and mixing manure is as follows: single-blade W-shaped drum working body installed on tracks (aerator type) and rotates with frequency 460 rpm, at which the greatest homogeneity of the received manure-compost mix components distribution is observed δ = 0.95 and composting pad's structural indicator

θ = 90.1 with the lowest average value of power consumption P = 8.4 kW.

We have determined the dependencies between the average value of power consumption P and homogeneity of manure-compost mixture δ_W on frequencies of lower and upper working bodies n_1, n_2, the speed of the manure-compost mixture movement (speed of the PRT-10 conveyor) V and the l upper working body location relative to the lower one L as a result of the trailed fertilizer spreader PRT-10 with a double-drum mounted device for solid organic fertilizers grinding experimental studies. We have established rational design and technological parameters of the developed attachment device for solid organic fertilizers grinding as a result of solving a compromise problem, namely ensuring the greatest homogeneity of manure-compost mixture with low energy losses: n_1 = 320 rpm, n_2 = 170 rpm, V = 0.05 m s^{-1}, L = –0.4 m. The homogeneity of the manure-compost mixture is δ = 0.88, and power consumption P = 3.34 kW.

We have determined the dependences between the average value of the manure-compost mixture homogeneity δ_W with specific energy E and the kinematic parameters for the lower and upper working bodies λ_1, λ_2 relative to the lower one L as a result of the trailed fertilizer spreader PRT-10 with a double-drum mounted device for solid organic fertilizers grinding experimental studies. Analysis of the obtained data shows that for the kinematic coefficients λ_1 = 119.2 and λ_2 = 83.8 the maximum value of the manure-compost mixture homogeneity δ = 0.80 is observed. We have determined rational values of research factors from the condition of ensuring the minimum specific energy consumption of the process: E (λ_1 = 12.4, λ_2 = 12.4, L = –0.4 m) = 4.57 J kg^{-1}.

We have determined dependencies between the height of the formed composting pad H`, homogeneity δ_W and structural indicator θ of manure-compost mix and the average value of the expended power P and rotation frequency of lower and upper working bodies n_1, n_2, the aerator's speed V and the height of the output pad H as a result of experimental researches of the aerator with the double-drum hinged device for firm organic fertilizers grinding. We have established rational design and technological parameters of the developed mounted device for solid organic fertilizers grinding as a result of solving the compromise problem, namely ensuring the greatest homogeneity, structure and height of the manure-compost mixture with low energy losses are determined: n_1 = 293 rpm, n_2 = 180 rpm, V = 0.05 m s^{-1}, H = 0.62 m. The homogeneity of the manure-compost mixture is δ = 0.71, the composting pad's structural indicator is θ = 62.4%, the height of the formed pad is H` = 0.47 m, and the power consumption is P = 4.37 kW.

We have determined dependencies between the average value of homogeneity δ_W and the composting pad's structural indicator θ of manure-compost mixture with specific energy E and the kinematic values for the lower and upper working bodies λ_1, λ_2 as a result of experimental studies of an aerator with a double-drum attachment for solid organic fertilizers grinding. Rational values of research factors with the condition of ensuring the minimum specific energy consumption of the process have been determined: E (λ_1 = 168, λ_2 = 168, Q = 535 m^3 h^{-1}) = 0.0052 kW·h $m^{3\,-1}$. The above results complement the study (Mironov, 2006; Petunov, 2007; Kudrya, 2015) with the dependences of the manure-compost mixture homogeneity δ_W and the composting pad's structural indicator θ.

Conclusion

The physical-mathematical model of the mechanized composting of organic raw materials process in agroecosystems by technical equipment with drum-blade working bodies has been theoretically substantiated and experimentally investigated.

Modelling of the compost mixture mixing process by single-drum and double-drum blade working body in two variants of the forming composting pad placement has determined patterns for determination of the dependency of pad's height H` from the frequency of rotation n, the linear speed of movement of a working body (or compost mix) V and height of an initial pad H.

It has been established that considering that the height of the composting pad layer is equal, the usage of a double-drum working body in comparison with a single-drum one is more rational in terms of power loss indicators $P_{s.d.}$ = 5.9–6.2 kW, $P_{d.d.}$ = 6.3–6.8 kW (at a speed of n = 320 rpm). Single-drum working body provides higher indicators of the side forming, the particles range, and the structure of $\theta_{s.d.}$ = 29.9–44.7%, $\theta_{d.d.}$ = 48.8–52.3%, homogeneity $\delta_{s.d.}$ = 0.74, $\delta_{d.d.}$ = 0.75–0.78 (at a rotation frequency of n = 320 rpm).

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

EA – critical revision and approval of the final manuscript;
SP – analysis, interpretation and acquisition of data;
GG – study conception and design;
OB – drafting of the manuscript.

References

Aliiev, E., Pavlenko, S., Aliieva, O., Morhun, O. 2021. Accelerated biothermal composting of manure-compost mixture. – Agraarteadus, 32(2):169–181. DOI: 10.15159/jas.21.30

Singh, A., Tiwari, R., Chandrahas, Dutt, T. 2020. Augmentation of farmers' income in India through sustainable waste management techniques. – The Journal for a Sustainable Circular Economy (WM&R), 39(6):849–859. DOI: 10.1177/0734242X20953892

Baba, I.A., Banday, M.T., Khan, H.M., Khan, A.A. Unto, M. 2018. Economics of composting of poultry farm waste. – Journal of Entomology and Zoology Studies, 6(2):2925–2928. DOI: 10.20546/ijcmas.2018.706.250

Golub, G.A. 2007. Ahropromyslove vyrobnytstvo yistivnykh hrybiv. Mekhaniko-tekhnolohichni osnovy [Agro-industrial production of edible mushrooms. Mechanical and technological bases]. – Monograph: Kyiv. Agricultural science: 332 p. [In Ukrainian]

Golub, G.I., Kukharets, S.M., Marus, O.A., Pavlenko, S.I., Lopatko, K.G., Skorobogatov, D.V. 2017a. Mekhaniko-tekhnolohichni osnovy protsesiv vyrobnytstva orhanichnoyi produktsiyi roslynnytstva [Mechanical and technological bases of processes of production of organic crop products]. – Monograph: NUBiP Ukrayina: 431 p. [In Ukrainian]

Golub, G., Pavlenko, S., Kukharets, S. 2017b. Analytical research into the motion of organic mixture components during formation of compost clamps. – Eastern-European Journal of Enterprise Technologies, 3/1(87):30–35. DOI: 10.15587/1729-4061.2017.101097

Center for Clean Air Policy. 2019. High-level pre-feasibility analysis for a composting project in Arequipa. Prepared for: Municipalidad Provincial de Arequipa. – Prepared by: Center for Clean Air Policy on behalf of the Climate and Clean Air Coalition Municipal Solid Waste Initiative. February 2019. 83 p. https://www.waste.ccacoalition.org/sites/default/files/files/arequipa_high-level_pre-feasibility_study_final.pdf Accessed on 01/03/2022.

Kudrya, V.O. 2015. Obgruntuvannya parametriv robochoho orhanu rotorno-lopatevoho typu navisnoho modulya do rozkyduvacha orhanichnykh dobryv. [Substantiation of parameters of the working body of the rotor-blade type of the hinged module to the spreader of organic fertilizers]: – PhD thesis. National Scientific Center, Institute of Mechanization and Electrification of Agriculture, National Academy of Agricultural Sciences of Ukraine, Glevaha, Ukraine, 12/02/2015, 149 p. [In Ukrainian]

Kiyonori, H. 2021. Sustainable Recycling of Livestock Wastes by Composting and Environmentally Friendly Control of Wastewater and Odors. – Journal of Environmental Science and Engineering B, 10: 163–178. DOI:10.17265/2162-5263/2021.05.001

Modupe, S.A., Oluwaseyi, S.O., Olubukola, O.B., Olu, O. 2020. Waste Management through Composting: Challenges and Potentials. – Sustainability, 12:4456. DOI: 10.3390/su1211445

Mironov, V.V. 2006. Issledovaniye protsessa prigotovleniya organicheskikh udobreniy v aeratsionnom bioreaktore [Investigation of the process of preparing organic fertilizers in an aeration bioreactor]. – Mekhanizatsiya i elektrifikatsiya sel'skogo khozyaystva [Mechanization and electrification of agriculture], 5:9–11. [In Russian]

Nelson, V. 2002. Technical assessment of physical compost aeration mechanisms and the system effect on the mechanical and biological efficiency of composting. – In AIC 2002 Meeting, CSAE/SCGR Program. Paper No. 02-216. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.606.5554&rep=rep1&type=pdf Accessed on 01/03/2022.

Nghi, N.T., Romasanta, R.R., Hie, N.V., Vinh, L.Q., Du, N.X., Ngan, N.V.C., Chivenge, P., Hung, N.V. 2020. Chapter 3. Rice Straw-Based Composting. – Sustainable Rice Straw Management, pp. 33–41. DOI: 10.1007/978-3-030-32373-8_3

Pergolaa, M., Piccolob, A., Palesea, A.M., Ingraoc, C., Di Meod, V. Celanoe, G. 2018a. A combined assessment of the energy, economic and environmental issues associated with on-farm manure composting processes: Two case studies in South of Italy. – Journal of Cleaner Production, 172:3969–3981. DOI: 10.1016/j.jclepro.2017.04.111

Pergolaa, M., Persiania, A., Palesea, A.M., Di Meoc, V., Pastorea, V., D'Adamoa, C., Celanob, G. 2018[b]. Composting: The way for a sustainable agriculture. – Applied Soil Ecology, 123:744–750. DOI: 10.1016/j.apsoil.2017.10.016

Petunov, S.V. 2007. Sovershenstvovaniye tekhnologi prigotovleniya komposta iz otkhodov zhivotnovodstva i derevoobrabotki. [Improving the technology of preparing compost from animal waste and woodworking waste] – PhD thesis. Federal State Educational Institution of Higher Professional Education, Buryat State Agricultural Academy named after V.I. V.R. Filippov, Ulan-Ude, Russian Federation, 28/12/2006, 161 p. [In Russian]

Shevchenko, I. Aliiev, E. 2021. Improving the efficiency of the process of continuous flow mixing of bulk components. – Eastern-European Journal of Enterprise Technologies, 6/1(108):6–13. DOI: 10.15587/1729-4061.2020.216409

Agraarteadus
1 • XXXIII • 2022 33–42

Journal of Agricultural Science
1 • XXXIII • 2022 33–42

RELATIONSHIP BETWEEN ZN AND CD IN SOIL AND PLANT

Mijbil Mohammad Aljumaily, Hudhaifa Maan Al-Hamandi, Mohammed Jarullah Farhan, Hiba Abdullah Kareem

Department of Soil Science and Water Resources, College of Agriculture, Tikrit University, 21006, Tikrit, Iraq

Saabunud: Received: 15.02.2022

Aktsepteeritud: Accepted: 28.05.2022

Avaldatud veebis: Published online: 28.05.2022

Vastutav autor: Corresponding author: Hudhaifa Maan Al-Hamandi

E-mail:
hudhaifaalhamandi@tu.edu.iq

ORCID:
0000-0003-3558-2242 (MMA)
0000-0002-9222-8517 (HMA)
0000-0002-5885-6405 (MJF)
0000-0002-7999-6001 (HAK)

Keywords: synergistic, antagonistic, Zn to Cd molar ratio, plant species, bioavailability, uptake.

DOI: 10.15159/jas.22.19

ABSTRACT. The relationship between Zn and Cd uptake by plants is somewhat controversial according to the lack of information about this subject. The objective of this study was to increase our scientific understanding of soil about plant factors controlling Zn and Cd bioavailability and uptake. This experiment was carried out in the winter season of 2019. It aimed to solve the mystery of the Zn and Cd relationship in soil and plant uptake. Five plant species were under observation (carrot – *Daucus carota*, radish – *Raphanus sativus*, wheat – *Triticum aestivum* L., lettuce – *Lactuca sativa* and bean – *Vicia faba*). Plants were planted in plastic pots containing 2 kg sandy loam soil with duplicate and exposure to six Zn:Cd ratios (1:0.5, 1:1, 2:1, 3:1, 4:1 and 5:1) with increasing elements molar ratio of Zn to Cd in soil. After 45 days, plants were harvested. Zn and Cd were determined in roots and shoots. Results showed, that at low molar ratios of Zn:Cd in soil, the relationship between these metals in soil is almost synergistic and both elements are accumulated easily in plant tissues, but at high molar ratios, the relationship between these metals is almost antagonistic where Cd be more competitive to Zn uptake by plants. It was concluded that the 2:1 Zn:Cd ratio in the soil is the border between synergistic and antagonistic relationships.

Introduction

Heavy metals are naturally accruing in soil, but their excessive accumulation of them in the environment creates serious ecological problems (Badora, 2002). Because this enhances plant uptake causing accumulation of those metals in plant tissues and leading to high phytotoxicity and change in the plant community (Zayed *et al.*, 1998). The mobility of any heavy metals in the soil-plant system depends on their availability, which is influenced by soil heavy metal content, soil pH, type of clay minerals, cation exchange capacity, organic matter content, $CaCO_3$ content and plant species (Narwal, Singh, 1998; McLaughlin, Singh, 1999; Aljumaily *et al.*, 2022). Both heavy metals zinc (Zn) and cadmium (Cd) belong to group twelve in the periodic table. Cd is a toxic element but Zn is an essential nutrient for living organisms and is relatively active in biochemical processes at low levels, which can be toxic at high levels (Meharg, 2011). Cakmak and Marshner (1993) and Wu *et al.* (1995) reported that interaction between different elements creates a different toxic effect on an ecosystem compared to that of a single pollutant. However, most researchers have focused on the uptake of Cd and Zn in the plant rather than the availability of those metals in the soil. Some of them reported that cadmium treatment increased Zn concentration in plant shoots (Narwal, Singh, 1998). Other researchers reported that Zn application reduced the concentration of cadmium in plants (Abdel-Sabour *et al.*, 1998). However, results by Haghiri (1974) showed that the addition of Zn significantly increased cadmium concentration in plant shoots. Moreover, the availability of each Zn and Cd can be also affected by phosphorus fertilizer application (Lee, Doolittle, 2004). According to the lack of information about the relationship between Zn and Cd, it seems to be somewhat controversial because there are reports of both antagonism and synergism phenomena between these elements in the uptake and transport processes, (Kabata-

Pendias, Szteke, 2015). Zn and Cd have very similar chemical properties; they are taken up and translocated by similar pathways and transporter proteins (Waters, Sankaran, 2011). During transport, metals are either bound to ligands, chelated with amino acids or incorporated into protein. In high concentrations, Zn and Cd are phytotoxic to most plants. Sensitive plants at low levels of heavy metals show some visible toxicity symptoms include, including reddish colouration, chlorosis, necrotic lesions, and growth reduction (Milner, Kochian, 2008). To avoid heavy metal uptake, some plants may restrict metal transport across the root endodermis, sequester metal at the root cell wall and in vacuoles or complex those metals with organic acids and specific metal-binding proteins to reduce toxic effects in the plant tissue (Manceau *et al.*, 2008). Non-accumulating plants typically contain 30–100 mg kg^{-1} dry weight Zn and 0.1–10 mg kg^{-1} dry weight Cd (Waters, Sankaran, 2011). Threshold values for hyperaccumulation in plants vary based on the metal properties. In comparison to non-accumulating plants, hyperaccumulation for Zn is defined as >1% dry weight, and a threshold value for Cd is 0.01% dry weight (Assunção *et al.*, 2003). Because of the enhanced metal uptake, the root systems of hyperaccumulate can substantially alter the chemical composition within the rhizosphere surrounding their roots (Ru *et al.*, 2006). Each soil minerals, organic material and soil organisms co-exist in the rhizosphere and create a highly complex environment by influencing and altering one another. It has been hypothesized that Zn controls Cd uptake by the plant – Cd molar ratio rather than exchangeable Cd or total soil Cd (Chaney *et al.*, 2009). However, recent studies showed a relationship between total soil Cd and exchangeable soil Cd with plant Cd uptake in some plant ecotypes (Rosenfeld, 2013).

Therefore, the objective of this study was to investigate the effect of some soil chemistry concepts on the uptake and availability of these two metals using five plants belonging to different families.

Materials and Methods

This study was carried out in a greenhouse in the experimental farm Tikrit University, Iraq (2018–2019) located at 34° 36'N latitude and 43° 41'E longitude at an altitude of 250 m above mean sea level. The climate of the study area is semi-arid and sub-tropical with an average annual rainfall of 150 mm. The rainfall occurs from October to April (rainy season), which has uneven distribution. Averages of annual temperature, relative humidity, wind speed, sunshine duration per day, and potential evapotranspiration were 17.4 °C, 52.9%, 2.8 m s^{-1}, 11.2 h, and 1986 mm, respectively. This study was carried out to investigate the effect of interaction between Zn and Cd in the soil on an accumulation of these metals in plant tissues using different Zn:Cd ratios and five crops, including wheat, lettuce, carrot, bean, radish, belonging to five plant families on sandy loam soil. The soil sample was air-dried, crushed, and passed through a 2 mm sieve for laboratory tests to determine soil characteristics. Soil pH was measured in the soil:water suspension 1:1 with a pH meter and electrical conductivity (EC) was measured by using the Rhoades method (Page *et al.*, 1982). Cation exchange capacity was measured according to (Hendershot *et al.*, 1993). Particle size distribution was determined by the pipette method (Day, 1965). Calcium carbonate was determined by using acid-base back titration and organic carbon was determined by dichromate oxidation (Page *et al.*, 1982). Some physicochemical properties of the studied soil are given in Table 1. The soil was neutral to slightly alkaline and low in EC, calcium carbonate, organic matter, and clay content. The cation exchange capacity was 15 $cmole_c$ kg^{-1}.

Table 1. Physicochemical properties of the studied soil

PSD g kg^{-1}	Clay	120
	Silt	200
	Sand	680
	Texture	sandy loam
pH		7.31
EC_e	dS m^{-1} at 25ºC	0.68
CEC	$cmol_c$ kg^{-1}	15.0
O.M.	g kg^{-1}	12.5
$CaCO_3$		30.41
Available Zn	mg kg^{-1}	0.538
Available Cd		0.0820

EC – electrical conductivity; CEC – cation-exchange capacity; O.M. – organic matter

Experimental method and procedure

Two grams of soil samples were placed in polyethene tubes and treated with a 40 ml solution of different Zn:Cd ratios in duplicate for each ratio (0.5:1, 1:1, 2:1, 3:1, 4:1 and 5:1). The solutions were prepared by using sulfate salts ($ZnSO_4$, $CdSO_4$) of both metals in a background of 0.01 M of $CaCl_2$. Samples were shaken for two hours and left to equilibrate overnight. Tubes were centrifuged at 2 500 rpm and the supernatants were filtered. The filtrates were analyzed to obtain Zn and Cd concentrations in each filtrate. The sorbed metal by soil was calculated with the following equation (Dandanmozd, Hosseinpur, 2010):

$$M = \left(\frac{C_i - C_f}{W}\right) \times V \quad (1)$$

where:

M – the concentration of adsorbed metal, mg kg^{-1};

C_i – the initial concentration of metal in an equilibrated solution, mg L^{-1};

C_f – the final concentration of metal in equilibrium solution after filtration, mg L^{-1};

V – the solution volume, ml;

W – the weight of the soil, g.

Isothermal adsorption models

Freundlich and Langmuir equations (Giles *et al.*, 1974) were applied to fit the data from isotherm studies (Eq. 2).

$$qe = K_f \, Ce^b$$
$$\text{(linear form) } \log qe = \log K_f + 1/n \log Ce \quad (2)$$

$$qe = \frac{K_L\, q_m\, Ce}{1 + K_L Ce} \quad (3)$$

where:

qe – the amount of adsorbed metal concentration at equilibrium, mg kg^{-1};

Ce – the concentration of the metal in solution at equilibrium, mg L^{-1};

q_m – the maximum adsorption of metal on soil, mg kg^{-1};

K_L (L kg^{-1}), K_f (L kg^{-1}) and b are constants.

Distribution coefficient K_d (Sposito, 1989):

$$K_d = \frac{S}{C} \quad (4)$$

where:

S – adsorb metal on solid phase, mg kg^{-1};

C – metal concentration in equilibrium solution, mg L^{-1}.

Agricultural pots experiment

About 50 plastic pots were filled with 2 kg of soil and fertilized with nutrient solution containing N, P and K (40, 30 and 40 ppm, respectively). After a week pots were planted with five types of plants and after two weeks of growing these plants were treated with solutions of contained six Zn:Cd ratios (1:0.5, 1:1, 2:1, 3:1, 4:1 and 5:1, which is equal to 1:0.5. 5:5, 20:10, 45:15, 80:20 and 125:25 ppm) in duplicate for each ratio, besides control treatment (0:0).

Plant harvest and analysis

Plants were harvested after eight weeks of growth and cut about 1 cm above pot soil. The green part (shoots) and the roots were washed with deionized water and 0.01 M HCl solution. Shoots and roots were separated, cut off and kept in separate paper bags for drying in an oven at 60 °C. Dry weight for each plant (shoot and roots) were homogenized by grinding in a plastic mixer and passed through a 1 mm sieve. A 0.5 g of dried sample was digested in 5 mL of tri-acid mixture HNO_3, H_2SO_4, HCl (2:1:1), and 1 ml of $HClO_4$ dropwise during digestion at 150 °C till the clear solution was obtained. The final solution was diluted to 50 ml with distilled water and filtered through Whatman No. 42 filter paper (Tandon, 2005). The concentration of Zn and Cd were determined in plant parts using the atomic absorption Unicam 969 AA spectrophotometer (Unicam Sistemas Analíticos Lda, Lisbon, Portugal).

Statistical analysis

Student t-test in SPSS V24 software was used to compare K_d for each method in Cd and Zn at a 5% significance level. In addition, pairwise comparison for Zn and Cd and shoots and roots for all plants in our study was done by using Duncan Multiple Range Test (D.M.R.T).

Results and Discussion

Sorption isotherms

Sorption isotherms batch experiments are very important in soil science because analysis of it is a useful technique to study the retention, availability of metals in soil and other important adsorption parameters (Dandanmozd, Hosseinpur, 2010). Many researchers have pointed out that Langmuir and Freundlich's isotherms are suitable for Zn and Cd adsorption studies (Shuman, 1975; Hooda, Alloway, 1994; Hanafi, Sjiaola, 1998; Maftoun *et al.*, 2004; Arias *et al.*, 2006). In this study, we try to investigate the effect of a different relationship between Zn and Cd in the soil on plant uptake for these two elements.

Figure 1 shows Zn and Cd adsorption on studied soil according to Langmuir and Freundlich equations when both elements exist together in soil solution with different ratios for each of them. The determination coefficient (R^2) for the Langmuir equation for both elements (Zn, Cd) ranged between (0.92–0.99) and for Freundlich equation R^2 ranged between (0.91–0.93). That means both equations succeeded in the mathematical description of Zn and Cd adsorption on solid phase (soil practical).

Langmuir equation

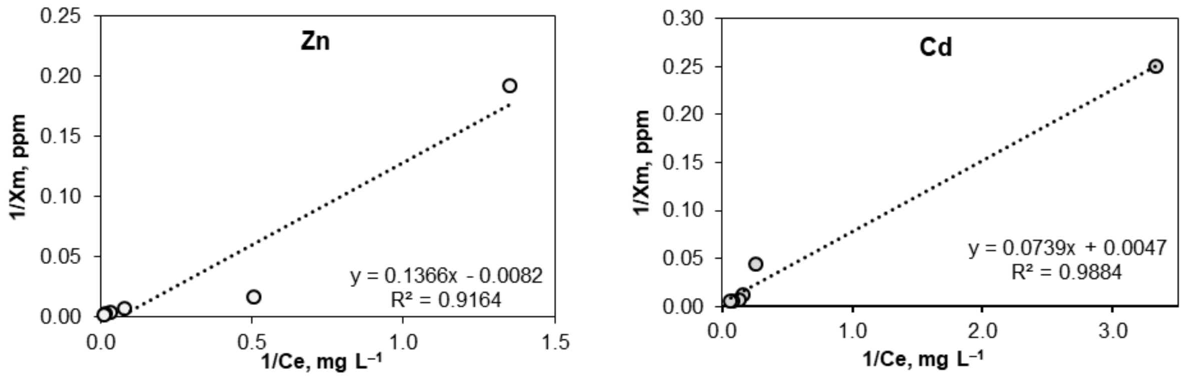


Figure 1. *Cont.*

Freundlich equation

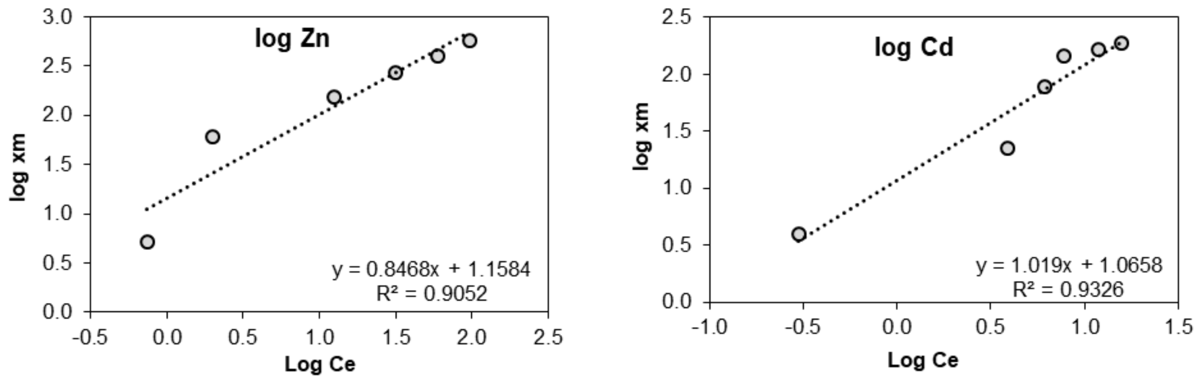


Figure 1. Langmuir and Freundlich equations for Zn and Cd in soil

Adsorption parameters for Langmuir and Freundlich equations are shown in Table 2. The amount of Zn adsorbed (Q_{max}) is 121.95 mg kg^{-1}, but (Q_{max}) for adsorbed Cd is 212.76 mg kg^{-1} on the same soil in this study. The difference in adsorbed elements may be attributed to their different adsorption affinities, and other factors related to ion characterization for example ionic size, electronegativity, charge:radius ratio, hydrate radius and so on. Many other types of research have reported the preferential adsorption of metals; they also found that the co-existence of metals reduces their tendency to be sorbed in the soil solid phase (Echeverria *et al.*, 1998).

Table 2. Langmuir and Freundlich equation parameters values

	Langmuir		Freundlich	
Cd	Q_{max}, mg kg^{-1}	212.76	1/n	0.98
	K_L, L g^{1}	0.063	K_f	11.63*
	K_L b, L kg^{-1}	13.40		
Zn	Q_{max}, mg kg^{-1}	121.95	1/n	1.18
	K_L, L g^{-1}	0.060	K_f	14.40*
	K_L b, L kg^{-1}	7.31		

* – means differ significantly at 5% according to the Students t-test between K_d for each equation in Cd and Zn

Bonding energy (K_L) for the Langmuir equation is similar for Zn and Cd (0.06 L g^{-1}) on the same soil, but Q_{max} values are different for Zn (121.95 mg kg^{-1}) and Cd (212.76 mg kg^{-1}). The difference in adsorbed metal quantities may be attributed to the soil pH because sorption of Cd is higher at high pH due to lower recombination with H_3O^+ ions compared to soils having low pH (Reed *et al.*, 2002). At a very low equilibrium concentration, the value of X/C represents the amount of adsorbed metal by the unit weight of the solid phase relative to that remained in the volume of the solution phase. This concept rearranged the Langmuir equation to the form X/C = K_Lb, which is termed the distribution coefficient (K_d) and designated by Iyengar and Raja (1983). Thus, K_d represents the sorption affinity of metal cations in a solution for the solid phase and this term can also be called (maximum buffering capacity). Although K_L values of the Langmuir equation are the same for Zn and Cd (0.06) L g^{-1}, the maximum buffering capacity is different widely from 7.31–13.40 L kg^{-1} for Zn and Cd respectively. This contradiction between K_L and K_Lb values resulted in Langmuir parameters is in disagreement with the results of many researchers. Higher bonding energy coefficient values have been related to specifically sorbed metal at high energy surfaces with low dissociation constant (Serrano *et al.*, 2005) and lower bonding coefficient values appear to be related to sorption on low energy surfaces with high dissolution constant (Ma, Rao, 1997; Adhikari, Singh, 2003). So, the relationship between bonding energy (1/n) and distribution coefficient (K_f) in Freundlich equation is more close to the previous scientific facts. Low 1/n value has high bonding energy with low dissociation constant (K_f) (Wong *et al.*, 2007). For Cd, 1/n value 0.99 and K_f value 11.63 L kg^{-1} and for Zn element, high 1/n value 1.18 has lower bonding energy with high dissolution constant value (K_f) 14.40. This fact may mean that the Freundlich equation is more suitable to describe Cd and Zn adsorption in the binary system than the Langmuir equation. Besides, the mean values of K_d at different equilibrium concentrations in this study for Zn and Cd are 11.82 and 12.66, respectively, also more close to Freundlich K_f than Langmuir K_Lb (Table 3).

Table3. K_d-values at different equilibrium concentrations for different ratios of Zn and Cd

Zn:Cd ratio, ppm	K_d-value	
	Cd	Zn
1:0.5	13.33	7.02
5:5	5.77	30.50
20:10	12.52	12.12
45:15	18.86	8.70
80:20	13.75	6.61
125:25	11.77	5.97
Mean	12.66	11.82

The results of Wen-Bo *et al.* (2009) indicated that K_d value for Zn was about 10 for competitive adsorption of Zn and Cd. Antoniadis and Tsadilas (2007) reported that the sorption of Cd into the soil can be well described by a Freundlich linear isotherm, whereas the closeness of Langmuir isotherm to the experimental results is low. Hanafi and Singh (1998) pointed out that the adsorption of Cd and Zn by Malaysian soils was best described by the Freundlich equation. The relatively high value of K_d indicates that the metal has been retained by the solid phase through sorption reactions, while relatively low values of K_d indicate that a large fraction of the metal remains in solution (Anderson, Christensen, 1988). Table 3 showed at very low concentrations of Zn and Cd 1:0.5 ppm, Cd adsorption is higher than Zn, whereas some equilibrium competitive has been achieved at 2:1 ratio but with higher concentrations 10:5 ppm, 12.52 K_d for Cd and 12.12 for Zn. In general, Zn concentration in the liquid phase increased with increasing Cd application and the solubility of Zn in soil solution was more complicated than the solubility of Cd as affected by interactions between them. Lee and Doolittle (2004) indicated that sorption and/or desorption of Zn and Cd affected pH in the soil solution system. The pH values increased with increasing Cd applications and values of pH decreased with increasing the concentration of Zn in soil solution.

Relationship between Zn and Cd in plant

Both elements Zn and Cd are taken up by the plant from the soil solution through the root hair epidermis, which is driven by passive transport through mass flow or diffusion mechanism (Waters, Sankaran, 2011). Pectins in the cell walls contain the carboxylic groups of polgalacturonic acid, which have a negative charge and act as cations exchangers in the cell wall. This negative charge cause accumulation of positively charged ions in the Donnan free space. Both elements, Zn and Cd, have a positive charge and therefore accumulation in the Donnan free space and in the plant, parts pass at first through roots and shoots (White, 2012).

Element bioavailability in soil solution is identified; interaction of soil properties with each other, but plant uptake of any element is a result of element bioavailability interaction with plant species and ecosystem. This study is carried out to investigate the optimum Zn: Cd ratio for plant uptake using five plant species – lettuce, carrot, bean, wheat, and radish, which belong to different plant families. Many previous studies showed both antagonistic and synergistic relationships between Zn and Cd by plant uptake of these two metals (Lagerwerff, Biersdorf, 1972; Oliver *et al.*, 1994; Nan *et al.*, 2002; Papoyan *et al.*, 2007). In our study, we used six Zn:Cd ratios (1:0.5–5:1) with increasing ionic strength for both metals to investigate the effect of the Zn: Cd ratio and ionic strength on plant uptake for these two metals.

Figure 2 shows that both elements were accumulated in all studied plants (roots and shoots) and increased as Zn and Cd increased in soil. According to our results, it may be stated that the ratio of Zn:Cd in soil solution controls the occurrence of synergism and antagonism between these metals. In addition, Shute and Macfie (2006) reported that interaction between Zn and Cd can be synergistic and antagonistic or they can have no effect on each other depending on growth conditions – Zn and Cd status of the soil, and plant species. Chaoui *et al.*, (1997) also mentioned that the increase of Cd and Zn in plant tissue might be related to the interaction between these metals and their combination in soil and soil characteristics.

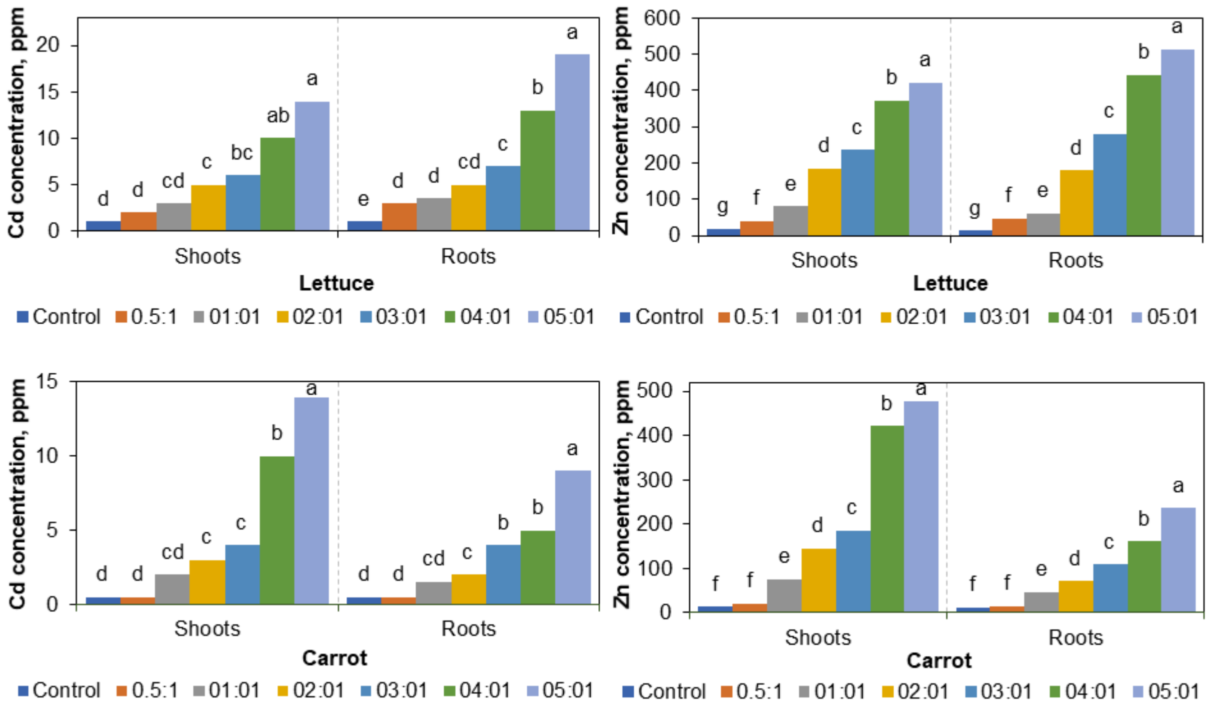


Figure 2. *Cont.*

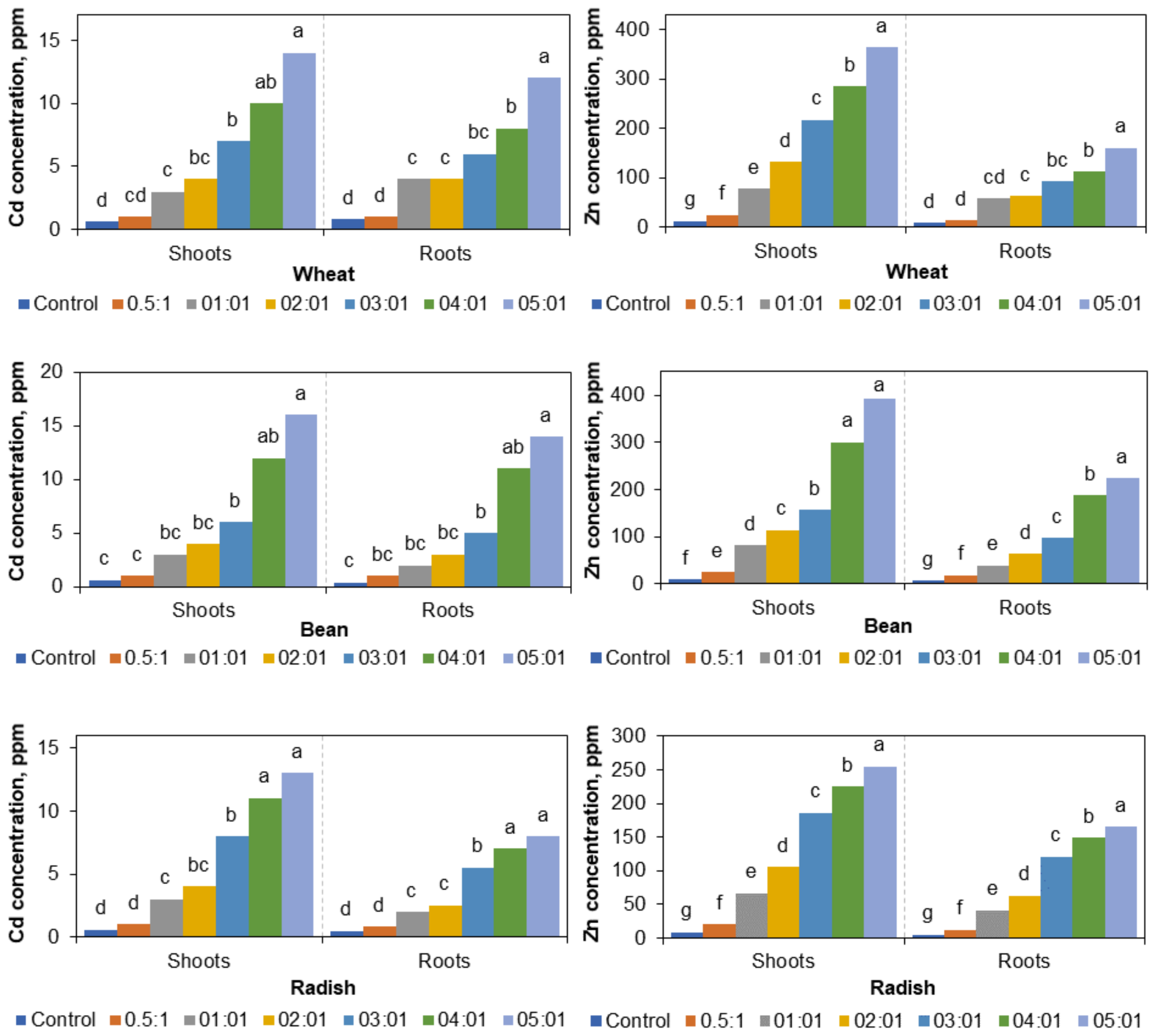


Figure 2. Zn and Cd concentration (ppm) in the studied plants (roots and shoots) (the different lowercase letters indicate a significant difference (P <0.05) by Duncan Multiple Range Test between different ratios)

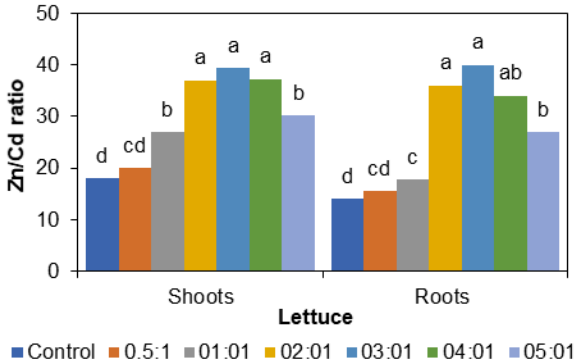
Zn and Cd combination in soil and soil characteristics

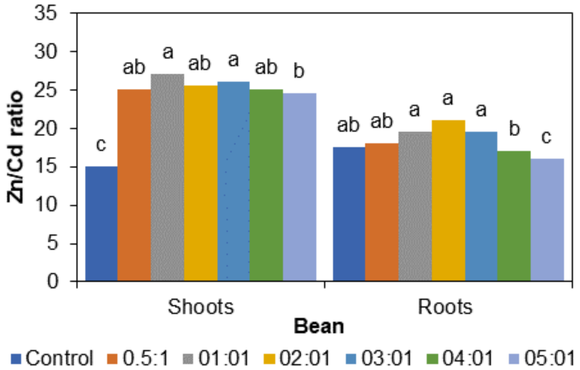
As we mentioned before, studied soil thermodynamic parameters showed that both elements Zn and Cd are available in soil solution at different ratios, but Cd at low concentration (1:0.5) seems to be more adsorbed than Zn. At equal Zn:Cd ratio (1:1), distribution coefficient (K_d) remarked opposite direction, high adsorbed Zn and high available Cd. The noteworthy relationship between Zn and Cd is at (2:1) ratio where K_d values for Zn and Cd are close (12.12 and 12.52, respectively).

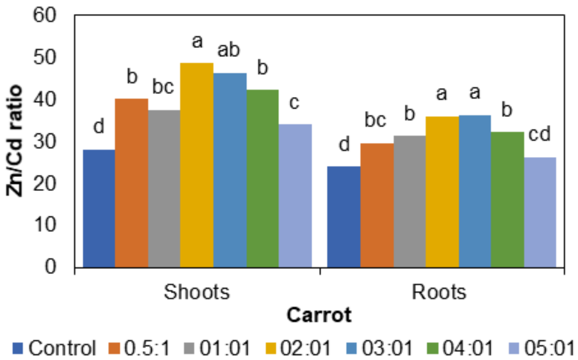
Over 2:1 Zn:Cd ratio, the relationship between these metals was more complicated because the opposite effect of these metals on soil pH and K_d value followed more availability and more retention for Zn and Cd.

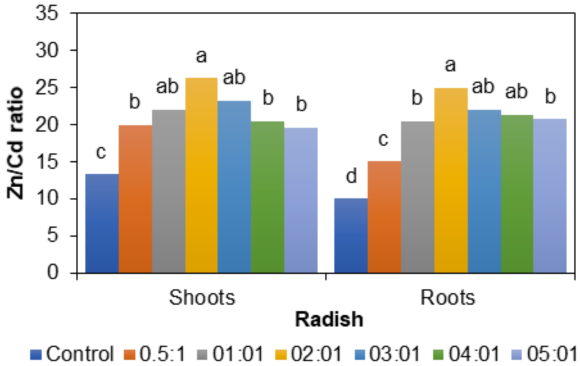
For all ratios of Zn and Cd, studied plants showed no Cd or Zn toxicity symptoms. At low ratios of Zn and Cd in soil, plant Cd content (green parts and roots) showed semi-close except wheat roots remarked more Cd content (4 ppm) compared to green parts. This result is in agreement with (Mahmood *et al.*, 2009) that the roots of wheat accumulated higher levels of Cd than shoots at low doses. Therefore, we like to demonstrate two reasons: 1) Cd tends to be more desorption in soil compared to other toxic elements (Lokeshwari, Chandrappa, 2006); 2) binding sites of clay particles, organic matter and calcium carbonate have a higher affinity to Zn than Cd. Therefore, according to these competition effects, increasing Zn concentration in soil solution results in more Cd desorption, Also, Shute and Macfie (2006) confirmed this fact.

A more important result in our study is illustrated in Figure 3, where is Zn and Cd ratio in green parts and roots of studied plants. At a low concentration of Zn:Cd ratio in soil, both elements increased and reached a maximum value at 2:1 ratio for all studied plants except lettuce and decreased over 2:1 Zn:Cd ratio in the soil. For the lettuce plant, the maximum value of Zn and Cd was at 3:1 Zn:Cd ratio in the soil. Lettuce contravention to this base may be attributed to the individual characteristics of plant species. It may be stated that at low concentrations of Zn:Cd ratio, the interaction relationship between Zn and Cd could be synergistic where Zn enhanced Cd desorption to be more available in soil solution. At 2:1 Zn:Cd ratio in soil, the distribution coefficient (K_d) was equal for each of these metals. At 2:1 Zn:Cd ratio in the soil the K_d values were equal for each of these metals(table3), but over 2:1 Zn to Cd ratio in soil Zn availability was found to be more than Cd according to studied soil thermodynamic parameters. The decrease of Zn:Cd ratio values in plant parts over 2:1 in soil showed a high competition relationship between these ions in combination which indicates some kind of antagonistic relationship. These findings are in agreement (Abou Auda, Ali, 2010). They stated that the effect of these two ions in combination was different when Zn to Cd ratio was (75/40 ppm). In our study, four of five plant species responded to the change in the relationship between Zn and Cd in soil solution – wheat, radish, carrot and bean except for lettuce. That can be attributed to plant species. Generally, soil thermodynamic parameters are good indicators to explain Zn and Cd bioavailability in soil solution and plant uptake. At low concentration ratios, Zn enhanced Cd desorption where both elements are accumulated easily in plant tissues via synergistic interaction relationship, At high molar ratios for both elements, Zn tends to decrease soil solution pH and enhanced Cd to be more available in soil solution and create highly competitive on plant roots via antagonistic interaction relationship.









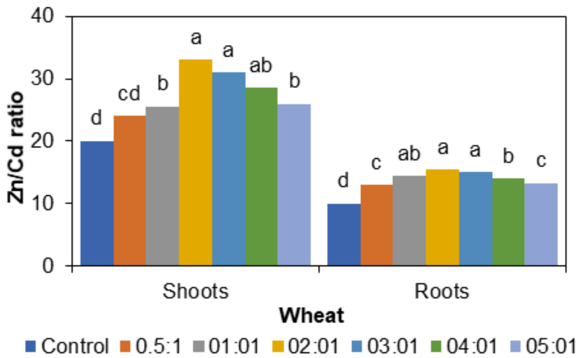


Figure 3. Zn and Cd ratio for studied plants (roots and shoots) (the different lowercase letters indicate a significant difference ($P < 0.05$) by Duncan Multiple Range Test between different ratios)

Conclusion

The result showed that a relationship between Zn and Cd in soil solution is reflected in the uptake of these two elements by the plant. At low Zn:Cd ratios, Zn adsorption enhanced Cd desorption into soil solution and both elements are accumulated easily in plant tissues. This synergistic relationship reaches a maximum value at 2:1 Zn:Cd ratio. At 3:1 Zn:Cd ratio and over, an antagonistic relationship starts and the accumulation level of these two elements depend on plant species.

Acknowledgements

The authors would like to thank Tikrit University for providing the laboratory equipment to conduct this research.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contributions

MMA – writing a manuscript, analysis, and interpretation of data;
MJF – acquisition of data, author of the idea, guided the research;
HAK– analysis and interpretation of data and is the corresponding author, guided the research;
HMA-H – critical revision and approval of the final manuscript, guided the research.

References

Abdel-Sabour, M.F., Mortvedt, J.J., Kelsoe, J.J. 1988. Cadmium-zinc interactions in plants and extractable cadmium and zinc fractions in soil. – Soil Science, 145(6):424–431.

Abou Auda, M., Ali, E.E.S. 2010. Cadmium and zinc toxicity effects on growth and mineral nutrients of carrot (*Daucus carota*). – Pakistan Journal of Botany, 42:341–351.

Adhikari, T., Singh, M.V. 2003. Sorption characteristics of lead and cadmium in some soils of India. – Geoderma, 114(1–2):81–92. DOI: 10.1016/S0016-7061(02)00352-X.

Aljumaily, M.M., Hudhaifa, A.H., Al-Obaidi, M.A., AL-Zidan, R.R. 2022. The effect of calcium carbonate content on the zinc quantity-intensity relationship in some soils of Mosul, Irak. – Ciencia & Tecnología Agropecuaria, 1:1–15. DOI: 10.21930/rcta.vol23_num1_art:2373

Anderson, P.R., Christensen, T.H. 1988. Distribution coefficients of Cd, Co, Ni, and Zn in soils. – Journal of Soil Science, 39(1):15–22. DOI: 10.1111/j.1365-2389.1988.tb01190.x

Antoniadis, V., Tsadilas, C.D. 2007. Sorption of cadmium, nickel, and zinc in mono-and multimetal systems. – Applied Geochemistry, 22(11):2375–2380. DOI: 10.1016/j.apgeochem.2007.06.001

Arias, M., Pérez-Novo, C., López, E., Soto, B. 2006. Competitive adsorption and desorption of copper and zinc in acid soils. – Geoderma, 133(3–4), 151–159. DOI: 10.1016/j.geoderma.2005.07.002

Assunção, A.G., Schat, H., Aarts, M.G. 2003. *Thlaspi caerulescens*, an attractive model species to study heavy metal hyperaccumulation in plants. – New Phytologist, 159(2):351–360. DOI: 10.1046/j.1469-8137.2003.00820.x

Badora, A. 2002. Bioaccumulation of Al, Mn, Zn and Cd in pea plants (*Pisum sativum* L.) against a background of unconventional binding agents. – Polish Journal of Environmental Studies, 11(2):109–116.

Cakmak, I., Marschner, H. 1993. Effect of zinc nutritional status on activities of superoxide radical and hydrogen peroxide scavenging enzymes in bean leaves. – Plant nutrition - from genetic engineering to field practice. Proceedings of the Twelfth International Plant Nutrition Colloquium, 21–26 September 1993, Perth, Western Australia, pp. 133–136. DOI: 10.1007/978-94-011-1880-4_21

Chaney, R.L., Green, C.E., Ajwa, H.A., Smith, R.F. 2009. Zinc fertilization plus liming to reduce cadmium uptake by Romaine lettuce on Cd-mineralized Lockwood soil. – The Proceedings of the International Plant Nutrition Colloquium XVI, UC Davis: Department of Plant Sciences, pp. 1–6. https://escholarship.org/uc/item/5js5s736

Chaoui, A., Ghorbal, M.H., El Ferjani, E. 1997. Effects of cadmium-zinc interactions on hydroponically grown bean (*Phaseolus vulgaris* L.). – Plant Science, 126(1):21–28. DOI: 10.1016/S0168-9452(97)00090-3

Dandanmozd, F., Hosseinpur, A. R. 2010. Thermodynamic parameters of zinc sorption in some calcareous soils. – Journal of American science, 6(7):298–304.

Day, P.R. 1965. Particle fractionation and particle-size analysis. – In Methods of Soil Analysis: Part 1 Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling, 9.1. Black, C.A. (Ed.) – American Society of Agronomy, Inc, pp. 545-567. DOI: 10.2134/agronmonogr9.1.c43

Echeverria, J.C., Morera, M.T., Mazkiaran, C., Garrido, J.J. 1998. Competitive sorption of heavy metal by soils. Isotherms and fractional factorial experiments. – Environmental Pollution, 101(2):275–284. DOI: 10.1016/S0269-7491(98)00038-4

Giles, C.H., Smith, D., Huitson, A. 1974. A general treatment and classification of the solute adsorption isotherm. I. Theoretical. – Journal of Colloid and Interface Science, 47(3):755–765. DOI: 10.1016/0021-9797(74)90252-5

Haghiri, F. 1974. Plant uptake of cadmium as influenced by cation exchange capacity, organic matter, zinc, and soil temperature. – American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, 2(3):180–183. DOI: 10.2134/jeq1974.00472425000300020021x

Hanafi, M.M., Sjiaola, J. 1998. Cadmium and zinc in acid tropical soils: I. Soil physico-chemical properties effect on their adsorption. – Communications in Soil Science and Plant Analysis, 29(11–14):1919–1931. DOI: 10.1080/00103629809370082

Hendershot, W.H., Lalande, H., Duquette, M. 1993. Soil reaction and exchangeable acidity. – In Soil sampling and methods of analysis (2nd ed.). Carter, M.R. (Ed.). – CRC Press Company: Boca Raton, USA, pp. 141–146.

Hooda, P.S., Alloway, B.J. 1994. Sorption of Cd and Pb by selected temperate and semi-arid soils: effects of sludge application and ageing of sludged soils. – Water, Air, and Soil Pollution, 47(3):235–250.

Iyengar, B.R.V., Raja, M.E. 1983. Zinc adsorption as related to its availability in some soils of Karnataka. – Journal of the Indian Society of Soil Science, 31(3):432–438.

Kabata-Pendias, A., Szteke, B. 2015. Trace elements in abiotic and biotic environments (1st ed.). – CRC Press, Taylor & Francis Group, Boca Raton, USA, 468 p.

Lagerwerff, J.V., Biersdorf, G.T. 1972. Interaction of zinc with uptake and translocation of cadmium in radish. – In Trace substances in environmental health — V. Hemphill, D.D. (Ed.). – Columbia, University of Missouri, USA, pp. 512–522.

Lee, J.H., Doolittle, J.J. 2004. Determination of soil phosphorus and zinc interactions using desorption quantity-intensity relationships. – Korean Journal of Soil Science and Fertilizer, 37(2):59–65.

Lokeshwari, H., Chandrappa, G.T. 2006. Impact of heavy metal contamination of Bellandur Lake on soil and cultivated vegetation. – Current Science, 622–627. DOI: 10.2307/24094365

Ma, L.Q., Rao, G.N. 1997. Chemical fractionation of cadmium, copper, nickel and zinc in contaminated soils. – Journal of Environmental Quality, 26(1):259–264. DOI: 10.2134/jeq1997.00472425002600010036x

Maftoun, M., Rassooli, F., Ali Nejad, Z., Karimian, N. 2004. Cadmium sorption behavior in some highly calcareous soils of Iran. – Communications in Soil Science and Plant Analysis, 35(9–10):1271–1282. DOI: 10.1081/CSS-120037545

Mahmood, T., Gupta, K.J., Kaiser, W.M. 2009. Cadmium stress stimulates nitric oxide production by wheat roots. – Pakistan Journal of Botany, 41(3):1285–1290.

Manceau, A., Nagy, K.L., Marcus, M.A., Lanson, M., Geoffroy, N., Jacquet, T., Kirpichtchikova, T. 2008. Formation of metallic copper nanoparticles at the soil − root interface. – Environmental Science & Technology, 42(5):1766–1772. DOI: 10.1021/es072017o

McLaughlin, M.J., Singh, B.R. 1999. Cadmium in soils and plants. − In Cadmium in soils and plants. McLaughlin, M.J., Singh, B.R. (Eds.). − Springer Science+Business Media Dordrecht, Germant, pp. 1−9. DOI: 10.1007/978-94-011-4473-5

Meharg, A.A. 2011. Trace elements in soils and plants. − Experimental Agriculture, 47(4):739−739. DOI: 10.1017/S0014479711000743

Milner, M.J., Kochian, L.V. 2008. Investigating heavy-metal hyperaccumulation using *Thlaspi caerulescens* as a model system. − Annals of Botany, 102(1):3−13. DOI: 10.1093/aob/mcn063

Nan, Z., Li, J., Zhang, J., Cheng, G. 2002. Cadmium and zinc interactions and their transfer in soil-crop system under actual field conditions. − Science of the Total Environment, 285(1−3),187−195. DOI: 10.1016/S0048-9697(01)00919-6

Narwal, R.P., Singh, B.R. 1998. Effect of organic materials on partitioning, extractability and plant uptake of metals in an alum shale soil. − Water, Air, and Soil Pollution, 103(1):405−421. DOI: 10.1023/a:1004912724284.

Oliver, D.P., Hannam, R., Tiller, K.G., Wilhelm, N.S., Merry, R.H., Cozens, G.D. 1994. The effects of zinc fertilization on cadmium concentration in wheat grain. − American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, 23(4):705−711. DOI: 10.2134/jeq1994.00472425002300040013x

Page, A.L., Miller, R., Keeney, D.R. 1982. Methods of soil analysis, Part II. Chemical and Microbiological Properties (2nd ed.). − American Society of Agronomy, Soil Science Society of America, USA, 1159 p.

Papoyan, A., Piñeros, M., Kochian, L.V. 2007. Plant Cd^{2+} and Zn^{2+} status effects on root and shoot heavy metal accumulation in *Thlaspi caerulescens*. − New Phytologist, 175(1):51−58. DOI: 10.1111/j.1469-8137.2007.02073.x

Reed, R.L., Sanderson, M.A., Allen, V.G., Zartman, R.E. 2002. Cadmium application and pH effects on growth and cadmium accumulation in switchgrass. − Communications in Soil Science and Plant Analysis, 33(7−8):1187−1203. DOI: 10.1081/CSS-120003881

Rosenfeld, C.E. 2013. Heavy metal biogeochemistry: Cadmium and zinc dynamics at the plant-soil interface. − Dissertation, The Pennsylvania State University, August, 2013, 155 p.

Ru, S., Xing, J., Su, D. 2006. Rhizosphere cadmium speciation and mechanisms of cadmium tolerance in different oilseed rape species. − Journal of Plant Nutrition, 29(5):921−932. DOI: 10.1080/019041606 00649120

Serrano, S., Garrido, F., Campbell, C.G., Garcıa-González, M.T. 2005. Competitive sorption of cadmium and lead in acid soils of Central Spain. − Geoderma, 124(1−2):91−104. DOI: 10.1016/j.geoderma.2004.04.002

Shuman, L.M. 1975. The effect of soil properties on zinc adsorption by soils. − Soil Science Society of America Journal, 39(3):454−458. DOI: 10.2136/sssaj1975.03615995003900030025x.

Shute, T., Macfie, S.M. 2006. Cadmium and zinc accumulation in soybean: A threat to food safety? − Science of the Total Environment, 371(1−3):63−73. DOI: 10.1016/j.scitotenv.2006.07.034

Sposito, G. 1989. Soil adsorption phenomena. − In The chemistry of soils. Oxford University Press, New York, USA, 344 p.

Tandon, H.L.S. 2005. Methods of analysis of soils, plants, waters, fertilisers & organic manures. − Fertiliser Development and Consultation Organisation, New Delhi, India, 203 p.

Waters, B.M., Sankaran, R.P. 2011. Moving micronutrients from the soil to the seeds: genes and physiological processes from a biofortification perspective. − Plant Science, 180(4):562−574. DOI: 10.1016/j.plantsci.2010.12.003

Wen-Bo, X.U.E., Ai-Hua, Y.I., Zhang, Z.Q., Ci-Lai, T.A.N.G., Zhang, X.C., Jin-Ming, G.A.O. 2009. A new competitive adsorption isothermal model of heavy metals in soils. − Pedosphere, 19(2):251-257. DOI: 10.1016/S1002-0160(09)60115-6

White, P.J. 2012. Ion uptake mechanisms of individual cells and roots: Short-distance transport. − In Mineral nutrition of higher plants (3rd ed.). Marschner, P. (ed.). − Academic Press, Oxford, UK., pp. 7–48. DOI: 10.1016/B978-0-12-384905-2.00002-9

Wong, J.W.C., Li, K.L., Zhou, L.X., Selvam, A. 2007. The sorption of Cd and Zn by different soils in the presence of dissolved organic matter from sludge. – Geoderma, 3–4:310–317. DOI: 10.1016/j.geoderma.2006.08.026

Wu, Y., Wang, X., Li, Y., Ma, Y. 1995. Compound pollution of Cd, Pb, Cu, Zn, As in plant-soil system and its prevention. – In Contaminated soils. Prost, R. (ed.). – 3rd International Conference on the Biogeochemistry of Trace Elements, May 15–19, 1995, INRA, Paris, France, pp. 1–17.

Zayed, A., Lytle, C.M., Qian, J.H., Terry, N. 1998. Chromium accumulation, translocation and chemical speciation in vegetable crops. – Planta, 206(2):293–299. DOI: 10.1007/s004250050403

Agraarteadus
1 • XXXIII • 2022 43–47

Journal of Agricultural Science
1 • XXXIII • 2022 43–47

THE IMPACT OF NANO FERTILIZATION AND SALICYLIC ACID ON GROWTH, YIELD AND ANTI-OXIDANT CONTENTS IN ROCKET PLANT UNDER SALT STRESS

Duraid K. A. Al-Taey, Zahraa J. M. Al-Musawi

Department of Horticulture, Faculty of Agriculture, University of AL-Qasim Green, Babylon , Najaf road, Iraq

Saabunud: Received: 20.01.2022

Aktsepteeritud: Accepted: 24.04.2022

Avaldatud veebis: Published online: 24.04.2022

Vastutav autor: Corresponding author: Duraid K. A. Al-Taey

E-mail: duraidaltaey@gmail.com

ORCID:
0000-0003-3601-5573 (DKAAT)

Keywords: glutathione, ascorbic acid, salt stress, nano fertilization.

DOI: 10.15159/jas.22.10

ABSTRACT. This investigation aimed to study the effect of organic fertilizers, nano-fertilizers and salicylic acid on the growth and yield of rocket (*Eruca sativa* L.) and the content of active compounds and antioxidants when the plants were exposed to salt stress. The experiment was conducted using a randomized complete block design (RCBD) according to the split-plot system. The main factor was water quality (1.2 dS m^{-1} and 8 dS m^{-1}). While the combination treatments of Nano fertilizer, Salicylic acid and poultry manure were distributed in sub-plots and each treatment included three replicates. The treatments irrigated with saline water showed a reduction of glucosinolate and ascorbate contents (58 µg g^{-1} and 105.71 µg g^{-1}, respectively). Salinity led to an increase in glutathione and proline in the leaves (1146 and 2.2 µg g^{-1}, respectively), while the fertilization treatments (poultry manure + nano-NPK; poultry manure + salicylic acid + nano-NPK) resulted in an increase in the glucosinolate content of the leaves under salt stress (85.6 and 89.2 µg g^{-1}, respectively). The nano-NPK treatment achieved a high value of the leaves' ascorbic acid content under the unstressed conditions (166.73 µg g^{-1}), while the salicylic acid + nano-NPK treatment achieved the highest value of ascorbic acid under salt stress (137.4 µg g^{-1}). The combination of salicylic acid + poultry manure + nano-NPK obtained the highest value of glutathione content in the leaves (1950 µg g^{-1}) under the stress conditions. There is a positive correlation between salt stress and glutathione + proline, while the salt stress condition had a negative effect on glucosinolate, ascorbate and yield.

Introduction

Rocket (*Eruca sativa* L.) is a useful commercial crop with beneficial nutritional properties. Rocket plant leaves are rich in vitamins, biotin, thioglycosides, ascorbic acid, glutathione and retinol. Thioglycoside is considered one of the most important sulfur compounds responsible for the spicy taste in plants. Salinity is the most influential environmental factor limiting the productivity of crops (Chakrabarti, Ahmad, 2009).

Many plants depend on salt stress resistance, by producing effective antioxidants because of oxidative stress in cells due to the accumulation of free radicals, which cause the oxidation of the internal structures of the cell, especially the cell membranes (Kharusi *et al.*, 2019).

Water scarcity is one of the constraining factors for crop production; it plays a primary role in reducing crop production more than the reduction resulting from all other environmental factors (Bader *et al.*, 2020; Gar *et al.*, 2021).

Most strategically, crops are sensitive to salinity and crops drop between 20 and 50% of productivity under salt stress conditions, these reductions due to drought and soil salinity have two reasons. The first is the scarcity of irrigation water and the second is the high concentration of dissolved salts in the waters of the Tigris and Euphrates rivers, which are associated with low levels of water (Pengfei *et al.*, 2017; Al-Taey *et al.*, 2019). Because most crops are glycophytes and sensitive to salt stress, a high level of salinity is expected to cause a significant reduction in crop growth and production (Liu, Suarez, 2021). Salinity has plagued soil fertility and drastically affected the growth and survival of glycophytes in irrigated regions of the world since the beginning of recorded history. It is particularly common in arid and semi-arid areas where evapotranspiration exceeds annual precipitation and where irrigation is, therefore, necessary to meet crops' water needs (Manchanda, Garg, 2008).

Nanotechnology is a new multidisciplinary solution, especially in the agricultural and food sciences, which has led to new methods of solving many agricultural problems. Nanoparticles have other potential applications in agricultural systems, especially in foliar or ground fertilization operations (Ghorbani *et al.*, 2011). Furthermore, foliar fertilization should be supported with an organic fertilizer system to provide the needs of nutritional elements, especially under conditions of salt stress. Al-Juthery *et al.* (2020) noted that foliar application of nano-NPK 20-20-20 fertilizer optimized the growth, yield and concentration of nutrients in grains of wheat.

Salicylic acid is one of the plant hormones produced in plants and it plays an important role in regulating most of the biological activities of plants, such as plant growth, photosynthesis and flower regulation. Salicylic acid has received the attention of scientists and researchers due to its link with the defence systems inside the plant against the stresses to which the plant is exposed, particularly under conditions of salt stress, by reducing the production of oxidative systems and reducing the damage caused by these free oxygen radicals (Lateef *et al.*, 2021).

Materials and Methods

The study was conducted at the open field of Karbala research station with coordinates (32.61603N, 44.02488E) on October 15, 2018, the experiment was conducted with a randomized complete block design (RCBD) according to the split-plot system. The irrigation water quality (1.2 and 8.0 dS m^{-1}) were symbolized (W1 and W2) distributed to the main plot and the combination treatments (Table 1) were distributed in sub-plots. Each treatment included three replicates and soil analysis was conducted (Table 2). Irrigation was determined according to the plants' needs by placing sensors (Firstrate FST100–2006C, China) in each experiment unit. Irrigation was conducted based on depleting 50% of the field capacity.

Combination treatment (Table 1) poultry manure and traditional NPK fertilizer were applied directly to the soil, while salicylic acid and nano-NPK fertilizer were added as foliar spray applications three times every 14 days.

Table 1. The combination treatments

Treatment		Study dosages and concentrations
T1	Control	–
T2	NPK	1 g m^{-1}
T3	NPK^0	0.5 g m^{-1}
T4	Poultry manure	300 g m^{-1}
T5	Salicylic acid	50 mg L^{-1}
T6	SA + poultry manure (PO)	50 mg L^{-1}+300 g m^{-1}
T7	SA + NPK^0	50 mg L^{-1}+1 g m^{-1}
T8	PO + NPK^0	300 g m^{-1} + 1 g m^{-1}
T9	PO + SA + NPK^0	300 g m^{-1} + 50 mg L^{-1}+1 g m^{-1}

Table 2. Chemical and physical soil properties

Parameter	Value	Units
Clay	89	
Sand	141	Sandy loam, g kg^{-1}
Silt	770	
pH	7.23	
EC	3.4	dS m^{-1}
NaCl**%**	8.5	**%**
CO^{3-}	Nil	
HCO^{3-}	13×10^{-2}	
Ca^{+2}	92×10^{-3}	
Mg^{+2}	18×10^{-3}	
K^{+}	86×10^{-4}	mol·L^{-1}
Na^{+}	15×10^{-3}	
$SO4^{-2}$	12×10^{-3}	
Organic matter	1.6	%

Glucosinolate determination (mg g^{-1} dry weight)

The iron cyanide reduction method was used to determine the leaf content of glucosinolate sulfur glycosides (GLS), as described by Jezek *et al.* (1999). This depended on the reduction of iron cyanide by glucosinolate; then, the product was broken down in an alkaloid medium, liberating a yellow-coloured compound 1-thioglucose and its colour intensity was measured using a spectrophotometer (PG Instruments T60, UK) with a wavelength of 420 nm.

Glutathione determination (mg g^{-1} dry weight)

The glutathione content in the leaves was determined by Alscher (1989) using a dye (DTNB) that combines with the thiol group SH, in which the glutathione molecule is an alkaloid medium (pH = 8.9) to form the mixed disulphide, which releases the ion complex (yellow thiols). Colour intensity was measured using a spectrophotometer (PG Instruments T60, UK) with a wavelength of 412 nm.

Ascorbic acid contents in leaves (mg 100 g^{-1} fresh weight)

The vitamin C in leaves was estimated using the direct colour method (Horwitz *et al.*, 1970), which depended on the extent of 2,6-Dichlorophenolindophenol colour reduction by ascorbic acid in the sample based on the standard ascorbic acid.

Proline contents in leaves (mcg g^{-1} dry weight)

Proline colourimetric determination preceded, based on proline's reaction with ninhydrin, the ratio of 1:1:1 solution of proline, ninhydrin acid and glacial acetic acid was incubated at 100 ºC for 1 hour. The reaction was arrested in an iced bath and the chromophore was extracted with 1 ml toluene, the absorbance was determined at 520 nm, 0.1 gm of the shoot and root tissues were suspended with 1 ml of 3% sulfosalicylic acid and after centrifugation (10 min at 12 000 rpm). The reaction and determination of proline were carried out similarly, to those described above, the concentration of proline in tissues was determined depending on a standard curve of pure proline (Bates *et al.*, 1973).

Data analysis

Data were recorded and entered into MS Excel 2010. Data were analyzed using the GenStat 12 program analyze data. two-way ANOVA has been used and the means were compared with the LSD test ($P \leq 0.05$; Table 5).

Results and Discussion

Tables 3 and 5 showed significant differences when irrigating with different qualities of water, W1 (1.2 dS m^{-1}) achieved the best values of the vegetative and dry yield, leaves no., the leaf content of chlorophyll, glucosinolate and ascorbic acid, while the best values of glutathione and proline contents in leaves were achieved at W2 (8 dS m^{-1}) irrigation.

A significant difference among the combination treatments (Table 4), all treatments achieved a significant difference compared to control, the treatment T9 (poultry manure + SA + nano-NPK) achieved the highest values in vegetative and dry yield, leaves no., chlorophyll, glucosinolate, glutathione and proline content.

The addition of poultry manure, SA and nano-NPK individually achieved a significant increase in comparison with the control, in all studied parameters. The overlap of poultry manure, SA and NPK resulted in achieving the highest rates in all studied indicators compared to their use separately especially under irrigation level 8 dS m^{-1}, while the treatment T8 (poultry manure + nano-NPK) achieved the highest value in ascorbic acid contents in leaves.

The reduction of the studied indicators, because of irrigation with water level 8 dS m^{-1}, may be attributed to the osmotic effect caused by the increased salts in the soil and this leads to a decrease in the absorption of water by the plant. In turn, leads to a decrease in the permeability of nutrients, reflected negatively on cellular metabolism and vital activities inside the cell (Al-Khafajy *et al.*, 2020).

Table 3. Effect of water quality and treatment on some study parameters of rockets

Factors	Yield, kg ha^{-1}	Dry yield, kg ha^{-1}	Leaves, no. $plant^{-1}$	Chlorophyll, mg 100 g^{-1}	Glucosinolate, µg g^{-1}	Glutathione, µg g^{-1}	Ascorbic acid, mg 100 g^{-1}	Proline, mg g^{-1}
W1	10 700.8	1 531	20.41	109.96	110.7	754	136.51	1.18
W2	8 412.8	1 211	18.11	100.64	58	1 146	105.71	2.2
$LSD_{(0.05)}$	1 457.28	224.2	1.28	2.091	18.98	278.6	1.01	0.63
T1	5 632.0	978	15.83	93.07	49.5	556	93.3	0.91
T2	12 284.8	1 456	24.67*	109.77	90.8	978	140.99	2.22
T3	9 310.4	1 330	18.87	111.95	95.1	822	141.98	2.11
T4	9 979.2	1 151	16.43	99.65	73.3	675	114.64	1.64
T5	6 969.6	1 014	17.40	100.25	80.8	1 157	96.36	1.37
T6	10 612.8	1 466	20.60	110.73	86.9	1 259	109.33	1.54
T7	8 219.2	1 164	18.27	103.15	94.2	881	113.68	1.47
T8	9 152.0	1 276	18.07	101.45	90.1	867	144.35*	2.09
T9	1 3904.0*	2 103*	23.23*	117.69*	98.5*	1 355*	135.36	1.9
$LSD_{(0.05)}$	491.843	193.0	1.53	1.931	8.88	241.6	4.1	0.55

W – water qualities, 1.2 dS m^{-1} W1 , 8 dS m^{-1} W2; Treatments: Control –T1, 1 g m^{-1} NPK – T2, 0.5 g m^{-1} nano-NPK – T3, poultry manure (PO) 300 g m^{-1} – T4, salicylic acid (SA) 50 mg L^{-1} – T5, SA + PO – T6, SA + nano NPK – T7, PO + NPK^0 – T8, PO + SA + NPK^0 – T9

Table 4. The interaction treatments between the study factors

Factors	Yield, kg ha^{-1}	Dry yield, kg ha^{-1}	Leaves, no. $plant^{-1}$	Chlorophyll, mg 100 g^{-1}	Glucosinolate, µg .g^{-1}	Glutathione, µg g^{-1}	Ascorbic acid, mg 100 g^{-1}	Proline, mg g^{-1}
W1T1	6 195.2	1 018	16.27	102.43	3.07	0.750	5.52	0.80
W1T2	13 675.2	2 068	26.93	110.67	4.26	1.130	5.96	1.75
W1T3	11 352.0	1 491	19.27	114.23	4.95	1.270	6.16	1.52
W1T4	11 686.4	1 392	17.80	103.73	4.49	1.277	6.32	1.89
W1T5	7 884.8	1 236	18.20	100.53	4.23	1.060	6.11	1.35
W1T6	11 475.2	1 573	21.20	118.54	3.66	1.170	6.43	1.71
W1T7	8 782.4	1 345	19.20	105.43	4.75	1.440	6.21	1.51
W1T8	9 891.2	1 417	19.47	104.30	4.32	1.300	6.38	1.94
W1T9	15 382.4	2 237	25.40	129.75	5.03	1.610	6.33	2.00
W2T1	5 086.4	938	15.40	83.70	2.56	0.250	4.36	1.76
W2T2	10 894.4	1 844	22.40	108.87	3.54	0.450	5.1	3.54
W2T3	7 251.2	970	18.47	109.67	3.92	0.890	5.59	3.18
W2T4	8 272.0	910	15.07	95.57	3.29	0.797	5.46	2.85
W2T5	6 054.4	791	16.60	99.97	4.03	0.960	5.5	2.28
W2T6	9 750.4	1 359	20.00	102.93	2.97	0.630	5.58	2.63
W2T7	7 656.0	983	17.33	100.87	3.32	1.060	5.65	2.46
W2T8	8 395.2	1 135	16.67	98.60	3.83	0.840	5.77	2.72
W2T9	12 425.6	1 968	21.07	105.63	4.04	1.020	5.61	2.22
$LSD_{(0.05)}$	4 699.2	279.2	2.04	2.761	0.887	0.483	0.757	0.72

W – water qualities, 1.2 dS m^{-1} W1 , 8 dS m^{-1} W2; Treatments: Control –T1, 1 g m^{-1} NPK – T2, 0.5 g m^{-1} nano-NPK – T3, poultry manure (PO) 300 g m^{-1} – T4, salicylic acid (SA) 50 mg L^{-1} – T5, SA + PO – T6, SA + nano NPK – T7, PO + NPK^0 – T8, PO + SA + NPK^0 – T9

Table 5. ANOVA responses due to study factors

Source	Yield, kg ha^{-1}	Dry yield, kg ha^{-1})	Leaves, no. $Plant^{-1}$	Chlorophyll, mg 100 g^{-1}	Glucosinolate, µg g^{-1}	Glutathione, µg g^{-1}	Ascorbic acid, mg 100 g^{-1}	Proline, mg g^{-1}
Water qualities (W)	*	*	*	*	*	*	*	*
Treatments (T)	*	*	*	*	*	*	*	*
W × T	*	*	*	*	*	*	*	*

Significant at P <0.05, ANOVA; since the 2-way interaction was significant, it was used to explain the results

The increase of salts in the soil solution leads to a rise in the osmotic pressure of the soil solution, causing a decrease in the water availability and obstructing the transfer of water through the root system. In addition to the accumulation of sodium and chloride ions to the toxic limit, leading to a decrease in the activity of the meristematic tissues and inhibition of cell division and elongation (Sakr *et al.*, 2007). Furthermore, it affects the vegetative and root growth, causing a decrease in the rate of plant growth, which is ultimately reflected in yield and these results are consistent with what was reached by (Golezani *et al.*, 2011; AL-Taey *et al.*, 2019).

The irrigation water at level 8 dS m^{-1} decreased the leaf content of glucosinolate, Martínez-Ballesta *et al.*, (2015) indicated that glucosinolate compounds are affected by environmental stress negatively or positively and it has been found that the content of Arabidopsis leaves of total glucosinolate decreased during salt stress. Glucosinolate creation may be one of the acclimatization methods followed by plants. The decrease in total glucosinolate may be the result of the negative effect of salt stress on cellular metabolism processes and the production of glucosinolate has been affected. This may be due to the increase in the formation and activity of the myrosinase, which increases the hydrolysis of the glucosinolate (Radoicic *et al.*, 2008). The saline water led to a significant decrease in the content of ascorbic acid. It may be due to the negative effect of salinity, which disrupted the processes of cellular metabolism and affected the process of photosynthesis, thus reducing the carbohydrate compounds and carbon chains necessary to build other compounds (Deridder, Salvucci, 2007).

Tables 3 and 4 has been shown an increase in the glutathione content in the plant leaves during irrigation with 8 dS m^{-1} and this result has been indicated by (Koprivova *et al.* 2010; Lee *et al.* 2013). So, glutathione content is affected by environmental stress such as salt stress, leading to alteration of internal levels of glutathione under stress due to stimulation or modification in the gene expression responsible for glutathione production by reducing free oxygen radicals and delaying senescence (Hussain, 2016).

The salt stress led to an increase in the proline content in the leaves, as this is a mechanism followed by the plant in reducing Reactive oxygen species. The increase in salt leads to an increase in Reactive oxygen species inside the cells and this leads to damages inside the cell in association with the lipids that forms the plasma membrane. The plant works to increase the production of proline to reduce against cell ROS damage and regulate of osmotic pressure under stress conditions (Türkan, Demira, 2009).

Conclusion

Salinity led to an activated the non-enzymatic system against oxidative stress by an increase in glutathione and proline in the leaves. It reduced the other study growth parameters and yield while the combination treatment (poultry manure + nano-NPK; poultry manure + salicylic acid + nano-NPK) increased the glucosinolate content of the leaves under salinity.

Nano-NPK fertilizer achieved the highest value of the leaves' ascorbic acid content.

The treatment combination of (salicylic acid + poultry manure + nano-NPK fertilizer) got the highest value of glutathione content in the leaves under the salinity conditions.

Finally, there is a positive correlation between Salinity and glutathione + proline, while the salt stress condition has a negative effect on glucosinolate, ascorbate and yield.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Funding statement

This research did not receive any specific grants from funding agencies in the public, commercial, or not-for-profit sectors.

Author contributions

DKAA-T – designed the experimental setup, analyzed the data and results, wrote the manuscript.

ZJMA-M – performed greenhouse experiments and biochemical analyses.

References

Al-Juthery, H.W.A., Ali, E.A.H., Al-Ubori, R. N., Al-Shami, Q. M., AL-Taey. D. K. A. 2020. Role of foliar application of nano NPK, micro fertilizers and yeast extract on growth and yield of wheat. – International Journal of Agricultural and Statistical Science, 16(1):1295–1300.

Al-Khafajy, R.A., AL-Taey, D.K. A., AL-Mohammed, M.H.S. 2020. The impact of water quality, biofertilizers and selenium spraying on some vegetative and flowering growth parameters of *Calendula officinalis* L. under salinity stress. – International Journal of Agricultural and Statistical Science, 16(1):1175–1180.

Alscher, R.G. 1989. Biosynthesis and antioxidant function of glutathione in plants. – Physiologia Plantarum, 77(3):457–464. DOI: 10.1111/j.1399-3054.1989.tb05667.x

AL-Taey, D.K.A., Al-Naely, I.J.C., Kshash, B.H. 2019. A study on the effects of water quality, cultivars, organic and chemical fertilizers on potato (*Solanum tuberosum* L.) growth and yield to calculate the economic feasibility. – Bulgarian Journal of Agricultural Science, 25 (6), 1239–1245.

Bader, B.R., Abood, M.A., Aldulaimy, S.E.H., Al-Mehmdy, S.M.H., Hamdi, G.J.H. 2020. Effect of water deficit and foliar application of amino acids on growth and yield of eggplant irrigated by two drip systems under greenhouse conditions. – Agraarteadus, 1(31): 131–138. DOI: 10.15159/jas.20.20

Bates, L.S., Waldern, R., Teare. I. 1973. Rapid determination of free proline for water stress studies. – Plant and Soil, 39:205–207.

Chakrabarti, M.H., Ahmad, R. 2009. Investigating the possibility of using least desirable edible oil of *Eruca sativa* L., in bio diesel production. – Pakistan Journal of Botany, 41(1):481–487.

Deridder, B.P., Salvucci, M. 2007. Modulation of Rubisco activate gene expression during heat stress in cotton (*Gossypium hirsutum* L.) involves post-transcriptional mechanisms. – Plant Science, 172(2):246–252.

Gar, L.F., Bader, B.R., Al-Esawi, J.S.E., Abood, M.A., Sallume, M.O., Hamdi, G.J. 2021. Response of onion growth and yield grown in soils of semi-arid regions to foliar application of iron under water stress conditions. – Agraarteadus, 1(32):35–40. DOI: 10.15159/jas.21.06

Ghorbani, H.R., Safekordi, A.A., Attar, H., Sorkhabadi, S.M. 2011. Biological and non-biological methods for silver nanoparticles synthesis. – Chemical and Biochemical Engineering Quarterly, 25(3):317–326.

Golezani, K.G., Salmasi, S.Z., Dastborhan, S. 2011. Changes in essential oil content of dill (*Anethum graveolens*) organs under salinity stress. – Journal of Medicinal Plants Research, 5(14):3142–3145.

Horwitz, W., Chichilo, P., Reynolds, H. 1970. Official methods of analysis of the association of official analytical chemists. (11th ed.). – Association Official Analytical Chemists, Washington, D.C., 1015 pp.

Hussain, B.M.N., Akram, S., Raffi, S.A., Burritt, D.J., Hossain, M.A. 2016. Exogenous glutathione improves salinity stress tolerance in rice (*Oryza sativa* L.). – Plant Gene and Trait, 7(11):1–17. DOI: 10.5376/pgt.2016.07.0011

Jezek, J., Haggett, B.G.D., Atkinson, A., Rawson, D.M. 1999. Determination of glucosinolate using their alkaline degradation and reaction with ferricyanide. – Journal of Agricultural and Food Chemistry, 47: 4669–4674. DOI: 10.1021/jf9906026

Kharusi, L.A., Yahyai, R.A., Yaish, M.W. 2019. Antioxidant response to salinity in salt-tolerant and salt-susceptible cultivars of date palm. – Agriculture, 9(1):1–17. DOI: 10.3390/agriculture9010008

Koprivova, A., Mugford, S. T., Kopriva. S. 2010. Arabidopsis root growth dependence on glutathione is linked to auxin transport. – Plant Cell Reports, 29: 1157–1167. DOI: 10.1007/s00299-010-0902-0

Lateef, M.A., Noori, A.M., Saleh, Y. M., Al-Taey, D.K.A. 2021. The effect of foliar spraying with salicylic acid and calcium chloride on the growth, yield and storage traits of two strawberry cultivars, Fragaria × Ananassa Duch. – International Journal of Agricultural and Statistical Science, 17(2):611–615.

Liu, X., Suarez, D.L. 2021. Lima bean growth, leaf stomatal and nonstomatal limitations to photosynthesis and ^{13}C discrimination in response to saline irrigation. – Journal of the American Society for Horticultural Science, 146(2):132–144. DOI: 10.21273/JASHS04996-20

Manchanda, G., Garg, N. 2008. Salinity and its effects on the functional biology of legumes. – Acta Physiologiae Plantarum, 30:595–618. DOI: 10.1007/s11738-008-0173-3

Martínez-Ballesta, M., Castejón, D.A.D., Ochando, C., Morandini, P.A., Carvajal, M. 2015. The impact of the absence of aliphatic glucosinolate on water transport under salt stress in *Arabidopsis thaliana*. – Frontiers in Plant Science, 15(6): 1–12. DOI: 10.3389/fpls.2015.00524

Pengfei, Z., Yanyan, D., Masateru, S., Natsumi, M., Kengo, I. 2017. Interactions of salinity stress and flower thinning on tomato growth, yield and water use efficiency. – Communications in Soil Science and Plant Analysis, 48:22:2601–2611, DOI: 10.1080/00103624.2017.1411508

Radoicic, I., Redovnikovi, R.T., Delonga, K., Vorkapic-Furac. J. 2008. Glucosinolate and their potential role in the plant. – Periodium Biologorum, 110(4):297–309.

Sakr, M.T., El-Emery, M.E., Fouda, R.A., Mowafy, M.A. 2007. Role of some antioxidants in alleviating soil salinity stress. – Journal of Agricultural Sciences, 32:9751–9763.

Türkan, I., Demiral, T. 2009. Recent developments in understanding salinity tolerance. – Environmental and Experimental Botany 67(1):2–9. DOI: 10.1016/j.envexpbot.2009.05.008

Agraarteadus
1 • XXXIII • 2022 48–58

Journal of Agricultural Science
1 • XXXIII • 2022 48–58

INVESTIGATION OF PROPERTIES OF SUNFLOWER AND RAPESEED OILS OBTAINED BY THE SOXHLET AND MICROWAVE EXTRACTION METHODS

Valentyna Bandura[1], Larysa Fialkovska[2], Petro Osadchuk[3], Yuliia Levtrynskaia[3], Anna Palvashova[3]

[1]National University of Life and Environmental Sciences of Ukraine, 15 Heroyiv Oborony St., 03041, Kyiv, Ukraine
[2]Vinnytsia Institute of Trade and Economics regional subdivision of Kyiv National University of Trade and Economics, 87 Soborna St., 21050, Vinnytsia, Ukraine
[3]Odesa National University of Technology, 112 Kanatnaya St., 65039, Odessa, Ukraine

Saabunud: Received: 01.02.2022

Aktsepteeritud: Accepted: 15.04.2022

Avaldatud veebis: Published online: 15.04.2022

Vastutav autor: Corresponding author: Valentyna Bandura

E-mail: bandura_3@ukr.net

ORCID:
0000-0001-8074-3020 (VB)
0000-0002-4353-0963 (LF)
0000-0003-3312-0669 (PO)
0000-0003-1136-2720 (YL)
0000-0002-0852-3397 (AP)

Keywords: sunflower and rapeseed oil, extraction, microwave energy supply, Soxhlet, fatty acid composition of oils.

DOI: 10.15159/jas.22.17

ABSTRACT. The main purpose of the study was to evaluate the possibility of replacing hexane, which is traditionally used for the extraction of vegetable oils, with ethanol as a safer solvent when extracting oil from sunflower meals and rapeseed in the microwave field. Thus, the influence of the solvent type on physicochemical characteristics of oil and the low-fat meal was studied. The main indicators of the composition and quality of sunflower and rapeseed extraction oil were studied. The quality of oil and ways of its use in food products are mostly determined by its fatty acid composition. Analysis of the fatty acid composition of the oil was performed by the method of gas chromatography using a column HP-88 100 m* 0.25 mm*0.20 µm. The possibility of using oil in food was established by conducting pilot laboratory studies and investigating changes in physicochemical parameters during storage. The extraction by the Soxhlet method (hexane as a solvent) was compared with the method of extraction of raw materials in a microwave field (ethyl alcohol as a solvent). Studies of physicochemical parameters indicate the degree of oil oxidation (determination of peroxide and anisidine values). The peroxide value is an indicator of the content of primary oxidation products. The peroxide value of the oil obtained by the method of Soxhlet extraction (hexane as a solvent) was 5.0 (½O mmol) kg^{-1}. The peroxide value of the oil obtained by extraction in a microwave field (ethyl alcohol as a solvent) was 3.8 (½O mmol) kg^{-1}. The anisidine value is an indicator of the content of aldehydes in vegetable oils (secondary oxidation products). The anisidine value of the oil obtained by the method of Soxhlet extraction (hexane as a solvent) was 0.3 s.u. The anisidine value of oil obtained by extraction in a microwave field (ethyl alcohol as a solvent) was 0.2 s.u. Comparing the data of peroxide and anisidine values, it can be argued that the oil obtained by extraction of raw materials in a microwave field (ethyl alcohol as a solvent) had the best indicators. The acid value is one of the main qualitative indicators that characterize the degree of oil freshness. The acid value of the oil obtained by the method of Soxhlet extraction (hexane as a solvent) was 3.1 (mg KOH) g^{-1}. The acid number of the oil obtained by extraction in a microwave field (ethyl alcohol as a solvent) was 2.1 (mg KOH) g^{-1}. A comparison of the acid values of oils extracted from the raw material by different extraction methods shows that the oil obtained by the method of extraction of raw materials in a microwave field using ethyl alcohol as a solvent has the best acid value. Studies have shown that the oil, which was obtained by extraction of raw materials in a microwave field using ethyl alcohol as a solvent, had the best resistance to oxidation during storage (three months).

Introduction

Ukraine holds the leading position in the world's gross yield of sunflowers. The bulk of sunflower seeds is processed into oil, fodder cake and meal. According to the results of 2020, Ukraine remained the leader in the production and export of sunflower oil on the world market. In 2020, for the second time, the export of sunflower oil from Ukraine reached a record high of 6.9 million tons exceeding by 12% the 2019 record of 6.1 million tons (National Research Center, Institute of Agrarian Economics). Therefore, the development and implementation of up-to-date technologies for processing oilseeds, including sunflower seeds, remain relevant.

The increasing manufactured load on the environment and the threat of depletion of non-renewable natural resources caused the need to create and implement resource-saving energy-efficient and environmentally friendly production technologies. Improvement of the production of various products based on innovative methods of technological processes is a prerequisite for the development of the modern industry. One of the problems to be solved by innovative methods and technologies is the maximum extraction of useful products from raw materials. All vegetable oils are composed of fats (triglycerides) by 99–99.5% and have a high caloric content – 9 kcal g^{-1} of product. However, the value of vegetable oils is not limited to this only. In the 1930^{th,} it was found that vegetable oils contained substances necessary for human life, which could not be produced in the body. These compounds are fatty acids with two or more unsaturated bonds in the molecule, namely linoleic acid (18 carbon atoms and 2 double bonds) and linolenic acid (18 carbon atoms and 3 double bonds), which are called essential.

Nowadays, the most common methods of oil extraction are the method of mechanical pressing of raw materials and oil extraction with solvents (Beloborodov, 1966). At the present stage of the development of science and technology, the potential of microwave technology to increase the efficiency of many traditional industries and obtain products with new, better consumer qualities deserve recognition.

Formulation of the problem

A great experience has been gained in the use of microwave technologies in various industries to intensify the production process. However, in our opinion, there is very little research on the extraction of sunflower seeds with ethyl alcohol, and there is no reliable data on microwave extraction modes, or properties of the extracts obtained, which does not allow us to create appropriate technology and develop a microwave device for obtaining substances. These circumstances have determined the relevance of scientific research on the extraction of crude oil with solvents in the microwave field**.**

New methods are being developed since traditional ones have various disadvantages, e.g. they are more energy and time consuming, provide lower yields and are less environmentally friendly (Sharma *et al*, 2019). Physical methods of oil extraction allow for extracting only about 80% of the oil available in the oil material; therefore, another technology must be used to extract the remaining 20% (Puertolas *et al*, 2016). Extraction with a solvent has become widespread due to the simplicity and economy of the process (Mwaurah *et al*, 2020). Solvents are usually hexane and n-hexane, as they give the highest yield (95%) (Tan *et al.*, 2016). In particular, n-hexane is preferred due to its properties such as simple extraction, low latent heat of vaporization (330 kJ kg^{-1}), narrow boiling range (63–69 °C), high solubility and non-polarity. Unfortunately, the use of these solvents poses problems for health, safety and the environment, and therefore, despite their high efficiency of extraction, their use is not only harmful and toxic but also leads to air pollution (Konopka *et al*, 2016; Kumar *et al*, 2017). In addition, although it is approved for the food industry by the European Commission and the Food and Drug Administration (FDA), hexane is still considered and classified as hazardous and not the best for some international organizations (Castejón *et al*, 2018). However, the extraction of vegetable oil consumes large amounts of hexane, and therefore there is a need to study environmentally friendly technologies.

The oil is extracted from the raw material by pressing under the action of compressive external forces created in the press. This method ensures the extraction of high-quality oil, however, when pressed, about 8–14% of the oil remains in the cake (Ionescu *et al*, 2013). Extraction with a solvent allows the oil to be removed, leaving only 0.5–0.7% of oil in the meal (Topare *et al*, 2011) and can be used for raw materials having low oil content, as well as for the final extraction of oil from the cake after pressing. Some works present the results of the use of both pure solvents and mixtures (Hussain *et al*, 2018). Oil extraction provides maximum degrease of vegetable raw materials and is carried out by mass transfer. Mass transfer during the extraction of oil from particles of pre-crushed vegetable raw materials is the process of mass transfer on the surface of the particles and diffusion inside (Bandura *et al.*, 2021). Recently, research into new methods of extracting oil from raw materials, such as microwave extraction, has become widespread (Grasso *et al*, 2012).

Microwave-assisted extraction (MAE) is a new method, which can reduce the extraction time and solvent consumption. The study (Taghvaei *et al.*, 2014) aimed to evaluate the influence of MAE on oxidative stability and physicochemical properties of cottonseed oil. It was found that optimal conditions for extraction were as follows: irradiation time of 3.57 min; moisture content in cotton seeds of 14% and the ratio between cotton seeds and a solvent of 1:4, which resulted in the extraction efficiency of 32.6%, total phenolic content of 46 parts per million, 0.7% of free fatty acids, peroxide value of 0.2.

Replacement of toxic organic solvents from fossil sources with nontoxic ones of biorenewable origin in large-scale processes has been the subject of research (Ferreira *et al*, 2022). Although ethanol has been currently investigated as a hexane substitute for vegetable oil extraction, most studies are conducted on a laboratory scale and in batch assays. Initial parameters of a continuous and countercurrent extractor that indicates the technical possibility of a large-scale operation are still scarce. Here, a continuous extractor composed of fixed bed columns connected in series (resembling the so-called simulated moving bed extractor) for soybean oil extraction with anhydrous ethanol was experimentally reproduced by a multiple-batch solid-liquid extraction system. After a 5-stage extraction, the residual oil in the solid phase was 0.17% with a 99.2% extraction yield, confirming that ethanol was capable to exhaust the solid matrix with a reasonable extraction yield. Although the minimum solvent-to-feed ratio (S:F) for ethanol (S:F = 2.62:1) was higher than that for hexane (S:F = 0.36:1), benefits to food safety, reduction in handling danger, and less environmental impact reinforce ethanol as a safe and promising solvent for the extraction of vegetable oils in continuous equipment.

It is assumed that extracts from plant raw materials obtained using the influence of microwave electromagnetic field, acquire qualitatively new biochemical and biological properties in comparison with analogues obtained by traditional extraction methods. Bandura *et al* (2018) investigated the possibilities of reducing the duration of the extraction process of soybean and rapeseed, obtaining a higher yield of the target component, and increasing the number of valuable components (tocopherols) in the finished product. It was found that in the microwave intensifier, compared to the classical method of extraction, the extraction time of soybean and rapeseed is reduced to 70% and the yield of the target component increases by 30%.

Intensification of the technological processes in the production of vegetable oils is a topical scientific and practical task. It is assumed that extracts from the plant raw materials obtained by exposure to the electromagnetic microwave field possess qualitatively new biochemical and biological properties in comparison with similar extracts obtained utilizing the conventional extraction methods. The article deals with the possibility to reduce the duration of the extraction process of the soybean and canola seeds, achieving a great output of the target component, to increase the number of valuable components (tocopherols) in the finished product. It has been established that in the microwave intensifier, in contrast to the classic method of extraction, the extraction time of the soybean and canola seeds is reduced to 70%, but the output of the target component increases within the limits of 30%.

The ethanolic extraction of oil from sunflower collets was studied and compared with previous data, where hexane was used as an extraction solvent (Baümler *et al*, 2016). First, the extractive power of ethanol was determined by Soxhlet. It gave a higher yield of extracted material, and which content of soluble hexane components (oil phase) was similar to that obtained with n-hexane. When ethanol was used as the solvent, 70% less crystallizable waxes and at least 38% more tocopherols and phospholipids were extracted. In addition, ethanol showed great ability to extract sugar, mainly raffinose and sucrose, extracting over 75% of the initial sugar content. Then, the kinetics of ethanolic extraction was studied at 50 and 60 °C in a batch reactor. At equilibrium conditions, it was observed that extraction could be limited by the solubility of the extractable material. Oil effective diffusivities were 9.94×10^{-10} at 50 °C and 3.11×10^{-9} m^2 s^{-1} at 60 °C. From the point of view of the quality of the obtained products, this work demonstrated the feasibility of using ethanol as an alternative solvent to hexane in the oil extraction from sunflower collets.

The influence of ethyl alcohol concentration, temperature and productivity of sprinkling the material with an extraction agent on its oleaginous condition as well as on the output and fractional makeup of the extractive matters is evaluated in the research. It is determined that the productivity of sprinkling is the most influential factor within the investigated limits. Hydromodulus 1:1.7 with the use of refillable miscella of single sprinkling is achieved. Residual oleaginous condition of oilcake equals 0.6–0.9% (Matiukhov, Hladkyi, 2013).

A comparison of the extraction of cake obtained from sunflower seeds with different organic solvents was performed (Matiukhov, Hladkyi, 2013). It was found that ethanol extracts extractives from sunflower meal more slowly than petroleum and diethyl ethers. The latter extract extractives at almost the same speed. Sources cited in the paper argued that the best extractant for oil is absolute ethanol at near-boiling temperature; it also denatures protein to a lesser extent, but extracts phenolic compounds slightly worse than rectified ethanol (Matiukhov, Hladkyi, 2013). Burdo *et al* (2018) emphasize that the most important problems of human development (energy, ecology, food) are typical for the food industry, and their solution is related to finding new approaches to the thermal processing of raw materials. Prospects of electrical technologies of targeted energy supply for individual elements of food raw materials utilizing microwave processing are substantiated. Hypotheses of energy-efficient processes of dehydration, extraction and inactivation of microorganisms are formulated.

In this paper, we emphasize that the most important problems in human development (energy, ecology, food) are typical of the food-production sector, and their solutions are connected with the search for fundamentally new approaches to the thermal processing of raw materials. The prospects of electrotechnologies of targeted energy delivery for single elements of food raw materials are substantiated. Hypotheses for energy-efficient processes of dehydration, extraction, and inactivation of microorganisms are formulated.

Microwave extraction is a popular extraction method that has high productivity and extraction efficiency compared to other traditional methods. Microwave radiation interacts with the dipoles available in the sample matrix, causing them to oscillate in response to changing electromagnetic fields. Oscillation or rotation of dipoles during motion leads to the friction of molecules, which is converted into heat and transferred into the material due to thermal conductivity. In addition to dipoles from the solvent used in the extraction process, this heat leads to the formation of water vapour and electroporation effects that destroy the cell wall of oilseeds and enhance the efficient extraction of intracellular metabolites (Mwaurah *et al*, 2020).

Microwave radiation is a non-contact source of energy that provides efficient heating, minimum temperature gradient and selective heating if necessary (Burdo *et al*, 2016a). Therefore, the extraction time is significantly reduced (from 10 to 15 minutes), a smaller volume of solvent is used, both polar and non-polar solvents are contained, the extract yield is increased, and excellent sensory characteristics are achieved, *i.e.* colour, odour and aroma in products (Balasubramanian *et al*, 2011; Picó, 2013).

During the processes of the extraction of the plant cell, walls complicate diffusion processes that prevent the removal of target components (Edwards *et al*, 1997). However, when using a microwave field, the yield of extractives increases significantly, as stated in the scientific works of Western (Chemat, Cravotto, 2013, Flórez *et al*, 2015; Tewari *et al*, 2015), Asian (Bhuyan *et al*, 2015;Chan *et al*, 2015; Pan *et al*, 2003), and domestic scientists (Lebovka, Vorobiev, 2012; Burdo *et al*, 2016a; Burdo *et al*, 2018). Therefore, it can be concluded that the rupture of the cell membrane and the release of target components require not only the intensification of the molecule movement but also a significant increase in pressure.

As for the product quality and yield, microwave radiation allows direct binding of molecules by selective absorption; thus, it leads to high-quality products compared to traditional methods of heating and extraction (Khan, Rathod, 2018). The higher the power of the microwave field is, the faster the molecules move, and the higher the temperature and reaction rate is. On the other hand, low power increases the time required to reach the phase transition temperature (Zhang *et al*, 2018).

When using microwave extraction, non-polar solvents show the poor synergy between the solvent and microwave radiation due to their low dielectric penetrability. In addition, the mechanism of microwave heating is based on the rotation of molecules or dipoles in combination with ionic conductivity. For these reasons, polar solvents are best for microwave extraction because they have a high dielectric constant, absorb more microwave radiation, and promote conductivity. Moreover, polar solvents have shown better results than non-polar solvents in most cases (Khan, Rathod, 2018). Ethanol has excellent microwave absorption properties, while commonly used hexane is transparent to microwave radiation.

The main purpose of the study is to evaluate the possibility of replacing hexane, which is traditionally used for the extraction of vegetable oils, with a safer solvent, *i.e.* ethanol, when extracting oil from sunflower meal and rapeseed in the microwave field.

Materials and Methods

Sunflower seeds were taken from a consignment of seeds received at Vinnytsia Oil and Fat Plant. The moisture content of sunflower seeds was determined according to the standard (SSTU, State Standard of Ukraine). Sunflower seeds were processed by pressing by the technology of sunflower oil production approved by the enterprise. Samples of cake left after pressing were taken for further research of the extraction process. Rapeseed of the 'Champion' variety harvested in 2021 was used. Seed moisture content was determined according to the current standard (GOST 10856-96).

Hexane as an extractive solvent was obtained from Antecom LLC (Ukraine). Ethyl alcohol was obtained from the manufacturer, namely the State Enterprise SpirtLux (Ukraine).

Research methods are based on thermophysical analysis of the structure of the material and solvent. During the experimental research, there was used control and measuring equipment, and modern techniques and devices, including the authors' developments. Excel software packages were used for analytical research.

Laboratory equipment that was used included the laboratory sieve, thermostat TC-80 M2, thermometer TL-2K, electronic scales PS 750/c/1 RADWAG®, desiccators, tanks, flasks, boxes, drying cabinet SPT-200, drying cabinet 2B-151, analytical scales of the AS 310X series, an experimental stand of microwave action (developed by Odessa National Technological University), Agilent 8890 gas chromatograph (distributed by ALSI-Chrome (USA).

Soxhlet extraction was performed by GOST 10857-64. In this method, we weighed (40 g) of crushed sunflower meal (or crushed rapeseed) and transferred to a Soxhlet apparatus. The extraction was completed in 22–24 hours at a maximum temperature of 50–68.7 °C (boiling point of n-hexane). After the extraction process, the solvent residue was removed at 50 °C and reduced pressure using a rotary evaporator (Heidolph, Germany). For the further reduction of the amount of solvent, the extracted oil was transferred to a thermostat TC-80 M2 (Ukraine) at a temperature of 50 °C until a constant mass. The resulting oil was weighed and the oil yield was calculated.

The same experiments were performed with a solvent of ethyl alcohol. The extraction was completed in 22–24 hours at a maximum temperature of 50.0–78.3 °C (boiling point of ethyl alcohol). The determination was performed in triplicate for each solvent.

A microwave oven manufactured by Samsung (Korea, output power 425 W with a frequency of 2450 MHz) and a refrigerator connected to it were used

(Fig. 1). For each cycle of the experiment, 40 g of sunflower meal (or crushed rapeseed) was weighed and added solvent (n-hexane or ethyl alcohol) in a ratio of cake and solvent 1:3 in each cycle of experiments. The sunflower seeds or rapeseed were drained, then with solvent, it was placed in a glass flask and processed in the electromagnetic field for 10 to 20 minutes. Next, the kinetics of the process was investigated.

The main elements of the experimental microwave stand were a chamber in which a microwave field was created thanks to a magnetron, as well as a container in which the process of extraction of research objects took place: sunflower seed cake and winter rape of 'Champion' variety.

The principle of operation of the experimental stand was as follows: the extraction process took place in the container with the product under the action of a microwave field in chamber 1. Vapours of the extractant entered the reflux condenser 2, condensed and flew back into the reaction vessel with the test sample and solvent. Miscela was collected by syringe for further study of the oil concentration.

The extraction was completed in 10–20 minutes. For further reduction of the amount of a solvent, the extracted oil was transferred to a thermostat TC-80 M2 (Ukraine) at a temperature of 50 °C until a constant mass. The resulting oil was weighed and the oil yield was calculated.

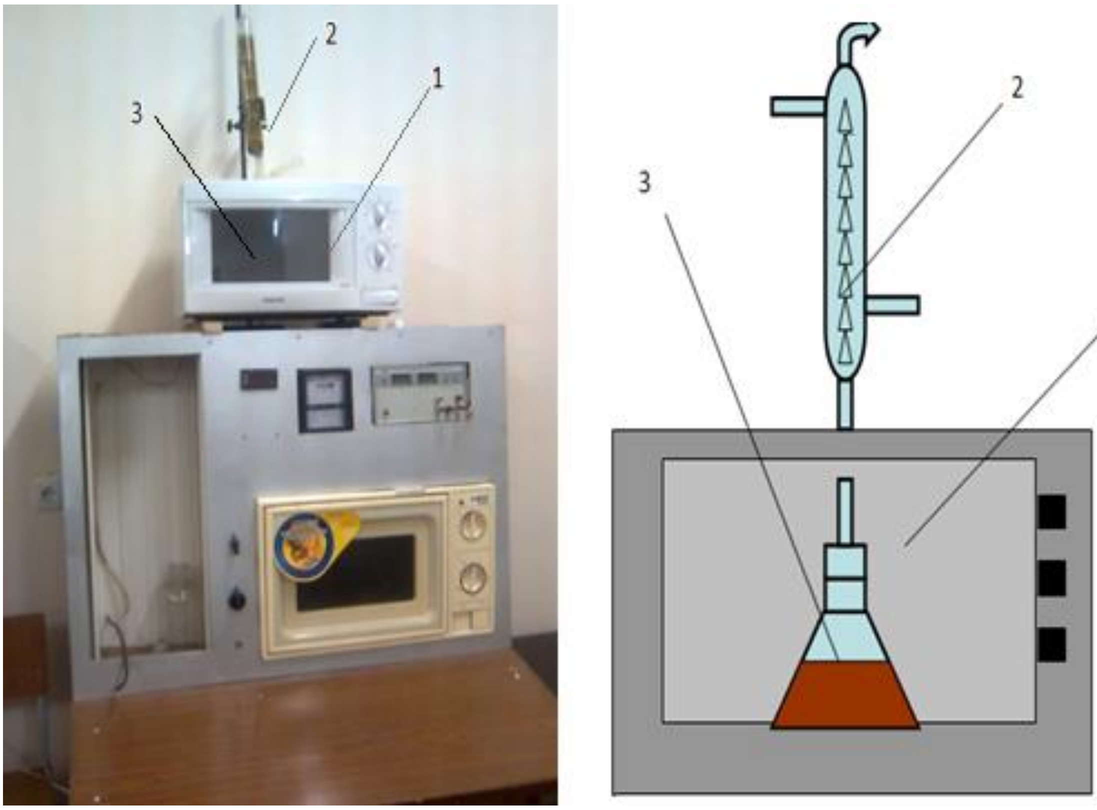


Figure 1. Photo and scheme of the experimental installation for oil extraction in a microwave field

To obtain a control sample (sunflower and rapeseed oil), there were used oils obtained at Vinnytsia Oil and Fat Plant using the current technology (extraction in a carousel extractor, hexane was used as solvent).

Analysis of the fatty acid composition of the oil was performed by the method of gas chromatography using a column of HP-88 100 m * 0.25 mm * 0.20 µm. The possibility of using oil in food was established by conducting pilot laboratory studies and studying changes in physical and chemical parameters during storage for three months.

Methodology of statistical processing of experimental data included the evaluations of observational errors in experimental results. Random errors was deleted from study results. In research was used verified measurement equipment and measurement errors was taking into account in results analyzing. The studies were repeated three times and mathematically processed using Microsoft Excel 2007 to ensure the accuracy of the results. The statistical error did not exceed 5% (with a 95% confidence level).

Results

Non-polar aliphatic hydrocarbons are used in classical oil extraction technologies due to their highest efficiency among solvents. It is known that the activation of reacting molecules is possible by heating substances, by releasing energy during the reaction, as well as by the absorption of radiation quanta by reagents (radioactive, light, electromagnetic, *etc.*), by ultrasound or electric discharge and even by hitting the bulb wall. An electromagnetic field was used to activate the molecules, which set the particles in motion. The forming particle layer promotes turbulence of the flow and efficient mixing of the reaction mass. The turbulence of the flow and the action of the electromagnetic field leads to changes in the mass transfer coefficient, the energy of initial connections and the speed of the process.

In the study of the extraction process without the influence of a microwave field, only under the action of temperature, hexane as a solvent is much more effective than ethyl alcohol (Fig. 2). Where No. 1 is for rapeseed + ethyl alcohol 0.5 mm fraction of the whole grain under 50 °C and No. 1 is for rapeseed + hexane 0.5 mm fraction of the whole grain under 50 °C.

Due to the use of the microwave field as an intensifying effect, the study was conducted with polar ethyl alcohol, the intensity of removal of which under the action of microwave radiation increased to the efficiency of hexane (Fig. 3), where No. 1 – results without the influence of a microwave field (hydro module 1:3) and No. 2 are results under the influence of a microwave field (hydro module 1:3).

The study of physicochemical parameters of sunflower extraction oil obtained by the Soxhlet method and extraction oil under the influence of microwave field was carried out by conventional methods of analysis set out in relevant standards and manuals on techno-chemical control of production and methods described in the State Standards of Ukraine (Table 1). Table 1 are shown shows the methods of sunflower oil testing.

Table 1. Methods of sunflower oil research

Indicator	Principle of the research method
A sampling of oil and preparation for analysis	According to SSTU 4349:2004
Mass fraction of moisture and volatile substances, %	According to SSTU ISO 662:2004
Mass fraction of non-fatty impurities,%	According to SSTU ISO 663-2003
Acid value, (mg KOH) g^{-1}	According to SSTU 4350:2004
Peroxide value, (½O mmol) kg^{-1}	According to SSTU 3960-2001
Mass fraction of phosphorus-containing substances in terms of stearooleolecithin,%	According to GOST 7824
Flashpoint, °C	According to GOST 9287
Anisidine value	According to SSTU ISO 6885 – 2002
Fatty acid composition of oil	According to SSTU ISO 5508-2001. Analysis of methyl esters of fatty acid by the method of gas chromatography

We conducted a study of sunflower extraction oil obtained by the Soxhlet method and extraction oil obtained under the influence of a microwave field. The results are shown in Table 2.

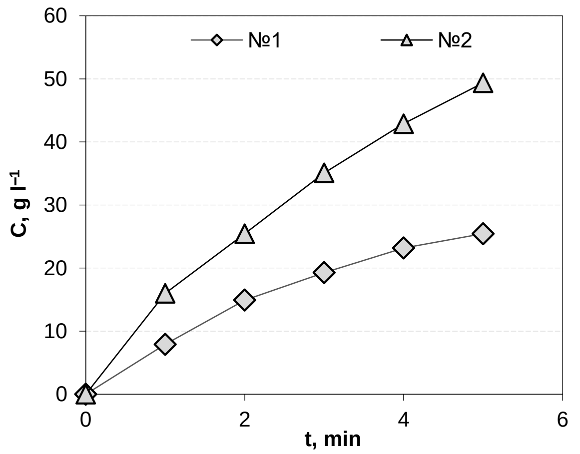


Figure 2. Dependence of concentration on time in the process of oil extraction with different solvents

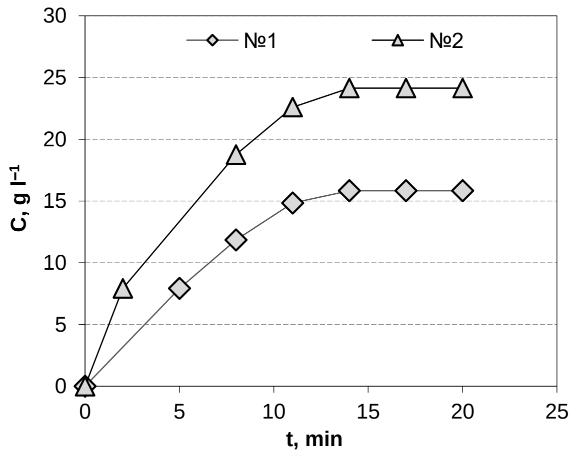


Figure 3. Dependence of concentration on time in the process of oil extraction with alcohol from rapeseed at a boiling point of a solvent of 78.3 °C

Table *2.* Physicochemical parameters of sunflower extraction oil obtained after extraction with solvents: hexane (samples No. 1, No. 3) and alcohol (samples No. 2, No. 4).

Indicator	Soxhlet method		Under the influence of a microwave field	
	Hexane as a solvent	Ethyl alcohol as a solvent	Hexane as a solvent	Ethyl alcohol as a solvent
Experimental sample	No. 1	No. 2	No. 3	No. 4
Mass fraction of moisture and volatile substances,%	0.18	0.17	0.19	0.16
Mass fraction of non-fatty impurities,%	0.05	0.04	0.05	0.03
Acid value, (mg KOH) g^{-1}	3.1	2.5	2.8	2.1
Peroxide value, (½O mmol) kg^{-1}	5.0	4.8	4.3	3.8
Mass fraction of phosphorus-containing substances in terms of stearooleolecithin,%	0.45	0.41	0.43	0.38
Anisidine value, s.u.	0.3	0.25	0.28	0.2
Flash point, °C	226	227	226	225

The studies of physicochemical parameters indicate the degree of oxidation of the oil (determination of the peroxide and anisidine values).

The peroxide value is an indicator of the content of primary oxidation products. The peroxide value of the oil obtained by the method of Soxhlet extraction (hexane as a solvent) was 5.0 (½O mmol) kg^{-1}. The peroxide value of the oil obtained by extraction in a microwave field (ethyl alcohol as a solvent) was 3.8 (½O mmol) kg^{-1}.

The anisidine value is an indicator of the content of aldehydes in vegetable oils (secondary oxidation products). The anisidine value of the oil obtained by the method of Soxhlet extraction (hexane as a solvent) was 0.3 s.u. The anisidine number of oil obtained by extraction in a microwave field (ethyl alcohol as a solvent) was 0.2 s.u.

Comparing the data of the peroxide and anisidine values, it can be argued that the best indicators were found in the oil obtained by the method of extraction of raw materials in a microwave field (ethyl alcohol as a solvent).

Studies have shown that oil, which is obtained by the method of extraction of raw materials in a microwave field using ethyl alcohol as a solvent, has the best resistance to oxidation during storage (3 months).

Chromatograms of the fatty acid composition of extraction oil are shown in the next results: No. 1 – sunflower, sample No. 1; No. 2 – sunflower, sample No. 2; No. 3 – sunflower, sample No. 3; No. 4 – sunflower, sample No. 4; No 5 – rapeseed oil; sample No. 1. It should be noted that the main guarantee of the nutritional value of oil is the fatty acid composition. Together with the generally accepted indicators of oil, we studied the fatty acid composition of sunflower extraction oil. The Agilent 8890 gas chromatograph (distributed by ALSI-Chrome (USA) was used to determine the fatty acid composition of the oil. The results are shown in Tables 3–6.

Table 3 Fatty acid composition of sunflower extraction oil (sample No. 1)

Reference designation of acid	Name of acid according to trivial nomenclature	Mass fraction of fatty acid (% to the sum of fatty acids)
$C_{6:0}$	Capronic acid	0.069
$C_{14:0}$	Myristic acid	0.067
$C_{16:0}$	Palmitic acid	6.491
$C_{16:1}$	Palmitoleic acid	0.089
$C_{18:0}$	Stearic acid	3.687
$C_{18:1}$	Oleic acid	28.366
$C_{18:2}$	Linoleic acid	59.233
$C_{20:0}$	Arachic acid	0.212
$C_{20:1}$	Eicosanoic acid	0.113
$C_{18:3}$	Linolenic acid	0.161
$C_{21:0}$	Heneicosylic acid	0.184
$C_{22:0}$	Behenic acid	0.694
$C_{24:0}$	Lignoceric acid	0.167

In accordance with SSTU 4492-2017, fatty acids of sunflower oil should mainly include the following fatty acids: myristic acid (up to 0.2%), palmitic acid (from 5.0 to 7.6%), palmiticoleic acid (up to 0.3%), stearic acid (from 2.7 to 6.5%), oleic acid (from 14.0 to 39.4%), linoleic acid (from 48.3 to 74.0%), linolenic acid (up to 0.3%), arachic acid (from 0.1 to 0.5%), gondoic acid (up to 0.3%), behenic acid (from 0.3 to 1.5%), and lignoceric acid (up to 0.5 %).

Table 4. Fatty acid composition of sunflower extraction oil (sample No. 2)

Reference designation of acid	Name of acid according to trivial nomenclature	Mass fraction of fatty acid (% to the sum of fatty acids)
$C_{16:0}$	Palmitic acid	6.871
$C_{16:1}$	Palmiticoleic acid	0.085
$C_{17:0}$	Margaric acid	0.061
$C_{18:0}$	Stearic acid	3.699
$C_{18:1}$	Oleic acid	25.836
$C_{18:2}$	Linoleic acid	59.535
$C_{20:0}$	Arachic acid	0.677
$C_{20:1}$	Eicosanoic acid	0.298
$C_{18:3}$	Linolenic acid	0.215
$C_{21:0}$	Heneicosylic acid	0.151
$C_{22:0}$	Behenic acid	0.822

Table 5. Fatty acid composition of sunflower extraction oil (sample No. 3)

Reference designation of acid	Name of acid according to trivial nomenclature	Mass fraction of fatty acid (% to the sum of fatty acids)
$C_{14:0}$	Myristic acid	0.081
$C_{16:0}$	Palmitic acid	6.877
$C_{16:1}$	Palmiticoleic acid	0.113
$C_{18:0}$	Stearic acid	3.270
$C_{18:1}$	Oleic acid	30.090
$C_{18:2}$	Linoleic acid	57.415
$C_{18:3}$	Linolenic acid	0.248
$C_{20:1}$	Gondoic acid	0.095
$C_{24:0}$	Lignoceric acid	0.206

Table 6. Fatty acid composition of sunflower extraction oil (sample No. 4)

Reference designation of acid	Name of acid according to trivial nomenclature	Mass fraction of fatty acid (% to the sum of fatty acids)
$C_{6:0}$	Capronic acid	0.189
$C_{8:0}$	Caprylic acid	0.053
$C_{14:0}$	Myristic acid	0.082
$C_{16:0}$	Palmitic acid	7.184
$C_{16:1}$	Palmiticoleic acid	0.174
$C_{17:0}$	Margaricoleic acid	0.407
$C_{17:1}$	Margaric acid	0.190
$C_{18:0}$	Stearic acid	3.532
$C_{18:1}$	Oleic acid	26.436
$C_{18:2}$	Linoleic acid	57.121
$C_{20:0}$	Arachic acid	0.186
$C_{20:3}$	Mead acid	0.671

Thus, having conducted laboratory studies, it can be stated that sunflower extraction oil obtained by the method of extraction of raw materials in a microwave field meets the requirements of SSTU 4492-2017.

The authors set the task to study organoleptic and physicochemical parameters of sunflower meals after these processes.

Table 7 shows the methods of research for sunflower meals. These methods are used in modern Ukrainian productions since the 1980-s and are validated for most of them.

The results of the study of sunflower meals obtained after oil extraction by the methods of extraction in the Soxhlet apparatus and microwave field are shown in

Table 8. Hexane as a solvent in traditional extraction methods, and as a Soxhlet apparatus, demonstrate better results.

Thus, the obtained sunflower meal meets the requirements of SSTU 4638: 2006 "Sunflower meal. Specifications".

There was also conducted the study on the fatty acid composition of rapeseed oil obtained by the method extraction of rapeseed meal in a microwave field with hexane and ethyl alcohol as solvents by SSTU 8175: 2015 "Rapeseed oil. Specifications".

Table 7. Methods of research of sunflower meal

Indicator	The principle of the research method
A sampling of meal and preparation of samples for analysis	According to GOST 13979.0-86
Colour, odour, amount of dark spots and trifles	According to GOST 13979.4-68
Mass fraction of moisture and volatile substances,%	According to GOST 13979.1-68
Mass fraction of fat and extractives,%	According to GOST 13979.2-94
Mass fraction of crude protein,%	According to GOST 13496.4
Mass fraction of crude fibre,%	According to GOST 13496.2

Table 8. Organoleptic and physicochemical parameters of sunflower meal were obtained after extraction with hexane (No. 1, No. 3) and alcohol (No. 2, No. 4), respectively

Indicator	Sample No. 1	Sample No. 2	Sample No. 3	Sample No. 4
Appearance	homogeneous bulk mass	homogeneous bulk mass	homogeneous bulk mass	bulk mass, available small beeps
Colour	grey	grey	grey	grey
Odour	Inherent in sunflower meal without odour			
Mass fraction of moisture and volatile substances,%	8.3	8.1	7.9	7.5
Mass fraction of fat and extractives,%	1.49	1.5	1.5	1.47
Mass fraction of crude protein,%	36.5	36.9	36.7	36.8
Mass fraction of crude fibre in terms of absolutely dry matter,%	25.4	25.5	25.1	25.6

Table 9. Fatty acid composition of rapeseed oil (sample No. 1, hexane as a solvent)

Reference designation of acid	Name of acid according to trivial nomenclature	Mass of fatty acid (% to the sum of fatty acids)
$C_{16:0}$	Palmitic acid	7.53
$C_{16:1}$	Palmiticoleic acid	0.141
$C_{18:0}$	Stearic acid	3.154
$C_{18:1}$	Oleic acid	27.655
$C_{18:2}$	Linoleic acid	60.078
$C_{18:3}$	Linolenic acid	0.157
$C_{20:0}$	Arachic acid	0.220
$C_{20:1}$	Gondoic acid	0.115
$C_{22:0}$	Behenic acid	0.463
$C_{22:1}$	Erucic acid	0.483

Table 10. Fatty acid composition of rapeseed oil (sample No. 2, ethyl alcohol as a solvent)

Reference designation of acid	Name of acid according to trivial nomenclature	Mass fraction of fatty acid (% to the sum of fatty acids)
$C_{14:0}$	Myristic acid	0.1
$C_{16:0}$	Palmitic acid	7.3
$C_{16:1}$	Palmiticoleic acid	0.16
$C_{18:0}$	Stearic acid	2.98
$C_{18:1}$	Oleic acid	28.79
$C_{18:2}$	Linoleic acid	58.56
$C_{18:3}$	Linolenic acid	0.23
$C_{20:0}$	Arachic acid	0.19
$C_{20:1}$	Gondoic acid	0.16
$C_{22:0}$	Behenic acid	0.48
$C_{22:1}$	Erucic acid	0.5

After comparing, the results assumed that with microwave influence we obtain a higher concentration of major fatty acids in samples. This means that the quality of oil samples is improved. All the studies show that microwave technology is a powerful tool for the implementation of food nanoenergy technologies (Burdo *et al*, 2016b). Compared to traditional technologies, they will significantly increase the concentration of biologically active substances and reduce the processing time, creating technologies for processing food raw materials that fully meet modern requirements for resource and energy efficiency, environmental safety and market economy.

Thus, the use of microwave technologies in the oil and fat industry is a new and promising scientific approach to the improvement of traditional processes of extraction of crude oil and production of finished products.

Discussion

Analyzing the obtained results, one can trace the influence of the choice of solvent and the product treatment method. The extraction by the Soxhlet method (hexane as a solvent) was compared with the method of extraction of raw materials in a microwave field (ethyl alcohol as a solvent) shown in Figure 2 and Figure 3. The studies of physicochemical parameters indicate the degree of oxidation of the oil (determination of peroxide and anisidine values).

The peroxide value is an indicator of the content of primary oxidation products. The peroxide value of the oil obtained by Soxhlet extraction (hexane as a solvent) was 5.0 (½O mmol) kg^{-1}. The peroxide value of the oil obtained by extraction in a microwave field (ethyl alcohol as a solvent) was 3.8 (½O mmol) kg^{-1}.

The anisidine value is an indicator of the content of aldehydes in vegetable oils (secondary oxidation products). The anisidine value of the oil obtained by Soxhlet extraction (hexane as a solvent) was 0.3 s.u. The anisidine value of the oil obtained by extraction in a microwave field (ethyl alcohol as a solvent) was 0.2 s.u.

Comparing the data of peroxide and anisidine values, it can be argued that the best indicators were found in the oil obtained by the method of extraction of raw materials in a microwave field (ethyl alcohol as a solvent).

The acid value is one of the main qualitative indicators that characterize the degree of oil freshness.

The acid value of the oil obtained by the method of Soxhlet extraction (hexane as a solvent) was 3.1 (mg KOH) g^{-1}. The acid value of the oil obtained by extraction in a microwave field (ethyl alcohol as a solvent) was 2.1 (mg KOH) g^{-1}. That let us say that obtained in microwave field oils have better oxidation resistance.

A comparison of the acid values of oils extracted from the raw material by different extraction methods shows that the oil obtained by the method of extraction of raw materials in a microwave field using ethyl alcohol as a solvent has the best acid value. Accordingly, the obtained results make it possible to recommend the microwave method for implementation in the production of vegetable oils with ethyl solvents. The next step is the patenting of this method and the development of technological conditions for the production of vegetable oils. Since a more detailed study of the effect of a microwave field on the product is required. The microbiological and technological studies of the finished product obtained using new technology are necessary.

The given in the revived studies of the use of the microwave field for the intensification of extraction processes are confirmed by the results of this work. The discrepancy for some target components is because they are insoluble in Ethyl alcohol, which in turn is a polar solvent. The choice of polar solvents is justified for microwave devices by the dipole shift effect. Thus, if the main target component in the extraction is those fatty acids that are insoluble in alcohol, combined or other methods of extraction should be considered.

Study on the microwave field influence has been carried out by authors for more than 20 years. As a result of research on the efficiency of using a microwave field in drying processes, PhD and doctoral thesis was published by the authors: Extraction of coffee in a microwave continuous operation (Levtrinskaya Y., 2017, PhD), Scientific and Practical Substantiation of Energy Efficient Technologies for Oilseed Raw Material Processing based on Mechanical and Electromagnetic Intensifiers (Bandura V., 2021, Sc.Doct.), Scientific and technical foundations for creating energy-efficient equipment for improving the quality of vegetable oils (Osadchuk P., 2021, Sc.Doct.). With the use of fundamental research in the field of studying the effect of a microwave field, innovative equipment is being created, as shown in the publications of the authors (Burdo *et al*, 2020). The principles of directional energy action and microwave exposure at the product capillary level are used in extraction to intensify and increase the energy efficiency of processes. The main difference of this study is a deeper study of the use of various solvents for the extraction of oils. Obtained results deepen the understanding of the expediency of using a microwave field for various "solid-liquid" systems and further introducing these technologies into production.

This study correlates with research by Ferreira *et al.* (2022), Burdo *et al.* (2018), and Baümler (2016), which assume that extracts from plant raw materials in which the solvent is ethanol and obtained using a microwave field, acquire qualitatively new biochemical and biological properties compared to analogues obtained by traditional methods of extraction with hexane. Since ethanol is non-toxic and safe but extracts extractives more slowly than n-hexane, it is advisable to perform the extraction in a microwave field. The physicochemical parameters of extraction of sunflower oil obtained by the method of extraction in a microwave field (solvent – ethyl alcohol) have the best indicators in terms of peroxide and anisidine numbers. A comparison of the acid numbers of oils extracted from the raw material by different extraction methods shows that the oil obtained by the method of extraction in a microwave field using ethyl alcohol as a solvent has the best acid value.

Conclusion

The results of the study showed that the use of microwave leads to the increase in the efficiency of the process of oil extraction, oil density, oxidative stability, oil color and meal protein. Based on the results obtained in our studies, we can say that the use of microwave extraction with ethyl alcohol as a polar solvent was effective for improving the quality properties of the extracted oil.

The studies have shown that oil, which is obtained by extraction of raw materials in a microwave field using ethyl alcohol as a solvent, has the best resistance to oxidation during storage (3 months). The use of a microwave field in the process of extracting oil raw materials with ethyl alcohol as a polar solvent leads to a gradient-free wave supply of electromagnetic energy to polar molecules. Due to dipole shift effect, a powerful diffusion flow is forming. The extracted oils obtained from the raw material with electromagnetic intensification has the richest complex of components and better quality, than the same samples obtained in thermal methods only.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

VB, LF, YL – study conception and design;
VB, LF – acquisition of data;
YL, PO – analysis and interpretation of data;
AP – drafting of the manuscript;
VB, PO – critical revision and approval of the final manuscript.

References

Balasubramanian, S., Allen, J. D., Kanitkar, A., Boldor, D. 2011. Oil extraction from Scenedesmus obliquus using a continuous microwave system–design, optimization, and quality characterization. – Bioresource Technology, 102(3):3396–3403. DOI: 10.1016/j.biortech.2010.09.119

Bandura, V., Bulgakov, V., Adamchuk, V., Ivanovs, S. 2018. Investigation of oil extraction from the canola and soybean seeds, using a microwave intensifier. – INMATEH - Agricultural Engineering, 55(2):45–52.

Bandura, V., Kotov, B., Gyrych, S., Gricshenko V., Kalinichenko, R., Lysenko, O. 2021. Identification of mathematical description of the dynamics of extraction of oil materials in the electric field of high frequency. – Agraarteadus, 32(1):8–16. DOI: 10.15159/jas.21.01

Baümler, E.R., Carrín, M.E., Carelli, A.A. 2016. Extraction of sunflower oil using ethanol as solvent. – Journal of Food Engineering, 178:190–197. DOI: 10.1016/j.jfoodeng.2016.01.020

Beloborodov, V.V. 1966. Osnovni protsesy vyrobnytstva roslynnoyi oliyi. [The main processes of plant oil production]. – Moskva: Kharchova promyslovistʹ [Moscow: Food industry], 478 p. [In Russian].

Bhuyan, D.J., Vuong, Q.V., Chalmers, A.C., van Altena, I.A., Bowyer, M.C., Scarlett, C.J. 2015. Microwave-assisted extraction of *Eucalyptus robusta* leaf for the optimal yield of total phenolic compounds. – Industrial Crops and Products, 69:1–10. DOI: 10.1016/j.indcrop.2015.02.044

Burdo, O.G., Bandura, V.N., Levtrinskaya, Y.O. 2018. Electrotechnologies of targeted energy delivery in the processing of food raw materials. – Surface Engineering and Applied Electrochemistry, 54(2): 210–218. DOI: 10.3103/S1068375518020047

Burdo, O., Bezbakh, I., Kepin, N., Zykov, A., Yarovyi, I., Gavrilov, A., Bandura V., Mazurenko, I. 2020. Studying the operation of innovative equipment for thermomechanical treatment and dehydration of food raw materials. – Eastern-European Journal of Enterprise Technologies. 5(11)(101):24–32. DOI: 10.15587/1729-4061.2019.178937

Burdo, O.G., Syrotyuk, I.V., Alhury, U., Levtrinska, J.O. 2016a. Microwave energy as an intensification factor in the heat-mass transfer and the polyextract formation. – Problemele energeticii regionale, 1(36): 58–71 DOI: 10.5281/zenodo.1217259

Burdo, O.G., Zykov, A.V., Terziev, S.G., Ruzhitskaya, N.V. 2016b. The nanotechnological innovation in food industry. – International Journal of Engineering Research and Applications, 6(3):144–150.

Castejón, N., Luna, P., Señoráns, F.J. 2018. Alternative oil extraction methods from *Echium plantagineum* L. seeds using advanced techniques and green solvents. – Food Chemistry, 244:75–82. DOI: 10.1016/j.foodchem.2017.10.014

Chan, C.H., Lima, J.J., Yusoff, R., Ngoh, G.C. 2015. A generalized energy-based kinetic model for microwave-assisted extraction of bioactive compounds from plants. – Water Environment Research, 88(10):1192–1229. DOI: 10.1016/j.seppur.2015.01.041

Chemat, F., Cravotto, G. 2013. Microwave-assisted extraction for bioactive compounds: Theory and practice. – Food Engineering Series, Springer New York, USA, 240 p. DOI: 10.1007/978-1-4614-4830-3

Edwards, A., Deen, W.M., Daniels, B.S. 1997. Hindered transport of macromolecules in isolated glomeruli. I. Diffusion across intact and cell-free capillaries. – Biophysical Journal, 72(1):204–213. DOI: 10.1016/S0006-3495(97)78659-4

Ferreira, M.C., Gonçalves, D., Bessa, L.C.B.A., Rodrigues, C.E.C., Meirelles, A.J.A., Batista, E.A.C. 2022. Soybean oil extraction with ethanol from multiple-batch assays to reproduce a continuous, countercurrent, and multistage equipment. – Chemical Engineering and Processing - Process Intensification, 170: 108659. DOI: 10.1016/j.cep.2021.108659

Flórez, N., Conde, E., Domínguez, H. 2015. Microwave assisted water extraction of plant compounds. – Journal of Chemical Technology and Biotechnology, 90(4):590–607. DOI: 10.1002/jctb.4519

Grasso, F.V., Montoya, P.A., Camusso, C.C., Maroto, B.G. 2012. Improvement of soybean oil solvent extraction through enzymatic pretreatment. – International Journal of Agronomy, Special Issue, Oilseeds Crops: Agronomy, Science, and Technology 12: 1–7. DOI: 10.1155/2012/543230

Hussain, S., Shafeeq, A., Anjum, U. 2018. Solid liquid extraction of rice bran oil using binary mixture of ethyl acetate and dichloromethane. – Journal of the Serbian Chemical Society, 83:911–921. DOI: 10.2298/JSC170704023H

Ionescu, M., Ungureanu, N., Biriş, S. Voicu, G., Dilea, M. 2013. Actual methods for obtaining vegetable oil from oilseeds. – 2nd International Conference on Thermal Equipment, Renewable Energy and Rural Development, 20–22 June, Politehnica University of Bucharest, Romania, pp. 167–172.

Khan, N.R., Rathod, V.K. 2018. Microwave-assisted enzymatic synthesis of speciality esters: A mini-review. – Process Biochemistry, 75:89–98. DOI: 10.1016/j.procbio.2018.08.019

Konopka, I., Roszkowska, B., Czaplicki, S., Tanska, M. 2016. Optimization of pumpkin oil recovery by using aqueous enzymatic extraction and comparison of the quality of the obtained oil with the quality of cold-pressed oil. – Food Technology and Biotechnology, 54(4):413–420. DOI: 10.17113/ftb.54.04.16.4623

Kumar, S.J., Kumar, G.V., Dash, A., Scholz, P., Banerjee, R. 2017. Sustainable green solvents and techniques for lipid extraction from microalgae: A review. – Algal Research, 21:138–147. DOI: 10.1016/j.algal.2016.11.014

Lebovka, N., Vorobiev, E., Chemat, F. 2012. Enhancing extraction processes in the food industry (1st ed). – Taylor & Francis Group, LLC CRC Press, Boca Raton, FL, USA, 518 p.
Matiukhov, D.V., Hladkyi, F.F. 2013. Influence of technological parameters on the results of sunflower meal extraction with ethyl alcohol. – Bulletin of the KhDUHT, Kharkiv, Ukraine, 2:132–137.
Mwaurah, P.W., Kumar, S., Kumar, N., Attkan, A.K., Panghal, A., Singh, V.K., Garg, M.K. 2020. Novel oil extraction technologies: Process conditions, quality parameters, and optimization. – Comprehensive Reviews in Food Science and Food Safety, 19:3–20. DOI: 10.1111/1541-4337.12507
Pan, X., Niu, G., Liu, H. 2003. Microwave-assisted extraction of tea polyphenols and tea caffeine from green tea leaves. – Chemical Engineering and Processing: Process Intensification, 42(2):129–133. DOI: 10.1016/S0255-2701(02)00037-5
Picó, Y. 2013. Ultrasound-assisted extraction for food and environmental samples. – TrAC Trends in Analytical Chemistry, 43:84–99. DOI: 10.1016/j.trac. 2012.12.005
Puertolas, E., Alvarez-Sabatel, S., Cruz, Z. 2016. Pulsed electric field: Groundbreaking technology for improving olive oil extraction. – INFORM - International News on Fats, 27(3):12–14.
Sharma, M., Dadhwal, K., Gat, Y., Kumar, V., Panghal, A., Prasad, R. Kaur, S., Gat, P. 2019. A review on newer techniques in extraction of oleaginous flaxseed constituents. – Oilseeds and Fats, Crops and Lipids, 26:14–21. DOI: 10.1051/ocl/2019006
Taghvaei, M., Jafari, S.M., Assadpoor, E., Nowrouzieh, S, Alishah, O. 2014. Optimization of microwave-assisted extraction of cottonseed oil and evaluation of its oxidative stability and physicochemical properties. – Food Chemistry, 160: 90–97. DOI: 10.1016/j.foodchem.2014.03.064
Tan, Z.J., Yang, Z.Z., Yi, Y.J., Wang, H.Y., Zhou, W.L., Li, F.F., Wang, C.Y. 2016. Extraction of oil from flaxseed (*Linum usitatis-simum* L.) using enzyme-assisted three-phase partitioning. – Applied biochemistry and biotechnology, 179(8):1325–1335. DOI: 10.1007/s12010-016-2068-x
Tewari, S., Ramalakshmi, K., Methre, L., Mohan Rao L.J. 2015. Microwave-assisted extraction of inulin from chicory roots using response surface methodology. – Journal of Nutrition & Food Sciences, 5:342–349. DOI: 10.4172/2155-9600. 1000342
Topare, N.S., Raut, S.J., Renge, V.C., Khedkar, S.V., Chavan, Y.P., Bhagat, S.L. 2011. Extraction of oil from algae by solvent extraction and oil expeller method. – International Journal of Chemical Sciences, 9:1746–1750.
Zhang, Z., Su, T., Zhang, S. 2018. Shape effect on the temperature field during microwave heating process. – Journal of Food Quality, Article ID 9169875, 24 p. DOI: 10.1155/ 2018/9169875

Agraarteadus
1 • XXXIII • 2022 59–66

Journal of Agricultural Science
1 • XXXIII • 2022 59–66

EFFECT OF DIFFERENT LEVELS OF CHARCOAL AND NITROGEN ON GROWTH AND YIELD TRAITS OF BROCCOLI

Prayusha Bhattarai[1], Babita Lamichhane[1], Puja Subedi[1], Amit Khanal[1], Saroj Burlakoti[1], Jiban Shrestha[2]

[1]*Department of Horticulture and Plant Protection, Institute of Agriculture and Animal Science, Lamjung Campus, Sundarbazar Municipality, Ward No. 07, Lamjung, 33600, Nepal*
[2]*Nepal Agricultural Research Council, National Plant Breeding and Genetics Research Centre, Khumaltar, Lalitpur Metropolitan City, Ward No. 15, Lalitpur, 44700, Nepal*

Saabunud: Received: 19.11.2021

Aktsepteeritud: Accepted: 05.02.2022

Avaldatud veebis: Published online: 05.02.2022

Vastutav autor: Corresponding author: Prayusha Bhattarai

E-mail:
prayushab499@gmail.com (PB)
lbabita02@gmail.com (BL)
subedip929@gmail.com (PS)
agstdamit@gmail.com (AK)
sburlakoti129@gmail.com (SB)
jibshrestha@gmail.com (JS)

ORCID:
0000-0002-2724-270X (PB)
0000-0002-8019-7880 (BL)
0000-0002-8376-7535 (PS)
0000-0003-0907-8253 (AK)
0000-0003-3328-7573 (SB)
0000-0002-3755-8812 (JS)

Keywords: *Brassica oleracea* L. var. *italica*, soil conditioner, nitrogen fertilizers, nutrition.

DOI:10.15159/jas.22.02

ABSTRACT. Charcoal is a carbon-rich organic matter, which serves as a soil conditioner when applied to agricultural fields. When used in combination with nitrogen fertilizers, it has a synergistic effect that boosts plant growth. However, charcoal application alone or in combination with nitrogen fertilizer on vegetable crops is not fully understood. Therefore, a pots experiment was carried out to investigate the effect of charcoal and nitrogen levels on the growth and yield of broccoli. The variety of broccoli used was Centauro. The experiment was laid out in a two-factor Completely Randomized Design with five replications during the winter season of 2019–2020 at Sundarbazar, Lamjung, Nepal. Treatments consisted of four levels of charcoal (0%, 2.5%, 5%, and 7.5% per weight of soil) and three levels of nitrogen (0, 187.5 and 375 kg N ha^{-1}). Results revealed that increasing nitrogen levels from 0 to 375 kg N ha^{-1} significantly increased the number of leaves, leaf area, head diameter, head weight and aboveground biomass. The maximum head weight per plant (258.77 g) was found by applying a nitrogen level of 375 kg N ha^{-1} and the lowest value at 0 kg N ha^{-1}. The application of increasing levels of charcoal significantly improved root length, leaf area and head diameter. It was concluded from the results that the optimum nitrogen level for broccoli production could be 375 kg N ha^{-1}.

Introduction

Broccoli (*Brassica oleracea*, L. var. *italica*) is a green-leaf Cole vegetable that belongs to the mustard family (*Brassicaceae*). This plant is native to the Mediterranean region but can be successfully grown in our country. It is a fast-growing; cool-season crop that is resistant to mild frost and has an optimum temperature in the range of 18–24 °C. It is an annual plant that may reach a height of 50 cm or more and is mainly grown for its edible flower buds and stalks. Broccoli is more nutritious than any other vegetable of the same 30 genera (Al-Taey *et al*., 2019). It is extremely nutritive due to its high content of vitamin A and C, thiamine, niacin, riboflavin, calcium, and carotenoids that have a plausible effect on maintaining good human health and have potent anti-diabetic, anticarcinogenic, anti-inflammatory, and antioxidant properties (Moreira-Rodríguez *et al*., 2017; Hamza, Al-Taey, 2020).

The term "charcoal" refers to various carbonized materials with varying combustion qualities (Wood, Baldwin, 1985). It is a fine-grained, light-weighted, porous solid obtained by partially burning or heating carbonaceous materials at a higher temperature with limited oxygen access by the method known as pyrolysis. Black carbon, elemental carbon, pyrogenic carbon, and biochar are used interchangeably to describe charcoal. Charcoal is chemically and microbially stable, and it has existed in the environment for millennia because of its polycyclic aromatic composition (Glaser *et al*., 2001). Because of its long-lasting nature, charcoal can be used as a long-term carbon sink for CO_2 (Glaser *et al*., 2002). Charcoal in agriculture has recently received attention as a useful technique for raising crop yield, improving soil fertility, increasing fertilizer use efficiency, and as a carbon sequestration option (Ogawa, Okimori, 2010). When applied to agricultural soil, it improves the soil's physical, chemical, and biological properties (Laird *et al*., 2010). The effects of charcoal on plant growth and yield vary greatly depending on the experimental setting, soil qualities, charcoal supply, crop nature, and climatic conditions (Mukherjee, Lal, 2014). Charcoal treatment on various crops resulted in a statistically significant 10% increase in mean yield in an experiment using statistical meta-analysis (Jeffery *et al*., 2015). Treatment of lettuce and Chinese cabbage plants in pots with rice husk charcoal enhanced the final biomass, root biomass, plant height, and leaf number (Carter *et al*., 2013). According to Vaccari *et al*. (2015), adding charcoal to tomato cultivation improved soil quality and fertility and promoted plant growth, however, yield increase was not obtained due to the tomato's indeterminate habit. McDonald *et al*. (2019) reported a similar outcome, in which charcoal treatment had no effect on cabbage yield but had a beneficial impact on soil quality. Overall, the beneficial response to the charcoal application on crop growth and production is obtained in a tropical environment where the soil is deficient in nutrients (Crane-Droesch *et al*., 2013) and in acid soils (Liu *et al*., 2013), which is mainly due to liming property of alkaline charcoal. However, in a temperate climate with alkaline soil, it has a short-term effect on crops and plants (Rousk *et al*., 2013; Borchard *et al*., 2014; Tammeorg *et al*., 2014; Wei *et al*., 2021).

Nitrogen(N) being an essential element for successful plant growth, nitrogen fertilization for many decades has been a powerful tool in improving yield, productivity, and quality of food crops and vegetables (Wang *et al*., 2008; Leghari *et al*., 2016). It is a major indispensable constituent of proteins, nucleic acids, phytohormones, and other cellular components in plants, and contributes 40–50% of crop yield (Marschner, 2012). Its use has an immediate effect on plant cell division and cell enlargement, resulting in better crop growth and establishment (Xin *et al*., 2014). According to Yoldas *et al*. (2008), nitrogen application resulted in increased yield, the average weight of main and secondary heads, and diameter in broccoli when compared to the control. As a result, adding extra N to the soil reduces the overall risk of successful broccoli production while increasing broccoli growth and yield (Dhakal *et al*., 2016; Bika *et al*., 2018; Tripathi *et al*., 2020).

Charcoal is usually used as a soil conditioner rather than a fertilizer because of its low nutrient concentrations. As a result, combining charcoal with chemical fertilizers has a synergistic impact, resulting in increased plant growth responses (Gathorne-Hardy *et al*., 2009; Saarnio *et al*., 2013). Because nitrogen (N) is such an important component for plant growth, combining it with charcoal has resulted in large yield increases when compared to control, ranging from 266 % in radish to modest gains (between 12–64 %) in rice (Piash *et al*., 2019; Ali *et al*., 2020). However, other studies have found that using charcoal and nitrogen fertilizers together does not affect plant growth and yield (Mavi *et al*., 2018; Silitonga *et al*., 2018), and some have even found yield declines in particular conditions (Gaskin *et al*., 2010).

The interactions between charcoal and fertilizers employed and between charcoal and crops necessitate more research and understanding before the charcoal application is adopted as a regular agricultural practice by farmers. Furthermore, because most charcoal trials are conducted on cereal crops, there is little information on the dose-dependent effect of charcoal and nitrogen on vegetable production. In addition, the impact of charcoal on broccoli production is unknown. Therefore, this experiment was conducted to determine the individual effect of charcoal and nitrogen on broccoli's growth and yield and assess their combined impact on broccoli production.

Material and Methods

Experimental site

A pots experiment was conducted at the Horticulture Farm of the Institute of Agriculture and Animal Science (IAAS), Lamjung, Nepal from September 2019 to February 2020. The farm is located at 28°7' North latitude and 84° 25' East longitude, with an altitude of 632 m above sea level having a sub-tropical climate. The climatic data during the experiment is given in Table 1.

Table 1. Climate data of the experimental location in 2019–2020

Months	Temp., °C		Rainfall,	Relative humidity,
	max.	min.	mm	%
2019				
September	28	18	266.55	78
October	26	12	70.36	65
November	25	6	11.76	58
December	20	3	0.00	50
2020				
January	18	3	32.73	46
February	22	4	69.96	46

Description of experimental materials

"Centauro" variety of Broccoli was grown in this experiment. This variety can be cultivated in the Lamjung district of Nepal. The seeds were obtained from Dawadi Agrovet, Narayangarh, Chitwan, Nepal. The source of the nitrogen fertilizer was urea (46% N).

The urea, single superphosphate (SSP) and muriate of potash (MOP) were obtained from the same Agrovet. Charcoal particles were produced at the farm by the pyrolysis method, collecting dry woods from nearby forests following the procedures as explained by Artiola and Wardell (2017).

Experimental layout, design and cultural practices

A pots experiment was conducted in a two-factorial Completely Randomized Design with 12 treatments and 5 replications. Charcoal was one factor with four levels at the rate of 0, 125, 250 and 375 g charcoal pot^{-1} (=0, 2.5, 5 and 7.5% by soil weight). Similarly, nitrogen was another factor with three different levels at the rate of 0, 11 and 22 g N pot^{-1} (=0, 187 and 375 kg N ha^{-1}). A single pot (top diameter of 22.5 cm, base diameter of 16.5 cm and height of 18 cm) with a single plant in it was considered as an experimental unit. Five kg of soil, farmyard manure (FYM) at the rate of 10 tons ha^{-1}, charcoal and nutrient as per the treatments were mixed and filled in the pot. Altogether, there were 60 experimental pots.

Seeds were sown in the nursery bed of 1×1 m on September 21, 2019. One-month-old, robust and healthy seedlings were transplanted into the pots during evening time and light irrigation was done immediately. The standard agronomical practices such as irrigation, intercultural operations and insecticide application were then adopted for healthy crop growth as per requirement.

Phosphorus and potassium to the plants were supplemented at the rate of 175:80 kg PK ha^{-1} (MOALD, 2020). Half of the required dose of nitrogen (as per treatment) as urea with the full dose of phosphorus as Single Superphosphate (SSP) and potash as Muriate of Potash (MOP) was applied as basal dose. Half of the remaining nitrogen was applied in two split doses at 30 DAT (Days after Transplanting) and 45 DAT (Table 3). Micronutrient, Agroliv^{TM} at the rate of 2.5 mL per litre of water was sprayed with a hand sprayer at 20, 35 and 50 DAT. Harvesting was done when the head of broccoli was at the green tight stage.

Table 2. Details of factors used in treatments in the experiment

Factor A (Nitrogen levels)	Factor B (Charcoal levels)
N1:	C1:
0 kg N ha^{-1} = 0 g N pot^{-1}	0 % by soil weight = 0 g charcoal pot^{-1}
N2:	C2:
187.5 kg N ha^{-1} = 11 g N pot^{-1}	2.5 % by soil weight = 125 g charcoal pot^{-1}
N3:	C3:
375 kg N ha^{-1} = 22 g N pot^{-1}	5 % by soil weight = 250 g charcoal pot^{-1}
	C4:
	7.5 % by soil weight = 375 g charcoal pot^{-1}

Where soil weight=5 kg

Table 3. NPK application at basal and split-dose for pot experiment on broccoli

Fertilizers	Basal dose (g pot^{-1})	Split dose (g pot^{-1})
Urea	N1: 0, N2: 5.5 and N3: 11	At 30 DAT (N1: 0, N2: 2.75 and N3: 5.5). At 45 DAT (N1: 0, N2: 2.75 and N3: 5.5)
SSP	30 g	
MOP	3.6 g	

SSP – single superphosphate and MOP – muriate of potash, N1, N2 and N3 – nitrogen levels (treatments)

Data observation

The uprooted plants were taken to the laboratory, where the root was removed. The number of leaves, leaf area (cm^2), root length (cm), head diameter (cm), head weight (g) and aboveground biomass (g) were then recorded on the same day of harvesting using a measuring scale and electric weighing balance.

Data analysis

Data were recorded and entered into MS Excel 2016. Data were analyzed using the F-test in R-Studio 1.1.463 with R 3.5.2. Completely randomized design two-way ANOVA was used to analyze data. Treatment means were compared with Duncan's multiple range tests ($P \leq 0.05$).

Results and Discussion

Mean square values and probabilities of growth and yield traits of broccoli are given in Table 4. Charcoal levels significantly affected only three traits; leaf area, root length and head diameter but did not significantly affect the rest of the traits. Nitrogen significantly affected all traits but its interaction with charcoal levels did not significantly affect the traits (Table 4). The number of leaves per plant did not vary statistically with various levels of charcoal and their combination with nitrogen (Table 5 and 7). However, the number of leaves varied from 10 to 14 with the mean value of 12 with the application of nitrogen levels (Table 6). The highest number of leaves (14) was observed at 375 kg N ha^{-1} and was followed by 187.5 kg N ha^{-1}. The lowest number of leaves (10) was at 0 kg N ha^{-1} (Table 6). Application of charcoal and nitrogen significantly (<0.05) improved leaf area, however, there was no interactive effect (Table 5, 6 and 7). In the case of charcoal, the treatment that received 7.5% produced a plant with a maximum leaf area (482.83 cm^2) that was at par with treatment that received 5%. The minimum leaf area (396.01 cm^2) was produced in the plant receiving 2.5% (Table 5). Likewise, in the case of nitrogen, the best average of leaf area (632.09 cm^2) was produced when broccoli received the highest nitrogen dose of 375 kg N ha^{-1} that was followed by broccoli receiving 187.5 kg N ha^{-1}. The minimum leaf area (130.50 cm^2) in broccoli was produced in control and the average value obtained was 431.75 cm^2 (Table 6). Root length significantly (<0.05) differed with various levels of charcoal and nitrogen but had no significant interactive effect (Table 5, 6 and 7). An increasing level of charcoal increased root length in broccoli with the longest root length (28.19 cm) at 7.5% that was at par with 5% and the shortest root length (20.77 cm) at control (Table 5). Similarly, 187.5 kg N ha^{-1} produced the longest root length (28.03 cm) in broccoli, which was at par with 375 kg N ha–1, and shortest root length (19.28 cm) at control. The average root length was 24.48 cm (Table 6).

Table 4. Mean square values and probabilities of growth and yield traits of broccoli at Lamjung, Nepal during the winter season of 2019–2020

Traits	Degree of freedom (df)			Mean square values			Probabilities		
	Nitrogen levels	Charcoal levels	Nitrogen × charcoal	Nitrogen levels	Charcoal levels	Nitrogen × charcoal	Nitrogen levels	Charcoal levels	Nitrogen × charcoal
No. of leaves	2	3	6	116.217	0.378	1.794	<0.001	0.815	0.200
Leaf area, cm^2	2	3	6	14 10 676	21 265	3 528	<0.001	0.024	0.752
Root length, cm	2	3	6	423.65	175.15	39.73	<0.001	0.001	0.245
Head diameter, cm	2	3	6	506.589	4.054	0.898	<0.001	0.025	0.607
Head weight, g	2	3	6	281 135	1 087	1 076	<0.001	0.380	0.413
Aboveground biomass, g	2	3	6	2 486 375	19 164	30 750	<0.001	0.299	0.081

Table 5. Effect of different levels of charcoal on No. of leaves, leaf area, root length, head diameter, head weight and above-ground biomass of broccoli at Lamjung, Nepal during the winter season of 2019–2020

Charcoal levels (%/soil weight)	No. of leaves	Leaf area, cm^2	Root length, cm	Head diameter, cm	Head weight, g	Aboveground biomass, g
C1 (0 g charcoal pot^{-1})	12	412.93b	20.77c	12.62b	149.91	483.19
C2 (125 g charcoal pot^{-1})	12	396.01b	22.55bc	12.79b	146.93	433.51
C3 (250 g charcoal pot^{-1})	12	435.22ab	26.42ab	13.34ab	164.17	488.89
C4 (375 g charcoal pot^{-1})	12	482.83a	28.19a	13.75a	161.64	519.87
Mean	12	431.75	24.48	13.13	155.67	481.36
SEM	0.28	20.3	1.38	0.28	23.65	31.9
F test	NS	*	**	*	NS	NS
LSD (0.05)	0.804	57.774	3.950	0.799	23.651	90.616

NS – not significant, * – significant at 0.05 level of probability, ** – significant at 0.01 level of probability, SEM – standard error of mean, LSD – least significant difference. Means followed by the same letters in the same column are not significantly different at the 0.05 level of probability.

Table 6. Effect of different levels of nitrogen on number of leaves, leaf area, root length, head diameter, head weight and above-ground biomass of broccoli at Lamjung, Nepal during the winter season of 2019–2020

Nitrogen levels	No. of leaves	Leaf area, cm^2	Root length, cm	Head diameter, cm	Head weight, g	Above-ground biomass, g
N1 (0 g N pot^{-1})	10c	130.50c	19.28b	7.40c	26.11c	94.27c
N2 (11 g N pot^{-1})	13b	532.65b	28.03a	15.15b	182.11b	565.65b
N3 (22 kg N pot^{-1})	14a	632.09a	26.13a	16.84a	258.77a	784.17a
Mean	12	431.75	24.48	13.13	155.67	481.36
SEM	0.24	17.6	1.20	0.69	7.20	27.6
F test	***	***	***	***	***	***
LSD (0.05)	0.696	50.033	3.421	0.692	20.483	78.476

*** – significant at 0.001 level of probability. SEM – standard error of mean. LSD – least significant difference. Means followed by the same letters in the same column are not significantly different at the 0.05 level of probability

Application of charcoal and nitrogen significantly (<0.05) improved head diameter, however, there was no interactive effect (Table 5, 6 and 7). In the case of charcoal, a level of 7.5 % produced the head of greatest diameter (13.75 cm) that was at par with the charcoal concentration of 5% and control produced the head of the smallest diameter (12.62 cm) (Table 5). Similarly, increasing the application of nitrogen also increased the head diameter of broccoli. The highest head diameter (16.84 cm) was recorded at the highest nitrogen level of 375 kg N ha^{-1} that was followed by a nitrogen application of 187.5 kg N ha^{-1}, while the lowest head diameter (7.40 cm) was found at 0 kg N ha^{-1} (Table 6). The application of charcoal and its combination with nitrogen did not bring a significant difference (<0.05) in the head weight (Table 5 and 7). However, the application of different doses of nitrogen did affect head weight (Table 6). Head weight increased with elevation of nitrogen doses ranging from 26.11 to 258.77 g, with the highest head weight (258.77 g) at the highest nitrogen dose of 375 kg N ha^{-1} and lowest head weight at control (Table 6). Aboveground biomass production did not differ significantly (<0.05) with various charcoal levels and their interaction with nitrogen (Table 5 and 7). In contrast, it did vary significantly with various nitrogen levels, with the maximum value of biomass (784.17 g) produced at 375 kg N ha^{-1}, followed by 187.5 kg N ha^{-1}. The minimum aboveground biomass (94.27 g) was produced at 0 kg N ha^{-1} (Table 6).

The charcoal application did not bring significant changes in the most of growth and yield parameters of broccoli. The non-significant effect coincided with several other findings where charcoal amendment did not improve crop productivity of some temperate vegetables and root crops (Hammond *et al*., 2014; Boersma *et al*., 2017). The reasons behind the non-efficacy of charcoal could be several interacting factors such as charcoal ageing and nutrient content of used charcoal. In this experiment, the charcoal used was pure, uninoculated, and inactivated. Charcoal if incorporated without activation, its high adsorption capacity (AC) and cation exchange capacity (CEC) could lead to absorption and fixing of available nutrients and water in the soil (Schmidt, 2008). As a result, until it has been charged or aged organically, plant development may be impeded or not helped by its administration, at least in the beginning (several months to a year). The "ageing" of charcoal is linked to the notion of expanding the reactive surface on a burned product to improve nutrient retention, bioavailability, and transport in the soil (Mia *et al*., 2017). Another possible explanation for the lack of significance is the low nutrient content of the charcoal employed in the experiment, which was insufficient to cause beneficial changes in broccoli growth and yield. However, charcoal alone significantly affected root length and had some statistical effect on leaf area and head diameter of broccoli. Higher charcoal levels resulted in longer root length (Xiang *et al*., 2017), most likely as a result of direct interactions between charcoal and root particles, as indicated by visual observation of charcoal particles grouped and bound around the crop's root and root hairs (Lehmann *et al*., 2011; Prendergast-Miller *et al*., 2014). Furthermore, charcoal's ability to improve physical and chemical properties of a given soil, such as nutrient or water availability and retention, porosity, aeration, PH, CEC *etc*., is likely to improve root length and other morphological characteristics of broccoli, such as leaf area and head diameter (Glaser *et al*., 2002; Zoghi *et al*., 2019).

Table 7. Interactive effect of different levels of nitrogen and charcoal on No. of leaves, leaf area, root length, head diameter, head weight and above-ground biomass of broccoli at Lamjung, Nepal during the winter season of 2019–2020

Nitrogen × Charcoal levels	No. of leaves	Leaf area, cm^2	Root length, cm	Head diameter, cm	Head weight, g	Above-ground biomass, g
N1C1	9	125.08	13.76	7.25	24.20	89.75
N1C2	10	125.80	16.22	6.99	26.57	91.13
N1C3	10	118.30	21.30	7.55	26.29	88.67
N1C4	10	152.83	25.84	7.80	27.39	107.52
N2C1	13	509.01	22.84	14.60	164.32	530.60
N2C2	13	486.62	25.70	15.25	164.65	464.80
N2C3	13	526.28	32.64	15.31	190.04	540.00
N2C4	14	608.69	30.94	15.43	209.42	727.20
N3C1	14	604.70	25.70	16.00	261.21	829.20
N3C2	15	575.60	25.72	16.14	249.57	744.60
N3C3	15	661.07	25.32	17.17	276.19	838.00
N4C4	13	686.97	27.78	18.03	248.09	724.88
Mean	12	431.75	24.48	13.13	155.66	481.36
F test	NS	NS	NS	NS	NS	NS
LSD	1.393	100.064	6.843	1.387	40.969	156.953

NS – not significant at 0.05 level of probability

Nitrogen levels were found to have a substantial impact on broccoli growth and yield traits in the study. Almost all of the evaluated growth and yield-related parameters were significantly higher in the crop fertilized with a higher level of nitrogen, 375 kg N ha^{-1}. The improved performance of most of the traits studied must be linked to improved plant metabolism because of higher nitrogen application levels. Because nitrogen is a significant component of proteins, nucleic acids, phytohormones, and chlorophyll in plants, its application may have accelerated plant growth, resulting in increased leaf number, leaf area, and root length in broccoli plants (Marschner, 2012; Dhakal *et al*., 2016). According to Ghoneim (2005), a rise in the number of leaves could be related to the positive effect of nitrogen, which boosts meristemic activity and so increases the number of tissues and organs (leaves). Nitrogen stimulates the production of cytokinin in plant roots, resulting in increased cytokinin transfer to the leaves and, as a result, increased cell division. As a result, leaf area and leaf expansion increase noticeably. Hence, as the nitrogen dose increases, so does the leaf area (Kaur, Sharma, 2020). These promotive effects of nitrogen on vegetative growth ultimately led to more photosynthetic activities and buildup of photosynthates and enhanced head diameter, head weight and above-ground biomass in broccoli (Bika *et al*., 2018; Kaur, Sharma, 2020).

The combined effect of charcoal and nitrogen fertilizer on broccoli was non-significant, contrary to the findings of several previous studies that revealed a synergistic relationship between the two and showed the greatest plant growth responses when they were applied together (Steiner *et al*., 2007). However, Mavi *et al*. (2018) found that using charcoal with or without N fertilizer did not affect plant yield. When applied to high-input vegetable cropping systems, Boersma *et al*. (2017) also found that wood-based charcoal had no meaningful effect. The reason behind this could be decreased mineralization of nitrogen due to the high C/N ratio present in wood charcoal (Deenik *et al*., 2010; Demspter *et al*., 2012). Charcoal although serves as a long-term nutrient source, its application in soil temporarily decreases N availability to crops (Santalla *et al*., 2011).

Conclusion

Nitrogen applications can increase the growth and productivity of broccoli. Applying charcoal to the broccoli plant improved only the leaf area, root length, and head diameter, with no significant changes in the majority of the traits studied. In addition, combining charcoal and nitrogen levels did not affect the plant's growth or yield. The findings of this experiment suggest that the use of 375 kg N ha^{-1} has a positive and promoting effect on the growth and yield of broccoli.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

PB –Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.
BL, PS, SB – Performed experiment and data analysis; Wrote the paper.
AK – Conceived and designed the experiment, supervision of the experiment, revision of the manuscript.
JS – Critical revision of manuscript, data analysis and wrote manuscript.
All the authors read and approved the final manuscript.

References

Ali, I., Ullah, S., He, L., Zhao, Q., Iqbal, A., Wei, S., Shah, T., Ali, N., Bo, Y., Adnan, M., Amanullah, Jiang, L. 2020. Combined application of biochar and nitrogen fertilizer improves rice yield, microbial activity and N-metabolism in a pot experiment. – PeerJ, 8:e10311. DOI: 10.7717/peerj.10311

Al-Taey, D.K.A., Al-Shareefi, M.J.H., Mijwel, A.K., Al-Tawaha, A.R., Al-Tawaha, A.R. 2019. The beneficial effects of bio-fertilizers combinations and humic acid on growth, yield parameters and nitrogen content of broccoli grown under drip irrigation system. – Bulgarian Journal of Agricultural Science,25(5):959–966.

Artiola, J., Wardell, L. 2017. Guide to making and using biochar for gardens in Southern Arizona. AZ1752.

Bika, R., Bhandari, N., Khanal, A. 2018. Response of different doses of nitrogen on broccoli (*Brassica oleracea*var.*italica*) in Lamjung district. – International Journal of Applied Sciences and Biotechnology, 6(3):270–273. DOI: 10.3126/ijasbt.v6i3.21184

Boersma, M., Tobiszewska, A. W., Murphy, L., Eyles, A. 2017. Impact of biochar application on the productivity of a temperate vegetable cropping system. – New Zealand Journal of Crop and Horticultural Science, 45(4):277–288. DOI: 10.1080/01140671.2017.1329745

Borchard, N., Siemens, J., Ladd, B., Moeller, A., Amelung, W. 2014. Application of biochars to sandy and silty soil failed to increase maize yield under common agricultural practice. – Soil and Tillage Research, 144:184–194. DOI: 10.1016/j.still.2014.07.016

Carter, S., Shackley, S., Sohi, S., Tan, B., Haefele, S. 2013. The impact of biochar application on soil properties and plant growth of pot grown lettuce (*Lactuca sativa*) and cabbage (*Brassica chinensis*). – Agronomy, 3:404–418. DOI: 10.3390/agronomy3020404

Crane-Droesch, A., Abiven, S., Jeffery, S., Torn, M. 2013. Heterogeneous global crop yield response to biochar: A meta-regression analysis. – Environmental Research Letters, 8(4):8. DOI: 10.1088/1748-9326/8/4/044049

Deenik, J.L., McClellan, T., Uehara, G., Antal, M.J., Campbell, S. 2010. Charcoal volatile matter content influence plant growth and soil nitrogen transformations. – Soil ScienceSociety of America Journal, 74(4):1259–1270. DOI: 10.2136/sssaj2009.0115

Dempster, D.N., Gleeson, D.B., Solaiman, Z.M., Jones, D.L., Murphy, D.V. 2012. Decreased soil microbial biomass and nitrogen mineralization with Eucalyptus biochar addition to a coarse textured soil. – Plant Soil, 354(1–2):311–324. DOI: 10.1007/s11104-011-1067-5

Dhakal, M., Shakya, S.M.,Bhattarai, S. 2016. Yield and quality of broccoli (*Brassica oleracea* L. var. *Italica*Plenck.) cv. calabrese affected by nitrogen and farm yard manure in Chitwan, Nepal. – Journal of Basic and Applied Plant Science, 1(1):102.

Gaskin, J.W., Speir, R.A., Harris, K., Das, K.C., Lee, R.D., Morris, L.A., Fisher, D.S. 2010. Effect of peanut hull and pine chip biochar on soil nutrients, corn nutrient status, and yield. – Agronomy Journal, 102(2):623–633. DOI: 10.2134/agronj2009.0083

Gathorne-Hardy, A., Knight, J., Woods, J. 2009.Biochar as a soil amendment positively interacts with nitrogen fertiliser to improve barley yields in the UK. – IOP Conference Series: Earth and Environmental Science, 6(37):372052.DOI: 10.1088/1755-1307/6/37/372052

Ghoneim, I.M. 2005. Effect of nitrogen fertilization and its application system on vegetative growth, fruit yield and quality of sweet pepper. – Journal of Agriculture and Environmental Sciences, 4:58–77.

Glaser, B., Haumaier, L., Guggenberger, G.,Zech, W. 2001. The 'Terra Preta' phenomenon: A model for sustainable agriculture in the humid tropics. – Naturwissenschaften, 88(1):37–41. DOI: 10.1007/s001140000193

Glaser, B., Lehmann, J., Zech, W. 2002. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal – A review. Biology and Fertility of Soils, 35(4):219–230. DOI: 10.1007/s00374-002-0466-4#citeas

Hammond, J., Shackley, S., Prendergast-Miller, M., Cook, J., Buckingham, S., Pappa, V.A. 2014. Biochar field testing in the UK: Outcomes and implications for use. – Carbon Management, 4(2):159–170. DOI: 10.4155/cmt.13.3

Hamza, O.M., Al-Taey, D.K.A. 2020. A study on the effect of Glutamic acid and benzyl adenine application upon growth and yield parameters and active components of two broccoli hybrids. – Int. J. Agricult. Stat. Sci., 16(1):1163–1167.

Jeffery, S., Abalos, D., Spokas, K., Verheijen, F.G.A. 2015. Biochar effects on crop yield. In Biochar for environmental management science, technology and implementation (2nded.) (Eds. J. Lehman, S.Joseph). – London: Earthscan, pp. 301–325.

Kaur, G., Sharma, M. 2020. Effect of nitrogen fertilization and summer season vegetables as intercrops on growth and yield of broccoli (*Brassica oleracea* L. var. *italica*). – International Journal of Agricultural Science, 5:136–143.

Laird, D.A., Fleming, P., Davis, D.D., Horton, R., Wang, B., Karlen, D.L. 2010. Impact of biochar amendments on the quality of a typical midwestern agricultural soil. – Geoderma, 158(3–4):443–449. DOI: 10.1016/j.geoderma.2010.05.013

Leghari, S.J., Wahocho, N.A., Laghari, G.M., Laghari, A.H., Bhabhan, G.M., Talpur, K.H., Bhutto, T.A., Wahocho, S.A., Lashari, A.A. 2016. Role of nitrogen for plant growth and development: A review. – Advances in Environmental Biology, 10(9):209–218.

Lehmann, J., Rillig, M.C., Thies, J., Masiello, C.A., Hockaday, W.C., Crowley, D. 2011. Biochar effects on soil biota – A review. Soil Biology and Biochemistry, 43(9):1812–1836. DOI: 10.1016/j.soilbio.2011.04.022

Liu, X., Zhang, A., Ji, C., Joseph, S., Bian, R., Li, L., Pan, G., Paz-Ferreiro, J. 2013. Biochar's effect on crop productivity and the dependence on experimental conditions-A meta-analysis of literature data. – Plant and Soil, 373(1–2):583–594. DOI: 10.1007/s11104-013-1806-x

Marschner, P. 2012. Marschner's mineral nutrition of higher plants. (3rd ed.). - Elsevier/Academic Press, London, pp. 684.

Mavi, M.S., Singh, G., Singh, B.P., Sekhon, B.S., Choudhary, O.P., Sagi, S., Berry, R. 2018. Interactive effects of rice-residue biochar and N-fertilizer on soil functions and crop biomass in contrasting soils. – Journal of Soil Science and Plant Nutrition,18(1): 41–59. DOI: 10.4067/S0718-95162018005000201

McDonald, M., Bakker, C., Motior, R. 2019. Evaluation of wood biochar and compost soil amendment on cabbage yield and quality. –Canadian Journalof Plant Science, 99(5):624–638.DOI: 10.1139/CJPS-2018-0122

Mia, S., Dijkstra, F.A., Singh, B. 2017. Long-Term aging of biochar: A molecular understanding with agricultural and environmental implications. – Advances in Agronomy, 141:1–51. DOI: 10.1016/bs.agron.2016.10.001

Moreira-Rodríguez, M., Nair, V., Benavides, J., Cisneros-Zevallos, L., Jacobo-Velázquez, D.A. 2017. UVA, UVB light, and methyl jasmonate, alone or combined, redirect the biosynthesis of glucosinolates, phenolics, carotenoids, and chlorophylls in broccoli sprouts. – International Journal of Molecular Sciences, 18(11):2330. DOI: 10.3390/ijms18112330

Mukherjee, A., Lal, R. 2014. The biochar dilemma. Soil Research, 52(3):217–230. DOI: 10.1071/SR13359

Ogawa, M., Okimori, Y. 2010. Pioneering works in biochar research, Japan. – Australian JournalofSoil Research, 48(7):489–500. DOI: 10.1071/SR10006

Piash, M.I., Hossain, Md.F., Parveen, Z. 2019. Effect of biochar and fertilizer application on the growth and nutrient accumulation of rice and vegetable in two contrast soils. – Acta Scientific Agriculture,3(2):74–83.

Prendergast-Miller, M.T., Duvall, M., Sohi, S.P. 2014. Biochar-root interactions are mediated by biochar nutrient content and impacts on soil nutrient availability. – European Journal of Soil Science, 65(1):173–185. DOI: 10.1111/ejss.12079

Rousk, J., Dempster, D.N., Jones, D.L. 2013. Transient biochar effects on decomposer microbial growth rates: Evidence from two agricultural case-studies. – European Journal of Soil Science, 64(6):770–776. DOI: 10.1111/ejss.12103

Saarnio, S., Heimonen, K., Kettunen, R. 2013. Biochar addition indirectly affects N_2O emissions via soil moisture and plant N uptake. – Soil Biology and Biochemistry, 58:99–106. DOI: 10.1016/j.soilbio.2012.10.035

Santalla, M., Omil, B., Soalleiro, R.R., Merino, A. 2011. Effectiveness of wood ash containing charcoal as a fertilizer for a forest plantation in a temperate region. – Plant and Soil, 346(1):63–78. DOI: 10.1007/s11104-011-0794-y

Schmidt, H.P. 2008. Ways of making Terra Preta: Biochar activation. https://www.ithaka-journal.net//wege-zu-terra-preta-aktivierung-von-biokohle?lang=en. Accessed on 28/02/2022.

Silitonga, M., Sipayung, P., Sitorus, I., Siahaan, R., Hutauruk, S., Fajar, T., Sarumaha, S., Panjaitan, D. 2018. The effect of biochar dose and NPK fertilizer on the production and growth of pakchoi plant. IOP Conference Series: Earth and Environmental Science, 205(1):012028. DOI: 10.1088/1755-1315/205/1/012028

Steiner, C., Teixeira, W.G., Lehmann, J., Nehls, T., Macêdo, J. de., Blum, W., Zech, W. 2007. Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. – Plant Soil, 291(1): 275–290. DOI: 10.1007/s11104-007-9193-9

Tammeorg, P., Simojoki, A., Mäkelä, P., Stoddard, F., Alakukku, L.,Helenius, J. 2014. Biochar application to a fertile sandy clay loam in boreal conditions: Effects on soil properties and yield formation of wheat, turnip rape and faba bean. – Plant and Soil, 374:89–107. DOI: 10.1007/s11104-013-1851-5

Tripathi, S., Patel, J.M., Singh, N., Naik, J., Naik, V.R. 2020. Effect of different NPK levels on growth and yield attributes of broccoli (*Brassica oleracea* L.) under South Gujarat condition. – International Journal of Chemical Studies, 8(3):1335–1339. DOI: 10.22271/chemi.2020.v8.i3r.9385

Vaccari, F.P., Maienza, A., Miglietta, F., Baronti, S., Lonardo, S., Giagnoni, L., Lagomarsino, A., Pozzi, A., Pusceddu, E., Ranieri, R., Valboa, G., Genesio, L. 2015. Biochar stimulates plant growth but not fruit yield of processing tomato in a fertile soil. – Agriculture Ecosystems and Environment, 207:163–170. DOI: 10.1016/j.agee.2015.04.015

Wang, Z., Li, S., Malhi, S. 2008. Effects of fertilization and other agronomic measures on nutritional quality of crops. – Journal of the Science of Food and Agriculture, 88:7–23. DOI: 10.1002/jsfa.3084

Wei, W., Liu, S., Cui, D., Ding, X. 2021. Interaction between nitrogen fertilizer and biochar fertilization on crop yield and soil chemical quality in a temperate region. – The Journal of Agricultural Science,159(1–2):106–115. DOI: 10.1017/S0021859621000277

Wood, T.S., Baldwin, S. 1985. Fuelwood and charcoal use in developing countries. – Annual Review of Energy, 10:407-429. DOI: 10.1146/annurev.eg.10.110185.002203

Xiang, Y., Deng, Q., Duan, H., Guo, Y., 2017. Effects of biochar application on root traits: A meta-analysis. Global Change Biology Bioenergy, 9:1563–1572. DOI: 10.1111/gcbb.12449

Xin, C., Qing-wei, Y., Jia-lin, S., Shuang, X., Fu-chun, X., Ya-jun, C. 2014. Research progress on nitrogen use and plant growth. – Journal of Northeast Agricultural University, 21(2):68–74. DOI: 10.1016/S1006-8104(14)60036-2

Yoldas, F., Ceylan, S., Yagmur, B., Mordogan, N. 2008. Effects of nitrogen fertilizer on yield quality and nutrient content in broccoli. – Journal of Plant Nutrition, 31(7):1333–1343

Zoghi, Z., Hosseini, S.M., Kouchaksaraei, M.T., Kooch, Y., Guidi, L. 2019. The effect of biochar amendment on the growth, morphology and physiology of *Quercus castaneifolia* seedlings under water-deficit stress. – European Journal of Forest Research, 138(1):967–979. DOI: 10.1007/s10342-019-01217-y

Agraarteadus
1 • XXXIII • 2022 67–73

Journal of Agricultural Science
1 • XXXIII • 2022 67–73

RESEARCH OF A CONTACT STRESSES IN SWIVEL ELEMENTS OF FLEXIBLE SHAFT IN SCREW CONVEYOR FOR TRANSPORTATION OF AGRICULTURAL MATERIALS

Volodymyr Bulgakov[1], Jüri Olt[2], Semjons Ivanovs[3], Oleksandra Trokhaniak[1], Jaroslav Gadzalo[4], Valerii Adamchuk[5], Mykhailo Chernovol[6], Simone Pascuzzi[7], Francesco Santoro[7], Margus Arak[2]

[1]*National University of Life and Environmental Sciences of Ukraine, 15 Heroiv Oborony St., UA 03041 Kyiv, Ukraine*
[2]*Estonian University of Life Sciences, Institute of Forestry and Engineering, 56 Kreutzwaldi St., 51006 Tartu, Estonia*
[3]*Latvia University of Life Sciences and Technologies, 5 Cakstes Blvd., LV 3001 Jelgava, Latvia*
[4]*National Academy of Agrarian Sciences of Ukraine, 9, Mykhailo Omelyanovych-Pavlenko St., UA 01010, Kyiv, Ukraine*
[5]*Institute of Mechanics and Automation of Agricultural Production of the National Academy of Agrarian Sciences of Ukraine, 11 Vokzalna St., Glevakha Stl., Vasylkivsky Dist., UA 08631, Kyiv Region, Ukraine*
[6]*Central Ukrainian National Technical University, University Ave., 8, UA 25006 Kropivnitskyi, Kirovograd region, Ukraine*
[7]*University of Bari Aldo Moro, Department of Agricultural and Environmental Science, Via Amendola 11 165/A, 70126 Bari, Italy*

Saabunud: Received: 12.03.2022

Aktsepteeritud: Accepted: 28.04.2022

Avaldatud veebis: Published online: 28.04.2022

Vastutav autor: Corresponding author: Jüri Olt

E-mail: jyri.olt@emu.ee

ORCID:
0000-0003-3445-3721 (VB)
0000-0003-4302-3176 (JO)
0000-0002-9072-1340 (SI)
0000-0002-4671-5824 (OT)
0000-0002-5028-2048 (JG)
0000-0003-0358-7946 (VA)
0000-0003-3048-6833 (MC)
0000-0002-6699-3485 (SP)
0000-0001-9115-8265 (FS)
0000-0001-7466-6612 (MA)

Keywords: bulk agricultural material, contact stress, flexible screw conveyor, pipe, section.

DOI: 10.15159/jas.22.12

ABSTRACT. The paper presents the new design of the rotating part with ball-bearing swivel joints between its sections for flexible screw conveyors. The new design provides for the improvement of the operation efficiency and loading capacity, the enhancement of the technological capabilities and the reduction of the admissible curvature radius. The contact stresses in the swivel element as the most loaded area in the rotating part have been analysed. It has been established that the maximum contact stresses arise at the points of contact between the ball and the flat surface of the slot in the cylindrical bushing. The recommended design limitation range for the cavity cone angle is within about 30–50°. The relation between the loads and the stresses depending on the operating conditions has been modelled with the use of computer modelling. The comparison of the computer modelling results and the obtained calculation data has proved that the difference between the respective values varies within the range of 11–26%.

Introduction

The equipment for continuous transportation of agricultural materials is the basis for the comprehensive mechanisation of the loading/unloading operations that are implemented to raise the productivity of labour and the efficiency of production (Lech, 2001; Gill, 2003; Loveikin, Rogatynska, 2011; Evstratov *et al.*, 2015; Lyashuk *et al.*, 2015; Olanrewaju *et al.*, 2017; Karpeenko *et al.*, 2021). In agricultural and industrial production, there exists a whole range of machinery for the loading and discharge of bulk materials (grain crops, compound animal feedstuff, mineral fertilisers, sand, commercial salt, shredded metal chips etc.).

The completed review has resulted in a conclusion that, in the case of curvilinear transportation routes, flexible screw conveyors, the rotating part of which is designed as several individual screw sections connected with swivel joints, represent the least resource-intensive technology for bulk material transportation (Frey *et al.*, 2012; Hevko *et al.*, 2016, 2017, 2018a; Trokhaniak *et al.*, 2020). However, the existing flexible screw conveyors do not fully meet the operation requirements applied to such types of conveyors. For example, the use of continuous helical spirals as flexible augers results in their rapid failure due to the action of alternating cyclic loads (Olanrewaju *et al.*, 2017; Baranovsky *et al.*, 2020; Evstratov *et al.*, 2020; Hevko *et al.*, 2018b and 2020).

Sectioned augers feature structural complexity, complicated production techniques and high material intensity, as regards their production. In operation, they have increased power consumption (Tian *et al.*, 2018; Hevko *et al.*, 2021) and damage the transported material and the internal surfaces of the flexible pipes (Rohatynskyi *et al.*, 2016; Manjula *et al.*, 2017; Hevko *et al.*, 2019). Hence, developing new designs of the flexible screw-type operating parts in auger conveyors and analysing the selection of their parameters to improve the operating efficiency of such conveyors is a task of current concern.

The purpose of the work was theoretical research and calculation definition of contact stresses in swivel elements of a flexible shaft in a screw conveyor.

Materials and Methods

To increase the operating efficiency and throughput of flexible screw conveyors and enhance their process capacities, the authors have developed various designs of sectioned augers with ball swivel joints between the sections.

The sectioned operating part of the screw conveyor is designed as the identical spirals 1 and 2, each made from a flat bar with a thickness of δ and supported by n section core rods (Fig. 1). The ends of the spirals are rigidly attached by their inside edges to the left split-design bushing 3 and the right splined bushing 4, respectively. The said bushings are rigidly connected via the rotation spring coil 5. Inside the spring coil, the swivel bolt joint passes. The bolt shank 6 is splined and its free right end is inserted into the right internally splined bushing so that the splines of the bolt and the bushing interact with each other.

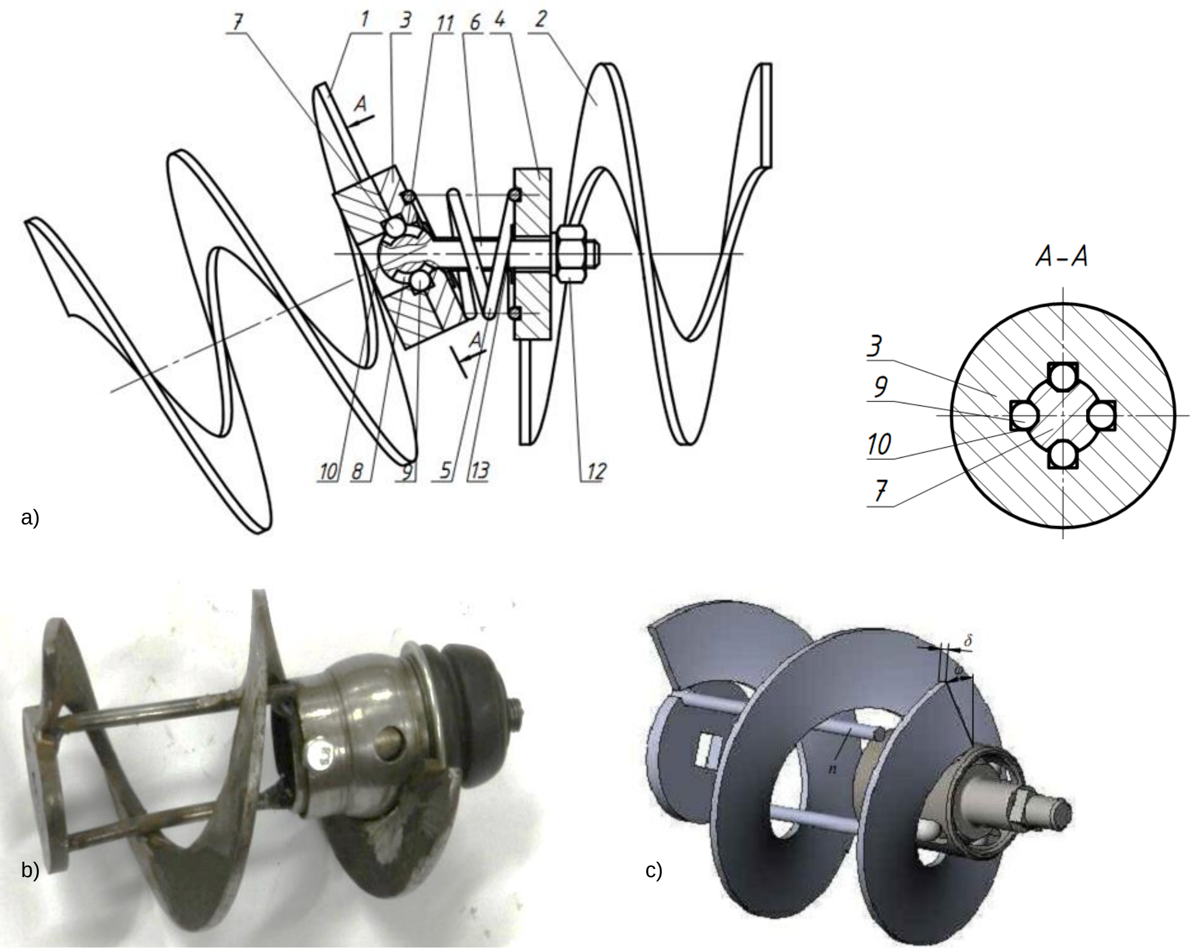


Figure 1. Structural layout (a), general view (b) and 3-D model (c) of auger section for screw conveyor

The left end of bolt 6 is made in the form of the spherical head 7, on the surface of which four equally spaced races with semi-circular cross-sections are symmetrically positioned on the respective great circles. The races interact with the balls 9, which are freely placed in the internal spherical cavities 10 of the left bushing 3. The spherical surface 7 of bolt 6 interacts with the semi-spherical aperture 11 of bushing 3. The latter is assembled from its two halves, which are rigidly connected with the use of standard methods and provide for the free rotation of the head 7 of the bolt 6. Thus, bolt head 7 in the bushing 3 acts as a universal joint. The two screw sections 1 and 2 are connected by the bolt joint with the nut 12. To seal the bolt connection, the shank of bolt 6 is covered with the elastic jacket 13, which prevents the bulk material from entering the friction zone.

In Figures 1b and 1c, the general view and 3-D model of the screw auger section, respectively, are shown. The sectioned auger operates as follows. When one helical spiral section rotates, the rotary motion is imparted by the spiral 1 to the left split-design bushing 3, the ball 9, the spherical bolt head 7, the splined bolt shank 6, the right splined bushing 4 and finally to the spiral 2. An additional rotary motion transmission path is the spring 5, which is rigidly attached by its ends to the left 3 and right 4 bushings.

To determine the contact stresses, the analysis has been carried out for the most strained element in the swivel joint auger, which is the ball that has a contact at three points with different surfaces in the joint and transfers the main torque T (Fig. 2). As the swivel joint, the two axes of which are displaced by a certain angle rotates, the ball moves on the surface of the casing and the surface of the race. This motion involves sliding, which implies the rise of friction forces. These forces depend on many factors. Each friction force is aligned with the respective instantaneous line of travel of the ball and is at a right angle to the line of action of the respective pressure force. The three friction forces F_{f1}, F_{f2} and F_{f3} are shown in Figure 2. Their lines of action change in the course of the ball rotation.

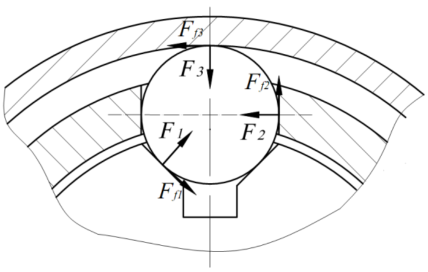


Figure 2. Analytical model for determining parameters of forces acting on the ball, when it transfers torque

The ball is under the action of the three forces F_1, F_2 and F_3 applied to it by the conical cavity, the slot in the cylindrical bushing and the spherical part of the casing, respectively. Each of the forces generates significant contact stresses. The stresses have to be analysed to determine the design parameters and limits that ensure the integrity and operating capacity of the swivel joint structure. At all three points of contact, the types of contact surfaces are different. The force F_1 acts in the area of contact between the ball and the conical surface of the race. This contact can be analysed as the contact between the spherical surface and the equivalent cylindrical surface. The contact in the area of action of the force F_2 is between the spherical surface of the ball and the plane.

The last of the three points, where the force F_3 is transferred, features an inside spherical contact. As is obvious from the above, the contact surfaces in the three cases under consideration are different. Therefore, it is necessary to analyse and calculate them individually. In the case of the contact between two spheres (the contact between the ball and the spherical surface of the bushing), the curvatures in the principal planes of the bodies have the following values:

$$k_{11} = k_{12} = \frac{1}{r} \cdot \tag{1}$$

$$k_{21} = k_{22} = \frac{1}{R+r}, \tag{2}$$

where r – radius of the ball, $R+r$ – radius of the spherical surface of the bushing.

As the spherical contact is an inside contact, the radius of the greater sphere has to be assumed with the minus sign, therefore, the respective coefficients appear as follows:

$$A = B = \frac{1}{2}\left(\frac{1}{r} - \frac{1}{R+r}\right) = \frac{R}{2r(R+r)}, \tag{3}$$

where A is the mean curvature:

$$\sum k = 2(A+B) = \frac{2R}{r(R+r)} \cdot \tag{4}$$

The contact patch for a force of F is a circle with the following radius:

$$a = \sqrt[3]{\frac{3\eta F}{2\sum k}}, \tag{5}$$

where

$$\eta = 2\frac{1-\nu^2}{E} \cdot \tag{6}$$

E and ν – Young's modulus of elasticity and Poisson's ratio, respectively, for the material of the ball and the swivel joint (they are assumed both to be made of steel).

The maximum pressure on the contact patch surface:

$$p_0 = \frac{1}{\pi}\sqrt[3]{\frac{3F\left(\sum k\right)^2}{2\eta^2}} \cdot \tag{7}$$

The mean pressure within the contact patch:

$$p = \frac{2}{3} p_0 . \tag{8}$$

After substituting the expressions for all the coefficients, the following final formula is obtained for the calculation of the maximum pressure at the contact between the ball and the spherical surface of the bushing:

$$p_{03} = \frac{1}{\pi} \sqrt[3]{\frac{3F_3 R^2 E^2}{2r^2 (R+r)^2 (1-\nu^2)^2}} . \tag{9}$$

The calculation of the contact stresses at the contact between the ball and the plane is of a similar type, but the values of the coefficients and the curvature are determined assuming that the radius of the plane is equal to infinity (its curvature is equal to zero).

Thus:

$$A = B = \frac{1}{2r} ; \tag{10}$$

$$\sum k = 2(A+B) = \frac{2}{r} . \tag{11}$$

After appropriate transformations, the maximum pressure at the contact between the ball and the flat surface of the slot in the cylindrical bushing is represented by the following relation:

$$p_{02} = \frac{1}{\pi} \sqrt[3]{\frac{3F_2 E^2}{2r^2 (1-\nu^2)^2}} . \tag{12}$$

The task of calculating the pressure at the contact between the ball and the conical cavity is somewhat more complex. Since the pressure force F_1 acts at a right angle to the generatrix of the cone, it is necessary to assume the interacting contact surfaces as a spherical one (the ball) and a cylindrical one (the cone), with a mean radius at the point of contact. The mean radius of the equivalent cylinder at the point of contact has to be equal to the radius of the line produced by the intersection of the cone with the perpendicular plane.

According to Rogatynska *et al.*, (2015):

$$K' = \frac{K}{\cos\gamma} , \tag{13}$$

where K and K' – the curvature of the conic section that is at a right angle to the axis of the cylinder and the curvature of the conic section that is at an angle γ to this plane, respectively.

Angle γ is the cone apex angle, that is, the angle between the perpendicular to the cone generatrix and the cone base plane. The cone base radius R_k at the contact between the ball and the cavity determines the curvature K' and, taking into account the geometrical considerations, they are calculated by the following formulae:

$$R_k = r\cos\gamma ; \tag{14}$$

$$K' = \frac{1}{r\cos\gamma} . \tag{15}$$

Hence, the curvature of the equivalent cylinder is equal to:

$$K = \frac{1}{r} , \tag{16}$$

while its radius is equal to:

$$R_c = r . \tag{17}$$

The radius of the equivalent cylinder is identical to the radius of the ball, which significantly reduces the contact stress at the internal contact.

Using the formula (Grote, Feldhusen, 2007), the following is obtained:

$$A = \frac{1}{2r} ; \tag{18}$$

$$B = 0. \tag{19}$$

Accordingly, the sum of curvatures is equal to:

$$\sum k = 2(A+B) = \frac{1}{r} . \tag{20}$$

After substituting the above-mentioned coefficients into the expression for the calculation of contact stresses and applying the respective tabulated reference data, the following formula is obtained for the calculation of the contact stresses at the surface of the cavity:

$$p_{01} = \frac{0{,}4}{\pi} \sqrt[3]{\frac{3F_1 E^2}{8r^2 (1-\nu^2)^2}} . \tag{21}$$

The values of the forces applied at the points of contact can be expressed in terms of the torque T:

$$F_1 \cdot \cos\gamma = F_2; \tag{22}$$

$$F_1 \cdot \sin\gamma = F_3; \tag{23}$$

$$F_2 = T \cdot (NR \cdot \cos\alpha)^{-1}, \tag{24}$$

where α – angular displacement of the bolt with a spherical head; N – number of the balls in the joint.

Finally, the following formulae are obtained for the calculation of the contact stresses:

$$p_{01} = \frac{0{,}4}{\pi} \sqrt[3]{\frac{3TE^2}{8NRr^2 (1-\nu^2)^2 \cos\alpha \cos\gamma}} . \tag{25}$$

$$p_{02} = \frac{1}{\pi} \sqrt[3]{\frac{3TE^2}{2NRr^2 (1-\nu^2)^2 \cos\alpha}} . \tag{26}$$

$$p_{03} = \frac{1}{\pi} \sqrt[3]{\frac{3TRE^2 \mathrm{tg}\gamma}{2Nr^2 (R+r)^2 (1-\nu^2)^2 \cos\alpha}} . \tag{27}$$

Thus, the formulae have been obtained for the calculation of the contact stresses in the most loaded element, which is the ball that has a contact at its three points with different surfaces of the structure and takes part in the transfer of the main torque T.

It has been established by the authors that various methods can be used to select such geometric parameters of the swivel joint that ensure, under the given contact forces and with the use of adequate materials, the conditions, in which the maximum stresses do not exceed the permissible ones.

Results and Discussion

Using the results of the PC-assisted calculations carried out based on the system of equations (25–27) and assuming that $R = 17$ mm, $r = 4.75$ mm, $N = 4$ and $E = 2{\cdot}10^{11}$ N m^{-2}, $\nu = 0.25$, the graphic relations between the contact stresses and the cavity cone angle γ, the angular displacement of the spherical head bolt α and the torque T have been plotted, as shown in Figure 3.

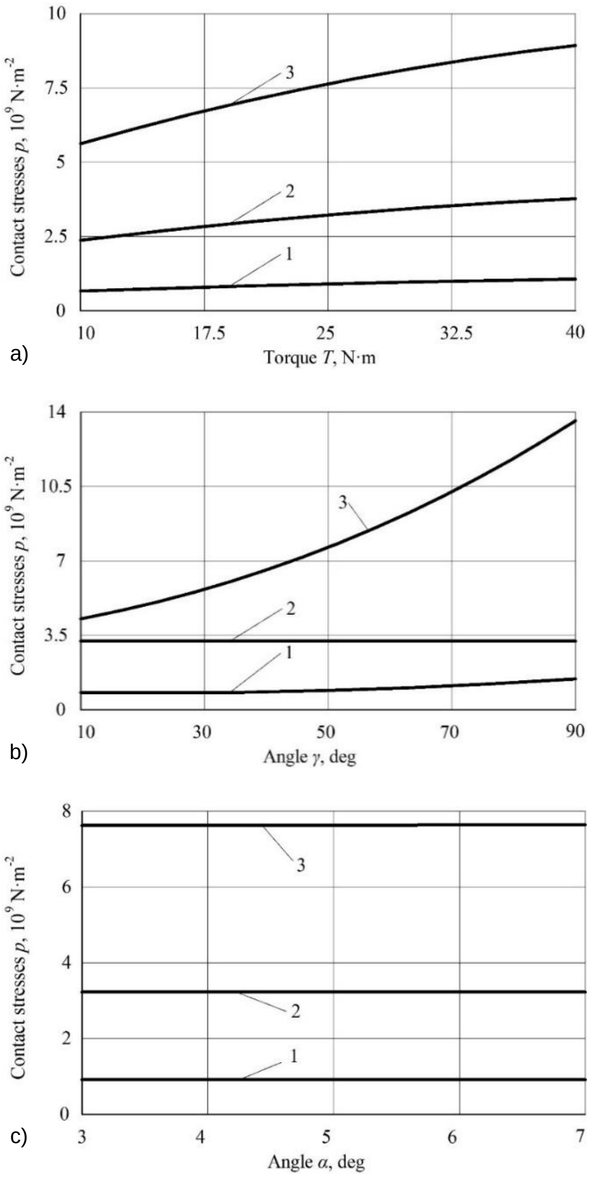


Figure 3. Graphic relations between contact stresses p and torque T (a), cavity cone angle γ (b) and angular displacement of spherical head bolt α (c): 1 – p_{02} ; 2 – p_{02} ; 3 – p_{03}

The analysis of the obtained diagrams (Fig. 3) and equations (25–27) has proved that, when the parameters of the joint are selected correctly, the maximum contact stresses arise at the point of contact between the ball and the flat surface of the slot in the cylindrical bushing. They can be calculated with the use of the formula for p_{02}. The recommended structural limitation range for the cavity cone angle is approximately 30–50 degrees. When these limits are exceeded, the stresses in other elements of the swivel joint sharply rise. The main element in the transfer of the torque is the contact at the flat surface of the slot in the cylindrical bushing. The rather small values of the contact stresses that arise in the cavity can be explained by the large contact patch area extending along almost the whole ball seating line.

It has been established that the maximum effect on the magnitude of the contact stresses p arising in the elements of the swivelling-section auger is produced by the torque T (Fig. 3a, its variation within the range of 10–40 Nm results in the stresses p increasing by 35–37%). The other factors that affect the magnitude of the contact stresses are the cavity cone surface generatrix angle γ (Fig. 3b, when γ increases from 30 to 50°, the stresses rise by 9–21%) and the angular displacement α of the spherical head bolt (Fig. 3c, when α varies from 3 to 7°, the stresses increase by 0.3%).

To find the optimum design characteristics of the screw auger sections, computer simulation has been carried out to determine the contact stresses in auger components concerning the operating conditions.

Within the Solid Works application environment, a computer model has been generated for an auger section in the flexible screw conveyor complete with the swivel-joint transmission devices attached to the section. The general view of the model with the applied load is shown in Figure 4. One intermediate element is rigidly fixed (shown on the left in Fig. 4), and the torque is applied to the other one (as shown on the right).

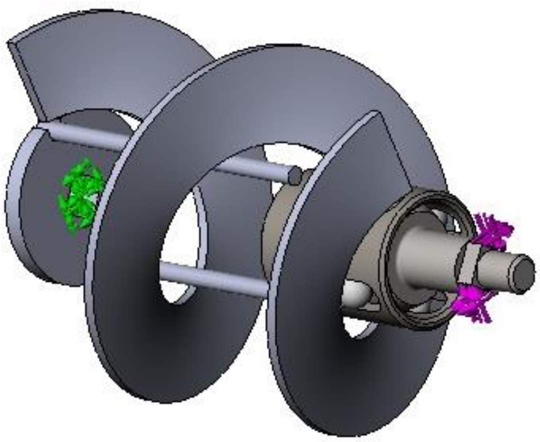


Figure 4. Model of a section with load applied to it

Because of the modelling process, the following graphic representation of the stresses that arise in the auger components under the action of the applied torque (Fig. 5) has been displayed in the application window.

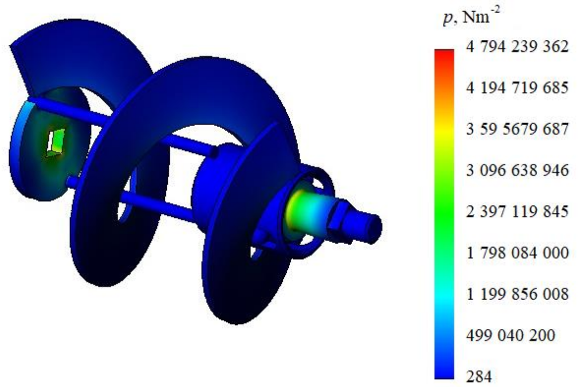


Figure 5. Diagram of stresses in components of auger section

The analysis of the obtained results has proved the agreement of the obtained values and the respective graphic relations plotted on their basis. The comparison of the computer modelling results and the data obtained using calculation has shown that the difference between the corresponding values varies within the range of 11–26%.

Conclusion

It has been established that the maximum contact stresses arise at the points of contact between the ball and the flat surfaces of the slot in the cylindrical bushing. The recommended range of structural limitation for the cavity cone angle lies within about 30–50 degrees.

It has been proved that the maximum effect on the magnitude of the contact stresses p generated in the components of the swivel-joint sectioned auger is produced by the torque T (when it varies within the range of 10–40 Nm, the stresses p increase by 35–37%). At the same time, the magnitude of the contact stresses also depends on the cavity cone surface generatrix angle γ (if γ is increased from 30 to 50°, the stresses rise by 9–21%) and on the angular displacement of the spherical head bolt α (when α changes from 3 to 7°, they increase by 0.3%).

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contributions

VB, JO, OT – study conception and design;
VB, JO – drafting of the manuscript;
VB, VA, JO, MA, OT – analysis and interpretation of data;
JG, MA, MC, SI, SP, FS – acquisition of data.
JO – critical revision and approval of the final manuscript.
All authors have read and agreed to the published version of manuscripts

References

Baranovsky, V., Trahanska, O., Pankiv, M., Bandura, V. 2020. Research of a contact impact of a root crop with a screw auger. – Research in Agricultural Engineering, 66(1): 33–42. DOI: 10.17221/75/2017-RAE

Evstratov, V.A., Linnik, Y.N., Linnik, V.Y., Grigoryev, V.I., Suxarnikova, V.A. 2020. Structural and parametric synthesis of screw modules of technological machines. – IOP Conference Series: Materials Science and Engineering, 843(1):012016. DOI: 10.1088/1757-899X/843/1/012016

Evstratov, V.A., Rud, A.V., Belousov. K.Y. 2015. Process modelling vertical screw transport of bulk material flow. – Procedia Engineering, 129: 397–402. DOI: 10.1016/j.proeng.2015.12.134

Frey, S., Dadalau, A., Verl, A. 2012. Expedient modeling of ball screw feed drives. – Production Engineering, 6 (2): 205–211. DOI: 10.1007/s11740-012-0371-0

Gill, D.R. 2003. Basics of flexible screw conveyors. – Plant Engineering, 57(1):46–48.

Grote, K.-H., Feldhusen, J. 2007. Dubbel: Taschenbuch für den Maschinenbau. – Springer, Deutchland, 1798 pp.

Hevko, B.M., Hevko, R.B., Klendii, O.M., Buriak, M.V., Dzyadykevych, Y.V., Rozum, R.I. 2018a. Improvement of machine safety devices. – Acta Polytechnica, Journal of Advanced Engineering, 58(1):17–25. DOI: 10.14311/AP.2018.58.0017

Hevko, R.B., Klendiy, M.B., Klendiy, O.M. 2016. Investigation of a transfer branch of a flexible screw conveyer. – INMATEH - Agricultural Engineering, 48(1):29–34.

Hevko, R., Rohatynskyi, R., Hevko, M., Lyashuk, O., Trokhaniak, O. 2020. Investigation of sectional operating elements for conveying agricultural materials. – Research in Agricultural Engineering, 66(1):18–26.

Hevko, R.B., Strishenets, O.M., Lyashuk, O.L., Tkachenko, I.G., Klendii, O.M., Dzyura, V.O. 2018b. Development of a pneumatic screw conveyor design and substantiation of its parameters. – INMATEH - Agricultural Engineering, 54(1):153–160.

Hevko, R., Vitrovyi, A., Klendii, O., Liubezna, I. 2017. Design engineering and substantiation of the parameters of sectional tools of flexible screw conveyers. – Bulletin of the Transilvania University of Brasov, 59(10):39–46.

Hevko, R., Zalutskyi, S., Hladyo, Y., Tkachenko, I., Lyashuk, O., Pavlova, O., Pohrishchuk, B., Trokhaniak, O., Dobizha, N. 2019. Determination of interaction parameters and grain material flow motion on screw conveyor elastic section surface. – INMATEH - Agricultural Engineering. 57(1):123–134.

Hevko, R., Zalutskyi, S., Tkachenko, I., Lyashuk, O., Trokhaniak, O. 2021. Design development and study of an elastic sectional screw operating tool. – Acta Polytechnica. 61(5):624–632. DOI: 10.14311/AP.2021.61.0624

Karpeenko, A., Kuznetsov, Y., Bychkova, T., Kravchenko, I., Aldoshin, N., Kalashnikova, L. 2021. Grain auger conveyor-distributor. – INMATEH - Agricultural Engineering, 65(3):39–46. DOI: 10.35633/INMATEH-65-04.

Lech, M. 2001 Mass flow rate measurement in vertical pneumatic conveying of solid. – Powder Technology, 114(1–3):55–58.

Loveikin, V., Rogatynska, L. 2011. A model of loose material transportation by means of high-speed conveyors with elastic operating devices. – Bulletin of I. Puluj Ternopil National Technical University, 16:66–70.

Lyashuk, O.L., Rogatynska, O.R., Serilko, D.L. 2015. Modeling of the vertical screw conveyer loading. – INMATEH - Agricultural Engineering, 45(1):87–94.

Manjula, E.V.P.J., Hiromi, W.K. Chandana, A.B., Melaaen, M.C. 2017. A review of CFD modelling studies on pneumatic conveying and challenges in modelling offshore drill cuttings transport. – Powder Technology, 305:782–793, DOI: 10.1016/j.powtec.2016.10.026. ISSN 0032-5910.

Olanrewaju, T.O., Jeremiah, I.M., Onyeanula, P.E. 2017. Design and fabrication of a screw conveyor. – Agricultural Engineering International: CIGR Journal, 19(3):156–162.

Rogatynska, O., Liashuk, O., Peleshok, T., Liubachivskyi, R. 2015. Investigation of the process of loose material transportation by means of inclined screw conveyers. – Bulletin of I. Pyliui Ternopil National Technical University, 79:137–143.

Rohatynskyi, R.M., Diachun, A.I., Varian, A.R. 2016, Investigation of kinematics of grain material in a screw conveyor with a rotating casing. – Bulletin of Kharkiv Petro Vasylenko National Technical Univarsity of Agriculture, 168:24–31.

Tian, Y., Yuan, P., Yang, F., Gu, J., Chen, M., Tang, J., Su, Y., Ding, T., Zhang, K., Cheng, Q. 2018. Research on the principle of a new flexible screw conveyor and its power consumption. – Applied Sciences (Switzerland), 8(7):1038. DOI: 10.3390/app8071038

Trokhaniak, O.M., Hevko, R.B., Lyashuk, O.L., Dovbush, T.A., Pohrishchuk, B.V., Dobizha, N.V. 2020. Research of the bulk material movement process in the inactive zone between screw sections. – INMATEH - Agricultural Engineering, 60(1):261–268, DOI: 10.35633/INMATEH-60-29.

Agraarteadus
1 • XXXIII • 2022 74–80

Journal of Agricultural Science
1 • XXXIII • 2022 74–80

PRODUCTIVITY AND STABILITY OF FOOTHILL MEADOW SPECIES IN THE BALKAN MOUNTAINS CONDITIONS

Natalia Georgieva[1], Valentin Kosev[1], Dimitar Mitev[2], Ina Stoycheva[1]

[1]*Institute of Forage Crops (IFC), 89 Gen. Vladimir Vazov St, 5800 Pleven, Bulgaria*
[2]*Research Institute of Mountain Stockbreeding and Agriculture (RIMSA), 281 Vasil Levski St, 5602 Mladost, Troyan, Bulgaria*

Saabunud:
Received: 14.10.2021

Aktsepteeritud:
Accepted: 13.03.2022

Avaldatud veebis:
Published online: 13.03.2022

Vastutav autor:
Corresponding author: Natalia Georgieva

E-mail: imnatalia@abv.bg

ORCID:
0000-0002-4151-4644 (NG)
0000-0003-3292-4200 (VK)
0000-0002-4151-4644 (IS)

Keywords: meadow grasses, evaluation, productivity, stability parameters.

DOI: 10.15159/jas.22.03

ABSTRACT. The creation of grasslands with the participation of species of local origin, suitable for the climatic conditions of the region and with increased productivity and stability of yield is an important condition for ensuring sustainable or organic feed production. For ecological assessment of meadow species in the semi-mountainous regions of Balkan Mountains according to indicators and parameters related to productivity and stability, an experiment is carried out in the period 2011–2019 in the following variation: *Festuca rubra* L., *Lolium perenne* L., *Dactylis glomerata* L., *Arrhenatherum elatius* P.B., *Festuca arundinacea* Schreb., *Briza maxima* L., *Trisetum flavescens* L., *Agrostis alba* L. The experiment is performed by the block method, and the methods of regression, variance and nonparametric analysis are used to assess the stability. According to the values of most of the calculated stability parameters (bi, Si2, λi, σ2i, PP, W2, $S^{(3)}$, $S^{(6)}$, $NP^{(1)}$) *Dactilis glomerata* shows good ecological stability. Complex evaluation by GGE biplot analysis identifies *Festuca rubra* L. as a species that favourably combines high productivity with relative stability. *Dactilis glomerata* and French ryegrass are characterized by high stability and yield close to the average for the group. These species are suitable for growing in a wide range of environmental conditions.

Introduction

The irrational use and management of natural resources, as well as non-compliance with the biological characteristics of individual species by their adaptability, is one of the causes of the crisis in modern agriculture. Its authorization is related to the application of methods for ecological assessment of adaptability and stability of species and scientifically based organization of production (Korzun, Brujlo, 2011; Rybas, 2016). The basis of the adaptive potential is the variability, characterized by the terms stability and plasticity (Dragavtcev, 2000).

When creating a grassland, the ecological conditions of the environment are decisive for the choice of species. Under extreme environmental conditions that occur during the growing season, some of them show greater compensatory capabilities and plasticity than others (Dimova *et al.*, 2006). Studies by several authors (Chourkova, 2007; Naydenova, Mitev, 2010; Mitev *et al.*, 2013) show that in mountainous and semi-mountainous areas, the creation of grasslands from species that do not meet local habitats leads to their rapid degradation. Those of local origin can form stable, long-lasting and highly productive grasslands in specific environmental conditions. In addition, the use of species suitable for the respective climatic conditions and with increased yield stability is an important condition in ensuring sustainable or organic feed production (agriculture) (Uhr, Ivanov, 2015; Shamsutdinov *et al.*, 2016).

The study aims to assess meadow species by indicators and parameters related to productivity and stability in the semi-mountainous regions in the Balkan Mountains conditions.

Material and Methods

In the conditions of the present experiment, the created grass stands included cereal meadow species, which are typical for the semi-mountainous regions of the Central Balkan Mountains (Totev, 1984; Totev, Valkov, 1988). The experimental activity was carried out in the Research Institute of Mountain Stock-breeding and Agriculture (RIMSA) (Troyan) in the period 2011–2019, with the following variants: V1 – *Festuca rubra* L., V2 – *Lolium perenne* L., V3 – *Dactilis glomerata* L., V4 – *Arrhenatherum elatius* P.B., V5 – *Festuca arundinacea* Schreb., V6 – *Briza maxima* L., V7 – *Trisetum flavescens* L., V8 – *Agrostis alba* L. The stands investigated in this study were situated at an altitude of 430 m.

Meteorological conditions during the 9-year experimental period were characterized by an average daily temperature of 11 °C and a precipitation sum of 858 mm. In general, the amount of precipitation in individual years was close to the average for the experimental period, except for the years 2012 and 2013, when the amount of precipitation averaged up to 35% higher, which corresponds to the more biomass formation. The soil type was Planosol. Tillage included ploughing and pre-sowing tillage, which brings it to a garden condition. Sowing was manual, with a rate of 800 seeds $m^{2\,-1}$. All seeds were from local populations. The experiment was based on the block method, in the 4-fold repetition of the variants. The grasses were cut in the phase of complete earring and fresh mass yield was reported.

For statistical data processing Statgraphics Plus Version 2.1, analysis of variance was used to determine the influence of grassland, environment (year) and their interaction. The stability of the variants was assessed by the following analyzes and parameters: regression analysis – in which the regression coefficient (bi) and variance of regression deviation (Si^2) were calculated (according to Eberhart, Russell, 1966), the parameters ai (linear response to environmental effects) and λi (deviation from the linear response) (according to Tai, 1979); variance analysis – by the parameter $\sigma^2 i$ by Shukla (1972), mean-variance component (PP) according to Plaisted and Peterson (1959), ecovalence (W2) according to Wricke (1965) and Annicchiarico (2002); and nonparametric analysis – through the parameters: "PI" of Lin and Binns (1988); $S^{(1)}$, $S^{(2)}$, $S^{(3)}$, $S^{(6)}$ by Huhn (1990) and Nassar and Huhn (1987); $NP^{(1)}$, $NP^{(2)}$, $NP^{(3)}$, $NP^{(4)}$ by Thennarasu (1995) and “KR” Kang (1988). The mean component of variation (PP) of Plaisted and Peterson (1959) was a measure of the contribution of the variant/grassland to its interaction with the environment and was calculated from the total by pair-wise analysis. The Annicchiarico method offers a reliability index (Wi), which was used in the present study to assess the probability that a grassland will perform below the environmental average or below any standard used. The coefficient of total adaptability 'A' was calculated by the method of Valchinkov (1990). A model of GGE biplot was made according to the method of Yan (2002), which used the values of the first two main components (PC1 and PC2).

Results and Discussion

Dispersion analysis

The analysis of the variance in terms of fresh mass yield (t ha^{-1}) shows that the effect of all three factors year (environment), meadow species (grassland) and the interaction between them is statistically significant at a high level (Table 1). The environmental factor has the strongest influence on productivity – 94.71% (Fig. 1), which is why meadow species show a significant variation in yield by year. The strength of the influence of the interaction environment × grassland is significantly lower (4.10%) than that of the environment and slightly exceeds the influence of the grass factor (1.19%).

Table 1. Analysis of variance for green mass productivity in meadow species

Source of variation	DF	Sum of Squares	Mean Square	Significance
Environment (year)	8	44641.111	558.0139	**
Species	7	561.7778	80.254	**
Species × environment	56	1933.2222	34.5218	**
Env./Gen.	64	6397.3333	99.9583	**
Env./Species 1 – *Festuca rubra* L.	8	894.2222	111.7778	**
Env.Species 2 – *Lolium perenne* L.	8	232.00	29.00	**
Env./Species 3 – *Dactilis glomerata* L.	8	542.2222	67.7778	**
Env./Species 4 – *Arrhenatherum elatius* P.B.	8	803.5556	100.4444	**
Env./Species 5 – *Festuca arundinacea* Schreb.	8	1563.5556	195.4444	**
Env./Species 6 – *Briza maxima* L.	8	363.5556	45.4444	**
Env./Species 7 – *Trisetum flavescens* L.	8	1102.2222	137.7778	**
Env./Species 8 – *Agrostis alba* L.	8	896.00	112.00	**
Residue	71			

Significance – * P < 0.05, ** P < 0.01

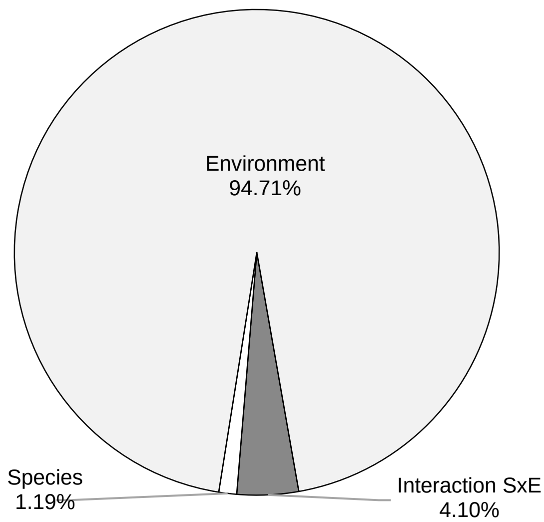


Figure 1. Influence of environmental factors, species and their interaction in terms of green mass yield in the studied meadow grasses

Productivity

The data on the yield obtained from the studied species (Fig. 2) in the period 2011–2019 vary widely, from 10.5 to 33.0 t ha^{-1} fresh mass. The average values for the period of this trait determine as the most productive species *Festuca arundinacea* Schreb. (21.0 t ha^{-1}), *Agrostis alba* L. (20.0 t ha^{-1}) and *Festuca rubra* L. (19.9 t ha^{-1}). High productivity is demonstrated by *Festuca arundinacea* Schreb. in 2012 and 2013 with an average yield of 31.0–33.0 t ha^{-1}, followed by *Agrostis alba* L. with 30.0 t ha^{-1} in 2012, and *Arrhenatherum elatius* P.B. and *Trisetum flavescens* L. by 29.5 and 29.0 t ha^{-1} in 2013, respectively. It should be noted that in the individual experimental years, there is no strictly defined one-way in the data on the yield of the fresh mass of the studied plant species. However, *Festuca rubra* L. and *Festuca arundinacea* Schreb. Are of some interest, as they show high yields during half of the 9-year experimental period. They are suitable components in the creation of artificial grasslands in the foothills in the Balkan Mountains conditions. We have also reported high productivity and adaptability of *Festuca rubra* L. in the foothills in the Balkan Mountains conditions in our previous studies (Georgieva *et al.*, 2018). The high productive potential of *Festuca arundinacea* Schreb. has been established by a number of researchers in different geographical areas. Tîtei *et al.* (2019) indicate the yield of green mass of different varieties and *Festuca arundinacea* Schreb., between 30.83 and 36.96 t ha^{-1} in the region of Chişinău (Moldova), Dronova *et al.* (2016) – from 24.3 to 32.5 t ha^{-1} in irrigation in the region of Volgograd (Russia), a Frydrych *et al.* (2020) – between 15.96 and 19.61 t ha^{-1} in the Beskydy region, Czech Republic.

Arrhenatherum elatius P.B., *Dactilis glomerata* L. and *Trisetum flavescens* L. have relatively limited productive possibilities during the experimental period, whose yields on average for the period vary in the range 18.0–18.7 t ha^{-1} statistically proven lowest yields are formed *by Lolium perenne* L. and *Briza maxima* L., on average by 16.9 and 11.6% below the group average. *Trisetum flavescens* L. and *Briza maxima* L. are species that are less studied in our country.

Although with lower productivity, they are defined as valuable forage species, are preferred by animals (Sanz *et al.*, 2011; Macháč, 2014; Zueva, Tsipchenko, 2018) and are suitable for inclusion in grasslands in semi-mountainous and mountainous areas (Sackl *et al.*, 2012).

The proven influence of the environmental factor (year) on the variation of the yield of meadow grasses gives grounds to evaluate their ecological stability.

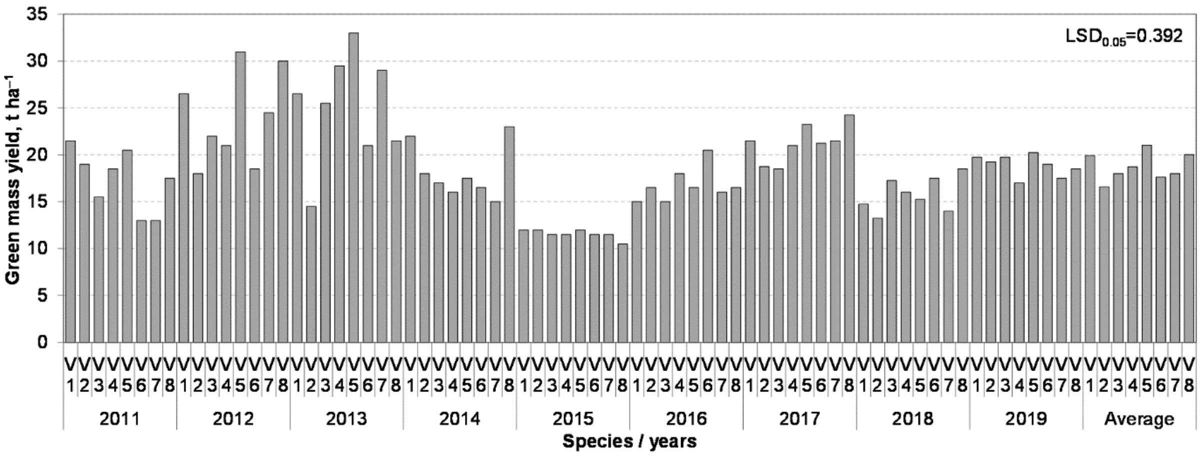


Figure 2. Productivity of meadow grasses (green mass t ha^{-1}) during the period 2011–2019 (V1 – *Festuca rubra* L.; V2 – *Lolium perenne* L.; V3 – *Dactilis glomerata* L.; V4 – *Arrhenatherum elatius* P.B.; V5 – *Festuca arundinacea* Schreb.; V6 – *Briza maxima* L.; V7 – *Trisetum flavescens* L.; V8 – *Agrostis alba* L.)

Ecological stability

The phenotypic stability of plants can be divided into two main types, stability in a biological and agronomic sense. Resistance in the biological sense refers to the ability of a plant population to maintain relative constancy (homeostasis) at the level of the trait in different environments, with low variation between them. Stability in the agronomic sense shows that the same population responds positively to improvements in growing conditions and can perform well above average in different areas (Sabaghnia *et al.*, 2015). In the conditions of the present experiment, to clearly differentiate meadow grasses by ecological stability, three types of parameters were used (Tables 2 and 3). Of the studied plant species, the *Dactylis glomerata* L. showed relatively good stability, judging by the coefficient of linear regression (bi = 0.93). The values of the stability variant according to the regression analysis, as well as those of most indicators in the other two types of analyzes (λi, σ2i, PP, W2, $S^{(3)}$, $S^{(6)}$, $NP^{(1)}$), are low and mathematical proof, which suggests that it has a definite advantage over other grasses. The linear regression coefficient characterized as stable *Lolium perenne* L. (bi = 0.30) and *Briza maxima* L. (bi = 0.54). The same species received different scores according to the values of the parameters of Plaisted and Peterson (1959), Wricke (1965), Annicchiarico (2002) and Lin and Binns (1988). The established differences in the assessment of the stability of the individual parameters are because the various methods are based on different concepts of stability. For the study period, *Festuca arundinacea* Schreb. (bi = 1.62), *Trisetum flavescens* L. (bi = 1.32) and *Festuca rubra* L.(bi = 1.17) are characterized by instability, which under the same growing conditions show more pronounced responsiveness.

Table 2. Parameters of phenotypic stability of meadow grasses by Green mass yield

Type	Eberhart and Russell (1966)		Tai (1979)		Shukla (1972)	Plaisted and Peterson (1959)	Wricke (1965)	Annicchiarico (2002)
	bi	Si^2	ai	λi	$\sigma^2 i$	PP	W^2	Wi
Festuca rubra L.	1.17	4.23**	1.17	17.93	4.10	6.607	142.35	98.33
Lolium perenne L.	0.30**	6.27**	0.30	25.99	18.72	12.232	457.35	79.63
Dactilis glomerata L.	0.93	1.98**	0.93	8.91	1.43	5.232	65.35	91.43
Arrhenatherum elatius P.B.	1.07	5.84**	1.07	24.38	5.13	7.155	173.01	92.57
Festuca arundinacea Schreb.	1.62**	3.44**	1.62	14.69	12.33	9.710	316.13	100.48
Briza maxima L.	0.54**	6.87**	0.54	28.44	10.73	9.708	316.01	85.18
Trisetum flavescens L.	1.32**	4.45**	1.32	18.79	6.06	7.429	188.35	86.69
Agrostis alba L.	1.06	9.50**	1.06	38.98	11.22	8.970	274.68	97.57

Significant at P = 0.05 – *; P = 0.01 – **

Table 3. Non-parametric indicators for stability and adaptability in meadow species

Species	Huhn (1990); Nassar and Huhn(1987)				Thennarasu (1995)				Lin and Binns (1988)	Kang (1988)	Valchinkov (1990)
	$S^{(1)}$	$S^{(2)}$	$S^{(3)}$	$S^{(6)}$	$NP^{(1)}$	$NP^{(2)}$	$NP^{(3)}$	$NP^{(4)}$	Pi	KR	A
Festuca rubra L.	2.39	4.44	6.81	2.64	2.00	0.26	0.41	0.46	6.06	5.00	5.88
Lolium perenne L.	2.67	5.28	11.88	5.19	2.44	0.69	0.74	0.75	33.61	16.00	3.83
Dactilis glomerata L.	2.22	3.53	8.19	3.94	1.22	0.50	0.49	0.65	14.83	6.00	4.36
Arrhenatherum elatius P.B.	2.61	4.86	10.00	4.34	1.33	0.40	0.42	0.67	11.28	7.00	5.54
Festuca arundinacea Schreb.	1.94	2.75	3.47	2.00	2.11	0.33	0.38	0.31	3.28	8.00	5.19
Briza maxima L.	2.72	5.75	12.55	4.55	2.33	0.89	0.69	0.74	23.11	12.00	4.21
Trisetum flavescens L.	2.17	3.50	9.33	4.67	1.56	0.74	0.63	0.72	14.17	10.00	4.83
Agrostis alba L.	3.11	7.11	11.13	4.13	2.78	0.35	0.54	0.61	8.67	8.00	5.09

In general, the significantly greater influence of the environment-grassland interaction factor compared to the influence of the grassland factor implies a greater instability of the studied meadow species in terms of yield. This is confirmed by the calculated values of the parameter Si^2, especially for the white vole (9.50). In this type, there is an instability of linear type with a proven value of Si^2. The instability is due to the significant differences in yields between the individual experimental years, as obviously the weather conditions have a strong influence.

The nonparametric coefficients for determining the phenotypic stability are presented in Table 3. The first two nonparametric coefficients for assessing the phenotypic stability of Nassar and Huehn (1987) – Si (1) and Si (2) identify the most stable species of *Festuca arundinacea* Schreb. and *Trisetum flavescens* L., and Si (3) and Si (6) define the representatives of the *Festuca* species as stable. Plant populations that show a lower value of Thennarasu (1995) parameters are considered the most stable. As such, according to Npi (1), *Dactylis glomerata* L. and *Arrhenatherum elatius* P.B. are the most stable, while the other coefficients Npi (2), Npi (3) and Npi (4) determine *Festuca arundinacea* Schreb. as the most stable. Stress-tolerant feed species are increasingly needed for the ecological and economic sustainability of extensive livestock systems (Annicchiarico *et al.*, 2002), as well as in global warming conditions (Katova, 2008).

Rank Sum (KR) Kang (1988) uses both yield and 'σi2' as selection criteria. Here the species of *Lolium perenne* L. (16), *Briza maxima* L. (12) and *Trisetum flavescens* L. (10) are characterized by the highest stability, which is distinguished by yields around and below the average in the totality of the studied plant species. According to the "KR" parameter, the fourth and fifth positions are occupied by the species *Festuca arundinacea* Schreb. and *Agrostis alba* L., which are less ecologically stable but have the highest yield of green mass.

The coefficient of general adaptability gives a lower estimate of the species of *Lolium perenne* L.) (A = 3.83) and *Briza maxima* L. (A = 4.21) for the experimental conditions. From the point of view of this coefficient, *Festuca rubra* L. and *Arrhenatherum elatius* P.B. receive high marks. They could also be grown in less favourable environmental conditions, as they combine good productivity with greater adaptability.

GGE biplot analysis

According to Farshadfar (2008), stability is not a sufficient criterion for assessing plant populations, as stable species are often low yielding. Therefore, other approaches are needed, which include an integrated assessment of yield and stability in an index. The GGE biplot is a complex analysis system according to which most of the aspects of the genotype-environment interaction, presented in tabular form, can be represented graphically. In this way, the visual assessment of the species and the identification of the "mega" environment are significantly simplified. The first two main components (PC1 and PC2) can be easily plotted on a two-dimensional graph so that the interaction between each species and the defined environment can be visualized. The GGE biplot allows for visual ranking of species through their productivity and stability in several environments. The data show that PC1 and PC2 represent 89.8% of the total variability that results from the interaction of the species with the environment (Fig. 3). Only the first two main components are presented, as this model emphasizes the best-observed patterns and levels of unnecessary data. In Figure 3, the abscissa "X", or the productivity line, passes through the beginning of the coordinate system of the biplot with an arrow indicating the positive end of the axis. The "Y" axis (stability axis) passes through the beginning of the biplot, perpendicular to the "X" axis. Thus, the average yield of genotypes is estimated by the projection of their markers on the "X" axis, and the stability – by the projection on the "Y" axis. The axis with the arrow marked with a circle passing through the centre of the coordinate system represents the average value of the species on the studied feature. From left to right, the species are classified by average yield. In the vertical direction, the mean value for the abscissa intersects the mean value for the ordinate. The intersection point at the same time represents the average yield. According to the graphic image, the meadow species *Festuca arundinacea* Schreb., *Agrostis alba* L. and *Festuca rubra* L. are characterized by the highest productivity, and *Briza maxima* L. and *Lolium perenne* L., respectively, with the lowest. The species of *Lolium perenne* L. and *Agrostis alba* L. are characterized by the greatest variability of yield, while *Dactilis glomerata* L., *Festuca rubra* L., *Arrhenatherum elatius* P.B. show significant stability of the trait. The position of *Festuca rubra* L. in the figure defines it as a favourable combination of high productivity with relative stability. Ivanov *et al.* (2018) point out that simultaneous assessment of yield and stability provides important information about the value of a population as it is based on the reliability of differences in yield and the variant of interaction with the environment. In this way, a generalized assessment is obtained, arranging the populations and species in descending order according to their economic value.

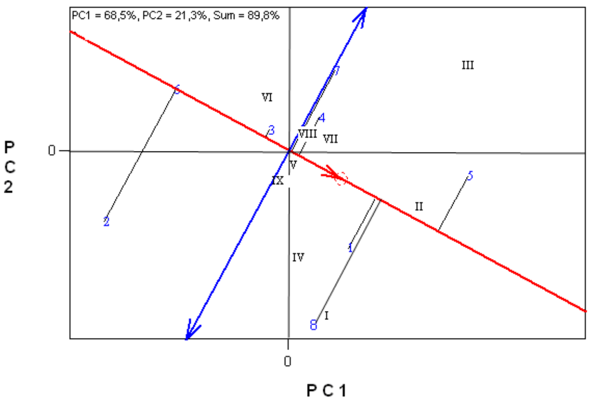


Figure 3. GGE biplot analysis for Green mass yield of meadow grass plant populations (1 – *Festuca rubra* L.; 2 – *Lolium perenne* L.; 3 – *Dactilis glomerata* L.; 4 – *Arrhenatherum elatius* P.B.; 5 – *Festuca arundinacea* Schreb.; 6 – *Briza maxima* L.; 7 – *Trisetum flavescens* L.; 8 – *Agrostis alba* L.; I–IX – years (environments) of cultivation from 2011 to 2019)

Conclusion

Through the analysis of the variant, a proven influence of the factors environment, type and type-environment interaction has been established. The environment has the strongest influence on the yield of fresh mass – 94.71% of the total variation. The influence of the species-environment interaction (4.10%) and the species (1.19%) is significantly weaker.

The assessment of the stability of the studied eight species of meadow grasses in the foothills in the Balkan Mountains conditions by the methods of regression, variance and nonparametric analysis is not one-way as it is based on different concepts of stability. According to the values of most of the calculated stability parameters (bi, Si2, λi, σ2i, PP, W2, $S^{(3)}$, $S^{(6)}$, $NP^{(1)}$) *Dactilis glomerata* L. shows good ecological stability. Positive assessments can also be given to the low-yielding species of *Lolium perenne* L. (bi = 0.30, 16.6 t ha^{-1}) and *Briza maxima* L. (bi = 0.54, 17.60 t ha^{-1}). The most unstable, but with a high yield of fresh mass is *Festuca arundinacea* Schreb. (bi = 1.62; 21.00 t ha^{-1}).

Complex evaluation by GGE biplot analysis identifies *Festuca rubra* L. as a species that favourably combines high productivity with relative stability. *Dactilis glomerata* L. and *Arrhenatherum elatius* P.B. are characterized by high stability and yield close to the average for the group. These species are suitable for growing in a wide range of environmental conditions.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

NG – critical revision and approval of the final manuscript;
VK – analysis and interpretation;
DM – study conception, design and acquisition of data;
IS – drafting of the manuscript.

References

Annicchiarico, P. 2002. Genotype x environment interactions: challenges and opportunities for plant breeding and cultivar recommendations (No. 174) – FAO Plant.

Chourkova, B. 2007. Botanical composition and productivity of birdsfoot trefoil in mixtures with Meadow Grasses in Bulgaria. – Journal of Balkan Ecology, 10(1):57–61.

Dimova, D., Valcheva, D., Zaprianov, St., Mihova, G. 2006. Ecological plasticity and stability of yield from winter barley varieties. – Field Crops Studies, 3(2): 197–203.

Dragavtcev, V.A. 2000. Integration of biodiversity and genome technology for crop improvement. – National Institute of Agrobiological Resourses, Tsucuba, Japan, 93–95.

Dronova, T.N., Burtseva, N.I., Nevezhin, S.Yu., Ivina, I.P. 2016. Productivity of tall fescue when conjunctively used for forage and seeds. – Kormoproizvodstvo, 12:29–33.

Eberhart, S.A.T., Russell, W.A. 1966. Stability parameters for comparing varieties. – Crop Science, 6:36–40.

Farshadfar, E. 2008. Incorporation of AMMI stability value and grain yield in a single nonparametric index (GSI) in bread wheat. – Pakistan Journal of Biological Science, 11(14):1791–1796.

Frydrych, J., Jezerska, L., Zegzulka, J., Bradačova, J. 2020. Energy grass research in the Beskydy region in connection with non-food land use. – Waste Forum, 2:90–98.

Georgieva, N., Kosev, V., Mitev, D. 2018. Ecological estimation of swards grown in the region of Middle Balkan Mountains. – Journal of BioScience and Biotechnology, 2–3:151–157

Huhn, M. 1990. Nonparametric measures of phenotypic stability. Part 1: Theory. – Euphytica, 47: 189–1990.

Ivanov, G., Uhr, Z., Delchev, G. 2018. Estimation of yield and stability of varieties of common winter wheat grown under organic and conventional agriculture. – New Knowledge Journal of Science, 7(2):265–272.

Kang, M.S. 1988. A rank-sum method for selecting high-yielding, stable corn genotypes. – Cereal Research Communication, 16: 113–115.

Katova, A. 2008. Study of perennial grass species and varieties for ornamental purposes. – Journal of Mountain Agriculture on the Balkans, 11(4):744–757.

Korzun, O.S., Brujlo, A.S. 2011. Adaptivnye osobennosti selekcii i semenovodstva sel'skohozyajstvennyh rastenij [Adaptive features of breeding and seed production of agricultural plants]. – Grodno, GGAU, 140. (in Russian)

Lin, C.S., Binns, M.R. 1988. A superiority measure of cultivar performance for cultivar×location data. – Canadian Journal of Plant Science, 68(1):193–198.

Macháč, R. 2014. Organic seed production of yellow oat grass – preliminary results. – Grassland Science in Europe, 19:502–504.

Mitev, D., Churkova, B., Iliev, M. 2013. Comparison of some grasses and legumes under conditions of the Central Balkan Mountains. – Journal of Mountain Agriculture on the Balkans, 16(5):1233–1246.

Naydenova, G., Mitev, D. 2010. Persistency of artificial swards with participation of red fescue on the slopes of the Central Balkan mountains.II. State of pure swards of red fescue. – Journal of Mountain Agriculture on the Balkans, 13(1):193–205.

Nassar, R., Huhn, M. 1987. Studies on estimation of phenotypic stability: tests of significance for nonparametric measures of phenotypic stability. – Biometrics, 43:45–53.

Plaisted, R.I., Peterson, L.C. 1959. A technique for evaluating the ability of selection to yield consistently in different locations or seasons. – American Potato Journal, 36:381–385.

Rybas, I.A. 2016. Breeding grain crops to increase adaptability. – Agricultural Biology, 51(5):617–626.

Sabaghnia, N., Karimizadeh, R., Mohammadi, M. 2015. Graphic analysis of yield stability in new improved lentil (*Lensculinaris* Medik.) genotypes using nonparametric statistics. – Acta Agriculturae Slovenica, 103(1):113–127. DOI: 10.14720/aas. 2014.103.1.12.

Sackl, T.P., Kaligarič, M., Ivajnšič, D., Škornik, S. 2012. Plant communities with yellow oat grass (*Trisetum flavescens* (L.) Pb.) in the submontane and montane regions of Slovenia. – Hacquetia, 11(2): 179–207.

Sanz, J., Bermejo, V., Muntifering, R., González-Fernández, I., Gimeno, B.S., Elvira, S., Alonso, R. 2011. Plant phenology, growth and nutritive quality of *Briza maxima*: responses induced by enhanced ozone atmospheric levels and nitrogen enrichment. – Environmental Pollution, 159(2):423–430.

Shamsutdinov, Z.Sh., Piskovatskiy, M., Novoselov, M., Tyurin, S., Kostenko, S.I., Perepravo, N.I., Kozlov, N.N., Agafodorova, M.N., Shamsutdinova, E.Z., Putsa, N M, Stepanova, G.V., Drobysheva, L.V, Zolotarev, V.N., Klimenko, I.A., Pilipko, S.V. 2016. Achievements, promising fields and goals in forage crop breeding and seed production. – Fodder Journal, 8:27–35.

Shukla, G.K. 1972. Some statistical aspects of partitioning genotype-environmental components of variability. – Heredity, 29:237–245.

Tai, G.C.C. 1979. Analysis of genotype-environment interactions of potato yield. – Crop Science, 19(4): 434–438.

Thennarasu, K. 1995. On certain non-parametric procedures for studying genotype-environment interactions and yield stability. – PhD Thesis, PJ School, IARI, New Delhi, India.

Tîtei, V., Blaj, V.A., Marusca, T. 2019. The productivity and the quality of green mass and hay from Romanian cultivars of *Festuca arundinacea*, grown in the Republic of Moldova. – Journal of Plant Development, 26:189–196.

Totev, T. 1984. Studying the use and improvement of natural meadows and pastures in the foothill, mountain and high mountain regions of Central Stara mountains. – DSc Thesis, Troyan, Bulgaria

Totev, T., Valkov, V. 1988. Investigation of grass mixtures in the pre-mountainous conditions of the Troyan regionand applying optimal mineral fertilization doses. – Troyan: Institute of mountain stockbreeding and agriculture, Bulgaria, 88 p.

Uhr, Z., Ivanov, G. 2015. Opportunities for increased yields in condition of biological farming system in wheat. – New Knowledge Journal of Science, 4(4): 35–41.

Valchinkov, S. 1990. Method for ranking genotypes with relatively high and stable yield. – Scientific reports of AU-Plovdiv, 35(4):161–165.

Wricke, G. 1962. Übereine Methode zur Erfassung der ökologischen Streubreite in Feldversuchen. – Zeitschrift für Pflanzenzüchtung, 47:92–96.

Yan, W. 2002. Singular-value partitioning in biplot analysis of multi-environment trial data. – Agronomy Journal, 94:990–996.

Zueva, G., Tsipchenko, E. 2018. Adaptation of species of the genus *Briza* L. in the conditions of Western Siberia. – IV All-Russian Youth Conference with the participation of foreign scientists (A.P. Belanova (ed.)), 8-12 October, Novosibirsk, 84–86.

Agraarteadus
1 • XXXIII • 2022 81–87

Journal of Agricultural Science
1 • XXXIII • 2022 81–87

ECONOMIC EFFICIENCY OF SWEET CORN GROWING WITH NUTRITION OPTIMIZATION

Yaroslava Hryhoriv[1], Valentyna Nechyporenko[2], Andrii Butenko[2], Margarita Lyshenko[2], Maksym Kozak[3], Iryna Onopriienko[2], Olena Shumkova[2], Viktoriia Shumkova[2], Lyudmyla Kriuchko[2]

[1]Vasyl Stefanyk Precarpathian National University, 57 Shevchenko St, UA7601841, Ivano-Frankivsk, Ukraine
[2]Sumy National Agrarian University, 160 H. Kondratieva St, UA40021, Sumy, Ukraine
[3]Kamianets-Podilskyi National Ivan Ohiienko University, 61 Ohiienko St, Kamianets-Podilskyi, UA32300, Ukraine

Saabunud: Received: 13.02.2022

Aktsepteeritud: Accepted: 06.04.2022

Avaldatud veebis: Published online: 06.04.2022

Vastutav autor: Corresponding author: Andrii Butenko

E-mail: andb201727@ukr.net

ORCID:
0000-0002-5892-9483 (YH)
0000-0001-8257-2720 (VN)
0000-0001-9639-9826 (AB)
0000-0002-6321-5178 (ML)
0000-0002-2734-6410 (MK)
0000-0003-1054-4717 (IO)
0000-0002-5971-3561 (OS)
0000-0003-4640-6359 (VS)
0000-0003-0528-210X (LK)

Keywords: corn, cultivation technology, yielding capacity, grain cost, profit, profitability.

DOI: 10.15159/jas.22.07

ABSTRACT. The efficiency of sweet corn production for grain has been studied; economic advantages of cultivation in comparison with other crops have been highlighted. The article presents the results of research on issues of improving the economic efficiency of technology elements for growing sweet corn of the variety Moreland F1 under conditions of Precarpathians of Ukraine. Taking into account the production strategy, have been outlined cost-effective resource-saving and intensive technologies which provide the stable yielding capacity of early-ripening hybrid of sweet corn under conditions of Precarpathians at the level of 4.99–6.65 t ha^{-1} accordingly with the profit of 370–500 € ha^{-1} and grain production profitability 112–135%. It is established that under the conditions of application of mineral fertilizers at the dose of $N_{135}P_{90}K_{125}$ + N_{60} + N_{30} in two stages the grain yield of corn increases compared to the absolute control (by 2.26 t ha^{-1}, or 30.3%) with increasing costs per 1 ha of sown area 68.23 €, or 26.4%). In proportion to the increase in yield, the amount of profit, which is 192.42 € ha^{-1}, also increased significantly.

Introduction

It has long been known that the constant cultivation of food grain is one of the main ways for the development of the agricultural sector of Ukraine. Nowadays, corn occupies one of the first places among grain crops (Zynchenko, 2013; Hadzalo *et al.*, 2016; Hryhoriv *et al.*, 2020a; Hryhoriv *et al.*, 2021a).

Every year, Ukraine's role in the world corn market becomes more important. Our country provides 3.5% of global corn cultivation. According to statistical data for 2015–2020, the average productivity of corn grain in our country was 6.6 t ha^{-1}. It should be noted that that year Ukraine has surpassed such world exporters as Brazil and China by yielding capacity (Pasternak, 2015).

It should be noted that in recent years Ukraine has taken one of the first places in the world in terms of economic parameters of agricultural complex, after having gained a deserved leading position of corn producer-exporter in the world market (Long *et al.*, 2018; Hryhoriv *et al.*, 2021b).

Everyone knows that the main purpose of developing components of varietal farming techniques of modern intensive corn hybrids is the opportunity to increase crop productivity. It is no secret that establishing the feasibility of any agricultural complex techniques only on the dynamics of the harvest is not enough, as the cost of its production is missed. Proceeding from this assumption, it is necessary to determine not only agrotechnical but also the economic expediency of growing the crop (Garkavy *et al.*, 2003; Vlashuk, 2017; Hryhoriv *et al.*, 2021b).

Currently, during the intensification of production, economic evaluation of technologies for growing crops under conditions of market relations is very important. It should be noted that in recent years, prices for, fertilizers, plant protection products, and energy resources have risen significantly. It has an impact on rising costs of corn production and, consequently, declining sales revenues (Vozhehova *et al.*, 2018). That is why, when developing technologies for corn growing, to prevent inefficient use of production resources it is necessary to take into account the strategy of production, its goals and the resource potential of agricultural enterprises, which stipulate their focus on intensification or resource-saving. Thus, intensive technology models are aimed primarily at ensuring maximum profits with sufficient cost recovery, and resource-saving technologies aim to achieve the highest recovery from the profits (Kaminskyi *et al.*, 2017; Hryhoriv *et al.*, 2020).

Taking into account the type and specialization of agricultural enterprises, it is necessary to develop and implement cultivation technologies that will guarantee the possibility of forming homogeneous grain consignment as it is important for large producers. In addition, the resource provision level of enterprises has a significant impact on the efficiency of grain production. Thus, at the low level of resource provision, the profitability of corn grain production does not reach 50%, and enterprises with a high level of resource provision can have much higher profitability – more than 74% (Lü *et al.*, 2019; Kaminskyi *et al.*, 2020; Dhakal *et al.*, 2020).

It is known that achieving the high yielding capacity of corn is possible only with an increase in production intensity level (Kaminskyi, 2015). Fertilizer cost occupies the largest share in the structure of changeable costs at intensive technologies of corn cultivation, as this crop is characterized by a high need for nutrients and to form 1 tonne of grain with the appropriate amount of by-products producers have to use 24–32 kg of nitrogen, 10–14 kg of phosphorus and 25–35 kg of potassium (Shpaar *et al.*, 2012; Tanchyk *et al.*, 2021).

The direction of resource-saving in corn cultivation technology provides for not only reduction of agrochemical and pesticide load on the agrocenosis, but also obligatory compensation of their action by replacing them with the latest high-tech products which increase plant resistance to environmental stress, micro fertilizers, plant growth stimulants and so on.

In general, innovative resource-saving technologies of corn growing are aimed at reducing direct labour costs, material consumption of products and production processes. The application of such technologies in agricultural enterprises helped to reduce the cost of 1 tonne of product by 15.2–23.8% (Shpaar *et al.*, 2012; Honcharenko, 2017). Varietal resources are an independent element of resource-saving in modern crop production, and the use of hybrids of different ripeness groups with the integrated application provides regulation of yielding capacity level and the level of production costs in corn cultivation technologies (Dziubetskyi *et al.*, 2007; Pashchenko *et al.*, 2009; Tonkha *et al.*, 2021).

However, it should be remembered that the general economic effect of growing sweet corn is determined by market conditions, government policy concerning the development of the grain industry, and most important factors, resource efficiency of implemented cultivation technologies, level and quality of products (Holosov, 2004; Landré *et al.*, 2020; Kvitko *et al.*, 2021).

The aim of the research based on an economic evaluation is to establish the efficiency of corn cultivation technologies for grain depending on the level of fertilization and determine the most appropriate of them to realize the potential of crop productivity with maximum use of agro-climatic and industrial resources under the Precarpathians conditions.

Material and Methods

Field research was conducted based on the dendrological park "Druzhba named after Zinovii Pavlyk" at Vasyl Stefanyk Precarpathian National University in Ivano-Frankivsk region on sod-podzolic surface-gleyed soil from 2018 to 2020; GPS coordinates latitude 58°56'65', longitude – 34°41'55".

According to the results of the soil survey, the soils of the study area are of average humus – 2.63%. The sum of absorbed bases is in the range of 11–12 mg eq. per 100 g of soil, saturation degree of the bases – 85%, soil solution reaction – acidic (pH of salt solution 4.1–4.4, hydrolytic acidity is negligible).

Field and laboratory studies were conducted by generally accepted methods of research in agronomy (Lytvynov, 2011; Bondarenko, 2001).

General and special methods were used in the research: field – to study the relationship of the object with biotic and abiotic factors; quantitative and weight – to account for the grain harvest, which was carried out in sections, taking into account clogging and humidity; mathematical and statistical – to determine the reliability of the data; comparative-calculated – for the economic evaluation of corn cultivation technologies.

The economic efficiency of corn cultivation was calculated according to modern generally accepted methods, namely by technological maps. While determining production costs, we included sums of wages, costs of soil tillage, herbicides, seeds, depreciation, maintenance and inspection, the cost of fuel and lubricants, fertilizers, and seed storage costs. Calculations of the economic efficiency of sweet corn cultivation are given in the prices for 2021.

Obtained results of the research were processed by methods of mathematical statistics: disperse calculations of field research data with the help of computers and software programs MS Excel 2010 and Agrostat 2013. The results of the yield evaluation were generalized and statistically processed by the means of a multi-factor analysis of variance (ANOVA) at the probability level of 95% ($P < 0.05$). The differences between the variants of the trials were significant. We used the recommendations of domestic scientists through the conduction of mathematical data processing (Ushkarenko *et al*., 2014).

The economic efficiency of sweet corn production was determined by using the standard methodology of calculation of the profitability level (Ushkarenko *et al*., 2014). Profitability level was calculated as the ratio of the obtained pure profit to the full expenditures required by a certain variant of cultivation technology.

The sowing was carried out according to the scheme of the experiment. Sugar maize hybrid Moreland F1 was used for sowing.

Research topics included the study of such factors as:

Factor A – nutrition background:

- without fertilizers;
- $N_{90}P_{90}K_{90}$;
- $N_{135}P_{90}K_{125}$+ N_{60}+ N_{30}.

Factor B – densification of plants, thousand ha^{-1}:

- 60;
- 70;
- 80.

The experiment was repeated four times. The total area of the experimental plot was 50 m^2, accounting area – of 10 m^2. Placement of repetitions was carried out by the continuous method, arrangement of variants – by the method of randomized split blocks.

The variant without fertilizers was the control. The following mineral fertilizers were used for the research: complex fertilizers in the form of nitrogen-phosphorus-potassium (16% of a.s.); ammonium nitrate (34.4% of a.s.). Fertilizers were introduced on the plots in spring under cultivation. Additional fertilization of sweet corn crops was carried out with nitrogen fertilizers according to the corresponding variants of the experimental scheme in the phase of 3–4 and 6–7 leaves.

During the experiments, meteorological observations of the following indicators were conducted: average air temperature, and precipitation amount. For studying meteorological indices, data were used from the weather station in Ivano-Frankivsk, Ukraine.

The weather conditions during the vegetation period of sweet corn growing during the research differed significantly from the average long-term data both in terms of temperature and precipitation indices (Figs. 1, 2).

General and special methods were used in the research:

- field – to study the interrelationship of the object with biotic and abiotic factors;
- quantitative and weight – to account for grain harvest which was carried out in every plot, taking into account littering and humidity;
- mathematical and statistical – to determine the reliability of the data;
- comparative-calculating – for the economic evaluation of corn cultivation technologies, which was carried out according to technological maps in the prices of July 2020.

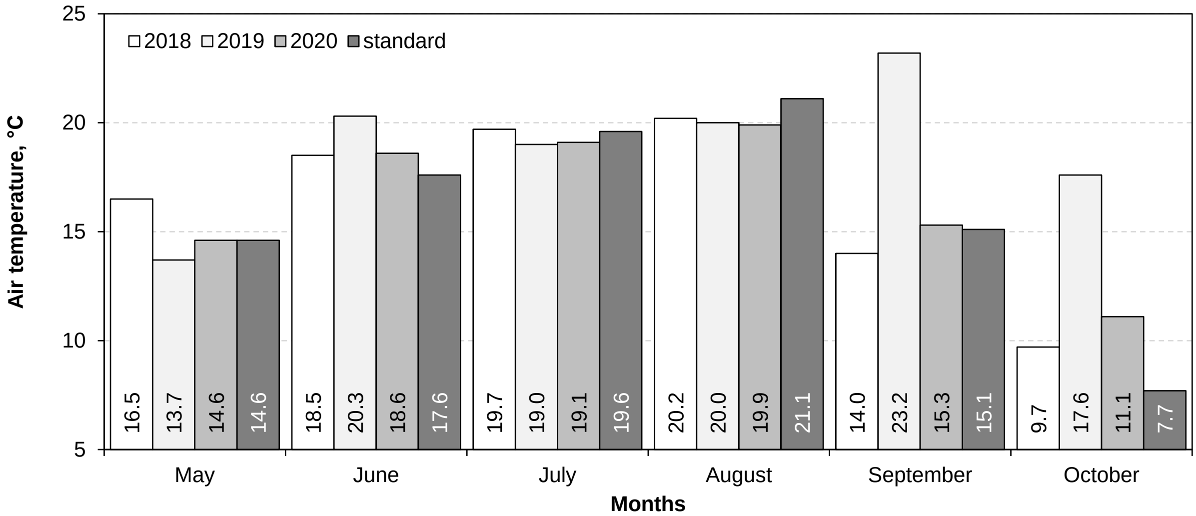


Figure 1. Air temperature (ºC) during vegetation period 2018–2020 of sweet corn

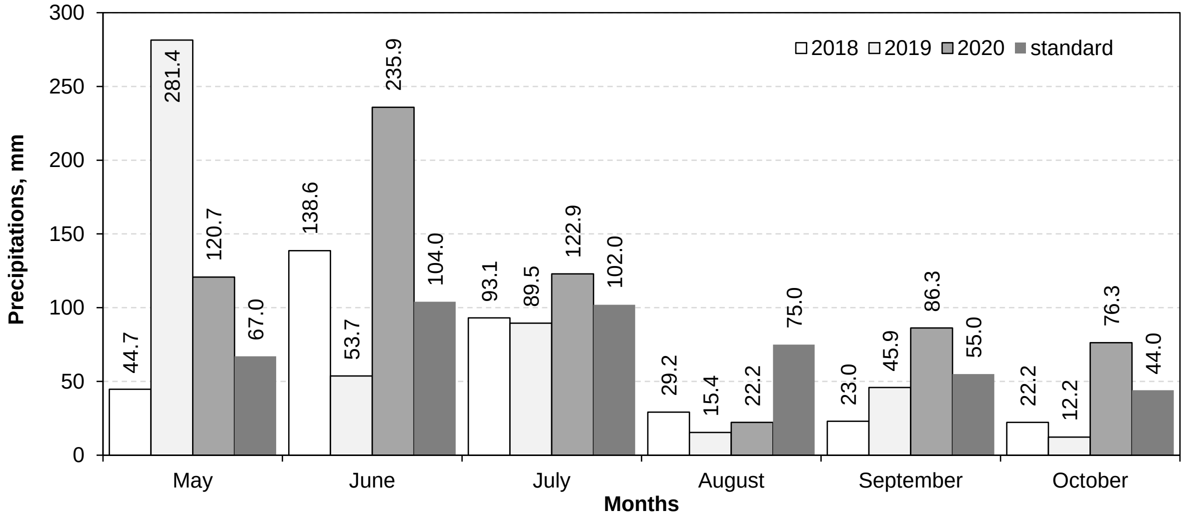


Figure 2. Precipitation amount (mm) during the vegetation period 2018-2020 of sweet corn

Results

The main index of the expediency for using a particular cultivation technology in agricultural production is its economic evaluation by the indices of production costs, the prime cost of one tonne of product, profit and profitability. Gradations of these indices depend on several factors, the most determining of which are the degree of technology intensity and the level of crop reaction to certain agro-technological measures and their combination in cultivation technology, which is manifested in changes in yielding capacity.

Productivity of early-ripening sweet corn, on average for 2018–2020, varied in a wide range – from 4.39 t ha^{-1} in the control variant with the agro-technical method and plant densification to 6.65 t ha^{-1} – with the application of $N_{135}P_{90}K_{125}$+ N_{60}+ N_{30} in two stages (Fig. 3).

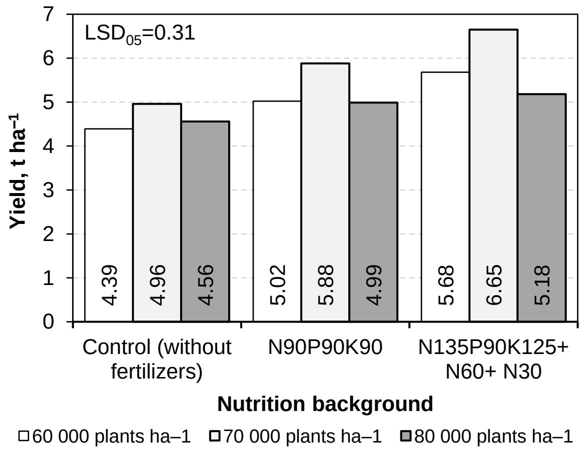


Figure 3. The yielding capacity of corn grain at a humidity of 14% depending on the density of plants and fertilizer doses average for 2018–2020, t ha^{-1}

It was have found that due to the intensive type of growth and high potential of individual productivity of plants, corn is characterized by a very low realization of potential productivity under undernutrition conditions close to the natural background of soil fertility. This is especially acute in case of insufficient moisture supply and on soils with low nutrient content, when already in the initial stages of plant development a weakened agrocenosis with minimal productivity is formed.

In our studies, the yielding capacity of corn in the variants without fertilizers, regardless of plant density, did not exceed 4.39 t ha^{-1}, which was stipulated by the insufficient amount of precipitation during vegetation and long-term removal of biogenic elements by crops with crop rotations for growing without fertilizers on sod-podzolic soil with the very low level of nutrient supply.

At the same time, the application of mineral fertilizers provided high yield increases – at the level of 0.63–2.26 t ha^{-1}, and a combination of different plant densities and doses of mineral fertilizers helped to increase their use efficiency. Thus, significant yield increases (0.63–2.26 t ha^{-1} with LSD_{05} = 0.31) were obtained from intensification means at all variants of the experiment, except for the control (without fertilizers). This indicates a high degree of positive reaction of corn to increase of intensity level of cultivation technologies.

The results of the research showed that the highest yields during the studied years were obtained in 2019 and they varied from 4.77 t ha^{-1} (in the control version) to 7.05 t ha^{-1} (for the application of mineral fertilizers at a dose of $N_{30}P_{45}K_{45}$ + N_{60} + N_{30} It should be noted that this year the optimal growing conditions for sugar corn were formed, which resulted in high crop productivity.

Such high increases in yielding capacity are provided by a significant increase in resource capacity of production. This, in its turn, stipulated a significant increase in production costs. On average during 2018–2020, production costs of growing corn increased in proportion to saturation of technology with intensification means: from 298.9–327.7 € ha^{-1} – for resource-saving models with limited doses of mineral fertilizers and plant density, and to 327.7–371.2 € ha^{-1} – for intensive technologies and high-intensity model with application of increased doses of fertilizers (Table 1).

Table 1. Economic indices of sweet corn cultivation depend on the background of nutrition and densification of plants, the average for 2018–2020

Variant	Density of plants, plants ha^{-1}	Prime cost, € t^{-1}	Costs per, € ha^{-1}	Net profit, €	Profitability level, %
Control (without fertilizers)	60 000	68.03	298.72	291.36	56
	70 000	61.15	303.36	300.80	59
	80 000	66.91	305.15	295.17	53
$N_{90}P_{90}K_{90}$	60 000	64.29	322.78	410.34	127
	70 000	55.26	324.96	390.56	120
	80 000	65.70	327.81	367.23	112
$N_{135}P_{90}K_{125}$+ N_{60}+ N_{30}	60 000	64.45	366.08	495.23	135
	70 000	55.81	371.04	491.68	132
	80 000	71.68	371.33	473.47	127

The maximum economic efficiency of growing sweet corn is provided by an agro-technological complex with a nutrition background of $N_{135}P_{90}K_{125}$+ N_{60}+ N_{30} and a plant density of 60 000 plants ha^{-1}. This is expressed in the highest index of profitability level – 135%. The lowest index of profitability level was in the variant without mineral fertilizers and plant density of 80 000 plants ha^{-1} and amounted to 53%. Analysis of economic efficiency concerning the production of commercial sweet corn cobs showed that cultivation of sweet corn is profitable even under unfavourable agricultural production conditions.

It should be noted that the application of mineral fertilizers in all variants of the experiment led to a reduction of prime cost, an increase in costs per 1 ha of crops and a significant increase in profits and level of production profitability. Whereas density increase of sweet corn plants from 60 to 70 000 plants ha^{-1} reduced the prime cost of commercial cobs of the crop, further densification of the crops led to the prime cost growth. Namely, densification of the crops to 80 000 plants ha^{-1} stipulated a decrease in profits and profitability level, while production costs per 1 ha remained almost at the same level as the variants where plant density was 70 000 plants ha^{-1}.

Discussion

There is little information on the economic consequences of different levels of fertilizer on the economic efficiency of growing sweet corn. The results of our study agree with the statement that the rationally scientifically sound application of nitrogen fertilizers on corn crops leads to a significant increase in the efficiency of growing crops from an economic point of view (Mulvaney *et al.*, 2006). We saw the above trend in our study: options with higher rates of mineral fertilizers were more cost-effective. However, some researchers note that there is no need to fertilize the crop, the best way is to apply the optimal dose of nitrogen and get the best result between yield and cost-effectiveness (Vanotti, Bundy, 1994). This statement is likely true.

However, it should not be forgotten that plant density is also an important factor in improving the economic efficiency of crops. It was determined that the influence of this element of agricultural technology differs in different genotypes of sweet corn. According to Yakunin's *et al.* (2011) research, some genotypes provided the best economic efficiency for 40 000 plants ha^{-1}, while others performed better for 50 000 plants ha^{-1}, depending on the length of the growing season. Note that the results of our study did not take into account the impact of the variety on economic efficiency. While the results of Eskandarnejad *et al.* (2013) indicate that, the best plant density for sweet corn in Iran is 90 000 plants ha^{-1} compared to 60 000 and 75 000 plants ha^{-1}. The Morris *et al.* (2000) study found that the yield of sweet corn increased with increasing plant density from 29 600 to 69 200 plants ha^{-1} in the study of varieties and hybrids.

However, there is a study that agrees with our results, namely that the yield of sweet corn increases to a certain number of ha^{-1} plants, and further thickening of crops harms productivity. It was found that the optimal plant density in the above study for the fresh market in sugar corn was considered 56 000 ha^{-1} plants (Landré *et al.*, 2020).

The optimal density of plants and the best options for fertilizers are the key to the efficient production of sweet corn and are highly dependent on the characteristics of the cultivated hybrid and environmental conditions. Thus, it is important to conduct research work for each area of cultivation, taking into account the range of varieties and hybrids, ecological, climatic, soil conditions and the level of agricultural development in the area.

Conclusion

It has been found that the economic efficiency of sweet corn growing technologies depends on the level of their intensity and is determined by the crop reaction to individual agricultural measures and their complex application in a single technological cycle. The results of the economic analysis of sweet corn agrotechnical showed that the best economic efficiency of crop production is ensured by applying mineral fertilizers standard $N_{135}P_{90}K_{125}$ + $N_{6}0$ + N_{30}, and plant density 60 000 plants ha^{-1}. This agro-technical complex provided the maximum profitability of cultivation of 135%.

There have been outlined economically efficient resource-saving, intensive technologies and technologies providing the stable yielding capacity of early-ripening sweet corn hybrid variety Moreland F1 at the level of 4.99–6.65 t ha^{-1} by the profit of 367.36–495.36 € ha^{-1} with the profitability of grain production at the level of 112–135%.

Implementation of norming production costs for their optimization in changing soil-climatic and organizational-economic conditions is rather promising in the direction of improving the technology of growing sweet corn with different intensities. Therefore, we recommend growing sugar corn for the needs of the market in the conditions of Precarpathia with the help of the above-mentioned technological operations, which will guarantee a high economic effect of crop production for farmers.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

YH – study conception and design, drafting of the manuscript;
VN – performed the literature data analysis and discussion of the results;
AB – analysis and interpretation of data and is the corresponding author;
ML – author of the idea, guided the research;
MK, IO – acquisition of data, drafting of the manuscript;
OS, VS, LK – critical revision and approval of the final manuscript.
All authors read and approved the final manuscript.

References

Bondarenko, H.L., Yakovenko, K.I. 2001. Metodyka doslidnoyi spravy v ovochivnytstvi ta bashtannykh kulʹturakh [Methodology of experimental business in vegetable growing and melons]. – Kharkiv. Osnova: 366 p. (In Ukrainian)

Dziubetskyi, B.V., Rybka, V.S., Cherchel, V.Yu. 2007. Suchasni problemy ta ekonomiko-enerhetychni aspekty vyroshchuvannya riznykh skorostyhlykh hibrydiv kukurudzy v Stepu Ukrayiny [Modern problems and economic and energy aspects of growing different precocity hybrids of corn in the steppe of Ukraine]. – Khranenie i pererabotka zerna, 5:14–17. (In Ukrainian)

Eskandarnejad, S., Khorasani, S.K., Bakhtiari, S., Heidarian, A.R. 2013. Effect of row spacing and plant density on yield and yield components of Sweet corn (*Zea Mays L. Saccharata*) varieties. – Advanced Crop Science, 3(1):81–88.

Garkavy, A.D., Petrichenko, V.F., Spirin, A.V. 2003. Konkurentospromozhnistʹ tekhnolohiy i mashyn [Competitiveness of technologies and machines]. – Textbook. Vinnytsia: VSAU. Tiras: 68 p. (In Ukrainian)

Holosov, O.O. 2004. Osoblyvosti formuvannya konkurentnoyi pozytsiyi zernovyrobnyka na svitovomu tovarnomu rynku [Features of formation of a competitive position of the grain producer in the world commodity market]. – Kultura narodov Prychernomoria, 50(2):18–24. (In Ukrainian)

Honcharenko, S.I. 2017. Innovatsiyni resursozberihayuchi tekhnolohiyi yak faktor pidvyshchennya efektyvnosti silʹsʹkohospodarsʹkoho vyrobnytstva [Innovative resource-saving technologies as a factor in improving agricultural efficiency production]. – Visnyk Kharkivskoho natsionalnoho tekhnichnoho universytetu imeni Petra Vasylenka, 185:131–142. (In Ukrainian)

Hryhoriv, Ya.Ya., Butenko, A.O., Davydenko, G.A., Radchenko, M.V., Tykhonova, O.M., Kriuchko, L.V., Hlupak, Z.I. 2020. Productivity of sugar maize of hybrid Moreland F1 depending on technological factors of growing. – Ukrainian Journal of Ecology, 10(2):268–272. DOI: 10.15421/2020_95

Hryhoriv, Y., Butenko, A., Nechyporenko, V., Lyshenko, M., Ustik, T., Zubko, V., Makarenko, N., Mushtai, V. 2021a. Economic efficiency of *Camelina sativa* growing with nutrition optimization under conditions of Precarpathians of Ukraine. – Agraarteadus, 32(2):232–238. DOI: 10.15159/jas.21.33

Hryhoriv, Ya.Ya., Masyk, I.M., Berdin, S.I., Kriuchko, L.V., Pshychenko, O.I., Moisiienko, V.V., Stotska, S.V., Panchyshyn, V.Z., Filon, V.I. 2021b. Influence of growing technology on Moreland F1 sweetcorn grain hybrid quality. – Ukrainian Journal of Ecology, 11(2):94–98. DOI: 10.15421/2021_84

Hadzalo, Ya.M., Hladii, M.V., Sabluk, P.T. 2016. Ahrarnyy potentsial Ukrayiny [Agrarian potential of Ukraine]. – Kyiv: Ahrarna nauka, 332 p. (In Ukrainian)

Kaminskyi, V.F. 2015. Tekhnolohiyi vyroshchuvannya silʹsʹkohospodarsʹkykh kulʹtur za riznykh system zemlerobstva [Technologies of cultivation of agricultural crops under different systems of agriculture]. – Scientific bases of effective of agricultural development in agrolandscapes of Ukraine. Kyiv: Edelveis, 190–221. (In Ukrainian)

Kaminskyi, V.F., Asanishvili, N.M. 2020. Ekonomichna efektyvnistʹ tekhnolohiy vyroshchuvannya kukurudzy riznoho rivnya intensyvnosti [Economic efficiency of maize growing technologies of different levels of intensity]. – Visnyk ahrarnoi nauky Prychornomoria, 3:27–34. DOI: 10.31521/2313-092X/2020-3(107)-4 (In Ukrainian)

Kaminskyi, V.F., Saiko, V.F., Dushko, N.M., Asanishvili, N.M. 2017. Scientific bases of efficiency of use of production resources in various models of technologies of cultivation of grain crops: monograph. [Naukovi osnovy efektyvnosti vykorystannya vyrobnychykh resursiv u riznykh modelyakh tekhnolohiy vyroshchuvannya zernovykh kulʹtur: monohr.]. Kyiv: Vinichenko, 580 p. (In Ukrainian)

Kvitko, M., Getman, N., Butenko, A., Demydas, G., Moisiienko, V., Stotska, S., Burko, L., Onychko, V. 2021. Factors of increasing alfalfa yield capacity under conditions of the forest–steppe. – Agraarteadus, 1(32):59–66. DOI: 10.15159/jas.21.10

Landré, A., Cornu, S., Meunier, J., Guerin, A., Arrouays, D., Caubet, M., Saby, N.P.A. 2020. Do climate and land use affect the pool of total silicon concentration? A digital soil mapping approach of frenchtopsoils. – Geoderma, 364 p. DOI: 10.1016/ j.geoderma.

Long, J., Cheng, H., Dai, Z., Liu, J. 2018. The effect of silicon fertilizer on the growth of chives. – IOP Conference Series: Earth and Environmental Science, 192: 1–6. DOI :10.1088/1755-1315/192/1/012065

Lü, H., Kang, J., Long, R., Xu, H., Chen, X., Yang, Q., Zhang, T. 2019. Effects of seeding rate and row spacing on the hay yield and quality of alfalfa in saline-alkali land. – Acta Prataculturae Sinica, 28(3):164–174. DOI: 10.11686/cyxb2018153

Lytvynov, S.S. 2011. Metodyka pol′ovoho dosvidu v ovochivnytstvi [Methods of field experience in vegetable growing]. – Moskva: RASHN VNIIO, 404 p. (In Ukrainian)

Dhakal, M., West, C.P., Villalobos, C., Brown, P., Green, P.E. 2020. Interseeding alfalfa into native grassland for enhanced yield and water use efficiency. – Agronomy Journal, 112(3):1931–1942. DOI: 10.1002/agj2.20147

Morris, T.F., Hamilton, G., Harney, S. 2000. Optimum plant population for fresh-market sweet corn in the Northeastern United States. – HortTechnology, 10(2):331–336. DOI: 10.21273/HORTTECH.10.2.331

Mulvaney, R.L., Khan, S.A., Ellsworth, T.R. 2006. Need for a soil-based approach in managing nitrogen fertilizers for profitable corn production. – Soil Science Society of America Journal, 70(1):172–182. DOI: 10.2136/sssaj2005.0034

Pashchenko, Yu.M., Borysov, V.M., Shyshkina, O.Yu. 2009. Adaptyvni ta resursozberihayuchi tekhnolohiyi vyroshchuvannya hibrydiv kukurudzy [Adaptive and resource-saving technologies for growing corn hybrids]. – Monograph: Dnipropetrovsk. Art-pres, 224 p. (In Ukrainian)

Pasternak, O. 2015. Perspektyvy kukurudzy v Ukrayini [Prospects for corn in Ukraine]. – Kyiv. Ahrobiznes sohodni, 7(230): 24–29. (In Ukrainian)

Shpaar, D., Hynapp, K., Dreger, D. 2012. Kukurudza: vyroshchuvannya, zbyrannya, zberihannya ta vykorystannya [Corn: cultivation, harvesting, storage and use]. – Kiev. Zerno, 464 p. (In Ukrainian)

Ushkarenko, V.O., Vozhehova, R.A., Holoborodko, S.P., Kokovikhin, S.V. 2014. Metodyka polovoho doslidu [Method of field experiment]. – Kherson, Hrin D.S., 448 p. (In Ukrainian)

Vanotti, M.B., Bundy, L.G. 1994. An alternative rationale for corn nitrogen fertilizer recommendations. – Journal of Production Agriculture, 7(2):243–249. DOI: 10.2134/jpa1994.0243

Yakunin, O.P., Okselenko, O.M., Zavertaliuk, V.F., Bielikov, Y.I. 2011. Agroeconomic efficiency of cultivation of sweet corn hybrids in dependence on the plants density. – Bulletin of the Institute of Grain Farming, 40:85–87.

Tanchyk, S., Litvinov, D., Butenko, A., Litvinova, O., Pavlov, O., Babenko, A., Shpyrka, N., Onychko, V., Masyk, I., Onychko, T. 2021. Fixed nitrogen in agriculture and its role in agrocenoses. – Agronomy Research, 19(2):601–611. DOI: 10.15159/AR.21.086

Vlashuk, A.M., Kolpakova, O.S. 2017. Stan i perspektyvy vprovadzhennia resursooshchadnykh, enerhozberihaiuchykh tekhnolohii vyroshchuvannia silskohospodarskykh kultur [Economic efficiency of growing maize hybrids of different maturity groups under irrigation conditions]. – II mizhnarod. nauk.-prakt. konf., Dnipro, pp. 22–24. (In Ukrainian)

Tonkha, O., Butenko, A., Bykova, O., Kravchenko, Y., Pikovska, O., Kovalenko, V., Evpak, I., Masyk, I., Zakharchenko, E. 2021. Spatial heterogeneity of soil silicon in Ukrainian phaozems and chernozems. – Journal of Ecological Engineering, 22(2):111–119. DOI: 10.12911/22998993/130884

Vozhehova, R.A., Vlashuk, A.M., Drobit, O.S. 2018. Ekonomichna efektyvnist′ vyroshchuvannya hibrydiv kukurudzy pry zroshenni Pivdennoho Stepu Ukrayiny [Economic efficiency of growing maize hybrids under irrigation of the Southern Steppe of Ukraine]. – Lviv, VLNAU, 22(1):253–259. (In Ukrainian)

Zynchenko, S. 2013. Stratehichnyy plan na 2020 rik [Strategic Plan 2020]. – Ahro Perspektyva, 10(161): 14–15. (In Ukrainian)

Agraarteadus
1 • XXXIII • 2022 88–94

Journal of Agricultural Science
1 • XXXIII • 2022 88–94

REDUTSEERIVATE SUHKRUTE SISALDUS EESTIS ENIMKASVATATUD KÖÖGIVILJADES SAAGIKORISTUSJÄRGSELT JA PÄRAST SÄILITAMIST

CONTENT OF REDUCING SUGARS IN MOSTLY GROWN VEGETABLES IN ESTONIA AFTER HARVESTING AND AFTER STORAGE

Sirje Jalakas[1], Mati Roasto[1], Tanel Kaart[2], Kristi Praakle[1], Mihkel Mäesaar[1], Terje Elias[1]

[1]Eesti Maaülikool, veterinaarmeditsiini ja loomakasvatuse instituut, veterinaarse biomeditsiini ja toiduhügieeni õppetool, Fr. R. Kreutzwaldi 62, 51006 Tartu
[2]Eesti Maaülikool, veterinaarmeditsiini ja loomakasvatuse instituut, tõuaretuse ja biotehnoloogia õppetool, Fr. R. Kreutzwaldi 62, 51006 Tartu

Saabunud: Received: 21.02.2022

Aktsepteeritud: Accepted: 01.04.2022

Avaldatud veebis: Published online: 01.04.2022

Vastutav autor: Corresponding author: Terje Elias

E-mail: terje.elias@emu.ee

ORCID:
0000-0001-6060-8892 (SJ)
0000-0002-7835-0647 (MR)
0000-0002-8936-768X (TK)
0000-0002-6605-7005 (KP)
0000-0001-5395-3233 (MM)
0000-0002-9111-1595 (TE)

Keywords: potato, beetroot, turnip, pumpkin, reducing sugar content, storage.

DOI: 10.15159/jas.22.05

ABSTRACT. The study examined the content of reducing sugars in various varieties of potato, beetroot, turnip and pumpkin most commonly grown in Estonia. This study aimed to determine the varieties of vegetables with the lowest levels of reducing sugars after harvesting and after storage at two different temperatures (3 and 8 °C). In the present study it was found that the potato variety with the lowest content of reducing sugars after harvesting and after six months of storage was potato variety 'Birgit' with 0.19 g 100 g^{-1}after harvesting, 0.98 g 100 g^{-1} after storage at 3 °C and 0.38 g 100 g^{-1} after storage at 8 °C, respectively. All three varieties of the beetroot, after harvest, contained a similar amount of reducing sugars. After six months of storage, the lowest content of reducing sugars was determined for variety 'Boro' with 1.22 g 100 g^{-1} at 3 °C and 0.96 g 100 g^{-1} at 8 °C, respectively. The lowest average concentrations of reducing sugars from turnips were after harvest in the variety 'Kohalik sinine' with 3.38 g 100 g^{-1}. Also after storage, the same variety had the lowest content of reducing sugars with 8.36 g 100 g^{-1} at 3 °C and 3.76 g 100 g^{-1} at 8 °C, respectively. From the pumpkin varieties, the lowest reducing sugars contents were determined for variety 'Gold Medal' with 2.64 g 100 g^{-1}after harvesting, 2.40 g 100 g^{-1} after storage at 3 °C and 1.90 g 100 g^{-1} after storage at 8 °C. It can be concluded that all studied vegetables stored at 3 °C contained higher amounts of reducing sugars than those stored at 8 °C.

Sissejuhatus

Köögiviljad sisaldavad erinevates kogustes suhkruid, sealjuures on erinev ka redutseerivate suhkrute sisalduse tase. Redutseeriv suhkur kuulub süsivesikute või looduslike suhkrute kategooriasse. Redutseerivad suhkrud on need, mis toimivad redutseerijana, kuna nende molekulaarstruktuuris on vabad aldehüüd- või ketorühmad. Redutseerivateks suhkruteks on glükoos, fruktoos, glütseeraldehüüd, laktoos, arabinoos ja maltoos, kuid mitte sahharoos (Considine ja Frankish, 2013). Köögiviljades sisalduvad redutseerivad suhkrud võivad kuumtöötlemisel, reageerides köögiviljades sisalduva aminohappe asparagiiniga, põhjustada kantserogeense ühendi akrüülamiidi teket (Mottram jt, 2002; Muttucumaru jt, 2017). Seetõttu on köögiviljasortides redutseerivate suhkrute sisalduste tuvastamine väga oluline, et leida madalate redutseerivate suhkrute sisaldusega sordid ning seeläbi vähendada võimalikku akrüülamiidi tekke ohtu toidus. Vältimaks redutseerivate suhkrute liigset kogunemist köögiviljadesse, tuleb neid kasvatada köögiviljaliikidele parimates sobivates tingimustes. Päikeselisel ja kuival suvel kasvanud köögiviljadel on redutseerivate suhkrute sisaldus enamasti kõrgem (sõltub stressori toimimise ajast), kui pilvisel suvel kasvanutel (Ohara-Takada jt, 2005; Bufler, 2013; Johansen jt, 2016). Stressoritel (nt kuumus, põud, toitainete puudus), mis mõjutavad taime kasvu varases staadiumis, on suurem mõju suhkrute sisaldusele, kui stressi teguritel kasvu hilises staadiumis (Bulgari jt, 2019). Mitmetes teadusuuringutes on kirjeldatud kasvukeskkonna mõju redutseerivate suhkrute sisaldusele köögiviljades, eriti selgelt väljendub köögiviljadele ilmastiku mõju sademetevaesel ja päikeselisel suvel (Ohara-Takada jt, 2005; Bufler, 2013; Johansen jt, 2016). Glükoosi- ja fruktoosisisalduse tõusu köögiviljades mõjutab ka kasvukeskkond, nt kaalikas tõusevad happelises ja aluselises keskkonnas glükoosi- ja fruktoosisisaldus (Gupta jt, 2001). Menamo (2012) Hollandis teostatud uuringus selgus, et kasvuhoonetingimustes kasvatatud kaalikates olid analüüsitud ühenditest suurimad sisaldusega glükoos – 28,09, fruktoos – 31,46, sahharoos – 29,90 ja tärklis – 24,06 g 100 g^{-1}. Avamaal kasvatamisel oli eelmainitud uuringus suurima sisaldusega glükoos – 33,51, fruktoos – 17,84, sahharoos – 23,39 ja tärklis 20,84 g 100 g^{-1}. Nendest tulemustest selgub, et kasvuhoones on keskkonnast tingitud stressorid paremini kontrollitud, seega jäävad uuritud ühenditest enamike sisaldused (v.a fruktoosil) madalamale tasemele kui avamaal (Menamo, 2012). Bethke jt (2009) uuringust selgus, et avamaal kasvatatud kartulitel esines kasvuajal erinevat laadi stressi ning sõltuvalt selle raskusastmest muutus ka mugula glükoosisisaldus. Kartuli varajases kasvustaadiumis esinev stress avaldab suuremat mõju suhkrute sisaldusele kui stressi toime kasvu hilises staadiumis (Bethke jt, 2009). Shinohara ja Suzuki (1981) artiklis toodi välja, et varjulisel alal kasvanud taimedel väheneb salatilehtede suurus ja lehtede arv, lehtede kuju kitsenes ning märgatavalt vähenes suhkru- ja askorbiinhappesisaldus. Eelnevast uuringust järeldub, et kui taimed kasvavad põuastes tingimustes, siis toimuvad vee puudusel taimedes kiired muutused, et hoida põuast tingitud stressi võimalikult madalana. Jaapanis koostatud ülevaateartiklis on toodud informatsioon fotosünteesi toimumise seosest veepuuduse ja päikesepaistes kasvamise vahel (Osakabe jt, 2014). Veepuudus koos ülemäärase päiksega (stressorid) vähendab fotosünteesi aktiivsust, millest tingituna redutseerivate suhkrute kasutamine taimede kasvamiseks ja õitsemiseks on pärsitud. Sellistes köögiviljades on redutseerivate suhkrute sisaldused suuremad (Van der Vyver ja Peters, 2017). Sahharoosi kogus, mis on lehtedest eksportimiseks saadaval, sõltub mitmetest parameetritest, nt fotosünteesi aktiivsusest (süsiniku sidumisest) ja ajutisest sahharoosi talletamisest vakuoolis. Porgandites toimub kogu kasvuperioodi jooksul sahharoosi taseme tõus, mis jätkub ka siis, kui porgandeid säilitada 2 °C juures (Bufler, 2013).

Koristusjärgsel säilitamisel mõjutavad tärklise ja suhkrute muundumist säilitamistemperatuurid. Erinevate köögiviljade säilitamisel jahedates ruumides nende suhkrusisaldus tõuseb (Xiao jt, 2018; Lina jt, 2019; Liu jt, 2021). Külmades säilitustingimustes muudetakse kartulite säilitamisel tärklis suhkruteks (Hou jt, 2017). Sloveenias teostatud uuringu põhjal (Jakopic jt, 2021) leiti, et kaalikates (sort 'Globus') tõusis suhkrute sisaldus koristuse järgselt 452 g kg^{-1}-lt kuivaines, külmikus säilitamisel 34. säilituspäevaks kuni 726 g kg^{-1} kuivaines. Pikemaajalisel säilitamisel, 34. kuni 62. päevani, toimus suhkrute sisalduse langus, mis jätkus katseperioodi (123 päeva) lõpuni (Jakopic jt, 2021). Sarnased trendid tuvastati glükoosi, fruktoosi ja sahharoosi osas. Saksamaal teostati põhjalik uuring porgandite tärklise- ja suhkrusisalduse kohta (Bufler, 2013). Uuringu teostamiseks tehti eelnevalt kindlaks kõrgemate tärklise- ja suhkrusisaldusega porgandisordid. Seejärel teostati uuringud juba taimede põllul kasvamise ajal ning samuti sellele järgnenud säilitamisel. Tulemustest selgus, et madalal temperatuuril (2 °C) säilitamine vähendas oluliselt tärklisesisaldust ja suurendas samaaegselt sahharoosisisaldust. Hiinas läbi viidud uuringu põhjal avaldatud teadusartiklist (Lina jt, 2019) selgub, et kartulite koristusjärgsel säilitamisel kolmel erineval temperatuuril (0, 4, 15 °C), oli kõige suurem glükoosi- ja fruktoosisisalduse tõus 0 °C-l säilitatud mugulates. Mõningal määral väiksem oli glükoosi ja fruktoosi tõus 4 °C-l säilitamisel ning 15 °C kraadi juures 30 päevasel säilitamisel toimus nii glükoosi- kui ka fruktoosisisalduse langus võrreldes koristusjärgse sisaldusega. Liu jt (2021) poolt avaldatud uuringust selgus, et 4 °C-l säilitades hakkas redutseerivate suhkrute sisaldus kartulis tõusma juba viiendal säilituspäeval ning redutseerivate suhkrute tõus kestis katse lõpuni, 30. päevani. Samas 20 °C-l säilitatud kartulites redutseerivate suhkrute tõusu, kogu katseperioodi jooksul, ei täheldatud (Liu jt, 2021). Säilitustingimused mõjutavad märkimisväärselt suhkrusisalduse vähendamist kartulites ja ebaõiged säilitamistingimused võivad põhjustada kõrgeid redutseerivate suhkrute koguseid köögiviljades (Xiao jt, 2018). Samuti kõrvitsate säilitamisel on kasutatavad temperatuurid väga olulised. Optimaalsed säilitamistingimused kõrvitsatele on temperatuur 10−13 °C ning suhteline õhuniiskus 50−70%. Kõrvitsad on madalamatel temperatuuridel tundlikud külmakahjustustele. Kvaliteeti arvesse võttes ei soovitata kõrvitsaid säilitada kauem kui 60−90 päeva (Gaskell, 1996; Biesiada jt, 2011).

Antud töö eesmärgiks oli välja selgitada erinevate köögiviljaliikide ja -sortide redutseerivate suhkrute sisaldused nii koristusjärgselt kui ka kahel erineval temperatuuril säilitatuna. Seejärel, töö tulemuste põhjal anda soovitused kuumtöötlemiseks sobilike köögiviljasortide kasvatamiseks ja kasutamiseks.

Materjal ja metoodika

Proovide kogumine

Eestis enimkasvatatud kartuli-, punapeedi-, kaalika- ja kõrvitsasortide tuvastamiseks tehti päringuid erinevatesse statistilisi andmeid haldavatesse asutustesse. Päringute tulemusel valiti analüüsimiseks viis enimkasvatatud kartulisorti: 'Birgit', 'Laura', 'Gala', 'Teele', 'Flavia', kolm punapeedisorti: 'Alto', 'Rodina', 'Boro', kolm kaalikasorti: 'Kohalik sinine', 'Globus', 'Skrene', ja kolm kõrvitsasorti: 'Gold Medal', 'Atlantic Gigant', 'Big Mac'.

Köögiviljade säilitamistingimused olid määratletud uuringu tellija poolt. Köögiviljade suhkrute sisaldusi analüüsiti koheselt pärast põllult koristamist ja pärast kuuekuulist kahel erineval temperatuuril (3 ja 8 °C) säilitamist. Kuna katsesse valitud kõrvitsasordid ei olnud vastupidavad säilitamisele (tegemist on kiirekasvuliste ja suuresaagiliste sortidega, millest osadel on väga õhuke koor), siis teostati redutseerivate suhkrute analüüsid kõrvitsatel pärast neljakuulist säilitamist. Värsketest köögiviljadest võeti igast sordist viis proovi, kuid proovide säilitamise probleemidest tingituna jäid analüüsidest välja ühe kartuli ja kahe kõrvitsa proovid. Säilitamisjärgselt võeti kõigist kartuli-, punapeedi- ja kaalikasortidest mõlema säilitustemperatuuri kohta viis proovi (v.a üks kaalikasort, millest õnnestus võtta vastavalt neli ja kaks proovi erinevate säilitustemperatuuride kohta). Kõrvitsatest õnnestus peale nelja säilituskuud võtta vaid üks proov sordi ja säilitustemperatuuri kohta (v.a sort ’Atlantic Gigant’ millest säilitustemperatuuril 3 °C ei õnnestunud võtta ühtki proovi). Kokku analüüsiti redutseerivate suhkrute sisalduse määramiseks köögiviljades koristusjärgselt 67 proovi ja pärast köögiviljade erinevatel temperatuuridel säilitamist 111 proovi. Kogu uurimisperioodi jooksul teostati köögiviljadest 178 redutseerivate suhkrute sisalduse analüüsi.

Proovide keemiline analüüs

Redutseerivate suhkrute (fruktoos ja glükoos) analüüsid teostati Veterinaar- ja Toidulaboratooriumis ning määramiseks kasutatid vedelikkromatograafilist (HPLC Agilent 120) analüüsimeetodit. Metoodika (NMKL 148:1993) põhineb ainete erineval jaotumisel mobiilse ja statsionaarse faasi vahel vedelikkromatograafi kolonnis, mis võimaldab neid retentsiooniaegade järgi eristada. Tahketest proovidest ekstraheeriti süsivesikud sooja veega, sadestati valgud ja eraldati rasv. Proovi filtraat süstiti suhkrute kolonni (NH_2-statsionaarne faas), kus toimus segu komponentideks jaotumine. Komponendid detekteeriti murdumisnäitajadetektoriga (*RI* detektor) ja tuvastati retentsiooniaegade järgi. Komponentide identifitseerimine toimus tunnusainete põhjal, kvantitatiivne sisaldus arvutati tunnusainega koostatud kalibreerimisgraafiku alusel. Metoodika määramispiirid olid fruktoosil ja glükoosil 0,1 g 100 g^{-1}.

Statistiline analüüs

Tulemused on esitatud kujul keskmine ± standardhälve. Redutseerivate suhkrute sisalduse erinevust erinevates köögiviljades ja erinevates säilitus-gruppides (värske *vs* säilitus 3 °C-l *vs* säilitus 8 °C-l) testiti kahefaktorilise dispersioonanalüüsiga. Kahefaktorilist dispersioonanalüüsi kasutati ka võrdlemaks erinevaid sorte ja säilitus-gruppe köögiviljaliikide siseselt. Köögiviljaliikide, sortide ja säilitus-gruppide paarikaupa võrdlemiseks kasutati Tukey *post-hoc* testi. Kuna redutseerivate suhkrute sisaldus oli parempoolselt ebasümmeetrilise jaotusega, viidi statistilised testid läbi logaritmitud andmetega. Tulemused loeti statistiliselt oluliseks P ≤0,05 korral. Statistilisteks analüüsideks ja jooniste konstrueerimiseks kasutati programmi R 4.0.3 (R Core Team, 2021).

Tulemused ja arutelu

Redutseerivate suhkrute sisaldus erinevates köögiviljades

Tabelis 1 on esitatud redutseerivate suhkrute keskmine sisaldus ± standardhälve erinevates köögiviljades koristusjärgselt, pärast kahel temperatuuril säilitamist ja kokku. Dispersioonanalüüsi tulemuste alusel on redutseerivate suhkrute sisaldus nii erinevates köögiviljades kui ka koristusjärgselt ja erinevatel temperatuuridel säilitamise järgselt statistiliselt oluliselt erinev (P <0,001). Kõrgeim on redutseerivate suhkrute sisaldus kaalikas ja seda nii koristusjärgselt kui ka pärast säilitamist, järgnevad kõrvits ning omavahel statistiliselt oluliselt mitteeristuvatena peet ja kartul. Nii kaalikas kui ka kartulis ja peedis redutseerivate suhkrute sisaldus säilitamisel kasvab, seejuures 3 °C-l enam kui 8 °C-l. Kõrvitsas säilitamise järgselt kõrgemat redutseerivate suhkrute sisaldust ei ilmnenud, aga see võib olla seotud kõrvitsa lühema säilivusajaga ning säilitamisjärgsete proovide nappusega.

Tabel 1. Keskmine ± standardhälve redutseerivate suhkrute sisaldus (g 100 g^{-1}) erinevates köögiviljades koristusjärgselt (värske) ning pärast kuuekuulist (kõrvitsal neljakuulist) säilitamist temperatuuridel 3 ja 8 °C. Keskmiste arvulistele väärtustele lisatud väiketähed näitavad redutseerivate suhkrute sisalduse erinevuse statistilist olulisust värsketes ja erinevatel temperatuuridel säilitatud köögiviljades (samas reas sama väiketäheta keskmised on statistiliselt oluliselt erinevad), suurtähed näitavad köögiviljaliikide erinevuse statistilist olulisust konkreetses säilitus-grupis ja kokku (samas veerus sama suurtäheta keskmised on statistiliselt oluliselt erinevad, P <0,05, Tukey *post-hoc* test).

Table 1. *Average ± standard deviation of reducing sugar content (g 100 g^{-1}) in different vegetables after harvesting (fresh) and after six-month (pumpkin four month) storage at temperatures 3 and 8 °C. Means without common small letters in the same row and means without common capital letters in the same column are statistically significantly different (P <0.05, Tukey post-hoc test).*

Köögivili *Vegetable*	Säilitus / *Storage*			Kokku / Total
	Värske *Fresh*	8 °C	3 °C	
Kartul *Potato*	0,28 ± 0,18 a, A	1,20 ± 0,74 b, A	1,75 ± 0,78 c, A	1,09 ± 0,87 A
Peet *Beetroot*	0,42 ± 0,32 a, A	1,27 ± 0,78 b, A	2,25 ± 2,51 b, A	1,31 ± 1,67 A
Kaalikas *Turnip*	5,36 ± 1,89 a, C	7,67 ± 3,72 ab, B	11,21 ± 3,74 b, B	7,86 ± 3,92 C
Kõrvits *Pumpkin*	2,66 ± 0,67 B	2,23 ± 0,58 A	2,90 ± 0,71 A	2,61 ± 0,65 B

Redutseerivate suhkrute sisaldus erinevates sortides köögiviljaliigiti

Joonisel 1 on toodud redutseerivate suhkrute sisaldused erinevates köögiviljade sortides nii koristusjärgselt kui ka pärast säilitamist temperatuuril 3 ja 8 °C.

Kartulites (joonis 1A) leiti madalaimad keskmised redutseerivate suhkrute sisaldused nii saagikoristusjärgselt kui ka pärast kuuekuulist säilitamist kahel erineval temperatuuril kartulisordist 'Birgit'. Kõige kõrgemate redutseerivate suhkrute sisaldusega kartulisort saagikoristusjärgselt oli 'Teele', kuid säilitusjärgselt kartulisort 'Laura'. Pärast kuuekuulist säilitamist

3 °C-l oli madalamate keskmiste redutseerivate suhkrute sisaldusega sort 'Birgit', mis sisaldas redutseerivaid suhkruid 0,98 g 100 g^{-1} ning kõrgeim redutseerivate suhkrute sisaldusega kartulisort oli 'Laura', mis sisaldas redutseerivaid suhkruid 2,66 g 100 g^{-1}. Seega sisaldas kartulisort 'Laura' redutseerivaid suhkruid keskmiselt 2,7 korda rohkem kui sort 'Birgit'. Ka Hiina uuringus (Lina jt, 2019) leiti, et kõige suurem glükoosi- ja fruktoosisisalduse tõus oli 0 °C-l säilitatud mugulates. Väiksem oli glükoosi ja fruktoosi tõus 4 °C-l säilitamisel. Sordid 'Laura' ja 'Birgit' olid ka 8 °C-l säilitades madalaima ja kõrgeima suhkrusisaldusega, kuid siis sisaldas kartulisort 'Laura' redutseerivaid suhkruid 4,7 korda rohkem kui sort 'Birgit'. Sarnased tulemused saadi Kedia jt 2022. aastal teostatud uuringus, kus erinevate kartulisortide säilitamisel üle 5 °C, jäi redutseerivate suhkrute sisaldus kõikide sortide puhul kuni 300-päevase säilitamise jooksul madalamale võrreldes erinevate kartulisortide säilitamisega vähem kui 100 päeva jooksul 2–5 °C juures.

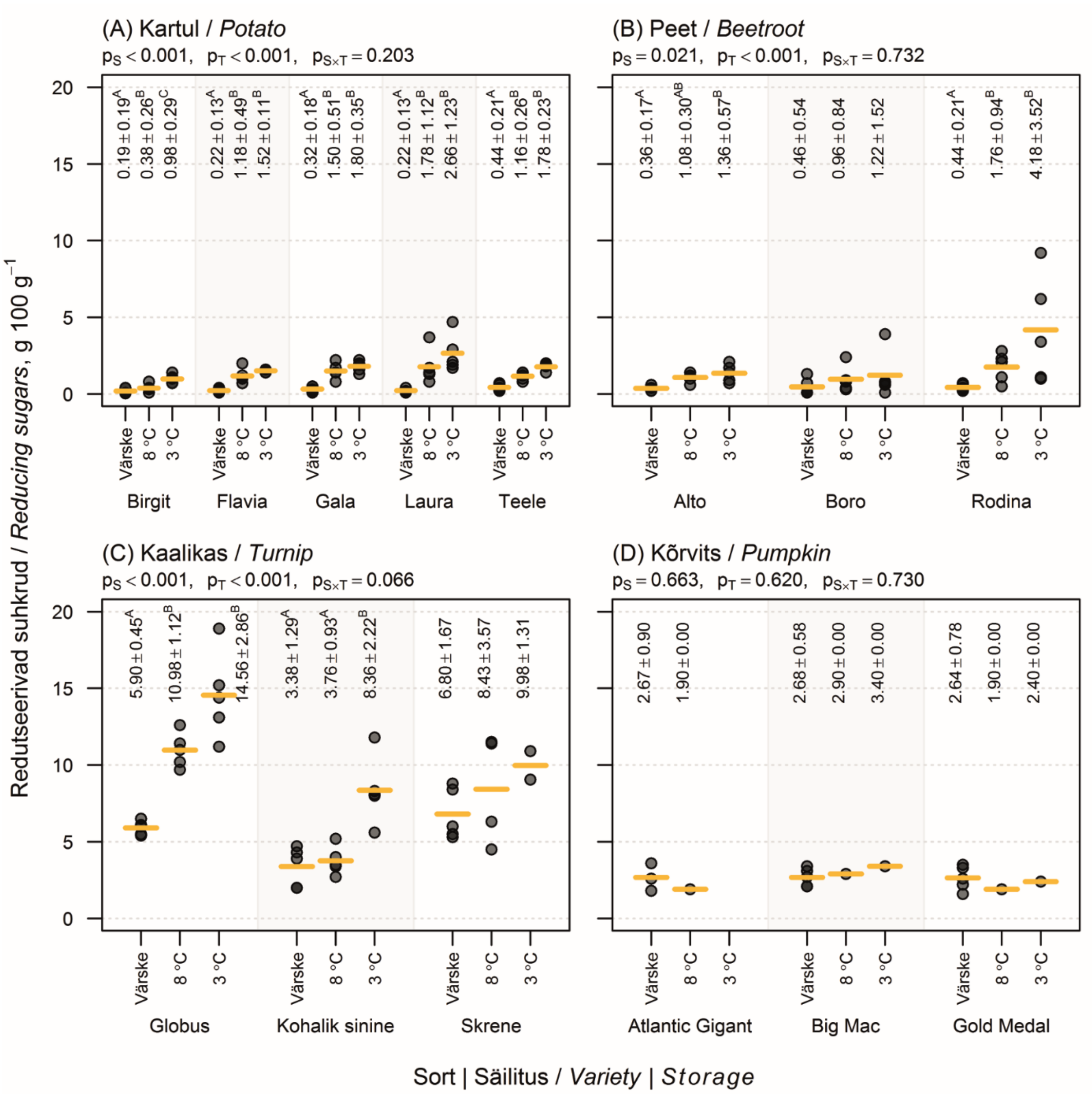
Nii nagu keskmiselt üle kõigi sortide ilmnes ka erinevate sortide analüüsist, et värsketes mugulates olid redutseerivate suhkrute sisaldused kõige madalamad ning sõltuvalt säilitustingimustest redutseerivate suhkrute sisaldus säilitamisel kasvas. Madalamal (3 °C) temperatuuril säilitades olid kõigis kartulisortides redutseerivate suhkrute sisaldused kõrgemad. Sarnaseid järeldusi on esitatud ka teaduskirjanduses, nt Martinez jt (2019) leidsid, et koristusjärgselt oli kartulites redutseerivate suhkrute sisaldus 23 mg kg^{-1} ning pärast neljakuulist säilitamist 8 °C-l oli redutseerivate suhkrute sisaldus tõusnud 34 mg kg^{-1}-ni. Vastavalt Sowokinos (2001) poolt avaldatule, põhjustab redutseerivate suhkrute tõusu kartulite säilitamise ajal toimuv külmmagustumine, mis seisneb kartuli tärklise lagunemises madalamate temperatuuride mõjul. Ameerikas läbiviidud uuringus (Sun jt, 2020) säilitati kahel erineval aastal kolme erinevat kartulisorti ('Russet Burbank', 'Dakota Russet' ja 'Easton') 7,8 °C-l 32 nädalat pärast põllult koristamist ning uuriti redutseerivate suhkrutega toimuvaid muutuseid. Tulemustest selgus, et kartulisort 'Russet Burbank', milles oli ühel aastal rohkem redutseerivaid suhkruid, sisaldas ka teisel katse teostamise aastal kõrgemal hulgal redutseerivaid suhkruid. Samuti täheldati, et madalamate redutseerivate suhkrute sisaldusega sortidel oli see sarnaselt mõlemal aastal. Samade katsete raames selgus veel, et väetamisel on mõju ka kartulite asparagiinisisaldusele – mida suurema normiga kartuleid väetati, seda enam sisaldasid need asparagiini. Sun jt, (2020) teostatud uuringus viidi läbi ka katsed toodetega, kust selgus samuti, et mida kõrgem oli toormaterjalis redutseerivate suhkrute sisaldus, seda enam sisaldasid küpsetatud tooted akrüülamiidi.

Joonisel 1B esitatud kolme enimkasvatatava punapeedi sordi redutseerivate suhkrute sisaldustest nähtub, et kõigil kolmel koristusjärgselt uuritud sordil oli redutseerivate suhkrute sisaldus sarnane, kuid madalaim oli see sordil 'Alto' ning kõrgeim sordil 'Boro'. Pärast peetide kuuekuulist säilitamist 3 °C-l sisaldas redutseerivaid suhkruid kõige rohkem sort 'Rodina' (9,5-kordne tõus võrreldes koristusjärgse sisaldusega) ja kõige vähem sort 'Boro' (2,6-kordne tõus võrreldes koristusjärgse sisaldusega). Pärast peetide säilitamist 8 °C juures sisaldas sort 'Rodina' redutseerivaid suhkruid enam kui sordid 'Alto' ja 'Boro'.

Kaalikatest (joonis 1C) oli kõige madalaimad redutseerivate suhkrute keskmised sisaldused saagikoristuse järgselt sordil 'Kohalik sinine' ning kõrgeimad keskmised sisaldused sordil 'Skrene'. Pärast kaalikate kuuekuulist säilitamist 3 °C juures sisaldas redutseerivaid suhkruid kõige rohkem sort 'Globus' ja kõige vähem sort 'Kohalik sinine'. Pärast kaalikate säilitamist 8 °C juures, sisaldas sort 'Globus' redutseerivaid suhkruid rohkem, kui sordid 'Skrene' ja 'Kohalik sinine'. Sloveenias teostatud uuringu (Jakopic jt, 2021) andmetel vähenes kaalikasordi 'Globus' kaal neljakuulisel säilitamisel külmkapis 30 ja keldris 17%. Uuringust selgus, et kuigi kaalikate mass langes mõlemal säilitusrežiimil, tuvastati intensiivsem langus pärast kolmekuulist külmkapis säilitamist. Kogu säilitamisperioodi kestel oli külmkapis säilitatud kaalikatel ühtlasem temperatuur, jäädes vahemikku 5 kuni 6 °C. Keldris oli väiksema kõikumisega temperatuuride vahemik tagatud poole säilitusperioodi kestel (vahemikus 3 kuni 7 °C), kuid seejärel tõusis temperatuur kuni 12 °C. Glükoosisisaldus tõusis külmikus säilitades koristusjärgselt 100 g kuivaines 23,6-lt 32,8 grammile ja fruktoosisisaldus 17,7-lt 18,9 grammile. Kuigi antud uuringus kaalikate kaalumist ei teostatud, oli massi vähenemine selgelt märgatav ning kaalikasordi 'Globus' redutseerivad suhkrud (glükoos ja fruktoos) tõusid kontsentratsioonilt 5,90 kuni sisalduseni 14,56 g 100 g^{-1}.

Kõrvitsatest (joonis 1D) oli saagikoristusjärgselt madalaima keskmiste redutseerivate suhkrute sisaldusega sort 'Gold Medal' ning kõrgeima sisaldusega sort 'Big Mac'. Siiski olid need vahed väga väikesed ja statistiliselt mitteolulised. Erinevalt teistest köögiviljadest ei suurenenud redutseerivate suhkrute sisaldus säilitamisel selgelt ühegi kõrvitsasordi puhul. Poolas (Biesiada jt, 2011) teostati kõrvitsatega uuringuid kolmel järjestikkusel aastal. Uuringus määrati redutseerivate suhkrute sisaldused koristusjärgselt ning pärast 90 päevast säilitamist 10 °C juures. Tulemused olid sarnased meie uuringus leitule, kus kõrvitsaid üle 8 °C juures säilitades redutseerivate suhkrute sisaldused langesid. Siiski ei saa redutseerivate suhkrute muutumise kohta kõrvitsates säilitamise käigus käesoleva uuringu põhjal selgeid järeldusi teha, sest kõrvitsad lihtsalt ei säilinud piisava arvu proovide võtmiseks.

Selgus, et madalad temperatuurid uuringusse kaasatud sortidele säilitamiseks ei sobinud, sest kõrvitsad riknesid. Sarnaseid tulemusi on esitatud ka teistes teadusartiklites (Gaskell, 1996; Biesiada jt, 2011).



Joonis 1. Redutseerivate suhkrute sisaldus erinevates (A) kartuli-, (B) peedi-, (C) kaalika- ja (D) kõrvitsasortides koristusjärgselt (värske) ja pärast kuuekuulist (kõrvitsal neljakuulist) säilitamist temperatuuridel 3 ja 8 °C. Joonistel esitatud punktid tähistavad redutseerivate suhkrute sisaldust üksikutes proovides; joonega on märgitud keskmine ja arvuliselt on esitatud keskmine ± standardhälve redutseerivate suhkrute sisaldus iga sordi ja säilitamistemperatuuri kombinatsiooni korral. Jooniste kohal toodud P-väärtused näitavad sordi (p_S), säilituse/temperatuuri (p_T) ja nende koosmõju ($p_{S \times T}$) statistilist olulisust (kahefaktoriline dispersioonanalüüs), keskmiste arvulistele väärtustele lisatud tähed näitavad säilitus-gruppide vaheliste erinevuste statistilist olulisust sama sordi korral (Tukey *post-hoc* test – ülaindeksis sama tähte mitte sisaldavad keskmised on statistiliselt oluliselt erinevad: P <0,05, tähtede puudumisel statistiliselt olulised erinevused säilitus-gruppide vahel puuduvad).

Figure 1. *Reducing sugar content in (A) potatoes, (B) beetroots, (C) turnips and (D) pumpkins at different varieties after harvest (Värske = Fresh) and after six month (pumpkin four month) storage at temperatures 3 and 8 °C. Single dots denote reducing sugar content in single samples; short horizontal lines mark average reducing sugar content and numerically are presented average ± standard deviation reducing sugar content by variety and storage combinations. P-values above the subfigures indicate statistical significance of variety (p_S), storage (p_T) and variety by storage interaction ($p_{S \times T}$) effects (two-way analysis of variance), letters added to mean values show statistical significance of between storage-groups differences by varieties (Tukey post-hoc test – mean values without common superscript letter are statistically significantly different: P <0.05, means without superscript letters are not statistically significantly different).*

Kokkuvõte ja järeldused

Antud töö eesmärgiks oli välja selgitada köögiviljade (kartulite, punapeetide, kaalikate ja kõrvitsate) sordid, mis nii koristusjärgselt kui ka kahel erineval temperatuuril (3 ja 8 °C) säilitatuna sisaldavad vähem redutseerivaid suhkruid.

Antud uuringus leiti, et erinevate köögiviljaliikide redutseerivate suhkrute sisaldused on erinevad. Samuti esinevad erinevused ühe liigi lõikes erinevatel sortidel.

Kõige madalama redutseerivate suhkrute sisaldusega sordid olid saagikoristusjärgselt ja ka pärast kuuekuulist säilitamist kahel erineval temperatuuril (3 ja

8 °C) kartulisort 'Birgit', punapeedisort 'Boro' (koristusjärgselt oli kõigil uuritud peedisortide sarnane redutseerivate suhkrute sisaldus), kaalikasort 'Kohalik sinine' ja kõrvitsasort 'Gold Medal'. Need uuritud sordid on sobilikumad kuumtöötlemiseks, seega tuleks soovitada köögiviljakasvatajatel neid tööstustele kasvatada.

Edaspidiste teadusuuringutega tuleb välja selgitada ka teiste oluliste tegurite mõju redutseerivate suhkrute sisaldusele köögiviljades, nt erinevate aastate ilmastikust tingitud erinevused ja kasvukoha mõju. Seejuures tuleb arvesse võtta, et aastatega võivad muutuda ka enimkasvatavate köögiviljade sordid erinevate köögiviljaliikide lõikes.

Tänuavaldused
Täname laboratoorsete analüüside ning seonduvate andmete eest Veterinaar- ja Toidulaboratooriumi-kolleege. Uurimustööd finantseeriti Maaeluministeeriumi rakendusuuringute projektist "Teatud köögiviljade sortide suhkrute sisalduse analüüsimine akrüülamiidi tekkimise potentsiaali hindamiseks nende töötlemisel" (T180164VLTR).
Uurimistööd on finantseerinud Eesti Teadusagentuur (PRG 1441, B220004VLVB).

Huvide konflikt / *Conflict of interest*
Autorid kinnitavad artikliga seotud huvide konflikti puudumist.
The authors declares that there is no conflict of interest regarding the publication of this paper.

Autorite panus / *Author contributions*
TE, MR, SJ – uuringu kava ja planeerimine;
SJ, TE, MR – andmete kogumine;
SJ, TK, TE, MR, KP – andmete analüüs ja interpretatsioon;
SJ, TE, MR, TK, KP, MM – käsikirja koostamine;
SJ, TE, MR, TK, KP, MM – käsikirja ülevaatamine ja heaks kiitmine.
TE, MR, SJ – study conception and design;
SJ, TE, MR – acquisition of data;
SJ, TK, TE, MR, KP – analysis and interpretation of data;
SJ, TE, MR, TK, KP, MM – drafting of manuscript;
SJ, TE, MR, TK, KP, MM – critical revision and approve the final manuscript.

Kasutatud kirjandus

Bethke, P.C., Sabba R., Bussan, A.J. 2009. Tuber water and pressure potentials decrease and sucrose contents increase in response to moderate drought and heat stress. – American Journal of Potato Research 86(6):519‒532. DOI: 10.1007/s12230-009-9109-8

Biesiada, A., Nawirska, A., Kucharska, A., Sokół-Łętowska, A. 2011. Chemical composition of pumpkin fruit depending on cultivar and storage. – Ecological Chemistry and Engineering A, 18(1):9–18

Bufler, G. 2013. Accumulation and degradation of starch in carrot roots. – Scientia Horticulturae 150: 251–258. DOI: 10.1016/j.scienta.2012.11.022

Bulgari, R., Franzoni, G., Ferrante, A. 2019. Biostimulants application in horticultural crops under abiotic stress conditions. – Agronomy, 9(6):306. DOI: 10.3390/agronomy9060306

Considine, J.A., Frankish, E. 2013. Quality assurance, teaching and research. – In A complete guide to quality in small-scale wine making (1st ed.). – Acadmic Press, pp 155–187. ISBN 978-0124080812

Gaskell, M. 1996. Pumpkin production in California. – Agriculture and Natural Resources. Publication 7222, University of California, pp. 1–4. ISBN 13:978-1-60107-850-6

Gupta, A.K., Singh, J., Kaur, N. 2001. Sink development, sucrose metabolising enzymes and carbohydrate status in turnip (*Brassica rapa* L.). – Acta Physiologiae Plantarum, 23(1):31–36. DOI: 10.1007/s11738-001-0019-8

Hou, J., Zhang, H., Liu, J., Reid, S., Liu, T., Xu, S., Tian, Z., Sonnewald, U., Song, B., Xie, C. 2017. Amylases StAmy23, StBAM1 and StBAM9 regulate cold-induced sweetening of potato tubers in distinct ways. – Journal of Experimental Botany, 68(9):2317–2331. DOI:10.1093/jxb/erx076

Jakopic, J., Veberic, R., Slatnar, A. 2021. Changes in quality parameters in rutabaga (*Brassica napus var.napobrassica*) roots during long term storage. – LWT - Food Science and Technology 147:111587. DOI: 10.1016/j.lwt.2021.111587

Johansen, T.J., Hagen, S.F., Bengtsson, G.B., Mølmann, J.A. 2016. Growth temperature affects sensory quality and contents of glucosinolates, vitamin C and sugars in swede roots (*Brassica napus L. ssp. rapifera Metzg*.). – Food Chemistry, 196:228–235. DOI: 10.1016/j.foodchem.2015.09.049

Kedia, P., Kausley, S.B., Rai, B. 2022. Development of kinetic models for prediction of reducing sugar content in potatoes using literature data on multiple potato varieties. – LWT - Food Science and Technology 155:112986. DOI: 10.1016/j.lwt.2021. 112986

Lina, Q., Xiea, Y., Guanb, W., Duana, Y., Wanga, Z., Sunc, C. 2019. Combined transcriptomic and proteomic analysis of cold stress induced sugar accumulation and heat shock proteins expression during postharvest potato tuber storage. – Food Chemistry 297:124991. DOI: 10.1016/j.foodchem. 2019.124991

Liu, X., Chen, L., Shi, W., Xu, X., Li, Z., Liu, T., He, Q., Xie, C., Nie, B., Song B. 2021. Comparative transcriptome reveals distinct starch-sugar interconversion patterns in potato genotypes contrasting for cold-induced sweetening capacity. – Food Chemistry 334:127550. DOI: 10.1016/j. foodchem.2020.127550

Martinez, E., Rodriguez, J.A., Mondragon, A.C., Lorenzo, J.M., Santos E.M. 2019. Influence of potato crisps processing parameters on acrylamide formation and bioaccesibility. – Molecules, 24(21): 3827. DOI: 10.3390/molecules24213827

Menamo, T.M. 2012 Investigating hormone regulation and sugar storage during tuber development in turnip plants (*Brassica rapa*). – MSc Thesis Report, Wageningen University, Wageningen, The Netherlands, April-December, 2012, 83 p. DOI: 10.13140/RG.2.2.33246.43849

Mottram, D.S., Wedzicha, B.L., Dodson, A.T. 2002. Acrylamide is formed in the Maillard reaction. – Nature, 419:448−449. DOI: 10.1038/419448a

Muttucumaru, N., Powers, S.J., Elmore, J.S., Dodson, A., Briddon, A., Mottram, D.S., Halford N.G. 2017. Acrylamide-forming potential of potatoes grown at different locations, and the ratio of free asparagine to reducing sugars at which free asparagine becomes a limiting factor for acrylamide formation. – Food Chemistry, 220:76−86. DOI: 10.1016/j.foodchem. 2016.09.199

NMKL 148. 1993. Fructose, glucose and saccharose. Liquid chromatographic determination in fruit and vegetable products. NordVal Interantional.

Ohara-Takada, A., Matsuura-Endo, C., Chuda, Y., Ono, H., Yada, H., Yoshida, M., Kobayashi, A., Tsuda, S., Takigawa, S., Noda, T., Yamauchi, H., Mori, M. 2005. Change in content of sugars and free amino acids in potato tubers under short-term storage at low temperature and the effect on acrylamide level after frying. − Bioscience, Biotechnology, Biochemistry, 69(7):1232–1238. DOI: 10.1271/bbb. 69.1232

Osakabe, Y., Osakabe, K., Shinozaki, K., Lam-Son, T. 2014. Response of plants to water stress. − Frontiers In Plant Science, 5(86):1–8. DOI: 10.3389/fpls. 2014.00086

R Core Team. 2021. R: A language and environment for statistical computing. – R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/. Accessed on 05.02.2022

Sun, N., Wang, Y., Gupta, S.K., Rosen C.L. 2020. Potato tuber chemical properties in storage as affected by cultivar and nitrogen rate: Implications for acrylamide formation. – Foods, 9(3):352. DOI: 10.3390/foods9030352

Shinohara, Y., Suzuki, Y. 1981 Effects of light and nutritional conditions on the ascorbic acid content of lettuce. – Journal of the Japanese Society for Horticultural Science. 50(2):239−346. DOI: 10.2503/ jjshs.50.239

Sowokinos, J. 2001. Biochemical and molecular control of cold-induced sweetening in potatoes. – American Journal of Potato Research. 78:221–236. DOI: 10.1007/BF02883548

Van der Vyver, C., Peters, S. 2017. How do plants deal with dry Days? – Frontiers for Young Minds, 5:58. DOI:10.3389/frym.2017.00058

Xiao, G., Huang, W., Cao, H., Tu, W., Wang, H., Zheng, X., Liu, J., Song, B., Xie, C. 2018. Genetic loci conferring reducing sugar accumulation and conversion of cold-stored potato tubers revealed by QTL analysis in a diploid population. – Frontiers in Plant Science, 9:315. DOI: 10.3389/fpls.2018.00315

Content of reducing sugars in mostly grown vegetables in Estonia after harvesting and after storage

Sirje Jalakas[1], Mati Roasto[1], Tanel Kaart[2], Kristi Praakle[1], Mihkel Mäesaar[1], Terje Elias[1]
[1]Estonian University of Life Sciences Maaülikool, Institute of Veterinary Medicine and Animal Sciences, Chair of Veterinary Biomedicine and Food Hygiene, Tartu
[2]Estonian University of Life Sciences Maaülikool, Institute of Veterinary Medicine and Animal Sciences, Animal Breeding and Biotechnology, Tartu

Summary

This study aimed to determine the content of reducing sugars of different vegetable species and varieties, both after harvest and stored at two different temperatures (3°C and 8°C) in Estonia. In the vegetable processing process, it is important to know the content of reducing sugars when preparing heat-treated products, because carcinogenic acrylamides can be formed during the heat treatment. A study of potatoes, beetroots, turnips and pumpkins was carried out to use vegetable varieties with a potentially lower acrylamide predisposition to heat treatment. Different vegetable species have different levels of reducing sugars. There are also differences between different varieties of the same vegetable species. The study covered the various most commonly grown potato, beetroot, turnip and pumpkin varieties in Estonia. The potato variety with the lowest content of reducing sugars after harvest and after six months of storage at two different temperatures (3°C and 8°C) was potato variety 'Birgit'. The potato variety with the highest content of reducing sugars after harvest was 'Teele', but after storage the potato variety 'Laura'. Of the beetroots, all three post-harvest varieties ('Alto', 'Rodina', 'Boro') had similar reducing sugars contents. After six months of storage (3 and 8°C), the beetroot variety 'Rodina' had the highest content of reducing sugars and the lowest content was determined for variety 'Boro'. The lowest average concentrations of reducing sugars from turnips were after harvest determined in the variety 'Kohalik sinine' and the highest average contents in the variety 'Skrene'. After storage of the turnips for six months at 3°C, the variety 'Globus' had the highest content of reducing sugars and the variety 'Kohalik sinine' had the lowest. From the pumpkins after harvest, the variety 'Gold Medal' had the lowest average reducing sugars content and the variety 'Big Mac' had the highest. Finally, it can be summarized that all studied vegetables stored at 3 °C contained higher amounts of reducing sugars than those stored at 8 °C.

Agraarteadus
1 • XXXIII • 2022 95–100

Journal of Agricultural Science
1 • XXXIII • 2022 95–100

EARTHWORMS (*Oligochaeta: Lumbricidae*) AND HEAVY METALS: CONTENT AND BIOACCUMULATION IN THE BODY

Mzia Kokhia, Manana Lortkipanidze, Oleg Gorgadze, Madona Kuchava, David Nebieridze

Institute of Zoology, Ilia State University, 3/5 K. Cholokashvili Ave, 0162, Tbilisi, Georgia

Saabunud: Received: 04.02.2022

Aktsepteeritud: Accepted: 01.05.2022

Avaldatudveebis: Published online: 01.06.2022

Vastutavautor: Corresponding author: Mzia Kokhia

E-mail: mzia.kokhia@iliauni.edu.ge

ORCID:
0000-0002-9654-7670 (MKo)
0000-0002-7075-5340 (ML)
0000-0002-5963-1777 (OG)
0000-0003-1295-1957 (MKu)
0000-0001-7768-9414 (DN)

Keywords: earthworms, heavy metals, copper, zinc, lead, *Aporrectodea rosea*, *Eisenia veneta*, *Allolobophora chlorotica*.

DOI: 10.15159/jas.22.20

ABSTRACT. Nowadays, when one of the most significant problems for mankind is saving the soil from pollution. It is well-known that one of the most important means of soil rehabilitation and remediation are soil inhabitants, their biodiversity and products of their life activity. Given the significant role of soil inhabitants in soil formation processes, it is important to consider their role in the processes of reprocessing and bioaccumulation of heavy metals. That especially concerns the earthworms, whose role in soil formation and maintenance of natural fertility is well-known and causes the interest of soil scientists and ecologists. The paper shows the degree of bioaccumulation of heavy metals (copper, zinc and lead) in the body of earthworms. Study involved three species of earthworms, which were collected in the vicinity of Tbilisi – *Aporrectodea rosea* (Savigny, 1826), *Eisenia veneta* (Rosa, 1886) and *Allolobophora chlorotica* (Savigny, 1826) – showed that earthworms of different species accumulate different amounts of heavy metals – copper, zinc and lead and, depending on the species, after being placed in heavy metals solutions, they demonstrate the different intensity of movement. The amount of heavy metals in the body of an earthworm depends on the structure of the body tissues and maybe on the structure of the skin-muscular sac.

Introduction

Soil is a layer of terrestrial biogeocenoses, where the transformation, decomposition, mineralization and humification of organic matter take place. In terrestrial ecosystems, there is no layer comparable to the soil, which would correspond to such a large number of ecological requirements of various groups of animals. Soil is one of the most valuable natural resources used by man for food production. The role of earthworms in soil formation and maintenance of natural soil fertility is well-known and interesting for soil scientists and ecologists. The knowledge gained to study earthworms is actively used in carrying out activities for environmental protection, in the development of programs for the restoration of natural ecosystems. The paper deals with the problem of soil and heavy metals, which are toxic, even at low concentrations and unlike organic compounds cannot be biodegraded into less harmful materials (Mudhoo, Mohee, 2011).

Nowadays in the presence of climate change, land degradation and biodiversity loss, soils have become one of the most vulnerable resources in the world. Notwithstanding the enormous scientific progress made to date, protection and monitoring of soil resources at national and global levels still face complicated challenges impeding effective on-the-ground policy design and implementation that varies widely from region to region. There is still insufficient global support for the protection and sustainable management of the world's soil resources.

Our society still is not sufficiently aware of the excessive danger of agriculture chemicalization. Currently, the dearth of healthy soil is a major problem resulting from enormous waste generation. Uncontaminated soil is vital for the survival of living things.

Caring for high productivity is primarily associated with the improvement of the biosphere. The continuous use of chemical fertilizers leads to a decrease in soil organic matter (SOM) combined with a deterioration in the quality of agricultural soils reducing their fertility (increases soil erosion and reduces humus formation). (Pahalvi *et al*., 2021).

Soil loss problem is one major issue, as soil formation is very long (thousands of years are needed to form only a few centimetres of soil depth) and 24 billion tonnes of topsoil are lost every year (Guterres, 2019). Soil erosion is a major global soil degradation threat to land, freshwater, and oceans (FAO, 2015; Borrelli *et al*., 2020). The consequences for farmers and communities are too important: loss of fertility, landslide, sediments accumulation in rivers, depletion of deepwater reservoirs and water pollution.

Soil-forming rocks are one of the main sources of chemical elements, which, due to the vital activity of earthworms, turn into vermicomposts – peat-like, dark and homogeneous mixtures (Gupta *et al.,* 2014; Babita, Thakur, 2015). At the same time, earthworms processing manure in both liquid and solid form produce vermicompost, which is an excellent fertilizer. Plant cells contain about 40 chemical elements – almost all found in the soil, but for normal growth and fruiting plants need only 16 of them (Semhi *et al*., 2009). These are the elements absorbed by plants from air and water – oxygen, carbon and hydrogen, and elements absorbed from the soil, among which macro elements are distinguished – nitrogen, phosphorus, potassium, calcium, magnesium, sulphur and heavy metals – molybdenum, copper, zinc, manganese, iron, boron and cobalt.

Based on the foregoing, each research conducted to study the problems of soil improvement and rehabilitation is very important and not only for Georgia. The importance of this problem has forced us to provide the study with the role of earthworms and vermitechnologies generally concerning soil remediation. In this case, in the process of vermicomposting, there were included the earthworms of the following species: *Eisenia andrei* (Bouche, 1972), *E. lagodechiensis* (Michaelsen, 1910) and *E.veneta* (Rosa, 1886).

Previous research (Striganova, 1980; Kokhia, 2011; 2021) has shown the importance of soil dwellers and their livelihoods for improving and maintaining soil quality and fertility. It is well known that in this case, earthworms play an important role in the soil formation process. Due to the high rate of food intake and motor activity, worms modify their habitat by changing the kinetics of various soil processes that directly or indirectly affect the growth of fertility (Bityutskiy, Kaidun, 2008). At the same time, the earthworms are an excellent indicator of soil conditions given their many important roles and sensitivity to problems such as low pH, compaction, waterlogging and intensive cultivation.

An important group of indicators that are the result of human influence on ecosystems and determine the ecological condition of the soil include soil erosion, fertilizer doses, soil profile, ploughed up areas, quality and quantity of organic and mineral compounds earthworms.

The results of numerous scientific studies (Edwards *et al*., 2010; Dai *et al*., 2004) showed a close correlation between the content of humus in various types of soil and the magnitude of the yields obtained, all other conditions being equal, and the crop technology (Maksimova, 2011). An indicator of the humus level reduction in the soils is one of the most important diagnostic features for the classification of soils with varying degrees of erosion. In this case, we tried to show that the soil invertebrates with their life activity have a significant role in the soil making process. The main objective of the research was to study the role of earthworms, as one of the main representatives of soil fauna, in soil enrichment and bioremediation. Taking into account the importance of their life activity and their role in the processing of all constituent elements of the soil, we tried to determine and evaluate their role in the processing of heavy metals.

Materials and Methods

Given the importance of the earthworms' vital activity in soil formation processes, we conducted a series of experiments to determine the rate of accumulation of some micronutrients.

Previous studies (Edwards *et al.,* 2010) have shown that the composition of vermicompost is represented by the following constituent elements (Maksimova, 2011) (Table 1).

Table 1. Vermicompost chemical composition

Elements	Amount, %
Humidity	65–70
Ash content	10–15
Humus	22–26
Total nitrogen	2.3–2.6
Total phosphorus	2.0–2.2
Total potassium	1.9–2.1
Ca	0.6–0.7
Mg	0.10–0.12
Cu	0.0011–0.0013
Zn	0.016–0.017
C/N	10–12

Analyzes to determine the chemical composition of vermicompost were carried out at the Laboratory of Vermitechnology of Scientific and Practical Center of the National Academy of Science of Belarus for Bioresources.

Using three species of earthworms – *Aporrectodea rosea* (Savigny, 1826), *Eisenia veneta* (Rosa, 1886) and *Allolobophora chlorotica* (Savigny, 1826), with the atomic-absorption spectrometry method, the content of heavy metals (Cu, Zn, Pb) were determined and compared in different species of earthworms. The material was collected near Tbilisi (41°43´00.07´´N; 44°49´30.07´´E) and 30 samples were analyzed.

A series of experiments were carried out. Acids of H_2SO_4, HNO_3, and HCl (Chemapol, Prague, Czech) were used in the experiments. Microelements were determined on an atomic-absorption spectrophotometer Opton FMD3 (Germany). The earthworms of the same species were placed in a solution with different concentrations of lead, zinc and copper (2000, 1500 and 50 µg). Distilled water was used as a control. Samples were processed in the following way: a mixture of 1.5 ml of concentrated HNO_3 and 6 ml of concentrated HCl was filled with worms dried to constant weight at a temperature of 105 °C and placed in Kjeldahl flasks (50 ml). After an hour, the flasks were carefully heated on closed electric stoves, avoiding the charring of the mixture, in the case of charring a few drops of HNO_3 were added to it (Reznichenko, 2016; Baibotaeva *et al*., 2019).

It should be noted that during the experiment we also observed the movement of worms, depending on their sizes and concentration of solutions.

By dry ashing, the samples were brought to full discolouration and then cooled. After cooling, several ml of water was added. All contents were mixed and filtered through an ashless filter Whatman paper (Germany) into volumetric flasks, and then the concentration of heavy metals was measured using a calibration curve (Korostelev, 1988).

Statistical analysis carried out by the method of linear regression and analysis of variance in R showed that there are no statistically significant differences between earthworms' species in terms of the content of trace elements in them, however, it should be noted that the intensity of movement of earthworm species differed depending on the concentration of heavy metals in solution. R version 4.2.0 (R Core Team, 2022) and the *multicompView* package (Graves *et al.*, 2019) were used to conduct the statistical analyses.

Results and Discussion

Earthworms of different species accumulate different amounts of copper, lead and zinc from solutions with different concentrations of these elements. The analysis of the data shows that the loss amount of lead and copper during the experiment depends on the species of earthworms and the duration of their storage in solutions with heavy metals. At the same time, the zinc loss for all three species of earthworms being placed in water is 40%, despite the solution concentration. The heavy metals distribution in the soil is important for the bioaccumulation by earthworms, as the main pathways for chemical absorption are the skin for soluble elements, gut transit and digestion (Weltje, 1998). There is a factor in the connection of heavy metals with tissues and the density of the skin-muscular sac.

The choice of these heavy metals for the experiments was due to their great importance for soil and soil fauna. The soil contains various copper compounds with specific chemical composition, solubility and accessibility to organisms. Copper is actively involved in the processes of tissue respiration and is a part of the enzyme ceruloplasmin (copper oxidase), which catalyzes the oxidation of vitamin C (Reznichenko, 2016; Baibotaeva *et al*., 2019).

No less important is zinc, an essential heavy metal for all living organisms. The content of gross zinc in the soil depends on the conditions of soil formation (Reznichenko, 2016; Baibotaeva *et al*., 2019).

Lead was not chosen as a vital element, unlike zinc, which is part of 45 enzymes and plays a huge role in changing their properties (Bityutsky, Kaidun, 2008). It was chosen as a toxic heavy metal, the amount of which has increased significantly in soils as a result of the development of industry, transport and chemicalization of agriculture. This factor is obvious and caused the unequal content, absorption and subsequent retention of heavy metals – copper, zinc and lead. There are various compounds of copper in the soil, specific for their chemical composition, solubility and accessibility to organisms. Have to be noted that some heavy metal ions are very important micronutrients for plant and human metabolism and are natural substances found usually at low levels, in soils (Gamalero, *et al*., 2009; Lokhande, *et al.*, 2010).

The conducted determinations showed that heavy metals in the bodies of three species of earthworms' *A. chlorotica*, *E. veneta* and *A. rosea* are contained in the following amounts (Fig. 1). As above mentioned the statistical analysis no statistically significant differences between earthworms' species.

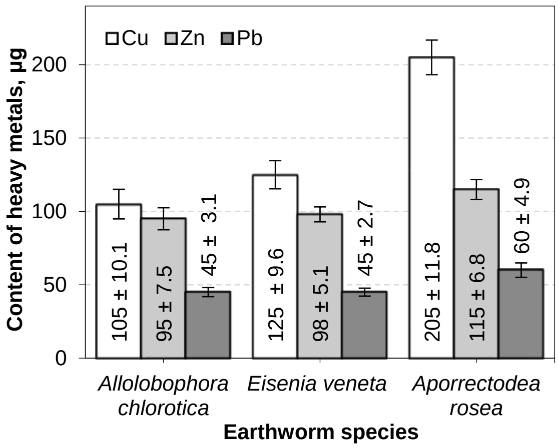


Figure 1. The content of heavy metals in the sample

Accumulation of heavy metals in the body of the earthworm and their retention

It should be mentioned, that earthworms are one of the most important indicators of soil health, and there have been many studies performed on the response to heavy metals of the earthworms and their role during their processing (Dai *et al*., 2004; Nahmani *et al*., 2007; Azizi *et al*., 2013; Panasin *et al*., 2015). The experiments have shown that in solutions containing lead ions, the mobility of worms initially increases, but after an hour the worms of the species *A. chlorotica* stop moving. *E. veneta* worms continue to move vigorously for 5–6 hours, and then stop moving from the very beginning in a solution with a concentration of 2000 µg, and then in more dilute solutions. The lead solution with a concentration of 2000 µg A. *rosea* worms continued intensive movement within 12 hours, and then stop moving.

As above mentioned, the statistical analysis did not show statistically significant differences between earthworms' species.

In solutions with zinc, all three species of earthworms' mobility continued for two days, while its intensity decreased with increasing concentration. Similarly, worms behave in solutions containing copper.

The comparisons showed that the mobility of the representatives of the species *A.rosea* is significantly higher than the mobility of *E.veneta*, or in particular, the species of the worms *A. chlorotica*, which can be explained by the different levels of skin-muscular sac development in different species of worms.

Interestingly, the absorption of zinc depends obviously on the size of the worm. We used worms of *A. rosea* species of different lengths. It turned out that a 4 cm worm absorbs 250 µg of zinc from a solution concentration of 2000 µg and a 9 cm worm size absorbs an amount of 800 µg.

Retention of heavy metals by the body of earthworms

The worms that absorbed ions of heavy metals were kept in clear water for 15 minutes and then checked the number of heavy metals that had passed into the water. It turned out that different species of earthworms accumulate and contain different amounts of heavy metals (Fig. 1). This effect is of great importance for soils since the water rinses heavy metals in different quant–ities, and, as a result, their migration occurs in the soil.

In addition, when taking earthworms or the soil itself for analysis, it is necessary to consider the factor of rain and watering. To achieve the effectiveness of the soil rehabilitation adding extra vermiculture should be added and seed new plants possessing special biological properties. The improvement of the grass grounds productivity is due to active organic fertilizers concentrated on the soil's surface (humus) and collecting the chemical energy caused by this process. Acceleration of humus amount addition will be possible by introducing vermiculture. We should emphasize that vermiculture should be specially chosen as "Regional vermiculture", a fluctuation of worms' number depending on the characteristics of the soil quality.

The development of vermiculture allows the growing of different types of invertebrates and soil microorganisms. It is well known that biodegradation of organic microorganisms promotes soil deactivation *in*- and *ex-situ*. The number of invertebrates is limited by soil qualities.

Ploughing-up, moistening, cultivation, vegetable cover and the presence of organic fertilizers – the earthworms, will help to secure the effect of soil fertility. Some factors require specific studies so that researchers can better understand the metabolism involved in the process (Singh, Singh, 2018). Vermicomposting protects the environment and augments crop productivity, which is why it is very interesting to study the vermicomposting process. The humus helps the soil to keep feeding elements in an available plant form. The existence of appropriate vegetation cover is necessary for the growth of vermiculture.

It is not excluded that several items from the proposed recommendations might be the theme of our further research.

All this indicates the importance of soil humus content. Thus, the enrichment of soil with organic matter is one of the important means of saving the soil from erosion.

Composting is defined as a bio-oxidative process leading to organic matter mineralization and transformation (Zucconi, de Bertoldi, 1987).

Conclusion

At last, we conclude that one of the most important ways to counteract soil erosion is the protection of soil macrofauna and its biodiversity.

The experimental results showed that the earthworms of different species – *Aporrectodea rosea*, *Eisenia veneta* and *Allolobophora chlorotica* – contain different amounts of heavy metals and, when placed in solutions, exhibit the different intensity of movement depending on the type of worms and the concentration of the solution.

The amount of heavy metals (lead, zinc, copper) in the body of worms depends on the structure of their tissue and maybe on the skin-muscular sac structure too.

Earthworms of various species from solutions with different concentrations absorb different amounts of heavy metals and this absorption is dependent on its size. Earthworms of various species, when placed in water, lose the different amounts of accumulated heavy metals, which is of great importance in the migration of heavy metals in the soil.

Acknowledgements

The paper was executed in the framework of the Project "Fauna of Georgia – Current Trends and Conservations". The authors have appreciated their colleagues at the Institute of Zoology for their support in providing this study.

The authors would like to say thanks to Dr Svetlana Maksimova from the Scientific and Practical Center of the National Academy of Sciences of Belarus for Bioresources for her support in providing this study.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethical statement

The authors confirm that all experiments were performed in accordance with relevant guidelines and regulations.

Author contributions

DN, MKo – study conception and design;
OG – acquisition of data;
ML, MKo – analysis and interpretation of data;
MKo, MKu– drafting of the manuscript;
MKo – critical revision and approval of the final manuscript.

References

Azizi, A.B., Lim, M.P.M., Noor, Z.M., Noorlidah, A. 2013. Vermiremoval of heavy metal in sewage sludge by utilizing *Lumbricus rubellus*. – Ecotoxicology and Environmental Safety, 90:13–20. DOI: 10.1016/j.ecoenv.2012.12.006

Babita, A.N., Thakur, M. 2015. Organic farming: A holistic approach towards sustainable fruit production. European Journal of Pharmaceutical and Medical Research. 2(6):108–115.

Baibotaeva, A., Kenzhaliyeva, G., Bosak, V. 2019. Tyazhelye metally v pochvakh urbanizirovannykh territorij. Heavy metals in soils of urbanized territories]. – Vestnik BGSHA: Nauchno-Metodicheskij Zhurnal Belorusskoj Gosudarstvennoj sel'skohozjajstvennoj Akademii [Bulletin BGSHA: Scientific and Methodological Journal of the Belarusian State Agricultural Academy], 4:126–130. [In Russian].

Bityutskiy, N.P., Kaidun, P.I. 2008. Vliyanie dozhdevykh chervej na podvizhnost` mikroelementov v pochve i ikh dostupnost` rasteniyam [Influence of earthworms on the mobility of heavy metals in the soil and their availability to plants]. – Pochvovedenie [Soil Science], 12:1479–1486. [In Russian].

Borrelli, P., Robinson, D.A., Panagos, P., Lugato, E., Yang, J.E., Alewell, C., Wuepper, D., Montanarella, L., Ballabio, C.2020. Land use and climate change impacts on global soil erosion by water (2015-2070). – Proceedings of the National Academy of Sciences. (PNAS), 117(36): 21994–22001. DOI: 10.1073/pnas. 2001403117

Dai, J., Becquerb, T., Rouillerc, J.H., Reversata, G., Bernhard-Reversata, F., Nahmania, J., Lavelle, P. 2004. Heavy metal accumulation by two earthworm species and its relationship to total and DTPA-extractable metals in soils. – Soil Biology & Biochemistry 36:91–98. DOI: 10.1016/j.soilbio. 2003.09.001

Edwards, C.A., Arancon, N.Q., Sherman, R.L. (Eds.). 2010. Vermiculture technology: Earthworms, organic wastes, and environmental management (1st ed.). – CRC Press, 624 p. DOI: 10.1201/b10453

FAO. 2015. Healthy soils are the basis for healthy food production. – Food and Agriculture Organization of the United Nations, Rome, Italy, 4 p. – https://www.fao.org/documents/card/en/c/645883cd-ba28-4b16-a7b8-34babbb3c505/ Accessed on 30/02/2022

Gamalero, E., Lingua, G., Berta, G., Glick, B.R. 2009. Beneficial role of plant growth promoting bacteria and arbuscularmycorrhizal fungi on plant responses to heavy metal stress. – Canadian Journal of Microbiology, 55:501–514.

Graves, S, Piepho, H, Dorai-Raj, LSwhfS. 2019. _multcompView: Visualizations of Paired Comparisons_. R package version 0.1-8, https://CRAN.R-project.org/package=multcompView

Guterres, A. 2019. 24 billion tons of fertile land lost every year, warns UN chief on World Day to Combat Desertification. – UN News, United Nations https://news.un.org/en/story/2019/06/1040561 Accessed on 30/02/2022

Gupta, R., Yadav, A., Garg, V.K., 2014. Influence of vermicompost application in potting media on growth and flowering of marigold crop. –International Journal of Recycling of Organic Waste in Agriculture, 3(1):47. DOI: 10.1007/s40093-014-0047-1

Kokhia, M. 2011. Sakartvelos maghalmtiani sadzovrebi da mati reabilitatsia: sakartvelos maghalmtiani sadzovrebis makroedaphoni, struktura, kveba, monitoringi (aghmosavlet sakartvelo). [Georgian high mountain pastures biodiversity: Macroedaphone, structure, feeding activity and monitoring]. – Contour, Tbilisi, Georgia, 110 p. [In Georgian]

Kokhia, M., Lortkipanidze, M., Gorgadze, O., Kuchava, M., Nebieridze, D. 2021. Soils of Georgia highlands and their biodiversity – In Proceedings of Global Symposium on Soil Biodiversity “Keep soil alive, protect soil biodiversity”. Rome, Italy. 19–22 April, 2021. Food and Agriculture Organization of the United Nations, pp. 35–40. DOI: 10.4060/cb7374en

Korostelev, P.P. 1988. Khimicheskiy analiz v metallurgii. [Chemical analysis in metallurgy]. – Uchebnoe posobiye dlya SPTU. - 2-ye izdaniye pererab i dop. [Textbook for SPTU. - 2nd edition revised and add.], 384 p. [In Russian]

Lokhande, R.S., Singare, P.U., Andhale, M.L., Acharya, A., Nair, A.G.C., Reddy, A.V.R. 2010. Determination of macro, micro nutrient and trace element concentrations in Indian medicinal plants using instrumental neutron activation analysis and atomic absorption spectroscopy techniques. – International Journal of Food Safety, Nutrition and Public Health, 3:33–44.

Maksimova, S. 2011. Progress in vermicomposting in Belarus, Russia and Ukraine. – Vermiculture Technology. CRC Press. pp. 565–579. DOI: 10.1201/b10453

Mudhoo, A., Mohee, R. 2011. Fate of heavy metals exposed to composting environments and composts. – Dynamic Soil, Dynamic Plant; 5 (Special Issue 2). – In book: Global Science Books, pp. 25–35.

Nahmani, J., Hodson, M.E., Black, S. 2007. A review of studies performed to assess metal uptake by earthworms. – Environmental Pollution, 145:402–424. DOI: 10.1016/j.envpol.2006.04.009

Pahalvi, H.N., Majeed, L.R., Rashid, S., Bisma, N., Kamili, A.N. 2021. Chemical fertilizers and their impact on soil health. – Microbiota and Biofertilizers, 2:1–20. DOI: 10.1007/978-3-030-61010-4_1

Panasin, V.I., Shatokhin, A.Yu., Rymarenko, D.A. 2015. Tsink v pochvah selskohozyaystvennyh ugodiy kaliningradskoy oblasti [Zinc in agricultural soils of Kaliningrad region]. – Agrohimicheskij vestnik [Agrochemical Bulletin], 5:45–48. [In Russian].

R Core Team, 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

Reznichenko, I.S. 2016. Akkumulyacziya tyazhelykh metallov pochvenno-podstilochnym tipom dozhdevykh chervej na primere Perelia diplotetratheca (Perel, 1967) v usloviyakh zagryazneniya tochechnym istochnikom emissii [Accumulation of heavy metals soil-litter type of earthworms on example Perelia diplotetratheca (Perel, 1967) in conditions a polluted point source emission]. – Sovremennye problemy nauki i obrazovanija [Modern Problems of Science and Education], 6:1–8. [In Russian].

Semhi, K., Abdalla, O. A. E., Khirbash, S. Al, Khan, T., Asaidi, S., Farooq, S. 2009. Mobility of rare earth elements in the system soils–plants–groundwaters: a case study of an arid area (Oman). – Arabian Journal of Geosciences, 2(2(sad):143–150. DOI: 10.1007/s12517-008-0024-y

Singh, A., Singh, G.Sh. 2018. Vermicomposting: A sustainable tool for environmental equilibria. – Environmental Quality Management. 27:23–40; DOI: 10.1002/tqem.21509

Striganova, B.R. 1980. Pitanie pochvennykh saprofagov [Feeding of soil saprophages] – Nauka, Moscow, Russia, 248 p. [In Russian]

Zucconi, F., de Bertoldi, M.D. 1987. Organic waste stabilization throughout composting and its compatibility with agricultural uses. – In Global bioconversion.Wise D.L. (ed). – CRC, Boca Raton, USA, pp. 109–137.

Weltje, L., 1998. Mixture toxicity and tissue interactions of Cd, Cu, Pb and Zn in earthworms (Oligochaeta) in laboratory and field soils: a critical evaluation of data. – Chemosphere 36:2643–2660.

Agraarteadus
1 • XXXIII • 2022 101–117

Journal of Agricultural Science
1 • XXXIII • 2022 101–117

TEHISMULLAD EESTI MULDADE KLASSIFIKATSIOONIS: NOMENKLATUUR, RAJAMINE JA ERINEVUSED-SARNASUSED NORMAALSELT ARENENUD MULDADEGA

TECHNOSOLS IN ESTONIAN SOIL CLASSIFICATION: NOMENCLATURE, ESTABLISHMENT AND DIFFERENCES-SIMILARITIES WITH NORMALLY DEVELOPED SOILS

Raimo Kõlli, Enn Leedu

Eesti Maaülikool, põllumajandus ja keskkonnainstituut, mullateaduse õppetool, Fr. R. Kreutzwaldi 5, 51006 Tartu

Saabunud: Received: 22.05.2022

Aktsepteeritud: Accepted: 07.06.2022

Avaldatud veebis: Published online: 07.06.2022

Vastutav autor: Corresponding author: Raimo Kõlli

E-mail: raimo.kolli@emu.ee

ORCID: 0000-0002-7725-3757

Keywords: technogenic soil or technosol, bare ground or non-soil, humus cover, subsoil, parent material, establishment, productivity.

DOI: 10.15159/jas.22.22

ABSTRACT. Technogenic soils (TS) or Technosols are year 2022 soils of Estonia. In Estonian Soil Classification (ESC) totally 17 technogenic soil species is listed (Table 1). By way or mode of their forming or establishing almost four TS groups (formed on heaps of wastes, instead of removed soil cover, on mixed soil horizons with parent materials and buried soil covers) have been separated. In dominating cases by technological elaborating works much more than only humus cover are enfold. In the vertical profile of different development stages TS the humus cover, consisting from fine earth subsoil and parent material may be presented (or occur). In the work separately the formed on mineral and organic (mostly peats) origin parent material TS are treated. Among mineral TS by their moisture conditions the automorphic, moist and wet soils are distinguished. Among peaty TS the formed on fen (sapric) and bog (fibric) peats soils are prevailed. The main difference between grounds (non-soil) and TS is their functioning. The real TS is as sustainably functioning assemblage of soil and plant covers or soil-plant system. The concordance or matching of presented in ESC TS' taxa with World Reference Bases for Soil Resources (WRB) and Polish Soil Classification taxa was elucidated by comparable analysis. The distribution and forming of soils associations with normally developed soils and non-soils (grounds) is characterised by mean of excerpts from digitalized large-scale soil map (1:10,000) and schematic distribution maps. In the work as well the peculiarities of establishing technologies of mineral and peaty TS is treated.

Sissejuhatus

Eesti aasta 2022 muld on tehismuld, mida leidub inimese tehisliku tegevuse kaasabil moodustatud mullkatete koosseisus. Üksnes huumuskatte piires muudetud muldasid ei peeta tehismuldadeks. Tehismuldkatte vertikaalses läbilõikes eristuvad huumuskate (pealismuld, epipedon), alusmuld (sisseuhte- või välja-sisseuhte horisontide kompleksid) ja lähtematerjal, mis võivad olla alg või erinevates arenguastmetes ja erineva tüsedusega (joonis 1). Kui mineraalsete tehismuldade huumuskate on moodustatud paljudel juhtudel mujalt teisaldatud materjalist (ennekõike huumusmullast või hästilagunenud madalsoo turbast), siis alusmuld on moodustunud ja lasub erinevate tehnoloogiliste võtetega ümbertöötatud looduslikel materjalidel, tehnoloogilise päritoluga jäätmetel või hoopiski paljandpinnastel. Ühesugusest materjalist moodustunud pealis ja alusmullaga tehismullad on iseloomulikud jääkturba lademetele loodud tehisturvasmuldadele. Sarnaselt kõigi teiste muldadega tuleks tehismuldkateteks lugeda vaid neid alasid, kus on moodustunud kestlikult talitlev muld-taim süsteem. Selles süsteemis loob muld sobivad kasvutingimused taimkattele. Taimkate produtseerides päikeseenergia abil õhust võetud CO_2 ning mullast võetud toiteelementide ja vee osavõtul muldade eluskomponentide talitlemiseks vajaliku aastaid kestva mulda juurde tuleva orgaanilise aine.

Sarnaselt mõistete "pinnas" ja "muld" eristamisega normaalsete muldade puhul, on vajalik ka tehismuldade puhul eristada mõisteid "tehispinnas" ja "tehismuld". Tehispinnased ehk "mittemullad" on kas tehnoloogiliselt (s.o pinnakatte ümberpaigutamise töödega) mõjutatud looduslike materjalide puistangud ja paljandid või tehnoloogiliste protsesside tagajärjel saadud jäätmete, olmeprügi jms materjali lademed. Tehismuldkatted on, sarnaselt normaalselt talitlevate muldadega, kestvalt talitlevad taim-muld süsteemid. Teisiti öeldes tähendab see seda, et elustikuta või elustiku poolest vaene tehispinnas on rikastunud mullaelustikuga ning talitleb sarnaselt normaalselt arenenud muldkatetega.

Joonis 1. Metsastuv tehismaastik Aidu ammendatud karjääri alal. Foto: T. Kõlli.
Figure 1*. Forested technogenic landscape on exhausted open-cast mine area of Aidu. Photo: T. Kõlli.*

Mõneti segadust tekitav on ka mõistete "tehislik muld" ja "tehislik muldkate" kasutamine, kuna igapäevases praktikas kasutatakse neid ka kui sünonüüme. Teaduspõhiselt võttes, on aga nii muldade klassifikatsioonides, kui ka ühe või teise mullaliigi leviku ja kasutamise seletamisel sisuliselt tegemist ikkagi teatud levikupindala omavate tehismuldkatetega. Mistahes erinevatest mullaliikidest koosnevale muldkattele on omane süsteemikindel talitlemine, liigile omane vertikaalse profiili ülesehitus ja levikukontuuride piiritlemise võimalus, nii looduses kui mullastiku kaartidel. Mõistet muld kasutatakse meie igapäevases praktikas traditsiooniliselt muldkatte tähenduses või olemaks selle sünonüümiks. Muld on üldisema tähendusega mõiste. Seda ei saa võtta (vastupidiselt muldkattele) kui süsteemselt talitlevat looduslikku keha. Tavatähenduses võib mullana võtta muldkatte erinevaid horisonte kui ka pinnast, kuid peamiselt siiski huumuskatteid ehk pealismuldasid. Muld võib olla ladustatud huumusmullana tehislikult rajatud vallidesse või aunadesse, mida kasutatakse kas muldkatte omaduste parandamiseks või tehismuldkatete rajamiseks. Looduslikku mulda võib esineda süsteemitute puistete kogumitena maapinnal tehnoloogiliselt rikutud maastikes. Looduslike muldade kõrval on kasutusel tehislikult koostatud substraadid või kasvupinnased ja erinevate komponentide tehislikul segamisel saadud kompostid. Ka taolisi tehismuldasid kasutatakse nii normaalse arenguga muldade parendamiseks kui ka tehismuldkatete huumuskatete rajamiseks.

Täpsustavat selgitust vajab ka tehismuldkatete tüsedus. Nii võib tehismuldade huumuskate olla vaid mõne sentimeetri paksune tingimustes, kus tehismulla algmaterjal on jäetud loodusliku arengu meelevalda. Teisalt, võib huumuskate olla moodustunud lähtematerjalile veetud huumusmulla või turba kihist. Selle tüsedus peaks ulatuma vähemalt 20 cm-ni. Tehnoloogilise materjali algne katmine huumusmullaga kiirendab olulisel määral täisväärtusliku muldkatte tekkimist. Tehismuldkatte kogutüsedus (huumuskate + alusmuld) peaks ulatuma vähemalt 40–50 cm-ni. Oluline on siinjuures see, et oleks piisav kogus mullapeenest ja saviosakesi, mis on normaalsete muldadega sarnaste režiimide kujunemise ja tehismuldkatte kestva talitlemise aluseks. Läbisegatud moreenidele rajatud tehismuldkatetes võivad suured peenese ja savi varud olla alusmulla all olevas lähtematerjalis.

Otstarbekas on käsitleda mineraalsete ja orgaaniliste tehismuldade rajamist, talitlemise ökoloogiat) ja kasutamist teineteisest lahus. Loomulikult eksisteerivad looduses üleminekuala mullad, millisteks on tehismuldade puhul erineva päritoluga mullakihte või segukomponente sisaldavad tehismullad.

Eesti muldade klassifikatsioonis eristatud tehismullad

Tehislikult rajatud muldade võtmise Eesti muldade klassifikatsiooni (EMK) tingis nende eristamise vajadus muldkatteta pinnastest ja normaalselt arenenud muldkatetega maadest Eesti suuremõõtkavalisel (1:10 000) mullastiku kaardil. Tehismuldade inventuuri, seisundi hindamise ja majandamise aluseks on nende muldade võimalikult detailne, kuid samas kohalikule praktikale sobiv jaotamine. Tehismuldade eristamise kriteeriumiks EMK-is on olnud muldkatete rajamise moodus, lähtematerjali päritolu ja ala veeolud. EMK tehismullaliikide nimekiri on esitatud tabelis 1. Tehismuldade hulka ei kuulu (paljand)pinnased ehk „mittemullad“, millised on samas tehismuldade rajamise alusmaterjalideks. Kuna Eesti tehislikult mõjutatud mullad ei ole enamjaolt täielikult tehislikud ehk mitteloodusliku päritoluga, vaid tehislike võtete abil looduses esinevatest materjalidest moodustatud muldkatted, nimetatakse EMK-s neid tehislikeks (Astover jt, 2013). Tehislikkuse määr suureneb reas tehisjas → tehislik → tehismuld. Eesti tehismuldade neli põhitüüpi on eristatud nende rajamise mooduse alusel.

Puistangumullad on rajatud kihiliselt või puistangute kujul ladustatud, vähemal või rohkemal määral tehislikult töödeldud looduslikele pinnakatetele (oosi-, sanduri-, mõhna- ja soosetted ning moreenid) või geoloogilise aluspõhja setetele (paekivi, liivakivi, mergel, savi, põlevkivi, diktüoneema kilt ehk graptoliitargilliit) (joonis 2). Väiksema osa tehismuldade lähtematerjalideks on olmeprügi või tööstusjäätmete (tuhk, poolkoks, šlakk) lademed.

Eemaldatud tehismuldkatted on rajatud eemaldatud normaalse arenguga muldkatete asemele. Nende lähtematerjalideks on enamjaolt endiste madalsoo- ja rabaturba ning pae, liiva, savi ja kruusa ammendatud karjääride põhjajäägid või pinnased. Mineraalsete jääkpinnaste katmine mujalt teisaldatud huumusmullaga kiirendab tehismuldkatte taimestiku algarengut ja intensiivistab mullatekkeprotsesside kulgu kuni sarnastumisele normaalselt arenenud muldadega. Märgade ja turbaste jääkpinnaste kultuurtaimede kasvuks sobivaid omadusi parandab karjääriala kuivendamine, mis on märgade tehismuldade kultuuristamise olulisim võte. Jääkturba-alade ühtlik taimkatte areng on võimalik üksnes turbasisese liigvee sügavuse täppisregulatsiooni kaudu, mis on tehnoloogiliselt keerukas toiming.

Rabaturba karjääride tehismuldade metsakasvatuslikke omadusi ja pioneertaimede produktiivsust parandab väetamine fosfori ja kaaliumiga ning lupjamine.

Segatud tehismuldkatete lähtematerjaliks on normaalse arenguga muldkatte erinevate omadustega mullahorisontide kohapealsel läbisegamisel saadud segu. Segatud tehismullaks nimetatakse mulda siis, kui taoline läbisegamine on toimunud praktiliselt kogu muldkatte tüseduse ehk valdavalt 50–80 cm ulatuses. Segatud tehismuldadeks ei kvalifitseeru mullad, millised on läbi segatud vaid huumuskatte ulatuses.

Tabel 1. Eesti muldade klassifikatsiooni tehismullaliikide nimestik
Table 1. *The list of Technosols in Estonian Soil Classification*

Tehismulla rühm (kood) *Technosol's group (code)*	Kood *Code*[1)]	Tehismulla liiginimetus *Species name of Technosols*[2)]	Levik[3)] *Distribution*
Puistangumullad (Tu)	Tua	Automorfne puistangumuld	xxx
Heap soils (Tu)	Tug	Gleistunud puistangumuld	xx
	TuG	Puistangu gleimuld	x
	TuM	Puistangu madalsoo-turbamuld	x
Eemaldatud mullad (Tx)	Txa	Automorfne eemaldatud muld	xx
Removed soils (Tx)	Txg	Gleistunud eemaldatud muld	xx
	TxG	Eemaldatud gleimuld	xx
	TxM	Eemaldatud madalsoo-turbamuld	xxx
	TxR	Eemaldatud rabaturbamuld	xxx
Segatud mullad (Ty)	Tya	Automorfne segatud muld	xx
Mixed soils (Ty)	Tyg	Gleistunud segatud muld	xx
	TyG	Segatud gleimuld	x
	TyM	Segatud madalsoo-turbamuld	x
Maetud mullad (Tz)	Tza	Automorfne maetud muld	xx
Buried soils (Tz)	Tzg	Gleistunud maetud muld	xx
	TzG	Maetud gleimuld	xx
	TzM	Maetud madalsoo-turbamuld	x

Meanings of codes' last letters: a – automorphic, g – undergleyic, G – epigleyic, M – fen peat, and R – bog peat; 2) For species name see columns I and II; 3) Leviku hinnang – stage of distribution: xxx – laialt levinud – widely distributed, xx – mõõdukalt levinud – moderately distributed, x – vähelevinud – scarce distributed.

Joonis 2. Punakaspruuni moreeni ja devoni liivakivi segu puistang: paremal silutud ja huumusmullaga kaetud puistangu tehismuld. Foto: T. Kõlli.
Figure 2. *Heap of red-brown moraine and Devon sandstone mixture: on the right - levelled and covered by humus rich material technogenic soil. Photo: T. Kõlli.*

Maetud tehismuldkatted on moodustatud normaalselt talitlevale muldkattele mujalt toodud muldsel materjalil, mille alla on maetud algne muldkate. Eristamise kriteeriumiks nende muldade puhul on vähemalt 50 cm tüseduse kattekihi olemasolu. Kattemuld võiks võimaluse korral olla kahekihiline – üle 30 cm alusmulla väärset pinnast ning selle peal vähemalt 20 cm huumusmulda. Kattemullad kujunenud tehismulla taimekasvatuslikke omadusi jääb edaspidi mingil määral mõjutama ka tema alla maetud muldkate.

Kõigi nelja tehismullarühma mineraalsete muldade hulgas eristatakse muldade niiskusrežiimi alusel automorfsed (parasniisked koos põuakartlikega – koodile on lisatud indeks "a"), ajutiselt liigniisked ehk niisked või gleistunud (indeks "g"), tugevasti liigniisked ehk märjad või glei- (indeksiga "G") mullad. Turvasmullad (madalsoo- (M) või raba- (R) mullad) on looduslikus olekus alaliselt liigniisked, kuid võivad tehisturvasmuldadeks muutmise korral olla intensiivsema majandamise huvides kas kuivendatud või hoopiski üle ujutatud. Tehisturvasmuldade kultuuristamise (kasutamisel põllumajanduskultuuride või metsa kasvatuseks) peamiseks eeltingimuseks on nende kuivendamine. Tehisturvasmuldade kasutamine märgviljeluses eeldab aga nende tehnoloogiliselt kontrollitava üleujutuse rajamist. Turvaste põhjakihtidele rajatud tehismullad võivad olla segunenud nende all lasuvate turba- või mineraalmulla erinevate kihtidega.

Eesti tehismuldade nimetuste ühilduvusest WRB klassifikatsiooniga

Referentsmulla *Technosols* detailsel iseloomustamisel ja rühmitamisel WRB *(World Reference Base for Soil Resources)* järgi kasutatakse selle süsteemi ees- ja järelliiteid ehk tunnussõnu (IUSS…2015). Iga WRB klassifikatsiooni tunnussõna ehk kvalifikaator (neid ei tõlgita), väljendab mingit kindlat omadust. Taoliste tunnussõnade kasutamine on eriti vajalik rahvusvahelistes, muldade nomenklatuuri puudutavates, lävimistes.

EMK iseärasuseks võrreldes WRB-ga on tehismuldade jaotamine neljaks rühmaks nende rajamise viisi järgi. Mõningate nende kohta on kasutusel ka konkreetsed mullanimed, kuid tavaliselt iseloomustatakse neid üldnimetusega *Technosols*, millele on lisatud mulla olemust täpsustav ees- ja/või järelliide. Detailsemal tehismuldade jaotamisel (s.o erimiteks ja variantideks) ei piirduta ainult rajamisviisi, algmaterjali päritolu ja veeoludega, vaid võetakse täiendavalt arvesse mulla lõimis (peenese ja korese sisaldus ning vahekord), tehnoloogilise huumuskatte olemasolu või puudumine, mineraalse ja orgaanilise päritoluga materjalide paiknemise iseloom (segatud või kihiline) ja vahekord, ala kallakus, tehislike tööde täiuslikkus jms.

WRB süsteem võimaldab iga konkreetse tehismulla detailsel iseloomustamisel kasutada vajalikul arvul erinevaid mulla omadusi iseloomustavaid tunnussõnu.

Loomulikult leiab globaalsel tasandil tehismuldade jaotamisel rohkem eriilmelisust võrreldes Eesti oludega, mis peegeldub ka kasutatavate ees- ja järelliidete ehk tehismulla variantide arvus. Nii on globaalses ulatuses kasutusel 11 eesliidet, millistest võiksid meie oludes kasutust leida *(ekranic, linic, urbic, spolic, garbic, isolatic, leptic, reductic, subaquatic* ja *hyperskelectic).* Tehismuldi iseloomustavaid järelliiteid on WRB süsteemis kokku 40, millistest meie oludes sobiks kasutada näitamaks (1) lõimist *arenic, clayic, loamic, siltic, skeletic;* (2) huumusseisundit *mollic, umbric, ochric, humic;* (3) happesust *alcalic, eutric, dystric;* (4) veeolusid *aridic, drainic, gleyic;* (5) mulla koostist *dolomitic, cal*caric, *lignic, hyperartefactic, toxic;* (6) moodustamise viisi, *novic, relocatic, transportic* ning (7) mullatekkeprotsesse *cambic, densic, stagnic, protospodic, calcic.*

Eestis vähelevivad tehismullad ja tehismuldadega piirnevad mullad

Lisaks EMK-s kajastatud tehismuldadele leidub nii Eestis nagu ka mujal maailmas rohkesti eripärase tekke ja omadustega tehismuldasid. EMK-i ei ole neid võetud väikese pindalalise leviku tõttu. Nii eristatakse WRB-s, lisaks EMK nelja tehismulla grupile (1) kaetud (*ekranic*) tehismullad, milliste pinnast on valdav enamus kaetud õhukese tiheda (ka kivistunud) kihiga; (2) geotekstiilist (*linic*) alusele rajatud mullad; (3) isoleeritud (*isolatic*) mullad, millistel puudub otsene kontakt maapinnaga (rajatud katustele või muudele alustele); (4) veealused (*subaquatic*) tehismullad (vett puhastava taimestikuga biotiigid, roostikud, veega kaetud ammendatud turbakarjäärid). Teatud hulgal tööstuslikke jäätmeid sisaldavad mullad on jäätmemullad (*spolic*) ning ehituslikku prahti ja jäätmeid sisaldavad mullad on linnamullad *(Urbic Technosols)*. Esineb tehismuldi, mis sisaldavad erineva mittelooduslikku päritoluga toksilisi materjale. Poola muldade klassifikatsioonis (Kabala *et al.,* 2020) on näiteks eristatud kuus kõrgema taksoni tehismulda: *Ekranosols, Industriosols* (tööstuslikult muudetud), *Edifisols* (ehitustel ja varemetel), *Constructosols* (alt geotekstiiliga kaitstud), *Aggerosols* (puistangutel) ja *Turbisols* (sügavalt läbisegatud). Mõningad näited tehismuldade ülesehituse kohta on esitatud joonistel 3 ja 4.

a b

Joonis 3. Järg
Figure 1. *Cont.*

c

d

Joonis 3. Tehismullad: (a) Maardu fosforiidikarjääri puistangu tehismuld. Foto: E. Asi; (b) Prügimäe (puistangu) tehismuld Stutgardi äärelinnas, Saksamaal. Foto: A. Karklins; (c) Tööstusest pärinevate jäätmete ja ehitusprahi segamisel moodustunud kihilised *Industriosols* (tööstuslikud mullad) Poolas. Foto: A. Greinert; (d) Maagikaevanduse ja lehkavate jäätmete läbisegatud materjalist moodustunud *Industriosols* Poolas. Foto: C. Kabała.

Figure 3. T*echnosols: (a) Technogenic soil on wastage heaps of Maardu phosphorous quarry. Photo: E. Asi; (b) Technosol's profile on dumping heap at suburb of Stutgard, in Germany. Photo: A. Karklins; (c) Stratified Industriosol with admixed industrial wastes and construction debris, in Poland. Photo: A. Greinert; (d) Industriosol developed from the mixed ore mining and smelting wastes, in Poland. Photo: C. Kabala.*

Joonis 4. Urbisol, mis on rajatud ehitusjäätmetele ning on taastamise käigus ettekavatsetult kaetud huumusmullaga. Foto: C. Kabała.
Figure 4*. Urbisol developed from the construction debris with humus-rich topsoil created intentionally during site reclamation. Photo: C. Kabala.*

Olulise pindala Eesti tehismuldadest saame, kui võtame kokku eraldiseisvad väikese pindalaga ja maastiku rajatistega piirnevad tehismullad. Vaatamata suhteliselt väiksele levikule täiustavad sellised tehismuldade ribad või kogumid olulisel määral maastike esteetilist ilmet ja pedo-ökoloogilist talitlemist. Taolised tehismullad esinevad maastikule rajatud maanteede ääres, piirnedes maanteega ühest ja korrastatud normaalsete muldadega teisest küljest (joonis 5). Sarnaste tehismuldkatete talitlemine saab alguse nende haljastamisega. Teatavasti on ka maaparandusega kuivendatavatel aladel otstarbekas kasvatada isegi tööde käigus fütomassi produtseerivaid taimkatteid sh. spetsiaalselt selleks külvatud kultuure, rikastamaks muldkatet värske orgaanilise ainega. Kui dreenide vahelised muldkatted koos hea tava järgi täidetud dreenikaevetega on oma olemuse järgi remonditud normaalsed mullad, siis suurte eesvoolukraavide kallastel on tegemist juba haljastatud tehismuldadega (joonis 6). Üsna sageli piirnevad tehismullad pinnaste ehk "mittemuldadega", mis võivad küll olla tehismuldade rajamise reserviks, kuid samas ei ole õige nimetada neid tehismuldadeks. Eestis on häid näiteid ka katustele rajatud (*isolatic*) tehismuldadest (joonis 7).

Joonis 5. Tehismulla rajamine tee pervedele. Foto: R. Kõlli.
Figure 5. *Establishing tehnogenic soils on waysides of road. Photo: R. Kõlli.*

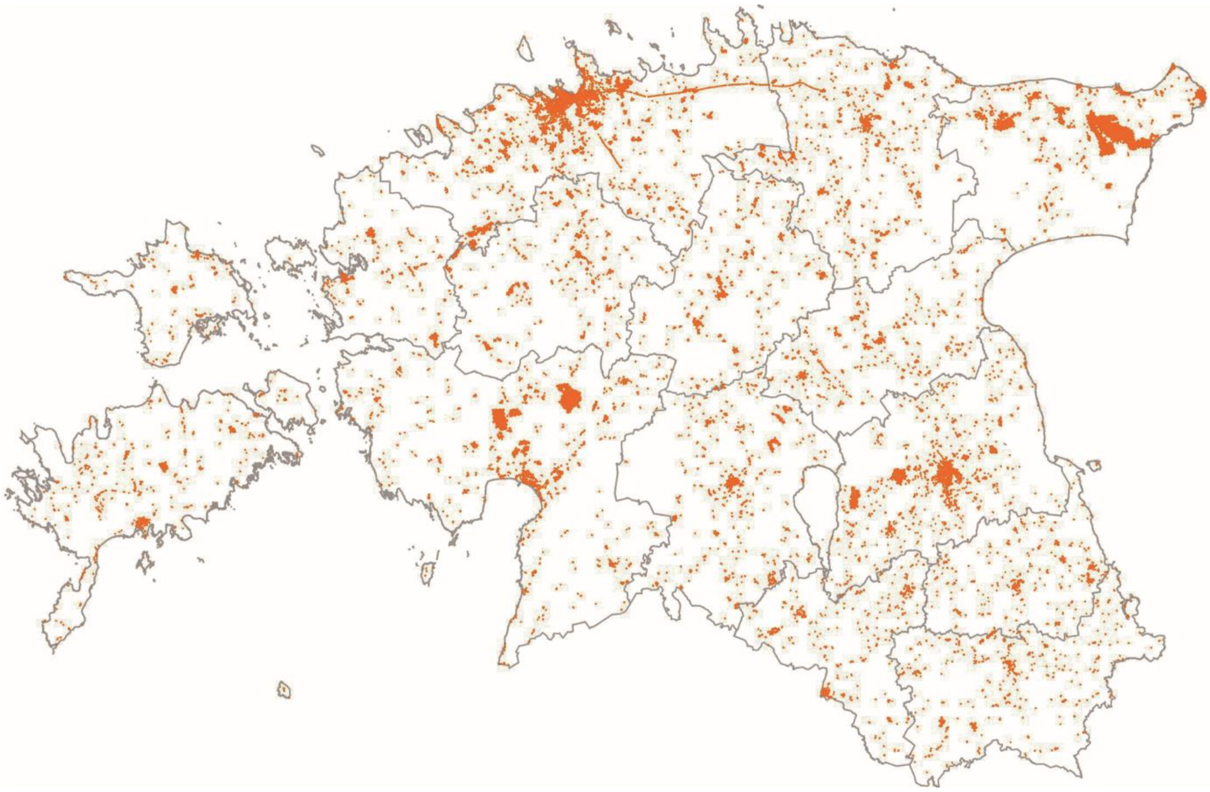
Joonis 6. Haljastatud tehismullad maaparandusobjekti eesvoolu kallastel Kuusikul. Foto: I. Silde.
Figure 6. *Greened technogenic soils on riverside of hydro-ameliorated area at Kuusiku. Photo: I. Silde.*

Joonis 7. EMÜ peahoone katusele rajatud tehismulla (*isolatic*) taimkate. Foto: E. Leedu.
***Figure 7**. Established on the roof of EULS main building a technogenic (isolatic) soil's plant cover. Photo: E. Leedu.*

Tehismuldade regionaalne levik ja nende rajamisest üldiselt

Tehismuldade rajamine kerkis päevakorda seoses vajadusega inventeerida ja korrastada suure ulatusega maa-alasid, millised said rikutud tehnoloogiliste pinnasetööde käigus või pinnakatete eemaldamisega maavarade kättesaamise otstarbel. Skemaatilisel kaardil (joonis 8) on tehismuldade levik näidatud koos paljandpinnastega, milliste summast moodustavad Priit Penu andmetel tehismullad hinnanguliselt *ca* 67% ja muldkatteta alad ehk korrastamist vajavad alad *ca* 33%. Kahjuks ei ole Eestis veel vajalikul määral juurdunud kaasaja hea tava, et kaevandamise lõppedes või maastikurajatiste ehituse järel ei jäeta tehislikult rikutud maa-ala korrastamata seisundisse. Igati mõistlik on nõue, et rikutud alad tuleks nii majanduslikust kui esteetilisest aspektist kujundada harmooniliselt talitlevaks maastiku osaks. Juhul kui ammendatud karjääride ja kokku kuhjatud puistangute alale ei ole plaanis rajada teid, ehitisi või muid maastikurajatisi, on igati mõistlik sinna rajada lähtematerjalile sobiv kestlikult talitlev muld-taim süsteem metsade või rohumaade näol. Rikutud territooriumide peamiseks korrastamise võtteks on seega metsaks, rohumaadeks või ka põlluks sobivate tehismuldkatete rajamine. Lisaks nendele võib mõningatel juhtudel olla otstarbekas hoopiski veekogude (veesilmade) rajamine maastiku rikastamiseks. Kõige sobivamad selleks on sügavad karjäärid ja täielikult ammendatud järvetekkelise madalsooturba karjäärid.

Eestis on ammendatud põlevkivikarjääride karbonaatseid ja suhteliselt kiviseid alasid rekultiveeritud metsadeks (Kaar jt, 1971; Kaar, Kiviste, 2010). Osa metsadest on istutatud otse tasandatud puistangule. Aidus ja Kohtlas on karjääre rekultiveeritud ka põldudeks, kus tasandatud stabiilse lasuvustihedusega puistangule on peale veetud eelnevalt kooritud alusmulda sisaldav huumusmulla kiht (Leedu, Murdam, 1996). Elektrijaamade tuhaväljade haljastamise probleemiks on olnud tuha väga suur leelisus. Nii on Ahtme elektrijaama tuhavälja pinnakiht neutraliseeritud rabaturbaga. Balti Elektrijaama tuhaväljade rekultiveerimisel on kasutatud aga moodust, kus tuha sisse kaevatud 0,5 m sügavused kaeved on täidetud neutraliseeriva rabaturbaga (joonis 9). Maardu väga õhukese moreenikihiga fosforiidikarjääride tugevasti kivised puistangud on olnud sobivad vaid metsastamiseks (Sarv, 1974). Puistangu koostises esinevad seal kaaliumi poolest rikas glaukoniit-liivakivi ja väga tugevasti happelise reaktsiooniga graptoliitargilliit (ehk diktüoneema kilt), mis võib puistangus õhuhapniku juurdepääsul süttida. Süttimised on toimunud isegi vaatamata tema sügavale puistangu alla matmisele.

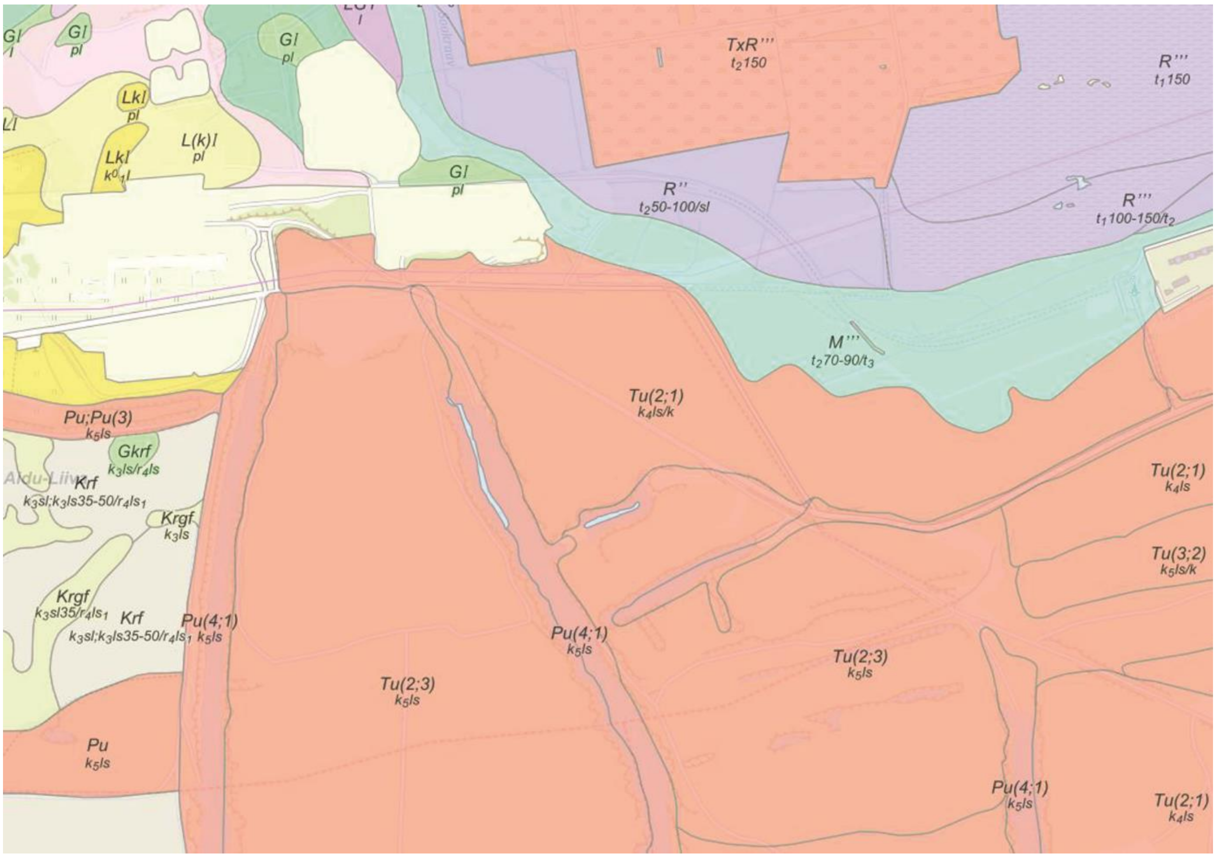


Joonis 8. Tehismuldade ja paljandpinnaste levik Eestis. Autor: P. Penu.
Figure 8. *Distribution of technogenic soils and bare grounds in Estonia. Author: P. Penu.*

Joonis 9. Balti soojuselektrijaama rabaturba pesadega neutraliseeritud ja haljastatud tuhaväli. Foto: E. Leedu.
Figure 9. *Neutralized by bog peat nests and greened up ash fields of Baltic heating electricity station. Photo: E. Leedu.*

Madalsoo jääkpinnaste valdavamaks taimestamist vajavaks materjaliks on keskmiselt või hästilagunenud pilliroo-, tarna-, lehtsambla- ja puuturbad. Vaid pinnalt kaevandatud (s.o mittetäielikult ammendatud) rabakarjääride jääkpinnased koosnevad halvasti või keskmiselt lagunenud turbasambla, kanarbiku, männi ja tarnaturvastest. Täielikult ammendatud rabakarjääride puhul koosneb jääkturbapinnas erinevatest siirdesoo ja madalsoo turbaliikidest, mis võivad olla segatud all lasuvate mineraalsete mullakihtidega.

Tehismuldade kasutamise planeerimisel on kõige olulisemad tegurid muldkatte potentsiaalne viljakus ning ala veerežiim. Potentsiaalne viljakus sõltub rekultiveerimistööde kvaliteedist, muldkatte lõimisest, huumuskatte seisundist ning tehismulla reljeefist ja ühtlikkusest. Põllukultuurid edenevad üksnes korraliku tehnoloogiaga rajatud ühtlaste omadustega parasniisketel tehismuldadel. Rohumaade rajamiseks sobivad lisaks parasniisketele muldadele ka gleistunud ning kuivendatud glei- ja madalsoo-turvasmullad. Metsakasvatust saab edendada kõige laiema ökoloogiliste tingimuste amplituudiga tehismuldkatetel. Sobivad on ka kirju mullastikuga alad. Teiselt poolt, leidub sobivaid puuliike ka kuivendamata tehis glei-muldadele. Samas ei ole võimalik arendada vähegi tõhusamat metsakasvatust kuivendamata turbast koosnevatele jääkpinnastele. Tehismuldade suurimaks leviku piirkonnaks on Kirde-Eesti, mida näitab Aidu kandi mullastiku kaardi väljavõte (joonis 10).



Joonis 10. Väljavõte digitaalselt suuremõõtkavaliselt (1:10 000) Eesti mullastiku kaardilt (Maa-amet, 2009).
Figure 10. *Excerpt from the digital large-scale (1:10,000) Soil Map of Estonia (Land Board, 2009).*

Mineraalsete tehismuldade rajamisest

Tehislike mineraalmuldade kvaliteet sõltub otstarbekohaselt tehtud töödest tehnoloogilise ja bioloogilise rekultiveerimise käigus. Tehnoloogilise rekultiveerimise algastmeks on puistangute või kihiti ladustatud algmaterjali kohale vedu ja paigaldamine. Selle jätkuna korrastatakse pinnase ehk „mittemullaga" maa-ala (tasandatakse, vajaduse korral ala kuivendatakse, võimaluse korral kaetakse huumusmullaga, ning reguleeritakse pindmise kihi reaktsioon taimkatte (kultuuri) kasvule sobivaks. Nimetatud töödega on loodud võimalused spontaanse loodusliku taimkatte ja koos sellega ka primitiivse (vähearenenud) tehismuldkatte arenguks. Muld-taim süsteemi talitlemine koos kamardumise ja huumushorisondi moodustumisega on tunduvalt kiirem algselt huumusmullaga kaetud tehismullal, võrreldes katmata aladega. Võimalikult täiuslikum rajamise tehnoloogia loob head eeldused bioloogiliseks rekultiveerimiseks. Bioloogilise rekultiveerimise põhitööks on tehnoloogiliselt kujundatud alale sobiva taimse materjali istutamine või seemnete külv. Eesmärgiga kiirendada taimkatte algarengut kasutatakse bioloogilisi preparaate ja väetamist.

Karjääride rekultiveerimine ehk tehismuldkatete rajamine sõltub kaevandatavast materjalist, kattematerjaliks sobiva pinnase olemasolust ja karjääri sügavusest. Tehismaastiku veekogudest kõrgemale jäävad alad taimestatakse laugematel kohtadel taimede külviga, järskudel kalletel mätastamise või hüdrokülviga. Bioloogiliselt rekultiveeritav pinnas peaks sisaldama muldade talitlemist tagavas koguses peenese- ja savirikast lähtematerjali, milline sõltub omakorda nii katendikihi lõimisest, kui ka selle tüsedusest. Viimasel ajal Eestis rajatud mineraalsed tehismullad koosnevad enamjaolt tasandatud algmaterjalist ja seda katvast huumuskattest. On selgunud, et 20–30 aastat tagasi moodustatud karbonaatsetel tehismuldadel on välja arenenud alusmullale omased sisseuhtumise tunnustega horisondid. Parimad tehismullad on need, kus mullapeenest sisaldavad kvaternaarsed setted on ladestatud võimalikult tüsedama kihina koreserikkale lähtematerjalile. Tüsedam ja savirikkam alusmuld tagab stabiilsema veerežiimi ja suurema taimedele omastatava produktiivvee varu.

Eesti oludes on leidnud ka tõestust, et lubi- ja dolomiitpae purustatud materjalil moodustunud tehismullad on omadustelt ja ülesehituse poolest sarnased rähkmuldadega (Reintam, Kaar, 1999), liivakarjääride tehismullad aga primitiivsete leedemuldadega. Tehismullad, mille huumuskate koosneb kõrge potentsiaalse viljakusega liivsavist ja kus ka alusmuld on savirikkam ning tüsedam on üsna kõrge viljakusega ehk võrreldavad normaalsete leostunud ja leetjate muldadega. Tehismullad kujunevad aegamööda üsna sarnasteks normaalselt arenenud muldadega ja sarnaselt nendega täidavad nad valdavas ulatuses kõiki ökosüsteemi talitlemiseks vajalikke ülesandeid.

Tehismuldkatete rajamise lähtematerjalid, kui ka nende kujunemise ökoloogilised tingimused on erinevalt normaalse arenguga muldkatetest heterogeensemad. Tehismuldkattes esineb rohkesti väikese pindalaga tehismulla erimeid ja variante. Vaatamata tehismuldade suurele heterogeensusele nende algarengu faasis, muutuvad tehismullad lähima kümnendi jooksul omadustelt ühtlikumaks ja seega ka kvaliteedilt paremaks (Reintam, Kaar, 1999; Huot *et al.*, 2015). Peamiseks tõukejõuks sellises arengus on produktiivse taimkatte olemasolu.

Tehisturvasmuldade rajamisest

Eestis on jääkturbasoid kokku *ca* 9500 ha, kusjuures nende suurimad alad asuvad Pärnumaal (*ca* 40%) ja Ida-Virumaal (*ca* 20%). Jääkturbaalade muutmine produktiivselt talitlevaks alaks on tõsine keskkonnaseisundi parandamise ja efektiivse maakasutuse probleem (Valk, 2005; EMTR, 2005–2008; Ramst, Orru, 2009; Kohv, Salm, 2012; Lode jt, 2015). Jaanus Paal (2011) on loetlenud korrastamise võimalustena taas-soostumisele kaasa aitamist, korrastamist märgviljeluse alaks (päide- ja pilliroog, paelrohi, suurekasvulised tarnad), kuivendussüsteemiga põllu-, rohu- või metsamaa rajamist, turbaaladele sobiva marjakasvatuse (mustikad, jõhvikad) arendamist, veekogude rajamist ning puhastuslodude kujundamist turba kaevandamisalade kuivendusvete puhastamiseks. Siia võiks ehk lisada ka esialgselt ammendatuteks peetud jääkturba kihtide täielikumat ammendamist, mis võiks võimaluse korral ulatuda kuni mineraalse aluspinnani. Samas tuleb arvestada, et mistahes turbalasundi alumised kihid erinevad suurel määral kaevandamise käigus eemaldatud pindmistest kihtidest.

Üheks olulisimaks taimeks märgade jääkturba alade taastamisel on suure liigirikkusega *Sphagnumi* perekonda kuuluvad samblad. Jääksoo taimestamise võimalikkus üksnes turbasammaldega või taimkattega, milles domineerivad turbasamblad, sõltub ennekõike nii jääkturvaste, kui ka sood toitvate vete keemilisest koostisest sh. saastatusest erinevate ainetega (Caroll *et al.*, 2009). Keeruliseks probleemiks taolise taimkatte rajamise puhul on turbasammaldele kasvuks vajaliku veetaseme reguleerimise tehnoloogia rakendamine, kuna seda probleemi ei saa lahendada üksnes kuivenduskraavide sulgemisega.

Ammendatud turbakarjääride jääk(turba)pinnase omadused ja sobivus taimkattele sõltuvad otseselt jääkpinnase turba liigist, lagunemisastmest *(fibric, mesic, sapric)*, koostisest ja omadustest. Üldreeglina on nii madalsoo- kui rabaturvaste alused turbad s.o mineraalsetele paleo-muldadele lähemal asuvad kihid, valdavalt keskmiselt kuni hästilagunenud. Erandi moodustavad vähese pindalalise levikuga nõmm-rabad, milliste rabaturba ladestumine on oma alguse saanud turvastunud paleo-leede-gleimuldadest. Taolised rabad ei ole oma arengus läbinud madalsoo arengufaasi. Jääkturba potentsiaalne viljakus ehk taime- ja metsakasvatuslikud omadused sõltuvad kaevandamise ehk jääkpinnase sügavusest ja turbalaama toitvatest vetest. Kõrgeima potentsiaalse viljakusega turvasteks on lubiolluste rikkast liikuvast pinnaveest (mis on ka hapnikurikas) toituvad loduturbad.

Karjääride jääkturbapinnaste tehismullaks muutmise peamisteks toiminguteks on ala kuivendamine ja sobiva, kestlikult toimiva, taimkatte moodustamine (Laine, Mikkinen, 1996; Höper *et al.*, 2008; Valgepea jt, 2021). Liialt aeglase loodusliku uuenduse põhjuseks on mineraalsetele muldadele sarnase huumuskatte ehk turbalaamade kasvukihi puudumine turbakihtide alumises osas. Sellega seoses puudub ka kestlikuks arenguks vajalik geneetiline materjal (seemned, elusad maapealsed osad jms). Rabade jääkturvas, mis on oluliselt happelisem võrreldes madalsoo turbaga, ei pruugi üldsegi olla halvasti lagunenud. Eriti oluline on siinjuures toitvate vete iseloom (sademed või pinnavesi) ja turbaaluste mineraalsete setete sügavus. Vajalikuks teabeks raba-karjääride taastamisel on jääkturba arengufaas (madalsoo või rabaturvas) ning lagunemisaste. Taolistele aladele tehisturbamuldade rajamise eelduseks on selle kuivendamise võimalikkus, mis omakorda sõltub eesvoolu rajamist võimaldavast hüdro-geoloogilisest situatsioonist.

Eestis leidub vähe kirjandust ja kogemust tehisturvasmuldade rajamise kohta. Samas on olemas uuemat kirjandust soomuldade endistele veeoludele vastava seisundi taastamise kohta Baltimaades, Poolas ja Saksamaal (Höper *et al.*, 2008; Kohv, Salm, 2012; Wilson *et al.*, 2012; SSTK, 2016; Pakalne *et al.*, 2021; Purre, 2021). Endise veerežiimi ja algsega sarnase kasvukihi loomist ei ole õige pidada tehisturvasmuldade rajamiseks, kuna tegemist on hoopiski turba liigveega küllastamise ja püüdega taastada turbalasundi algse ilmega katte- ehk kasvukiht. Kahjuks peetakse laialt levinud arvamuse kohaselt õigemaks soo loodusliku oleku taastamist kultuuride ja metsade kasvatamiseks sobiva tehisturvasmulla loomise asemel. Nende kahe suuna peamine erinevus on selles, et kui taastatud soodes on turvas valdavas osas veega küllastatud kuni maapinnani, siis tehisturvasmuldadel on vaja jätta kultuurtaimedele sobiva tüsedusega (30–50 cm) suhteliselt hästiõhustatud (veega mittetäielikult küllastunud) turbakiht. Kui soode taastamisel taotletakse võimalikult täielikumat turba mineraliseerumise peatamist, siis tehismulla majandamisel taotletakse võimalikult suurema uue fütomassi koguse tootmist. Negatiivseteks külgedeks esimesel juhul on madal produktiivsus, teisel aga varem ladestunud turba ja sama aasta varise mineraliseerumise intensiivistumine. Muret tekitab ka loodusliku oleku taastamise pikk ajaperiood, milleks kulub paljude autorite arvates keskmiselt 15 aastat. Ilometsa jt (2010) andmetel algas ammendatud freesturba aladel turba moodustumine isetaimestumisel alles 25 aastat pärast veetaseme tõstmist.

Kuivendamise puhul ei ole orgaanilise aine lagunemise/akumuleerumise bilanss ökosüsteemi tasemel üldsegi mitte või liialt suurel määral negatiivne tänu suurenenud aastaproduktiivsusele. Dilemma on siin selles, et kas kiivalt hoida olemasolevat turbamulla varu, leppides sealjuures selle vähema iga-aastase juurde tulekuga või tagada suurema hulga turba kulutamisega ka suurem aastaproduktiivsus. Sealjuures võiks kulutatud turvast käsitleda kui turbale lisaväärtuse andmist või väärtustamist tema arvel uuesti toodetud hoopiski väärtuslikuma taimse fütomassi (terad, puit jms) näol. Kulu kartes ei ole loota tulu! Rabade jääkturvaste taimestamisel on kasutatud nii sooturba arengufaasile sobivaid looduslikke taimeliike kui ka kultuurmetsamarjade istutamist (Noormets *et al.*, 2003; Starast jt, 2005), mis on sisuliselt turba väärindamine kõrgema tarbimisväärtusega taimseks produktiks.

Tehismuldade rajamise ja majandamise ökoloogilistest alustest

Eesti üldsus ei tohiks leppida taimkatteta paljandpinnaste või songermaade suhteliselt laia levikuga (joonis 10; EMTR, 2005–2008). Mitte pinnaste, vaid kestvalt talitleva tehismulla taimkatte abil on võimalik siduda olulisel hulgal vabalt saadavat päikeseenergiat ja süsihappegaasi fütomassi, kui energia looduslikku akumulaatorisse. Võib väita, et kaasaegne ühiskond omab piisavalt agronoomilisi kogemusi võimalikult suure fütomassi koguse tootmiseks pinnaühiku kohta. Samas vajatakse taimkatte tootlikkuse kõrval senisest rohkem teadmisi fütomassi kasutamisvõimaluste kohta, nii sellesse seotud energiaga manipuleerimisel ja tarbijani viimisel kui ka, vajaduse korral, pikaajalise ladustamise (deponeerimise) korraldamisel. Fütomassi seotud energia vajab ehk rohkemgi tähelepanu võrreldes energia tootmisega päikesepaneelide abil. Sest kuigi taimkatte energia tootmise intensiivsus on võrreldamatult väiksem päikesepaneelide omast, on taimkatte pindala (sh lehepinna indeks) võrreldamatult suurem päikesepaneelide kogupinnast.

Eelpoolöeldul on selge seos tehismuldade ja nende doonorite, paljandpinnaste, käitlemisega. Paljandpinnaste ja tehismuldade leviku võrdlusest selgub, et paljandpinnaste pindala on võrdlemisi suur (suhe tehismullad : paljandid = 2:1), kuid samas on paljandite pindala ehitustegevuse tulemusena pidevas suurenemises. Seega vajaks paljandpinnaste kasutamise strateegia senisest suuremat tähelepanu. Paljandpinnaste hulgast peaks kõigepealt eristama alad, millised sobivad oma materjali ja hüdroloogiliste tingimuste poolest tehismuldkatete rajamiseks peamiselt metsakasvatuse või rohumaade viljelemise otstarbel. Põldude rajamine, mis vajab eriti häid eeltingimusi, saab seniste kogemuste põhjal olla vaid marginaalne. Otstarbekas oleks olemasolevatest paljandpinnastest senisest rohkemal määral võtta tööstuslike ehitiste alla, luues selleks soodustusi maa-ala ostu või rendi osas. Alternatiiviks on ka (sobivate tingimuste olemasolul) veekogude rajamine. Lammutatud ehitustest pärinevate puistangute taaskasutusele võtmise võimalus tehismullana selgub jooniste 11 ja 12 võrdlusest.

Fütomassi tootmisel tehismuldadel, mis on oluline ka nende enda kestliku talitlemise seisukohast, eristub kaks etappi. Olles arengu algfaasis, vajab tehismuld uut orgaanilist ainet mullaelustiku võrgustiku väljakujunemiseks ja huumusvarude suurendamiseks. Kuid olles saavutanud tasakaalustunud huumusseisundi, saab loota iga aastal või pikema perioodi jooksul teatud fütomassi hulga eemaldamise ehk mujal kasutamise võimalusele, kas heintaimede fütomassi või puidu näol. Sarnaselt normaalsete muldadega sõltub ka mineraalsete tehismetsamuldade produktiivsus mulla lõimisest ja veeoludest. Potentsiaalse produktsioonivõime optimaalse ärakasutamise võtmeks on tingimustele sobivate puuliikide valik. Eestis on dokumenteeritud olukordi, kus endistele väheproduktiivsetele soostunud mineraalmuldadele rajatud tehismuldadele on kujunenud kõrge produktiivsusega (II–III boniteediga) metsad (Kaar, Kiviste, 2010).

Ka tehislike mineraalsete rohumaamuldade võimalikult parema majandamise võtmeks on mullale sobivate heintaimeliikide valik. Sobivaid liike leidub nii happeliste kui karbonaatsete muldade jaoks. Tehismuldade taimestamist rohumaadeks saab teha laiema ulatusega veeolude olemasoluga (põuakartlikest kuni alaliselt liigniisketeni) ning taimkatete muldkatetega ökoloogiliselt harmoonilisema (võrreldes põllumaadega) sobitamise võimalikkusega. Kui sobivat puistu koosseisu metsades tuleks näha pikas perspektiivis, siis rohumaade puhul on enam võimalusi ka liikide koosseisu muutmiseks lühema ajaperioodi jooksul.

Joonis 11. Kivise ehitusprahi puistangud: tehismuldade rajamiseks tuleks need purustada ning katta peeneserikka pinnase ja huumusmulla kihtidega. Foto: R. Kõlli.
Figure 11. *Heaps of stony construction wastes: for forming technosols these wastes must be crushed and covered by fine earth's and humus rich soil layer. Photo: R. Kõlli.*

Joonis 12. Ehituse kiviprügiga (purustatud telliskivid ja betoon) kaetud mullapind. Foto: A. Greinert.
Figure 12*. Construction rubble (crushed bricks and concrete) on the soil surface. Photo: A. Greinert.*

Tehismuldade laialdasemat kasutamist põllumaana häirib taimekasvatuslike omaduste suur heterogeensus ja vaid parasniiskete veeolude sobivus. Erandiks on paelrohu (päideroo) (*Phalaris arundinacea*); hariliku pilliroo (*Phragmites australis*); hundinuiade (*Typha* spp.) ja kõrgekasvuliste tarnade (Carex spp.) kultiveerimine alaliselt märgadel õhukese veekihiga (veealustel) muldadel. Taoliselt rajatud alade mullad on tehismullad, kuna vajavad oma talitlemiseks hästitoimivaid hüdro-tehnoloogilisi lahendusi. Ülalnimetatud märgalade ökosüsteemide fütomassi produktiivsused võivad sobiva agrotehnoloogia ja täiendava subsideerimise korral ulatuda 5–12 Mg C ha^{-1} a^{-1} (Mander *et al.*, 2012; Wichtmann *et al.*, 2016).

Nii uue fütomassi produtseerimise taseme, kui ka süsiniku aastabilansi seisukohalt ei ole meie arvates mõistlik ammendatud turbakarjääre taastada looduslike metsasoodega sarnaselt talitlevateks metsamaadeks. Eesti metsade inventuuri andmetel (KKA, 2019) on looduslikel madalsoo- ja rabamuldadel kasvava metsa keskmiseks hektaritagavaraks vastavalt 85(59) ja 87(81) tihumeetrit (sulgudes on puistu vanus aastates), kuid kuivendatud madal- ja siirdesoo muldadel 222(50) ja 205(69) tihumeetrit hektari kohta. Sellest johtuvalt on ka aasta juurdekasvudes mitmekordsed erinevused kuivendatud alade kasuks. Otstarbekas oleks rajada selleks sobivatele jääkturba pinnastele kuivendussüsteemiga metsamaad. Põhiliseks takistuseks selle teostamisel on tehnoloogilistele nõuetele vastava eesvoolu rajamise võimalikkus. Eesvoolu puudumisel metsaks sobivat tehisturvasmulda rajada ei ole praktiliselt võimalik. Autorite arvates on suuresti ebamõistlik metsastunud turba-alade lageraided, lagesoode saamise otstarbel.

Tehismuldadele rajatud ökosüsteemide produktiivsuse võrdlev analüüs

Nii põllu- kui metsamajanduse edukuse ning muldade (sh tehismullad) produktiivsuse seisukohalt on üheks olulisemaks näitajaks mistahes ökosüsteemi muldkatte suhtes sobiva taimkatte aastaproduktiivsus või olemasoleva fütomassi aastane juurdekasv. Teatavasti väljendatakse aastaproduktiivsust kas kuiva fütomassi, või sellesse seotud süsiniku või energia kaudu pinnaühiku kohta aasta jooksul. Antud töös on võrdluste aluseks võetud Mg ehk tonni C ha^{-1} a^{-1}. Kui tahetakse orgaanilise süsiniku aastakäibe näitajaid esitada ligikaudselt kuivmassina tuleks süsiniku mass korrutada 2-ga, kui aga CO_2-na siis 3,64-ga.

Ammendatud turbakarjääridele kuivendatud tehisturvasmullaga metsaökosüsteemide ja taastatud alaliselt liigniiskeks muudetud loodusliku sootaimkattega ökosüsteemide võrdlusest selguvad põhimõttelised erinevused süsiniku aastabilanssides s.o uue koguse CO_2 sidumist ökosüsteemi, selle emissioonist atmosfääri ja ladestumisest turvasmuldkattesse. Tähelepanu väärib väärarvamus, et jääksoode taastamisel looduslike soodega sarnaselt talitlevaks ökosüsteemiks on esimese järgu hüveks suur CO_2 sidumise võime ja, teiselt poolt, selle emissiooni vähenemine. Kui viimasena mainitud hüvega võib igati nõustuda, sest veega küllastatus konserveerib turba. Samas ei saa mingil juhul nõustuda, et taoliselt taastatud sood muutuvad suure CO_2 sidumise efektiivsusega ökosüsteemideks. Seda kinnitavad andmed fütomassi juurdekasvu aastakoguste kohta (Höper *et al.*, 2008; Mäkila, Saarnisto, 2008; Oleszczuk *et al.*, 2008; Inisheva *et al.*, 2011).

Sooökosüsteemide talitlemisest lähtuvalt on fütomassi produktiivsuse kõrval väga oluliseks näitajaks ka uue turba moodustumine (Ilomets, 1994; Nilsson *et al.*, 2018). Uno Valgu poolt tehtud ülevaadetest (1988; 2005) selgub, et Eesti raba- ja madalsooturba lasundite pika perioodi turba juurdekasvud (arvutatuna süsinikule) on olnud aasta keskmisena vastavalt *ca* 0,130 ja 0,230 Mg C ha^{-1} a^{-1}. Turba kuivmassina väljendades oleksid vastavad aastakogused 0,260 ja 0,460 Mg turba kuivmassi hektari kohta, millised on aasta jooksul endasse sidunud vastavalt *ca* 0,47 ja 0,84 Mg CO_2 hektari kohta. Eelpoolmainitud kogustes turbamassi tootmiseks, selles oleva orgaanilise süsiniku talletamiseks või ekvivalentse koguse süsihappegaasi sidumiseks atmosfäärist peaks nendel soomuldadel moodustunud ökosüsteemide aastaproduktiivsus olema hinnanguliselt vastavalt piirides – rabades 0,4–0,5 ja madalsoodes 0,9–1,2 Mg C ha^{-1} a^{-1}. Euraasia ühe suurima pindalaga Vasjugani rabamassiivi keskmine aastaproduktiivsus ulatub piiridesse 1,7 kuni 2,6 Mg C ha^{-1} a^{-1} ning emissioon CO_2-C-na 0,48–0,90 Mg C ha^{-1} a^{-1} (Inisheva *et al.*, 2011). Anna-Helena Purre (2021) on Eesti rabade uurimisel saanud turbasambla domineerimisega rabade aastaproduktiivsuseks 1,0–1,6 Mg C ha^{-1} a^{-1}. Iirimaal tehtud uurimustes on aasta keskmine süsiniku sidumine olnud 2,8 Mg C ha^{-1} a^{-1}, kusjuures sõltuvalt taimeliigist ja mikroreljeefist on see varieerunud piirides 1,1–5,8 Mg C ha^{-1} a^{-1} (Byrne, Farrell, 2005; Wilson *et al.*, 2012). Turba produtseerimise efektiivsus on võrreldes madalsoodega suurem raba ökosüsteemides, kuid keskmine fütomassi aastaproduktiivsus on suurem madalsooökosüsteemides.

Võrdluseks olgu öeldud, et kõrge boniteediga metsaökosüsteemid leostunud, leetjal ja kahkjal mullal seovad autorite andmetel ühe aasta jooksul ökosüsteemi fütomassi 5,5–6,3 Mg C hektari kohta, millest 1,2–1,9 Mg C ha^{-1} akumuleerub puurinde tüvedesse. Leedemuldadel kasvavate madala boniteediga männikute poolt seotud aastakogused on vastavalt 2,9–3,7 ja 0,17–0,25 Mg C ha^{-1} a^{-1}. Samas ei ole põllu ja kultuurrohumaade ökosüsteemide aastaproduktiivsused metsa omadest sugugi väiksemad. Nii produtseerib kahkjale mullale külvatud rukkipõld 5,1–6,2 Mg C ha^{-1} a^{-1} (sellest terad 0,8–1,3 ja põhk 1,5–2,5), odrapõld 3,7–5,4 Mg C ha^{-1} a^{-1} (sellest terad 1,1–1,4 ja põhk 0,7–1,3) ja kartulipõld 3,3–5,0 Mg C ha^{-1} a^{-1} (sellest mugulad 1,6–2,5) (Kõlli, Kivi, 1974). Seoses pikema kasvuperioodiga on põldheinapõldude aastaproduktiivsus veelgi suurem. Nii on korraliku tehnoloogia korral kahe niite kõrreliste heinasaagid ulatunud 6,3–6,6 ja liblikõieliste omad 5,9–6,4 Mg C ha^{-1} a^{-1} (Older, 2007). Samas moodustab see vaid *ca* kolmandiku aasta kogu juurdekasvust (Bender, 2006).

Taimkatteta turvasmullal uue fütomassi massi tootmist ei toimu, seega ei akumuleeru ka uut turvast. Taimestamata jääkturvaste süsiniku emisioon on kirjandusallikate ülevaate (Wilson *et al.*, 2012) järgi väga suurtes piirides varieeruv, ulatudes 0.6 kuni 11.2 Mg C ha^{-1} a^{-1} kohta, kuid valdavalt on süsiniku emissioon vahemikus 1,9–4,1 Mg C ha^{-1} a^{-1}. Vaatamata kuivendamisele on mõned turbaliigid üsna vastupidavad lagunemisele, mille tõttu tekib soodne olukord, kus kuivendamisega tekkinud suuremad süsinikukaod turvasmuldkattest kompenseeritakse puistute suurema produktiivsuse ehk süsiniku sidumisega taimkattesse (Byrne, Farrell, 2005). Kuid taimestamata turbapinnaste süsiniku aastabilanss on igal juhul negatiivne ja seda mitte ainult CO_2 emissiooni tõttu, vaid ka vees lahustunud orgaanilise süsiniku leostumise kaudu.

Tänuavaldused / Acknowledgments

Täname mullaseire ja uuringute büroo juhatajat Priit Penu, kolleege EMÜ Mullateaduse õppetoolist ja prof Alar Astoveri

Many thanks to head of soil monitoring and research bureau Priit Penu, to colleagues from the Chair of Soil Science of EULS and to prof. Alar Astover.

Huvide konflikt / Conflict of interest

Autorid kinnitavad artikliga seotud huvide konflikti puudumist

The authors declare that there is no conflict of interest regarding the publication of this paper.

Autorite panused / Authors contributions

RK – artikli kontseptsioon ja planeerimine / study conception and design;
RK, EL – andmete kogumine / acquisition of data;
RK – andmete analüüs / analysis of data;
RK, EL – illustreeriva materjali vormistamine / design of figures;
RK – käsikirja mustandi kirjutamine / drafting of manuscript; RK, EL – käsikirja lõplik toimetamine ja heaks kiitmine / critical revision and approval the final version of manuscript.

Technosols in Estonian soil classification: nomenclature, establishment and differences-similarities with normally developed soils

Raimo Kõlli, Enn Leedu
Estonian University of Life Sciences, Institute of Agricultural and Environmental Sciences, Chair of Soil Science, 5 Fr. R. Kreutzwaldi St., 51006 Tartu, Estonia

Summary

Formed on different origin natural and technologically elaborated and relatively voluminous mining wastes soil covers are consist from one or more species of technogenic soils (TS). As a rule by technological works in elaborating TS parent materials much more than only humus cover is enfolded. In the vertical profile of different development stages TS the humus cover, consisting from fine earth subsoil and parent material may be presented. In Estonian Soil Classification (ESC) totally 17 soil species is listed (Table 1). By the mode of their forming or establishment almost four TS groups (formed on heaps of wastes, instead of removed soil cover, on mixed soil horizons with parent materials and buried soil cover) have been separated. TS or Technosols by the World Reference Bases for Soil Resources (WRB) classification, are year 2022 soils of Estonia.

In the work the formed on mineral and organic (mostly peats) origin parent material TS are treated separately. Among mineral TS by their moisture conditions the automorphic, moist and wet soils are distinguished. Among peaty TS the formed on fen (sapric) and bog (fibric) peats soils are prevailed. The main difference between grounds (non-soil) and TS is their functioning. During the starting period of TS development, the permanently functioning assemblage of soil cover and plant cover or soil-plant system have been formed. Formed on non-soil material initial plant cover is the source of in every year formed new organic matter. Newly formed organic matter is needed for nutrition of soil organisms and for initiating biological turnover of chemical elements. As a result of this, the soil owns ability to produce plant phytomass and to proceed soil forming processes.

The concordance or matching of presented in ESC TS' taxa with WRB and Polish Soil Classification taxa was elucidated by the comparable analysis. The distribution and forming of TS in associations with normally developed soils and non-soils (grounds) was characterised by mean of excerpts from digitalized large-scale soil map (1:10,000) and from schematic TS and bare ground distribution maps. In the work as well the peculiarities of establishing technologies of mineral and peaty TS and their character of functioning is treated.

Kasutatud kirjandus / *References*

Astover, A., Reintam, E., Leedu, E., Kõlli, R. 2013. Muldade väliuurimine. – Eesti Maaülikool, Tartu, 70 lk.

Bender, A. (koostaja) 2006. Eritüübiliste rohumaade rajamine ja kasutamine. – EV Põllumajandus–ministeerium, Jõgeva SAI, Jõgeva-Tallinn, 756 lk.

Byrne, K.A., Farrell, E.P. 2005. The effect of afforestation on soil carbon dioxide emissions in blankett peatland in Ireland. – Forestry 78(3):217–227. DOI:10.1093/forestry/cpi020

Carroll, J., Anderson, P., Caporn, S., Eades, P., O'Reilly, C., Bonn, A. 2009. *Sphagnum* in the peak district current status and potential for restoration. – Moors for the Future Report No 16. Derbyshire, UK, 121 p.

Eesti mahajäetud turbatootmisalade revisjon [EMTR] 2005–2008. – Ramst, R., Orru, M., Halliste L., Salo, V. (koostajad); 1. etapp (2005) Harju, Rapla ja Lääne maakond; 2. etapp (2006) Ida-Viru, Lääne-Viru, Jõgeva, Järva ja Tartu maakond; 3. etapp (2007)

Viljandi, Pärnu, Saare, Hiiu maakond ning 4. etapp (2008) Valga, Võru ja Põlva maakond. – Eesti Geoloogiakeskus, Tallinn.
Huot, H., Simonnotc, M.-O., Morela, J.L. 2015. Pedogenetic trends in soils formed in technogenic parent materials. – Soil Science 180(4/5):182–192. DOI: 10.1097/SS.0000000000000135
Höper, H., Augustin, J., Cagampan, J.P., Drösler, M., Lundin, L., Moors, E., Vasander, H., Waddington, J.M., Wilson, D. 2008. Restoration of peatlands and greenhouse gas balances. – In Peatlands and climate change. M. Strack (Ed). – IPS, Jyväskylä, Finland, pp. 182–210.
Ilomets, M. 1994. Turba juurdekasvust Eestis. – Rmt: Eesti Geograafia Seltsi aastaraamat (26. kd). J. Roosaare (toim.) – Teaduste Akadeemia Kirjastus, Tallinn, lk 13–18.
Ilomets, M., Pajula, R., Sepp, K., Truus, L. 2010. Keskkonnakorraldus, Maapõue alamprogramm. – Programmi projekt nr 14, Turba jääkväljade rekultiveerimine turbasammaldega. Lõpparuanne. http://www.ln.ee/files/arts/1011/Turbabe45a5a36afe49d68d387e9d21058a6f.pdf.19.05.2013. Külastatud 10.05.2022
Inisheva, I.I., Zemtsov, A.A., Novikov, S.M. 2011. Vasyugan mire: Natural conditions, structure and functioning. – Tomsk State Pedagogical University Press, Tomsk, Russia, 160 p.
IUSS Working Group WRB. 2015. World reference base for soil resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps. – World Soil Resources Reports 106. FAO, Rome.
Kaar, E., Kiviste, K. (koostajad) 2010. Maavarade kaevandamine ja puistangute rekultiveerimine Eestis. – Eesti Maaülikool, Tartu, 444 lk.
Kaar, E., Lainoja, L., Luik, H., Raid, L., Vaus, M. 1971. Põlevkivikarjääride rekultiveerimine. – Valgus, Tallinn, 116 lk.
Kabała, C., Greinert, A., Charzyński, P., Uzarowicz, L. 2020. Technogenic soils – soils of the year 2020 in Poland. Concept, properties and classification of technogenic soils in Poland. – Soil Science Annual, 71(4):67–280.
Keskkonnaagentuur [KKA] 2019. Statistiline mets: 20 aastat statistilist metsainventeerimist Eestis. – Keskkonnaagentuur, Tallinn, 151 lk.
Kohv, M., Salm, J.-O. 2012. Soode taastamisest Eestis. – Eesti Loodus, 4:10–16.
Kõlli, R., Kivi, E. 1974. Dinamika fitomassõ i zolnogo sostava selskohozjaistvennõh kultur [Dynamics of phytomass and ash composition of agricultural crops]. – EPA teaduslike tööde kogumik, 92:65–119. (In Russian)
Laine, J., Minkkinen, K. 1996. Effect of forest drainage on the carbon balance of a mire. – Scandinavian Journal of Forest Research. 11:307–312.
Leedu, E., Murdam, L. 1996. Eesti põlevkivikarjääride põlluks rekultiveerimisest ja kooritud huumusmulla mikrobioloogilisest seisundist selle säilitamisel. – Agraarteadus, 4(7):342–356.
Lode, E., Sepp, K., Truus, L., Ilomets, M., Pajula, R. 2015. Korrastatavate jääksoode valik. Aruanne. – Ökoloogia Keskus, Loodus- ja Terviseteaduste Instituut, Tallina Ülikool, Tallinn, 199 lk.
Mander, Ü., Järveoja, J., Maddison, M., Soosaar, K., Aavola, A., Ostonen. I., Salm, J.-O. 2012. Reed canary grass cultivation mitigates greenhouse gas emissions from abandoned peat extraction areas. – GCB Bioenergy 4(4):462–474. DOI: 10.1111/j.1757-1707.2011.01138.x
Mäkila, M., Saarnisto, M. 2008. Carbon accumulation in boreal peatlands during the Holocene – impact of climate variations. – In Peatlands and climate change. M. Strack (Ed). – IPS, Jyväskylä, Finland, pp. 24–43.
Nilsson, M., Sagerfors, J., Buffam, I., Laudonw, H., Eriksson, T., Grellez, A., Klemedtsson, L., Weslien, P., Lindroth, A. 2018 Contemporary carbon accumulation in a boreal oligotrophic minerogenic mire – a significant sink after accounting for all C-fluxes. – Global Change Biology 14:1–16. DOI: 10.1111/j.1365-2486.2008.01654.x
Noormets, M., Karp, K., Paal, T. 2003. Recultivation of opencast peat pits with Vaccinium culture in Estonia. – Ecosystems and Sustainable Development. – Wassex Institute of Technology Press, Boston, UK, pp. 1005–1014.
Older, H. 2007. Rohumaade niiteline kasutamine. – Rmt: Rohumaaviljeluse, karjakasvatuse ja haljastuse integratsioon. H. Older (koostaja). – Eesti rohumaade Ühing, Vali press OÜ, Põltsamaa, lk 103–117.
Oleszczuk, R., Regina, K., Szajdak, L., Höper, H., Maryganova, V. 2008. Impacts of Agricultural utilization of peat soils on the greenhouse gas balance. – In Peatlands and climate change. M. Strack (Ed). – IPS, Jyväskylä, Finland, pp, 70–97.
Paal, J. 2011. Jääksood, nende kasutamine ja korrastamine. – Keskkonnainvesteeringute Keskus, Tartu, 167 lk.
Pakalne, M., Ilomets, M., Pajula, R. 2021. Best practice book for peatland restoration and climate change mitigation. Experiences from LIFE peat restore project. – University of Latvia, Riga, 184 p.
Purre, A.-H. 2021. Carbon dioxide dynamics and recovery of vegetation on restored peatlands. – Thesis, Tallinn University. DOI: 10.13140/RG.2.2.18786.45764
Ramst, R., Orru, M. 2009. Eesti mahajäetud turbatootmisalade taastaimestumine. – Eesti põlevloodusvarad ja -jäätmed, 1-2:6–7.
Reintam, L., Kaar E. 1999. Development of soils on calcareous quarry detritus of open-pit oil-shale mining during three decades. – Proceedings of the Estonian Academy of Sciences. Biology, Ecology, 48(4):251–266.
Sarv, I. 1974. Metsa kultiveerimise viisidest Maardu ammendatud fosforiidikarjäärides. – Metsanduslikud uurimused, 11:224–240.

Soosaare soo taastamiskava [SSTK]. 2016. Eesti Looduse Fond, Tartu Ülikool, Arheovisioon. 39 lk.

Starast, M., Karp, K., Paal, T., Värnik, R., Vool, E. 2005. Kultuurmustikas ja selle kasvatamine Eestis. – Eesti Põllumajandusülikool, 65 lk.

Valgepea, M., Raudsaar, M., Karu, H., Suursild, E., Pärt, E., Sims, A., Kauer, K., Astover, A., Maasik, M., Vaasa, A., Kaimre, P. 2021. Maakasutuse, maakasutuse muutuse ja metsanduse sektori sidumisvõimekuse analüüs kuni aastani 2050. – Keskkonnaagentuur, Eesti Maaülikool, 164 lk. DOI: 10.15159/eds.rep.21.01.

Valk, U. 1988. Soode kasutamine. – Rmt: Eesti sood. Valk, U. (toim.). – Valgus, Tallinn, lk 187–217.

Valk, U. 2005. Eesti rabad [Estonian Bogs]: Ecological-Silvicultural Research. – Halo Kirjastus, Tartu, 314 lk.

Wichtmann, W., Schröder, C., Joosten, H. (eds.). 2016. Paludiculture – productive use of wet peatlands. Climate protection - biodiversity - regional economic benefits. – Schweizerbart Science Publishers Stuttgart, Germany, 37 p.

Wilson, D., Renou-Wilson, F., Farrell, C., Bullock, C., Müller, C. 2012. Carbon Restore – The potential of restored Irish peatlands for carbon uptake and storage. – The potential of peatlands for carbon sequestration. CCRP Report 15. – Environmental Protection Agency, Dublin, Ireland. 32 p.

Agraarteadus
1 • XXXIII • 2022 118–123

Journal of Agricultural Science
1 • XXXIII • 2022 118–123

APPLICATION EFFICACY OF NEWLY RELEASED PRE-MIXED HERBICIDE IN WINTER WHEAT: JOYSTICK®

Ebrahim Mamnoie[1], Mohammad Reza Karaminejad[2], Akbar Aliverdi[3], Mehdi Minbashi Moeini[2]

[1]*Plant Protection Research Department, Fars Agricultural and Natural Resources Research and Education Center, AREEO, Janbazan Blvd, Shiraz, 7155863511, Iran*
[2]*Department of Weed Research, Plant Pest and Disease Research Institute, AREEO, Yaman St, Tehran, 1985813111, Iran*
[3]*Department of Agronomy and Plant Breeding, Faculty of Agriculture, Bu-Ali Sina University, Shahid Mostafa Ahmadi Roshan St, Hamedan, 6516738695, Iran*

Saabunud: Received: 29.01.2022

Aktsepteeritud: Accepted: 28.04.2022

Avaldatud veebis: Published online: 28.04.2022

Vastutav autor: Corresponding author: Ebrahim Mamnoie, Akbar Aliverdi

E-mail:
e.mamnoie@areeo.ac.ir (EM)
a.aliverdi@basu.ac.ir (AA)

ORCID:
0000-0001-5993-8456 (EM)
0000-0003-3056-9153 (MRK)
0000-0002-0209-4755 (AA)
0000-0001-8626-6624 (MMM)

Keywords: chemical control, herbicide mixtures, surfactant.

DOI: 10.15159/jas.22.13

ABSTRACT. In a field experiment, the efficacy of the newly released pre-mixed herbicide, Joystick®, in comparison with other pre-mixed herbicides was evaluated in winter wheat, Iran. The treatments included: weedy check, weed-free check (hand-weeded), Bromicide®MA at 600 g a.i. ha^{-1} + Axial® at 60 g a.i. ha^{-1}, Othello® at 96 g a.i. ha^{-1}, Axial One® at 55, 65, 75, and 85 g a.i. ha^{-1}, Joystick® at 80, 94, and 108 g a.i. ha^{-1}. The latter three treatments mentioned were applied with and without non-ionic surfactant Citogate® at 0.1% v v^{-1}. The results revealed that all treatments significantly decreased the density and dry biomass of each weed species and increased the grain yield and biological yield of wheat. The highest performing treatment was Bromicide®MA + Axial®, followed by Joystick® at 108 g a.i. ha^{-1} plus Citogate®. The application of Joystick® at 108 g a.i. ha^{-1} plus Citogate® decreased the biomass of *Malva neglecta, Lolium rigidum, Hirschfeldia incana, Centaurea pallescens, Veronica persica, and Carthamus oxyacantha* up to 96.2, 78.1, 100, 91.0, 91.0, and 96.1%; respectively; with an 88% reduction in total weed dry biomass. Because of Joystick® at 108 g a.i. ha^{-1} plus Citogate® activity against weed species, the grain and biological yields of wheat improved up to 28% as compared to weedy check treatment.

Introduction

Wheat (*Triticum aestivum* L.) is the world's most important food crop belonging to the Poaceae family. In the 2010s, the wheat cultivation area in the world has increased from 215 to 219 million ha, increasing grain production from 640 to 761 million tonnes (FAO, 2020). Like other crops, weeds are considered a limiting factor in the production of wheat. They can reduce the quantity and quality of yield through their competition with wheat for space, light, water, and nutrients (Zimdahl, 2004). In Iran, yield loss of 20–25% has been reported if weeds are not controlled (Zare *et al.*, 2014). Therefore, weed control is very essential to maintain the potential yield in wheat. Currently, chemical weed control is the most important method in wheat because it is generally considered a non-row crop, limiting physical and mechanical weed control methods, leading to the increasing dependence of farmers on herbicides to manage weeds (Melander *et al.*, 2005). Until now, 40 selective herbicides have been labelled for use in wheat. Moreover, there are another 12 herbicides to which wheat is tolerant (Zandstra *et al.*, 2004).

Because of the continuous application of a single mode of action herbicide, weeds can develop resistance. All over the world, 353 out of 509 cases of herbicide-resistant weeds have occurred in wheat. In Iran, 15 out of 16 cases of herbicide-resistant weeds have occurred in wheat (Heap, 2022). Using mixtures of herbicides from a different mode of action is widely accepted to prevent (Lagator *et al.*, 2013) and manage (Comont *et al.*, 2020) herbicide-resistant weed development. When a mixture of herbicides having different modes of action is applied, weeds resistant to one herbicide will be controlled by a partner herbicide existing in the mixture (Abbas *et al.*, 2016). If a resistant weed has a negative cross-resistance, using a herbicide mixture can still control it (Beckie, Reboud, 2009).

In previous studies, the tank-mixed application of herbicides having different modes of action has shown complete control against weeds in wheat (Makvandi *et al.*, 2007; Ebrahim Pour *et al.*, 2012; Idziak *et al.*, 2012; Nazary-Alam *et al.*, 2013; Miklaszewska, Kierzek, 2014; Chan *et al.*, 2018; Pacanoski, Mehmeti, 2018).

Recently, the pre-mixed herbicides of diflufenican + iodosulfuron-methyl-sodium + florasulam were commercially registered with a trading name of Joystick® by Syngenta in 2017. In addition to wheat, this product can also be applied to barley, oats, rye, and triticale to control grasses and broadleaved weeds. According to the label, Joystick® should be applied at 94 g a.i. ha^{-1} (Anonymous, 2017).

The objectives of this research were 1) optimizing the dose of Joystick® by a non-ionic surfactant and 2) comparing its efficacy in comparison with other pre-mixed herbicides (Bromicide®MA, Othello®, and Axial One®).

Materials and Methods

A field experiment was conducted in Darab, Fars Province, Iran (28°45'N and 54°33'E, 1150 m above sea level) having long-term average precipitation of 160 mm yr^{-1}. The soil was a loam clay with 0.68% organic carbon, 7.9 pH, 0.68 dS m^{-1} electrical conductivity, 248 mg kg^{-1} K_2O, and 23 mg kg^{-1} P_2O_5.

The seedbed was fertilized with potassium sulfate at 100 kg ha^{-1} and triple superphosphate at 80 kg ha^{-1}, disc-plugged, and then levelled. The seeds of wheat (*T. aestivum* cv. Mehregan) were planted with a plant density of 400 plants $m^{2\,-1}$ on 28th November 2020. Each plot had a size of 8 × 1.3 m. Each plot consisted of eight rows with a 15 cm row spacing. The plots were one meter apart and watered using a drip irrigation system.

The experimental layout was a randomized complete block design comprising 13 treatments: weedy check, weed-free check (hand-weeded), Bromicide®MA at 600 g a.i. ha^{-1} + Axial® at 60 g a.i. ha^{-1}, Othello® at 96 g a.i. ha^{-1}, Axial One® at 55, 65, 75, and 85 g a.i. ha^{-1}, Joystick® at 80, 94, and 108 g a.i. ha^{-1}. The latter three treatments mentioned were applied with and without non-ionic surfactant Citogate® at 0.1% v v^{-1}. There were four replicates for each treatment. The active substance(s) of herbicide formulations used in this experiment is shown in Table 1. Each plot was divided into two subplots. One subplot was sprayed with the treatments and the other subplot was unsprayed to consider a weedy check treatment for comparison purposes. Herbicide treatments were applied at the stage of tillers formed (Zadoks' scale = 25) using a pressure backpack sprayer. It was equipped with a flat-fan 8002 nozzle and delivered 350 l ha^{-1} at 200 kPa.

Thirty days after spraying, the density of weeds was counted. Weed dry biomass was obtained after oven-drying at 70°C for 48 h. Weed control efficiency (WCE) representing the degree of reduction in the density or dry biomass of weeds due to herbicide treatment was determined using Equation 1.

$$\mathrm{WCE}\ (\%) = \frac{(\mathrm{A}-\mathrm{B})}{\mathrm{A}} \times 100, \tag{1}$$

where, A and B are the density or dry biomass of weeds in the unsprayed and sprayed subplots, respectively (Ghosh *et al.*, 2016).

At the stage of wheat grain ripening (Zadoks' scale = 87), height, no. spikes $m^{2\,-1}$, no. grains $spike^{-1}$ and 1000 grain-weight were measured. At the stage of wheat grain ripening (Zadoks' scale = 92), the grain yield and biological yield of wheat were measured. The changes in each trait of wheat (Y_i), as mentioned above, were determined using Equation 2

$$\mathrm{Y}_i\ (\%) = \frac{Y_s}{Y_u} \times 100, \tag{2}$$

where Y_s and Y_u are the amount of each trait in the sprayed and unsprayed subplots (weedy check treatment), respectively (Ghosh *et al.*, 2016).

Table 1. The active substance(s) of commercial products used in the study

Trade name	Formulation	Active ingrident(s)	Labeled rate	Manufacturer
Axial®	5% EC	Pinoxaden (50 g l^{-1})	60 g a.i. ha^{-1}	Syngenta
Axial One®	5% EC	Pinoxaden (45 g l^{-1}) + Florasulam (5 g l^{-1}) Cloquintocet-mexyl (11.25 g l^{-1}) (safener)	85 g a.i. ha^{-1}	Syngenta
Bromicide®MA	40% EC	Bromoxynil (200 g l^{-1}) + MCPA (200 g l^{-1})	600 g a.i. ha^{-1}	Nofam
Joystick®	47% WG	Diflufenican (400 g kg^{-1}) + Iodosulfuron-methyl-sodium (50 g kg^{-1}) + Florasulam (20 g kg^{-1}) + Cloquintocet-mexyl (100 g kg^{-1}) (safener)	108 g a.i. ha^{-1}	Syngenta
Othello®	6% OD	Diflufenican (50 g l^{-1}) + Iodosulfuron-methyl-sodium (7.5 g l^{-1}) + Mesosulfuron-methyl (2.5 g l^{-1}) + Mefenpyr-diethyl (22.5 g l^{-1}) (safener)	96 g a.i. ha^{-1}	Bayer Crop Science
Citogate®	100%	Alkylaryl polyglycol ether (surfactant)	0.1% v v^{-1}	Zarnegaran

After checking data normality, the data were subjected to analysis of variance using SAS 9.2 software. The means were separated using the Fishers' Least Significant Difference (LSD) test at the 5% level of significance.

Results and Discussion

The relative density and dry biomass of each weed species observed at the experimental site are shown in Table 2. The highest and lowest density was observed on *V. persica* (47.9%) and *H. incana* (6.9%), respectively. While, the highest and lowest weight was observed on *C. pallescens* (22.8%) and *L. rigidum* (10.4%), respectively. The analysis variance of the results of WCE showed the effect of herbicide treatments on the density and dry weight of each weed species (df = 11; $P \leq 0.01$). The best WCE on the density and biomass of each weed species was observed by tank-mixed herbicide Bromicide®MA + Axial®, followed by pre-mixed herbicide Joystick® at 108 g a.i. ha^{-1} along with tank-mixing surfactant Citogate® (Tables 3 and 4). The application of Joystick® at 108 g a.i. ha^{-1} plus Citogate® decreased the biomass of *M. neglecta, L. rigidum, H. incana, C. pallescens, V. persica, and C. oxyacantha* up to 96.2, 78.1, 100, 91.0, 91.0, and 96.1; respectively; with an 88% reduction in total weed dry biomass. Overall, Joystick® was less effective against *L. rigidum* than other weed species. The application of pre-mixed herbicides Othello® at 96 g a.i. ha^{-1}, Axial One® at 75 g a.i. ha^{-1}, and Joystick® at 94 g a.i. ha^{-1} was done based on the label. Among the latter three pre-mixed herbicides mentioned, the WCE on total weed density and dry biomass can be ranked as follows: Othello® > Joystick® > Axial One®. Based on the results of weed density, the WCE of Joystick® in the controlling of *C. pallescens, V. persica, C. Oxyacanthus* was higher than Axial One®. Based on the weed dry biomass results, the WCE of Joystick® improved control of *L. rigidum, C. pallescens, V. persica, C. Oxyacanthus* compared to Axial One®.

Table 2. The relative density and weight of weed species observed at the experimental site

Name	Plant family	Weight, %	Density, %
Carthamus oxyacantha L.	Asteraceae	20.6	13.4
Centaurea pallescens Delile.	Asteraceae	22.8	11.3
Hirschfeldia incana (L.) Lagr. Foss.	Brassicaceae	14.9	6.9
Lolium rigidum L.	Poaceae	10.4	11.6
Malva neglecta Wallr.	Malvaceae	18.6	8.6
Veronica persica Poir.	Plantaginaceae	12.4	47.9

Table 3. The weed control efficiency (%) of treatments on the density of weed species

Treatment	Rate	*M. neglecta*	*L. rigidum*	*H. incana*	*C. pallescens*	*V. persica*	*C. oxyacanthus*	Total
Bromicide®MA + Axial®	600 + 60 g a.i. ha^{-1}	100.0^{a}	80.4^{a}	100.0^{a}	92.3^{a}	92.1^{a}	100.0^{a}	92.86^{a}
Othello®	96 g a.i. ha^{-1}	82.3^{cd}	65.3^{bc}	85.2^{bc}	81.6^{ab}	$73.5^{b–d}$	$65.1^{e–g}$	73.2^{de}
Axial One®	55 g a.i. ha^{-1}	50.0^{h}	40.8^{e}	65.6^{f}	43.7^{f}	41.1^{f}	50.6^{h}	46.3^{j}
Axial One®	65 g a.i. ha^{-1}	60.2^{gh}	45.6^{de}	70.4^{ef}	55.3^{ef}	55.2^{ef}	54.9^{gh}	54.9^{i}
Axial One®	75 g a.i. ha^{-1}	68.0^{fg}	50.4^{de}	75.3^{de}	57.0^{ef}	57.5^{de}	55.4^{gh}	57.8^{hi}
Axial One®	85 g a.i. ha^{-1}	$80.4^{c–e}$	63.7^{bc}	85.3^{bc}	61.4^{de}	60.5^{de}	$75.2^{c–e}$	$64.5^{f–h}$
Joystick®	80 g a.i. ha^{-1}	65.5^{fg}	50.4^{de}	75.5^{de}	$58.8^{d–f}$	58.7^{de}	$60.1^{f–h}$	$59.5^{h–j}$
Joystick®	94 g a.i. ha^{-1}	$75.0^{d–f}$	55.9^{cd}	80.3^{cd}	$63.5^{c–e}$	63.7^{de}	$70.2^{d–f}$	$66.3^{e–g}$
Joystick®	108 g a.i. ha^{-1}	$85.2^{b–d}$	65.8^{bc}	90.0^{b}	$73.4^{b–d}$	$81.8^{a–c}$	84.4^{bc}	79.8^{cd}
Joystick® + Citogate®	80 g a.i. ha^{-1} + 0.1% v v^{-1}	$70.0^{e–g}$	55.6^{dc}	80.3^{cd}	$68.7^{b–e}$	$68.7^{c–e}$	$80.4^{b–d}$	70.5^{ef}
Joystick® + Citogate®	94 g a.i. ha^{-1} + 0.1% v v^{-1}	$90.0^{a–c}$	70.5^{ab}	100.0^{a}	$77.5^{a–c}$	$84.0^{a–c}$	90.6^{ab}	83.6^{bc}
Joystick® + Citogate®	108 g a.i. ha^{-1} + 0.1% v v^{-1}	95.0^{ab}	75.0^{ab}	100.0^{a}	88.8^{a}	88.9^{ab}	95.0^{a}	88.5^{ab}
$LSD_{0.05}$		12.4	13.0	9.0	15.2	15.9	10.3	8.1

In each column, the means followed by the same letter are not significantly different. Citogate® is a non-ionic surfactant.

Table 4. The weed control efficiency (%) of treatments on the dry biomass of weed species

Treatment	Dose	*M. neglecta*	*L. rigidum*	*H. incana*	*C. pallescens*	*V. persica*	*C. oxyacanthus*	Total
Bromicide®MA + Axial®	600 + 60 g a.i. ha^{-1}	100.0^{a}	83.0^{a}	100.0^{a}	95.1^{a}	95.0^{a}	100^{a}	95.8^{a}
Othello®	96 g a.i. ha^{-1}	88.2^{cd}	67.1^{bc}	85.1^{bc}	85.0^{bc}	$75.1^{b–e}$	$76.0^{d–f}$	80.9^{cd}
Axial One®	55 g a.i. ha^{-1}	55.1^{i}	43.2^{e}	65.1^{f}	49.0^{h}	46.0^{g}	60.1^{h}	54.1^{i}
Axial One®	65 g a.i. ha^{-1}	66.1^{h}	48.0^{e}	70.1^{ef}	58.01^{gh}	55.0^{fg}	65.0^{gh}	61.7^{hi}
Axial One®	75 g a.i. ha^{-1}	70.0^{gh}	53.1^{de}	75.1^{de}	60.1^{g}	$59.0^{e–g}$	$68.0^{f–h}$	65.2^{gh}
Axial One®	85 g a.i. ha^{-1}	85.1^{de}	64.1^{bc}	85.1^{bc}	$67.0^{e–g}$	$63.2^{e–g}$	$80.0^{c–e}$	$72.0^{e–g}$
Joystick®	80 g a.i. ha^{-1}	69.1^{h}	52.1^{de}	75.0^{de}	65.0^{fg}	$61.0^{e–g}$	$72.0^{e–g}$	$67.3^{f–h}$
Joystick®	94 g a.i. ha^{-1}	80.0^{ef}	58.2^{cd}	80.0^{cd}	70.4^{ef}	$66.1^{d–f}$	$78.0^{d–e}$	$74.0^{e–f}$
Joystick®	108 g a.i. ha^{-1}	$90.7^{b–d}$	78.0^{a}	90.0^{b}	80.1^{cd}	$82.0^{a–d}$	$90.1^{a–c}$	85.4^{bc}
Joystick® + Citogate®	80 g a.i. ha^{-1} + 0.1% v v^{-1}	76.4^{fg}	59.0^{dc}	80.0^{cd}	75.0^{de}	$71.1^{c–f}$	$86.0^{b–d}$	76.5^{de}
Joystick® + Citogate®	94 g a.i. ha^{-1} + 0.1% v v^{-1}	$94.2^{a–c}$	74.1^{ab}	100.0^{a}	$87.0^{a–c}$	$86.1^{a–c}$	95.0^{ab}	90.6^{ab}
Joystick® + Citogate®	108 g a.i. ha^{-1} + 0.1% v v^{-1}	96.2^{ab}	78.1^{a}	100.0^{a}	91.0^{ab}	91.0^{ab}	96.1^{ab}	92.4^{ab}
$LSD_{0.05}$		6.7	10.0	9.3	9.1	18.2	10.1	8.3

In each column, the means followed by the same letter are not significantly different. Citogate® is a non-ionic surfactant.

The results showed that the reduced doses of Axial One® (55 and 65 g a.i. ha^{-1}) had significantly lower WCE on the density and biomass of each weed species. While the WCE was not affected by a reduction in the dose of Joystick® from 94 to 80 g a.i. ha^{-1} (Tables 3 and 4). On the other hand, the increased dose of Joystick® (108 g a.i. ha^{-1}) improved significantly the WCE on the density and biomass of each weed species. However, the WCE was not affected by an increase in the dose of Axial One® from 75 to 85 g a.i. ha^{-1}.

Previously, it was reported that the tank mixing of Othello® and Atlantis® (a pre-mixed herbicide: mesosulfuron-methyl + iodosulfuron-methyl sodium) can completely control *Polygonum aviculare* L. in wheat (Ebadati *et al.*, 2019). In other studies, the tank mixing of Atlantis® + Bromicide®MA had shown excellent control efficacy against *Convolvulus arvensis* L. in wheat (Zalghi, Saeedipor, 2017). Veisi *et al.* (2018) reported that the tank mixing of Bromoxynil + MCPA could control *Carduus pycnocephalus* L., *Carthamus oxyacantha* M.B., *Galium tricornutum* Dandy, and *Sinapis arvensis* L. up to 100%.

The results showed that the addition of Citogate® to the spray solution could effectively improve the WCE of Joystick®. The treatment of Joystick® at 230 g ha^{-1} plus surfactant Citogate® could provide a favourable WCE; significantly similar to the treatment of Bromicide®MA + Axial®. This treatment reduced the density of *M. neglecta*, *L. rigidum*, *H. incana*, *C. pallescens*, *V. persica*, and *C. oxyacanthus* up to 95.0, 75.0, 100, 88.8, 89.9, and 95.0; respectively; with an 88.5% reduction in total weed density. Moreover, it reduced the dry biomass of *M. neglecta, L. rigidum, H. incana*, *C. pallescens*, *V. persica*, and *C. oxyacanthus* up to 96.2, 78.1, 100, 91.0, 91.0, and 96.1; respectively; with a 92.4% reduction in total weed dry biomass (Tables 3 and 4). It is established that the surface tension of spray solutions can be decreased by adding Citogate® (Aliverdi *et al.*, 2009), decreasing the contact angle of droplets with the surface of the leaf, increasing the deposition of the droplets on the surface of the leaf, increasing herbicide absorption and translocation, subsequently improving herbicide efficacy (da Silva Santos *et al.*, 2021).

The results of analysis variance for the data showed the effect of herbicide treatments on the height, no. spikes $m^{2\,-1}$, no. grains $spike^{-1}$, 1000 grain-weight, grain yield and biological yield of wheat (df = 12; P $\leq$0.01). The height of wheat was significantly decreased with increasing the dose of Joystick® and Axial One®. As compared to weed-free check treatment, increasing the dose of Axial One® from 55 to 85 g a.i. ha^{-1} decreased the height of wheat up to 6%. While increasing the dose of Joystick® from 80 to 108 g a.i. ha^{-1} decreased it up to 4%. Moreover, adding Citogate® to Joystick® spray solution decreased the height of wheat up to 7%. The latter treatment had no significant difference with Othello® (Table 5). The number of spikes $m^{2\,-1}$, the number of grains $spike^{-1}$, and 1000 grain-weight of wheat were increased with increasing dose of Joystick® and Axial One®. Adding Citogate® to Joystick® spray solution increased the number of spikes $m^{2\,-1}$, the number of grains $spike^{-1}$, and 1000 grain-weight of wheat up to 10, 23, and 27% as compared to weed-free check treatment, respectively (Table 5). In general, the changes of 1000 grain-weight were less than the number of spikes $m^{2\,-1}$ and the number of grains $spike^{-1}$. The number of spikes $m^{2\,-1}$ and the number of grains $spike^{-1}$ of wheat were dependent on the WCE of herbicides. Already, it is established that the greater the WCE of herbicides, the more the number of spikes $m^{2\,-1}$ and grains $spike^{-1}$ of wheat (Mahmood *et al.*, 2013; Mamnoie, Karaminejad, 2020). The grain and biological yields of wheat were improved by increasing the dose of Joystick® and Axial One®. Moreover, adding Citogate® to Joystick® spray solution significantly improved the grain and biological yields of wheat. The treatment of Joystick® at 108 g a.i. ha^{-1} plus Citogate® showed the greatest overall control after the weed-free check treatment (Table 6). Because of the WCE by Joystick® at 108 g a.i. ha^{-1} plus Citogate®, the grain and biological yields of wheat improved up to 28% as compared to the weedy check treatment. The improvement in the grain and biological yields of wheat have already been reported by Manea *et al.* (2016) using pinoxaden + florasulam, Makvandi *et al.* (2007) using tribenuron-methyl + diclofop-methyl, Ebadati *et al.* (2019) using mesosulfuron-methyl + iodosulfuron-methyl-sodium, and Mohammaddoust *et al.* (2011) using 2,4-D + MCPA.

Table 5. The effect of treatments on some wheat traits and the changes (%) in each trait in comparison with weedy check treatment

Treatment	Dose	Height		No. spikes $m^{2\,-1}$		No. grains $spike^{-1}$		1000 grain weight	
		cm	%	no.	%	no.	%	g	%
Bromicide®MA + Axial®	600 + 60 g a.i. ha^{-1}	90.2^{a-d}	100^{a}	446^{ab}	28.5^{a}	32.0^{a-c}	21.9^{ab}	42.2^{a-c}	10.5^{ab}
Othello®	96 g a.i. ha^{-1}	87.6^{d}	94.9^{b}	427^{a-e}	25.2^{a-c}	32.0^{a-c}	21.9^{ab}	41.5^{a-d}	10.2^{ab}
Axial One®	55 g a.i. ha^{-1}	94.4^{ab}	100.0^{a}	401^{e}	14.1^{e}	26.0^{g}	11.8^{f}	39.5^{d}	5.3^{c}
Axial One®	65 g a.i. ha^{-1}	93.1^{a-c}	100.0^{a}	405^{de}	15.2^{de}	27.0^{fg}	12.4^{ef}	39.8^{cd}	5.8^{c}
Axial One®	75 g a.i. ha^{-1}	88.7^{cd}	96.5^{ab}	409^{c-d}	16.4^{de}	28.0^{e-g}	13.1^{ef}	40.1^{cd}	7.6^{bc}
Axial One®	85 g a.i. ha^{-1}	87.6^{d}	94.9^{b}	418^{b-e}	20.5^{b-e}	30.0^{c-e}	17.6^{cd}	40.9^{a-d}	9.2^{ab}
Joystick®	80 g a.i. ha^{-1}	93.4^{a-c}	100.0^{a}	413^{c-e}	18.2^{c-e}	29.0^{d-f}	15.5^{de}	40.0^{cd}	9.7^{ab}
Joystick®	94 g a.i. ha^{-1}	89.0^{b-d}	97.4^{ab}	421^{b-e}	22.8^{a-d}	30.0^{c-e}	18.8^{b-d}	40.5^{b-d}	8.4^{a-c}
Joystick®	108 g a.i. ha^{-1}	88.8^{cd}	96.4^{ab}	429^{a-e}	25.8^{a-c}	31.0^{b-d}	19.2^{bc}	41.4^{a-d}	9.9^{ab}
Joystick® + Citogate®	80 g a.i. ha^{-1} + 0.1% v v^{-1}	91.3^{a-d}	100.0^{a}	425^{a-e}	21.9^{a-e}	31.0^{b-d}	21.5^{ab}	41.2^{a-d}	9.7^{ab}
Joystick® + Citogate®	94 g a.i. ha^{-1} + 0.1% v v^{-1}	89.6^{b-d}	100.0^{a}	433^{a-d}	26.7^{ab}	33.0^{ab}	22.2^{ab}	42.7^{ab}	10.7^{ab}
Joystick® + Citogate®	108 g a.i. ha^{-1} + 0.1% v v^{-1}	87.5^{d}	93.9^{b}	438^{a-c}	27.6^{ab}	34.0^{a}	23.6^{a}	42.9^{a}	10.8^{a}
Hand–weeded	–	95.0^{a}	100.0^{a}	455^{a}	29.2^{a}	34.5^{a}	24.3^{a}	43.0^{a}	11.0^{a}
$LSD_{0.05}$		5.3	4.7	31.0	7.9	2.9	3.6	2.3	3.1

In each column, the means followed by the same letter are not significantly different. Citogate® is a non-ionic surfactant.

Table 6. The effect of treatments on the grain and biological yields of wheat and their changes (%) in comparison with weedy check treatment

Treatment	Dose	Grain yield		Biological yield	
		t ha^{-1}	%	t ha^{-1}	%
Bromicide®MA + Axial®	600 + 60 g a.i. ha^{-1}	5.61$^{a–d}$	26.1^{ab}	15.3^{a}	26.0$^{a–c}$
Othello®	96 g a.i. ha^{-1}	5.4$^{a–e}$	25.1$^{a–c}$	14.6^{a}	25.1$^{a–c}$
Axial One®	55 g a.i. ha^{-1}	4.0^{f}	8.1^{e}	10.8^{d}	8.0^{g}
Axial One®	65 g a.i. ha^{-1}	4.1^{f}	10.0^{de}	11.3^{cd}	10.1^{g}
Axial One®	75 g a.i. ha^{-1}	4.2^{f}	13.0$^{c–e}$	11.4^{cd}	13.0^{fg}
Axial One®	85 g a.i. ha^{-1}	4.6$^{d–f}$	19.0$^{a–e}$	12.3^{cd}	19.0^{de}
Joystick®	80 g a.i. ha^{-1}	4.3^{ef}	16.1$^{b–e}$	12.1^{cd}	16.1^{ef}
Joystick®	94 g a.i. ha^{-1}	4.8$^{c–f}$	22.1$^{a–d}$	12.8$^{b–d}$	22.0^{cd}
Joystick®	108 g a.i. ha^{-1}	5.0$^{b–f}$	24.0$^{a–c}$	13.1^{bc}	24.0$^{b–d}$
Joystick® + Citogate®	80 g a.i. ha^{-1} + 0.1% v v^{-1}	5.3$^{a–e}$	25.0$^{a–c}$	14.5^{ab}	25.1$^{a–c}$
Joystick® + Citogate®	94 g a.i. ha^{-1} + 0.1% v v^{-1}	5.7$^{a–c}$	27.1^{ab}	15.5^{a}	27.1$^{a–c}$
Joystick® + Citogate®	108 g a.i. ha^{-1} + 0.1% v v^{-1}	5.9^{ab}	28.0^{ab}	15.6^{a}	28.0^{ab}
Hand–weeded	–	6.1^{a}	30.0^{a}	15.9^{a}	29.8^{a}
$LSD_{0.05}$		1.1	12.7	2.1	5.7

In each column, the means followed by the same letter are not significantly different. Citogate® is a non-ionic surfactant.

Conclusion

Based on the current results, it is not possible to recommend a reduced dose of Axial One® to control the weeds in wheat. Tank-mixing Bromicide®MA + Axial® can be effectively applied in wheat giving excellent control of broadleaf and grass weeds. Because of the weed control efficacy of Bromicide®MA + Axial®, the grain yields of wheat could be improved. The focus of this study was on the efficacy of the newly released pre-mixed herbicides, Joystick®. Joystick® applied at the labelled dose (108 g a.i. ha^{-1}) could control the density of weed species by 55–80% and the dry biomass of weed species by 60–80%. At the labelled rate, it did not provide improved control compared with the efficacy of the existing pre-mixed herbicide, Othello®. Increasing the dose of Joystick® (up to 108 g a.i. ha^{-1}) along with adding the nonionic surfactant, Citogate® improve weed control and should be a potential herbicide for use in wheat. When these two recommendations were applied, the density and dry biomass of weed species could be reduced by 75–100%.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contributions

EM – analysis and interpretation of data
MRK – acquisition of data
AA – writing, revision, and approve the final manuscript
MMM – acquisition of data

References

Abbas, T., Nadeem, M.A., Tanveer, A., Ahmad, R. 2016. Identifying optimum herbicide mixtures to manage and avoid fenoxaprop-p-ethyl resistant phalaris minor in wheat. – Planta Daninha, 34:787–793. DOI: 10.1590/S0100-83582016340400019

Aliverdi, A., Rashed-Mohassel, M.H, Zand, E, Nassiri-Mahallati, M. 2009. Increased foliar activity of clodinafop-propargyl and/or tribenuron-methyl by surfactants and their synergistic action on wild oat (*Avena ludoviciana*) and wild mustard (*Sinapis arvensis*). – Weed Biology and Management, 9:292–299. DOI: 10.1111/j.1445-6664.2009.00353.x

Anonymous. 2017. Registration report, part A. National Assessment Country France. SAP405210 WGH (Joystick®). URL: https://www.anses.fr/fr/system/files/phyto/evaluations/JOYSTICK_PAMM_2014-3624_PARTA.pdf Accessed on 25/04/2022

Beckie, H.J., Reboud, X. 2009. Selecting for weed resistance: herbicide rotation and mixture. – Weed Technology, 23:363–370. DOI: 10.1614/WT-09-008.1

Chan, B.S.H., Chiew, A.L., Grainger, S., Page, C.B., Gault, A., Mostafa, A., Roberts, M.S., Buckley N.A., Isbister, G.K. 2018. Bromoxynil and 2-methyl-4-chlorophenoxyacetic acid (MCPA) poisoning could be a bad combination. – Clinical Toxicology, 56: 861–863. DOI: 10.1080/15563650.2018.1433299

Comont, D., Lowe, C., Hull, R., Crook, L., Hicks, H.L., Onkokesung, N., Beffa, R., Childs, D.Z., Edwards, R., Freckleton, R.P., Neve P. 2020. Evolution of generalist resistance to herbicide mixtures reveals a trade-off in resistance management. – Nature Communications, 11:3086. DOI: 10.1038/s41467-020-16896-0

da Silva Santos, R.T., Vechia, J.F.D., dos Santos, C.A.M. Almeida, D.P., da Costa Ferreira M. 2021. Relationship of contact angle of spray solution on leaf surfaces with weed control. – Scientifc Reports, 11: 9886. DOI: 10.1038/s41598-021-89382-2

Ebadati, A., Gholamalipour-Alamdari, E., Avasaji, Z., Rahemi-Karizaki, A. 2019. Effect of application time of dual purpose herbicides and mixing herbicides on weeds control and wheat yield. – Journal of Plant Ecophysiology, 39: 192–209. [In Persian]

Ebrahim Pour, F., Mousawi, S.H., Moshatati, A., Mousavian, S.M. 2012. Effects of application time of chevalier herbicide and mixture of illoxan with granstar on wheat and weed in Ahwaz. – Electronic Journal of Crop Production, 4(1):31–42. [In Persian]

FAO. 2020. FAOSTAT database. – https://www.fao.org Accessed on 25/04/2022

Ghosh, D., Singh, U.P., Ray K., Das, A. 2016. Weed management through herbicide application in direct-seeded rice and yield modeling by artificial neural network. – Spanish Journal of Agricultural Research, 14: e1003. DOI: 10.5424/sjar/2016142-8773

Heap, I. 2022. The international survey of herbicide resistant weeds. – http://weedscience.com/Home.aspx Accessed on 25/04/2022

Idziak, R., Kierzek, R., Sip, D., Krawczyk, R. 2012. Possibility of using pinoksaden and florasulam in mixtures with other herbicides for weed control in winter wheat. – Progress in Plant Protection, 52:898–902. DOI: 10.14199/ppp-2012-154

Lagator, M., Vogwill, T., Mead, A., Colegrave, N., Neve, P. 2013. Herbicide mixtures at high doses slow the evolution of resistance in experimentally evolving populations of *Chlamydomonas reinhardtii*. – New Phytologist, 198:938–945. DOI: 10.1111/nph.12195

Mahmood, A., Iqbal, J., Chattha, M.B., Azhar, G.S. 2013. Evaluation of various herbicides for controlling grassy weeds in wheat. – Mycopath, 11:39–44.

Makvandi, M.A., Erzadeh, S.H., Golabi, M. 2007. Evaluation of herbicide and micronutrient combining efficiency in weed control and wheat yield. – Journal of Agricultural Science, 30: 125–133.

Mamnoie, E., Karaminejad, M.R. 2020. Evaluation time and rate application of prosulfocarb herbicide in the weed control of wheat in South Kerman. – Journal of Crop Production, 13: 51–66. DOI: 10.22069/EJCP.2020.17165.2269

Melander, B., Rasmussen, I.A., Bàrberi, P. 2005. Integrating physical and cultural methods of weed control: examples from European research. – Weed Science, 53:369–381. DOI: 10.1614/WS-04-136R

Miklaszewska, K., Kierzek, R. 2014. Efficacy of lower doses of aminopyralid + piroksysulam + florasulam (Lancet Plus 125 WG) applied with adjuvant in winter wheat. – Progress in Plant Protection, 54:451–455. DOI: 10.14199/PPP-2014-076

Mohammaddoust, H.R., Pourmorad, B., Asghari, A. 2011. The effect of nitrogen application and 2,4-D on weed density and weed architecture in winter wheat. – Iranian Plant Protection Research, 25:145–151. DOI: 10.22067/ JPP.V25I2.10101

Manea, D.N., Ştef, R., Pet, I., Ienciu, A.A., Grozea, I., Carabet, A. 2016. Control of *Avena fatua* Species (wild oat) - a weed in expansion in banat area. – Bulletin UASVM Agriculture 73 (1):44–48. DOI: 10.15835/buasvmcn-agr:12008

Nazary-Alam, J., Mousavi, V., Sihrabi, N., Sadeghi, N., Sadeghi-Shoa, M. 2013. Evaluation of herbicide for *Cerastium* sp. and *Vaccaria* sp. weed control in wheat (*Triticum aestivum* L.) fields of Lorestan, Alashtar. – Iranian Journal of Agronomy and Plant Breeding, 9: 55–65.

Pacanoski, Z., Mehmeti, A. 2018. POST herbicide programme for effective weed control in winter wheat (*Triticum aestivum* L.). – Agronomy Research, 16: 1796–1808. DOI: 10.15159/AR.18.177

Veisi, M., Baghestani, M.A., Minbashi, M.M. 2018. Study of tank mix application of dual propose and broad leaf herbicides for weed control in wheat fields. – Iranian Journal of Field Crop Science, 49:171–183. DOI: 10.22059/IJFCS.2017.228155.654282

Zalghi, Z., Saeedipor, S. 2017. Study the efficiency of Atlantis and its mixture with Duplosan Super and Bromicide MA herbicides for weeds controlling of wheat. – Journal of Plant Ecophysiology, 9:165–173.

Zandstra, B., Particka, P., Masabni, J. 2004. Guide to tolerance of crops and susceptibility of weeds to herbicides. – Extension Bulletin E-2833. Michigan State University, USA, 147 p.

Zare, A., Miri, H.R., Jafari, B. 2014. Effect of plant density and reduced dosages of iodosulfuron + mesosulfuron (Atlantis) on integrated weed management in wheat. – Journal of Plant Ecophysiology, 6: 38–93.

Zimdahl, R.L. 2004. Weed-crop competition: a review. (2nd Ed.). – John Wiley and Sons, New York, USA, 220 p.

Agraarteadus
1 • XXXIII • 2022 124–127

Journal of Agricultural Science
1 • XXXIII • 2022 124–127

SHORT COMMUNICATION: GUTTATION OF OAT AND WHEAT AND THE RESULTS OF ITS COMPARISON WITH THE YIELD

Edvin Nugis[1], Jaan Kuht[2]

[1]*Estonian Crop Research Institute, J. Aamisepa 1, 48309 Jõgeva, Jõgeva vald, Estonia*
[2]*Estonian University of Life Sciences, Fr. R. Kreutzwaldi 1, 51014 Tartu, Estonia*

Saabunud: Received: 14.10.2021

Aktsepteeritud: Accepted: 05.04.2022

Avaldatud veebis: Published online: 05.04.2022

Vastutav autor: Corresponding author: Edvin Nugis

E-mail: edvin.nugis@mail.ee

ORCID:
0000-0003-4444-7114 (EN)
0000-0002-9810-6035 (JK)

Keywords: relative guttation, relative yield, laboratory tests, spring wheat, oat.

DOI: 10.15159/jas.22.06

ABSTRACT. The present paper aims to give an overview of results collected in the Estonian Crop Research Institute related to the comparison between guttation and yield in grain crop cereals. The objects of research were oat variety 'Eugen' and wheat 'Manu', which went through the stages of germinating their seeds (*in vitro*), set them by sprouts down into the soil, and the emergence of sprouts under conditions of a hydrothermostat. Since transpiration in a hydrothermostat at an air temperature of 23 °C, and an extremely high value of air relative humidity was limited, therefore, due to this, the plant sprouts have begun to exude guttation fluid. As result, we have found that the amount of isolated gutted fluid correlates significantly with the grain yields of field trials indicators. The comparison between relative guttation and relative yield was described by a straightforward relationship. The entire experiment took about one week, and the first results of droplet prints on filter paper can be obtained after 60 hours. This was the novelty of our approach which provides the prerequisites for both increasing the reliability of conclusions regarding the yield obtained and its forecast.

Introduction

It is well known that during guttation fluid is released from the hydathode of the plant seedling (cereal) always if the amount of moisture becomes higher than its release during evaporation through the plant seedling (Barrs, 1966; Tumanov, Chiruk, 2012; Jauneau *et al.*, 2020). It should be noted that all this was known for a long time (Shardakov, 1928; Logvenkov, 1993).

In Estonia, the guttation method has used for the first time in the Estonian Research Institute of Agriculture and Land Improvement (Reppo, 1977).

The first time in Estonia was found a practical application how to use better this phenomenon in agricultural research (Kuht, Reintam, 2001; Nugis, Kuht, 2013; Nugis *et al.*, 2020). When it comes to determining the relationship between guttation and yield, then in earlier periods this problem was not the priority. Although the authors have long noted (Goatley, Lewis, 1966; Dieffenbach *et al.*, 1980; Tumanov, Chiruk, 2012) that the guttation fluid secreted by the sprout can be a good indicator as it quickly reacts to any changes in the soil conditions. In addition, an important question is at what physical state of the soil can be achieved in experiments with guttation the expected result. Here the problem rests on the assessment of soil compaction (Nugis *et al.*, 2020) and the assessment of water's biohydrological constants (Reppo, 1980). In the first case, the guttation plant responds by the amount of released guttation fluid to the bulk density of the soil, and in the second case, to its water content.

Nevertheless, it seems to us that such a simple and operational method is far from exhausting the possibilities of studying the soil. Production capability and containing both useful and negative chemical elements in the soil, as well as various harmful toxins that affect not only the health of the soil but also the quality of agricultural products.

A distinctive feature of these studies is that laboratory experiments were carried out in the course of field experiments of the Estonian Crop Research Institute (Edesi *et al.*, 2016; Kangor *et al.*, 2017).

In general, the problem of guttation can be approached with varying elaboration. We have chosen the easiest and most understandable way for the farmer, how to have an idea of the upcoming expected yield even before sowing already.

Material and Methods

The laboratory experiments were carried out (2015–2016) in the Saku Sector laboratory of the Estonian Crop Research Institute (ECRI). Work were supported by PhD L. Edesi (ECRI, seeds of 'Eugen'), and MSc T. Kangor (ECRI, seeds of 'Manu') from whose experimental fields soil samples were taken and seeds of the same crops were obtained. It should be noted that we did not determined plant yield and we have used some data from L. Edesi and T. Kangor.

The first stage of laboratory tests was germinating of seeds of the spring wheat (variety 'Manu') and oat (variety 'Eugen') at a temperature of 23 °C in a special thermostat TPS-3 for germinating seeds. At the same time, the thermostat for germinating seeds was previously converted into a hydrothermostat where all the free parts of the shelves were occupied under the containers with water. Due to this, a setting in the hydrothermostat where the relative humidity of the air was more than 90%, was created.

The germination process usually takes 24 hours. After that, the germinated seeds, five pieces per cylinder (270 cm^3 in volume; 6.4 cm in diameter and 8.4 cm in height) were introduced into the soil with three replicates of downward directed shoots (Nugis, Kuht, 2013). For this, a special stencil was used. Previously, the hole in the soil of the cylinder at a depth of 7 mm for wheat and 12 mm for oat were made.

The appearance of the first shoots in the cylinders with water drops on them, *i.e.* the guttation fluid could be seen after 48 hours. For fixing the guttation fluid, we are specially prepared 2x6 cm pieces of filter paper by which we have collected water droplets from the surface of the sprouts. Since the leaves of the filter paper were pre-treated with a 5% solution of copper sulphite and were well dried the water droplets were distinguishable on them. To facilitate the processing of the areas, the splotch on the filter paper (drop trace) had to be drawn around with a pen (Fig. 1).

Guttation fluid was collected three times a day every five hours. In total, it was possible to fix the guttation fluid on filter paper also once and the next day after which the collection ended. Since the roots of the plant had already reached the bottom of the cylinder and the results of collecting the guttation fluid turned out to be implausible. The processing of guttation fluid splotch on filter paper was carried out digitally by using the Foxit PDF Reader 8.3. Whereby which with the help of the corresponding blot areas (cm^2) were determined. The amount of guttation fluid was estimated with the help of the corresponding blot areas.

When recalculating areas in the values of relative units, we took the largest area as a unit and all other areas were calculated relative to this largest area. At the same time, it should be noted that a distinctive feature of this technique is that when receiving data on the harvest, we could not take into account copyright protection, claim their result. Therefore, we also presented the yield data in relative units. For example, the highest splotch value of guttation fluid on the filter paper, which was set at one relative unit, was 2.21 cm^2, and the yield was 5330 kg ha^{-1}, respectively (Fig. 2).

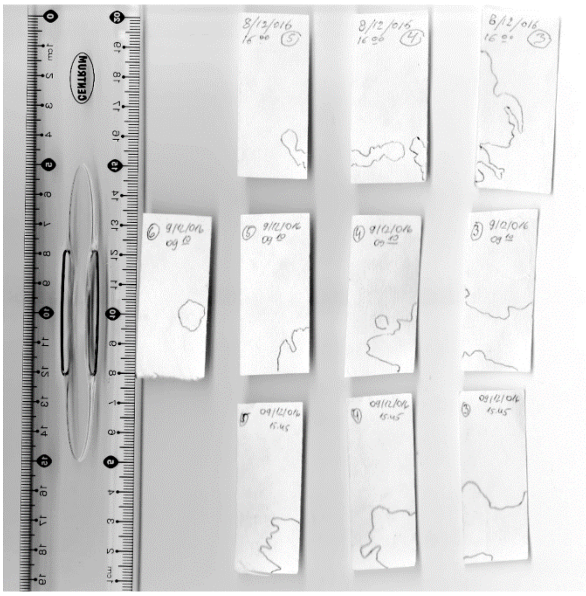


Figure 1. Example of splotch (drop trace) of guttation fluid on filter paper

What were the experimental treatments and in what soil and climatic conditions the field experiments were carried out for us, in this case, did not matter. The main thing for us was to carry out laboratory experiments on guttation with identical soils and with identical seeds.

The statistical estimation of data of the areas of a splotch of the guttation fluid and corresponding yield has been carried out by Student T-test at 0.05 significance level. The least significant difference (LSD) test as of right was used. In addition, the correlation coefficient (r) was calculated through the coefficient of determination (R^2) taking from it the square root.

Results and Discussion

The results of laboratory experiments on guttation with a variety of oat 'Eugen' are shown in Figure 2, and for spring wheat 'Manu' in Figure 3. Based on the above principles of treatments regarding the details of field experiments it can be seen that as different variants of experiments and different soil and climatic conditions did not have a significant outside influence on the relationship between guttation and yield. At the same time, attention is drawn to the rather high value of the coefficient of correlation (r).

According to the interaction between guttation and yield are shown in Figure 3, a strictly linear relationship with a very high coefficient of correlation (r) draws attention.

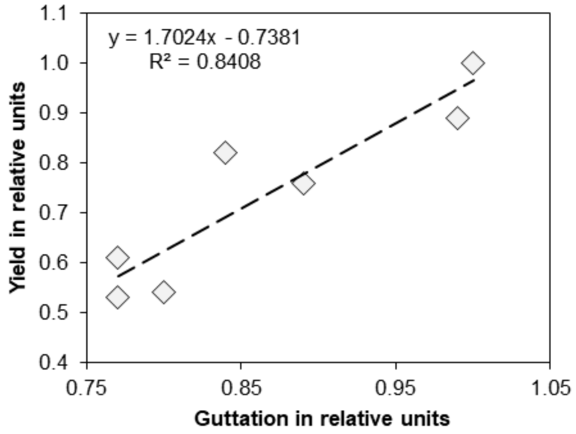


Figure 2. Results of guttation and comparison with the yield for variety 'Eugen' oat
Note: For relative yield $LSD_{0.05}$ = 0.17; for relative guttation $LSD_{0.05}$ = 0.09. Soil bulk density in the cylinder during laboratory tests was 1.15 ± 0.02 Mg m^{3-1} and water content was 23.0 ± 1.8%(kg kg^{-1}). The correlation coefficient r = 0.92

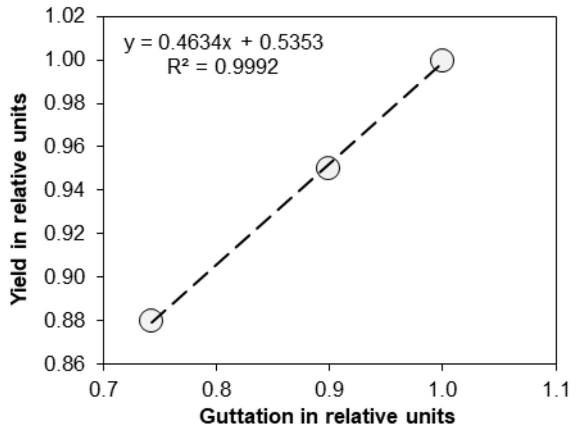


Figure 3. Results of guttation and comparison with the yield for variety 'Manu' spring wheat
Note: For relative yield $LSD_{0.05}$ = 0.32; for relative guttation $LSD_{0.05}$ = 0.15. Soil bulk density in the cylinder during laboratory tests 1.15 ± 0.02 Mg m^{3-1} and water content 19.8 ± 0.6%(kg kg^{-1}). The correlation coefficient r = 0.995

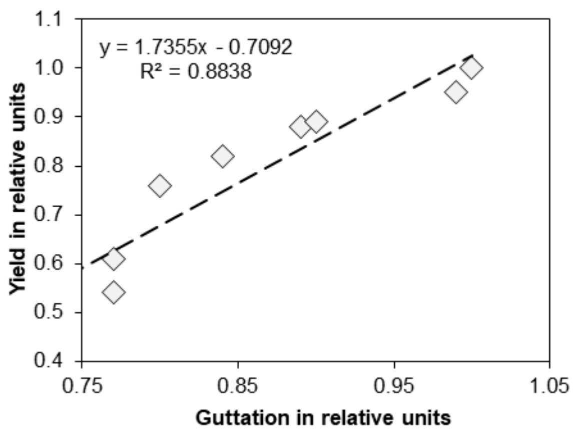


Figure 4. Results of guttation and comparison with the yield for oat (variety 'Eugen') and spring wheat (variety 'Manu') as a total
Note: for relative yield $LSD_{0.05}$ = 0.25; for relative guttation $LSD_{0.05}$ = 0.14. Soil bulk density in the cylinder during laboratory tests was 1.15 ± 0.02 Mg m^{3-1} and water content was 23.0 ± 1.8% (kg kg^{-1}) and 19.8 ± 0.6% (kg kg^{-1}). The correlation coefficient was r = 0.94.

Since for both types of cereals, the above results (Figs. 2, 3) of the soil physical properties did not differ significantly, therefore, it will be possible to combine the results obtained as a whole (Fig. 4).

Based on the obtained graph (Fig. 4), it can be emphasized that in the presence of various variants of experiments as well as different types of cereals, not to mention their different varieties, a rather close relationship was obtained between the guttation of seed sprouts and their final yield obtained during field experiments.

When analyzing the works of other authors (Goatley, Lewis, 1966; Dieffenbach *et al.*, 1980; Singh, Singh, 2013), none of them, except (Singh, 2014), with the thoroughness and depth of their study, did not establish the relationship between guttation and yield. Singh (2014) emphasizes the relationship between guttation and biological yield. One cannot but agree with this, but in our case, we claimed the results that are closer to the real practical situation of current agriculture.

If we restrict ourselves without using the guttation method only on the results of field experiments (at least 3-year data are required), then due to difficult weather conditions, harvests, depending on the various variants of experiments, cannot always give a reliable result. Since in laboratory experiments all the variants of the experiments under consideration are in the same conditions, it is quite clear that here the results will naturally be more reliable.

Also noteworthy is the fact that the possibilities of using the guttation method are far from being exhausted. A good example can be the studies of the authors (Goatley, Lewis, 1966; Singh, 2014) who, for the main cereals such as wheat, oat, barley and rye, set in a drop of isolated guttation fluid many chemical elements, such as amino acid, asparagine, pyridoxine *etc*., and to say nothing of pesticides. Such an example prompted us to think (Curtis, 1944) why not use the guttation method, in addition to our studies, as an indicator for assessing glyphosate residues in the soil. If by analogy, in a dairy farm, the feed was not of high quality, then this immediately affects the quality of milk. In our case is analogical, the clean (without glyphosates) of the isolated drop of guttation fluid on the sprout of grain crops provide prompt information about the cleanliness of the soil.

Finally, we can focus on the fact that based on our research and the examples given, we can be convinced of what many opportunities we could have if we use the guttation method in agricultural science and practice.

Conclusion

The present research has revealed the results of guttation and comparison with the yield when using 'Eugen' variety of oat and 'Manu' variety of spring wheat. This relationship for both, *i.e.* oat and spring wheat, has a strictly linear relationship with a sufficiently high coefficient of correlation (r). At the same time, when used with oat during field experiments, various experimental treatments and soil conditions did not have any significant effect on the specified relationship.

When considering the specified relationship for oat and spring wheat together, a similar linear relationship was obtained, which is the basis for the conclusion that many varieties and types of cereals do not provide a basis for confirming the relationship between guttation and yield will not have a linear relationship.

The guttation method has not lost its significance now and is a valid method for predicting the yield.

Acknowledgements

We are sincerely grateful to the Estonian University of Life Sciences, to the Estonian Academic Agricultural Society and to the Estonian Crop Research Institute including PhD Liina Edesi and MSc Tiia Kangor particularly.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

EN 60%, JK 40% − study of the concept and design;
EN 65%, JK 35% − data collection;
EN 65%, JK 35% − analysis and interpretation of data;
EN 75%, JK 25% − writing a manuscript;
EN 55%, JK 45% − critical revision and approval of the final manuscript.

References

Barrs, H.D. 1966. Root pressure and leaf water potential. – Science 152:1266–1268. DOI: 10.1126/science.152.3726.1266

Curtis, L.C. 1944. The influence of guttation fluid on pesticides. – Phytopathology 34:196–205.

Dieffenbach, H., Kramer, D., Lüttge, U. 1980. Release of guttation fluid from passive hydathodes of intact barley plants. I. Structural and cytological aspects. – Annals of Botany 45:397–401. DOI: 10.1093/oxfordjournals.aob.a085837

Edesi, L., Vettik, R. Võsa, T., Ilumäe, E., Karron (Akk), E., Plakk, T., Nugis, E., Kangor, T. 2016. Projekti „Ülevaade alternatiivsete mullaparandusainete kasutusvõimalustest ja tehnoloogiatest mahepõllumajanduslikus taimekasvatuses„ lõpparuanne. – Eesti Taimekasvatuse Instituut, 37 lk, http://www.maheklubi.ee/upload/Editor/alternatiivsed_mullaparandusained.pdf Viimati külastatud 01.10.2022

Goatley, J.L., Lewis, R.W. 1966. Composition of guttation fluid from rye, wheat, and barley seedlings. – Plant Physiology, 41:373–375. DOI: 10.1104/pp.41.3.373

Jauneau, A., Cerutti, A., Auriac, M.-C., Noël, L.D. 2020. Anatomy of epithemal hydathodes in four monocotyledon plants of economic and academic relevance. – PLoS ONE 15(9):e0232566. DOI: 10.1371/journal.pone.0232566

Kangor, T., Tamm, I., Tamm, Ü. 2017. Sordilehe suvinisu uute sortide tendentsid. – Taimekasvatuse alased uuringud Eestis 2017. Taimekasvatus 2017 konverentikogumik. Tupits, I., Tamm, S., Tamm, Ü., Toe, A. Eesti Taimekasvatuse Instituut, Eesti Maaülikool, Eesti, lk 68–78.

Kuht, J., Reintam, E. 2001. The impact of deep rooted plants on the qualities of compacted soils. – 10th International Soil Conservation Organization Meeting (May 24-29, 1999), Stott, D.E., Mohtar, R.H. and Steinhardt, G.C. (eds.), Purdue University, USDA-ARS National Soil Erosion Research Laboratory, pp. 632–636.

Logvenkov, S.A., 1993. O mehanizme guttacii u rastenij [The guttation mechanism in plants]. – Biofizika, 38(5):889–894. (In Russian)

Nugis, E., Tamm, K., Võsa, T., Plakk, T., Palge, V. 2020. Express-diagnostics method for assessment of soil compaction for different cultivation methods. Agraarteadus, 1(31):53–65. DOI: 10.15159/jas.20.04.

Nugis, E., Kuht, J. 2013. Method for assessment of soil physical properties by means of guttation plant. – Patent EE 05682 B1 - 2013-10-15.

Reppo, E. 1977. Opredelenie vlazhnosti pochvy metodom guttacii rastenij v faze prorastanija semjan [Determination of soil moisture by the method of plant guttation in the phase of seed germination]. Pochvovedenie] – Pochvovedenie, 12:98–110. (In Russian)

Reppo, E. 1980. Ocenka vlazhnosti avtomorfnyh pochv Estonii [Assessment of humidity of the Estonian automorphic soils]. – V Sb. Teoreticheskie osnovy i metody opredelenija optimal'nyh parametrov svoistv pochv [In Coll. Theoretical bases and methods for determination of optimum soil properties parameters]. Pochvennyi nauchno-issledovatal'skij institut im. Dokuchaeva [Docuchaev's Soil Research Institute], Moscow, 99–104. (In Russian)

Shardakov, S. 1928. K voprosu o fiziologicheskom znachenii guttacii [About the physiological meaning of guttation]. – Izvestiya Biologicheskogo Nauchno-Issledovatelskogo Instituta i Biologicheskoy stancii pri Permskom Gosudarstvennom Universitete, 6(4):193–208. (In Russian).

Singh, S., Singh, T.N. 2013. Guttation 1: Chemistry, crop husbandry and molecular farming. – Phytochemistry Reviews, 12:147–172. DOI: 10.1007/s11101-012-9269-x

Singh, S. 2014. Chapter Three - Guttation: New Insights into Agricultural Implications. – Advances in Agronomy, 128:97–135. DOI: 10.1016/B978-0-12-802139-2.00003-2

Tumanov, V.N, Chiruk, S.L. 2012. [Malyj praktikum po fiziologii rastenij] Small practical work on plant physics, 106 p. (In Russian).

Agraarteadus
1 • XXXIII • 2022 128–138

Journal of Agricultural Science
1 • XXXIII • 2022 128–138

EFFECTIVENESS OF DIFFERENT ADJUVANTS ON EFFICACY OF STELLAR (TOPREMAZONE PLUS DICAMBA) APPLIED AT REDUCED RATES IN MAIZE (*Zea mays* L.)

Zvonko Pacanoski[1], Alirami Saliji[2], Arben Mehmeti[3]

[1]*Faculty of Agricultural Sciences and Food, Ss. Cyril and Methodius University, 16-ta Makedonska brigade 3, Skopje, R.N. Macedonia*
[2]*Faculty of Agriculture and Biotechnology, University of Tetova, Ilinden St., nn. 1200 Tetovo, R.N. Macedonia*
[3]*Faculty of Agriculture and Veterinary, University of Prishtina, Bill Clinton St, nn. 10000, Prishtinë, Republic of Kosovo*

Saabunud: Received: 20.12.2021

Aktsepteeritud: Accepted: 07.05.2022

Avaldatud veebis: Published online: 07.05.2022

Vastutav autor: Corresponding author: Arben Mehmeti

E-mail: arben.mehmeti@uni-pr.edu

ORCID:
0000-0002-4250-7761 (ZP)
0000-0002-4682-190X (AS)
0000-0002-9212-4814 (AM)

Keywords: herbicide, adjuvant, maize, weeds.

DOI: 10.15159/jas.22.15

ABSTRACT. Field experiments were carried out in 2017 and 2018 on two individual farms that grew maize for grain, in Tetovo and Skopje locality, to determine the effectiveness of different adjuvants on the efficacy of Stellar applied at reduced rates. Herbicide treatment selectivity and influence on grain yield were estimated, as well. Both sites were naturally infested with a high population of *Polygonum lapathifolium* L., *Chenopodium album* L., *Echinochloa crus-galli* (L.) P. Beauv. and *Sorghum halepense* (L.) Pers. Overall efficacy of herbicides in control of weeds 28 DAT was ranged of 77% (Stellar + White oil applied at 0.125 + 0.2 L ha^{-1}) to 98% (Stellar + Trend applied at 0.75 + 1.0 L ha^{-1}) in Tetovo locality, and 64% (Stellar + White oil applied at 0.125 + 0.2 L ha^{-1}) to 99% (Stellar + DASH applied at 0.75 + 2.0 L ha^{-1}) in Skopje locality, respectively. In both localities, the efficacy of the full rate of Stellar (90 and 80%, respectively) was on the level of Stellar + White oil applied at 0.25 + 0.2 L ha^{-1} (90 and 78%, respectively). Herbicide efficacy 56 DAT was similar to the previous period of estimation. Efficacy of herbicide and herbicide plus adjuvants treatments in control of prevailing weeds 28 and 56 DAT ranged from 22–100% in Tetovo locality and 30–100% in Skopje locality, respectively. No visual maize injured was determined by any herbicide treatments in both localities for both years. Maize grain yields for each treatment in both localities generally reflected overall weed control.

Introduction

Maize (*Zea mays* L.) is the world's third most important cereal grain after wheat and rice (Kage *et al.*, 2013; Karavina *et al.*, 2014; Huma *et al.*, 2019). In North Macedonia, it is grown on an area of 33 967 hectares with an average grain yield of 4 277 kg ha^{-1} (State Statistical Office, 2020). Although there is a great potential for increasing its yield, as maize hybrids with high yield potential are under cultivation, the average yield is still far below as compared to the achievable potential of hybrids. Among various factors responsible for low yield, weed infestation is of supreme importance (Thobatsi, 2009; Peña-Asin *et al.*, 2013; Imoloame, Omolaiye, 2017; Iderawumi, Friday, 2018), particularly during the first weeks after sowing, in which, maize plants are strongly exposed to weed competition (Ghosheh *et al.*, 1996; Evans *et al.*, 2003; Sulewska *et al.*, 2012; Idziak, Woznica 2013), including such persistent species as *Chenopodium album, Echinochloa crus-galli* and *Sorghum halepense*. According to Dogan *et al.*, (2004) and Isik *et al.*, (2006), weeds occurrence in maize causes significant yield losses with an average of more than 29% in case of no weed control and more than 12% despite weed control applications. Averaged across the seven years (2007–2013), weed interference in maize in the United States and Canada caused an average of 50% yield loss, which equates to a loss of 148 million tons of maize valued at over U.S.$26.7 billion annually (Soltani *et al.*, 2016). Thus, poor maize competitiveness with weeds makes human intervention necessary.

The use of herbicides is the most effective and reliable method of weed control in maize fields (Kir, Doğan, 2009; Kierzek *et al.*, 2012; Noor *et al.*, 2012). For that purpose, in North Macedonia, many new herbicides for maize weed control were registered recently. One of them is Stellar (a.i. topremazone + dicamba). Dicamba is a well-known broadleaf weed control herbicide, which is either a benzoic acid (Golijan, 2015), or chlorophenoxy herbicide (Reigart, Roberts, 1999). Dicamba mimics a plant growth hormone, causing uncontrolled, abnormal and disorganized plant growth, disrupting normal plant functions that lead to plant death (Caux, 1993; Kelley, Riechers, 2007). On the other side, topremazone belongs to the new chemical class of pyrazolones or benzoylpyrazoles and was commercially introduced in 2006 (Grossmann, Ehrhardt, 2007; Zollinger, Ries, 2006). When applied as a post-emergence herbicide, it controls a wide spectrum of annual grass and broadleaf weeds (Ransom, Ishida, 2005; Porter *et al.*, 2005; Schonhammer *et al.*, 2006; Bollman *et al.*, 2007; Mahto *et al.*, 2020) and is safe to maize crop (Soltani *et al.*, 2007; Gitsopoulos *et al.*, 2010; Swetha *et al.*, 2015).

Sometimes, intensive herbicide use results in environmental pollution and the development of weed resistance. In addition, the cost of weed control is also too high (Zhang *et al.*, 2013). An effective way to reduce the side effect of the herbicide was to apply the lowest dose needed for biologically effective weed control (Kudsk, Streibig, 2003). Some previous studies showed that herbicide rates can be adjusted to the sensitivities of different weed species, weed growth stages, and environmental conditions and that the influences of these factors on herbicide efficacy can be quantified by conducting dose-response experiments (Christensen, Olesen, 1995; Kudsk, Streibig 2003; Pannacci, Covarelli 2009; Raimondi *et al.*, 2015).

In that direction, when herbicides are used at reduced rates (Praczyk, Adamczewski, 1996; Idziak, Woznica, 2013), added adjuvants to spraying liquid are necessary to improve the effectiveness of foliage-applied herbicidal treatment (Hazen, 2000; Penner, 2000; Curran, Lingenfelter, 2009; Idziak, Woznica, 2014), through increasing the retention of spray droplets, plant surface wettability and absorption of herbicide from spray deposit on plant surface into their cells (Sanyal *et al.*, 2006; Pacanoski, 2010; Whitford, Patton, 2016).

Although such studies have been carried out worldwide for more than 20 years (Kir, Dogan, 2009; Gołębiowska, Yıldırım, 2016), there is a lack of studies on the optimization of herbicide doses in maize in North Macedonia.

Because of that, the objective of this study was to determine the effectiveness of different adjuvants on the efficacy of Stellar applied at reduced rates and to determine its effect on maize weed control and grain yield.

Materials and Methods

Field experiments were carried out in 2017 and 2018 on two individual farms that cultivate maize for grain in Tetovo and Skopje locality, the Republic of North Macedonia, on Molic-vertic gleysol cumuligleyic and Fluvisol sandy loam, respectively (Filipovski, 2006) (Table 1).

Table 1. Localities, soil types and characteristics (%)

Characteristics	Locality	
	Tetovo	Skopje
Type	Molic-vertic gleysol cumuligleyic	Fluvisol sandy loam
Coarse	27.1	10.5
Fine sand	47.3	63.1
Clay+silt	25.6	26.4
Organic matter	1.86	2.66
pH	6.3	6.7

The seedbed was prepared by moldboard ploughing in the summer (immediately after wheat harvest), followed by two passes with a field cultivator, one in the autumn, and the second one in the spring, a few days before maize sowing. NPK 15:15:15 fertilizer was added before sowing at a rate of 400 kg ha^{-1}, while KAN fertilizer was added at a rate of 300 kg N ha^{-1} as ammonium nitrate (34% N) in two equal doses at 4–5 maize leaf stage (BBCH 14–15) and the beginning of stem elongation (BBCH 30). The experimental design was a randomized complete block with four replicates, and the area of the main plots was 21 m^2 (5 m long and 4.2 m wide, i.e., seven maize rows). The field studies were carried out with maize hybrid 'Kermes' produced by the KWC from Germany which was seeded in a well-prepared seedbed at a seeding rate of 25 kg ha^{-1} on May 10th, 2017 and April 28th, 2018 on Tetovo locality and May 17th, 2017 and May 3rd, 2018 in Skopje locality, respectively. The interrow/row spacing was 70/25 cm and the seeding depth was about 5 cm. The used herbicide was Stellar manufactured by the company BASF from Germany, and the following treatments were included in the study (Table 2).

All herbicide treatments were done POST in 4–6 maize leaf stage (BBCH 14–16), on June 10th, 2017 and May 28th, 2018 in Tetovo locality and, June 16th, 2017 and June 1st, 2018 in Skopje locality, respectively. During POST application broadleaved weeds were in the cotyledons – 4 leaf stage (BBCH 10–14), and grass weeds in the 3–5 leaf stage (BBCH 13–15). The full rate of Stellar (1.0 L ha^{-1}) was applied without adjuvant, while reduced Stellar rates (0.75; 0.50; 0.25 and 0.125 L ha^{-1}) were applied with recommended rates of all study adjuvants (White oil (COC) at 0.2; DASH (MSO) at 2.0 and Trend (NIS) at 1.0 L ha^{-1}). All herbicide and herbicide plus adjuvants treatments were applied with a CO_2-pressurized backpack sprayer calibrated to deliver a 300 L ha^{-1} aqueous solution at 220 kPa. An untreated control was included in the studies, as well. The estimation of weed population was done for 1 m^2 for each repetition. The control plots were left untreated during the entire experimental period.

Weed control efficacy was estimated at 28 and 56 days after treatment (DAT), by the weed plants counting from 1 m^2 area within each plot, and herbicide efficacy was calculated by Equitation 1 (Chinnusamy *et al.*, 2013).

Table 2. Trade names, herbicide active ingredients, adjuvants and time of application of herbicides in maize

Treatments	Herbicide active ingredients and adjuvants	Rate, L ha^{-1}	Time of application
Untreated control	–	–	–
Stellar	topremazone (50 g a.i L^{-1}.) + dicamba (160 g a.i. L^{-1}) with no adjuvant	1.0	*POST
Stellar + White oil	topremazone (50 g a.i L^{-1}.) + dicamba (160 g a.i. L^{-1}) + crop oil concentrate (COC)	0.75 + 0.2	POST
Stellar + DASH	topremazone (50 g a.i L^{-1}.) + dicamba (160 g a.i. L^{-1}) + methylated rapeseed oil (MSO)	0.75 + 2.0	POST
Stellar + Trend	topremazone (50 g a.i L^{-1}.) + dicamba (160 g a.i. L^{-1}) + nonionic surfactant (NIS)	0.75 + 1.0	POST
Stellar + White oil	topremazone (50 g a.i L^{-1}.) + dicamba (160 g a.i. L^{-1}) + crop oil concentrate (COC)	0.50 + 0.2	POST
Stellar + DASH	topremazone (50 g a.i L^{-1}.) + dicamba (160 g a.i. L^{-1}) + methylated rapeseed oil (MSO)	0.50 + 2.0	POST
Stellar + Trend	topremazone (50 g a.i L^{-1}.) + dicamba (160 g a.i. L^{-1}) + nonionic surfactant (NIS)	0.50 + 1.0	POST
Stellar + White oil	topremazone (50 g a.i L^{-1}.) + dicamba (160 g a.i. L^{-1}) + crop oil concentrate (COC)	0.25 + 0.2	POST
Stellar + DASH	topremazone (50 g a.i L^{-1}.) + dicamba (160 g a.i. L^{-1}) + methylated rapeseed oil (MSO)	0.25 + 2.0	POST
Stellar + Trend	topremazone (50 g a.i L^{-1}.) + dicamba (160 g a.i. L^{-1}) + nonionic surfactant (NIS)	0.25 + 1.0	POST
Stellar + White oil	topremazone (50 g a.i L^{-1}.) + dicamba (160 g a.i. L^{-1}) + crop oil concentrate (COC)	0.125+0.2	POST
Stellar + DASH	topremazone (50 g a.i L^{-1}.) + dicamba (160 g a.i. L^{-1}) + methylated rapeseed oil (MSO)	0.125 + 2.0	POST
Stellar + Trend	topremazone (50 g a.i L^{-1}.) + dicamba (160 g a.i. L^{-1}) + nonionic surfactant (NIS)	0.125 + 1.0	POST

*POST – 4–6 maize leaf stage (BBCH 14–16)

$$W_{CE} = \frac{W_{up} - W_{tp}}{W_{up}} \times 100, \qquad (1)$$

where W_{CE} – weed control efficiency
W_{up} – number of weeds in the untreated plots
W_{tp} – number of weeds in the treated plots

Maize injuries were estimated visually using a 0 to 100% scale, where 0% = no maize injury and 100% = complete maize plant death (Frans *et al.*, 1986). Maize plants injury was rated 14 and 28 DAT. The injury was visually rated by determining the average percentage of deformation, plant stunting, bleaching, chlorosis, or necrosis (or all) occurring in treated maize plants when compared with nontreated plants. Maize grain yields were determined by hand harvesting the central part of each plot 3.5 m^2 (1.4 m × 2.5 m) when the crop was mature, and recording the fresh weight of the harvested sample. Harvest in both localities was conducted between early and mid-October. The yield was adjusted to 15% moisture. Efficacy comparisons, as well as maize grain yields, were made between the full rate of Stellar without adjuvant and the reduced Stellar rates treatments with adjuvants.

During the present study, meteorological conditions throughout POST applications at both localities in both years favoured the action of Stellar and its reduced rates in mixtures with adding adjuvants (Table 3).

All statistical analyses were performed by using R 3.5.1 software. The data were tested for homogeneity of variance and normality of distribution (Ramsey, Schafer, 1997) and were log-transformed as needed to obtain roughly equal variances and better symmetry before ANOVA was performed. Data were transformed back to their original scale for presentation. Means were separated by using the LSD test at 5% of probability.

Table 3. Meteorological conditions during POST applications at Tetovo and Skopje localities in 2017 and 2018

Days of POST applications											
Tetovo locality						Skopje locality					
2017			2018			2017			2018		
June 10th			May 28th			June 16th			June 1st		
P, mm	T, ºC	AH, %	P, mm	T, ºC	AH, %	P, mm	T, ºC	AH, %	P, mm	T, ºC	AH, %
2	24	48	1	22	53	0	26	41	2	24	45

P – precipitations, T – temperature, AH – air humidity

Results and Discussion

Weed population

The weed population in both localities for both years has consisted mainly of summer broadleaves and grasses, annual and some perennial weeds. The weed community varied across locations. In Tetovo locality, the weed population has consisted of 13 weed species, and the total number of weeds was 333 plants m$^{2-1}$ (Table 4). The most prevailing among the 13 weed species were *Polygonum lapathifolium* (162 plants m$^{2-1}$), *Echinochloa-crus galli* (82 plants m$^{2-1}$) and *Chenopodium album* (26 plants m$^{2-1}$). In the Skopje locality, the weediness was lower in comparison with the previous one. The total number of weeds was 105 plants m$^{2-1}$. The most prevailing among the 12 weed species were *Echinochloa-crus galli* (34 plants m$^{2-1}$), *Sorghum halepense* (20 plants m$^{2-1}$) and *Chenopodium album* (16 plants m$^{2-1}$).

Table 4. Weed population (species and no, m$^{2-1}$) in maize crop at Tetovo and Skopje localities, averaged over 2017 and 2018

Weed species	Tetovo	Skopje
Polygonum lapathifolium L.	162	–
Chenopodium album L.	26	16
Galinsoga parviflora Cav.	9	–
Amaranthus retroflexus L.	9	7
Amaranthus lividus L.	5	–
Solanum nigrum L.	4	–
Xanthium strumarium L.	2	2
Echinochloa crus-galli (L.) P. Beauv.	82	34
Convolvulus arvense L.	9	6
Cirsium arvense (L.) Scop.	6	–
Rubus caesius L.	2	–
Sorghum halepense (L.) Pers.	9	20
Cynodon dactylon (L.) Pers.	8	10
Sinapis arvensis L.	–	3
Polygonum aviculare L.	–	2
Anagallis arvensis L.	–	2
Abutilon theophrasti Med.	–	2
Diplotaxis muralis (L.) DC.	–	1
Total weed species	13	12
Total weeds, no, m$^{2-1}$	333	105

Weed control and herbicide efficacy

The criterion for herbicide efficacy was taken as the percentage of weeds that are controlled by any particular treatment in comparison with untreated control. Efficacy of POST herbicides varied among treatments, weed species, and localities, respectively. Data regarding overall performances of herbicides efficacy presented in Tables 5 and 6 showed that all investigated treatments had a significant (P <0.05) effect on weed density per m^2, 28 and 56 days after their applications. Also, our results indicate that Stellar + adjuvant treatments, except the minimum ones (Stellar at 0.125 + adjuvants) provided mainly greater control of weeds compared to the use of Stellar applied alone at a recommended rate without adjuvant.

However, in both localities, the maximum weeds (333 and 105, respectively) were recorded in untreated control plots. Among herbicide and herbicide plus adjuvants treatments 28 DAT, minimum weed density in Tetovo locality were recorded in plots treated with Stellar + Trend and Stellar + DASH, applied at 0.75 + 1.0 L ha^{-1} and 0.75 + 2.0 L ha^{-1}, respectively (7 and 10, respectively). On the other side, maximum weed density was recorded in plots treated with Stellar applied at 0.125 L ha^{-1} with all studied adjuvants (White oil, Trend and DASH, respectively) (78, 73 and 72, respectively). In Skopje locality, same as in the previous one, minimum weed density was counted in plots treated with Stellar + DASH (0.75 + 2.0 L ha^{-1}) – 1, followed by Stellar + Trend (0.75 + 1.0 L ha^{-1}) – 3, while maximum weed density in herbicide treatments was observed in plots treated with Stellar applied at 0.125 L ha^{-1} with White oil – 28.0, followed by Stellar + DASH (0.75 + 2.0 L ha^{-1}) – 22.3 and Stellar + Trend (0.125 + 1.0 L ha^{-1}) – 21.5, respectively.

Reduction of the weed density was in positive correlation with herbicide efficacy. Overall efficacy of herbicides in control of weeds 28 DAT was ranged of 77% (Stellar + White oil applied at 0.125 + 0.2 L ha^{-1}) to 98% (Stellar + Trend applied at 0.75 + 1.0 L ha^{-1}) in Tetovo locality, and 64% (Stellar + White oil applied at 0.125 + 0.2 L ha^{-1}) to 99% (Stellar + DASH applied at 0.75 + 2.0 L ha^{-1}) in Skopje locality, respectively. In both localities, the efficacy of the full rate of Stellar (90 and 80%, respectively) was on the level of Stellar + White oil applied at 0.25 + 0.2 L ha^{-1} (90 and 78%, respectively) (Table 5).

Table 5. Effect of herbicidal treatments on weed density per m^2 and herbicide efficacy 28 DAT in maize crop in Tetovo and Skopje localities in 2017 and 2018, averaged over years

Treatments	Rate, L ha^{-1}	Weed density per m^2		Herbicide efficacy, %	
		Tetovo	Skopje	Tetovo	Skopje
Untreated control	–	333	105	–	–
Stellar	1.0	32de	22de	90^{d}	80^{cd}
Stellar + White oil	0.75 + 0.2	18^{abc}	5^{a}	95^{abc}	96^{a}
Stellar + DASH	0.75 + 2.0	10^{ab}	1^{a}	97^{ab}	99^{a}
Stellar + Trend	0.75 + 1.0	7^{a}	3^{a}	98^{a}	97^{a}
Stellar + White oil	0.50 + 0.2	23^{cd}	19^{cde}	93^{bcd}	82^{c}
Stellar + DASH	0.50 + 2.0	13^{abc}	12^{b}	96^{abc}	89^{b}
Stellar + Trend	0.50 + 1.0	11^{a}	13^{bc}	97^{ab}	88^{b}
Stellar + White oil	0.25 + 0.2	35^{e}	23^{e}	90^{d}	78^{d}
Stellar + DASH	0.25 + 2.0	27^{cde}	17^{bcde}	92^{cd}	84^{bc}
Stellar + Trend	0.25 + 1.0	21^{bcd}	16^{bcd}	94^{abcd}	85^{bc}
Stellar + White oil	0.125 + 0.2	78^{f}	38^{f}	77^{e}	64^{f}
Stellar + DASH	0.125 + 2.0	72^{f}	32^{f}	79^{e}	69^{ef}
Stellar + Trend	0.125 + 1.0	73^{f}	32^{f}	78^{e}	70^{e}
$LSD_{0.05}$	–	11.81	6.84	4.38	5.75
Random effect interactions POST herbicide treatments x locality				*	

*Significant at the 5% level according to a Fisher's protected LSD test at P <0.05.
POST treatments were applied in the 4–6 maize leaf stage (BBCH 14–16).
Weed control efficacy was estimated at 28 DAT.
Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at P <0.05.

Weed density 56 DAT, was similar to the previous period of estimation. In Tetovo locality, minimum weed density among herbicide and herbicide plus adjuvants treatments were recorded in plots treated with Stellar + Trend (0.75+1.0 L ha^{-1}) and Stellar + DASH (0.75 + 2.0 L ha^{-1}) – 5 and 7, respectively, while in Skopje locality, same as in the previous period of estimation, minimum weed density was observed in plots treated with Stellar + DASH (0.75 + 2.0 L ha^{-1}) and Stellar + Trend (0.75 + 1.0 L ha^{-1}) (1 and 2, respectively) (Table 6). From the other side, in Tetovo locality, maximum weed density were recorded in plots treated with Stellar + White oil (0.125 + 0.2 L ha^{-1}) – 72, followed by Stellar + DASH (0.125 + 2.0 L ha^{-1}) – 66 and Stellar + Trend (0.125 + 1.0 L ha^{-1}) – 65. Similar as in the Tetovo, in Skopje locality, maximum weed density in herbicide/adjuvants treatments were observed in plots treated with Stellar + White oil (0.125 + 0.2 L ha^{-1}) – 25 and Stellar + Trend (0.125 + 1.0 L ha^{-1}) and Stellar + DASH (0.125 + 2.0 L ha^{-1}) – 21 and 19, respectively. Overall herbicide efficacy 56 DAT was ranged of 78% (Stellar + White oil applied at 0.125 + 0.2 L ha^{-1}) to 99% (Stellar + Trend applied at 0.75 + 1.0 L ha^{-1}) in Tetovo locality and 76% (Stellar + White oil applied at 0.125 + 0.2 L ha^{-1}) to 99% (Stellar + DASH applied at 0.75 + 2.0 L ha^{-1}) in Skopje locality, respectively. Similar to in the previous period of efficacy estimation (28 DAT), in both localities, the efficacy of the full rate of Stellar (91 and 84%, respectively) was on the level of Stellar + White oil applied at 0.25 + 0.2 L ha^{-1} (89 and 82%, respectively) (Table 6).

Table 6. Effect of herbicidal treatments on weed density per m^2 and herbicide efficacy 56 DAT in maize crop in Tetovo and Skopje localities in 2017 and 2018, averaged over years

Treatments	Rate, L ha^{-1}	Weed density per m^2		Herbicide efficacy, %	
		Tetovo	Skopje	Tetovo	Skopje
Untreated control	–	333	105	–	–
Stellar	1.0	30^{de}	17^{de}	91^{cd}	84^{def}
Stellar + White oil	0.75 + 0.2	15^{ab}	6^{ab}	95^{abc}	94^{ab}
Stellar + DASH	0.75 + 2.0	7^{a}	1^{a}	98^{a}	99^{a}
Stellar + Trend	0.75 + 1.0	5^{a}	2^{a}	99^{a}	98^{a}
Stellar + White oil	0.50 + 0.2	20^{bc}	15^{cde}	94^{bc}	86^{cde}
Stellar + DASH	0.50 + 2.0	10^{a}	10^{bc}	97^{ab}	90^{bc}
Stellar + Trend	0.50 + 1.0	12^{ab}	10^{bc}	96^{ab}	90^{bc}
Stellar + White oil	0.25 + 0.2	34^{e}	18^{e}	89^{d}	83^{ef}
Stellar + DASH	0.25 + 2.0	28^{cde}	13^{cde}	91^{cd}	88^{cd}
Stellar + Trend	0.25 + 1.0	21^{bcd}	12^{cd}	94^{b}	89^{bcd}
Stellar + White oil	0.125 + 0.2	72^{f}	35^{g}	78^{e}	67^{g}
Stellar + DASH	0.125 + 2.0	66^{f}	29^{f}	80^{e}	72^{g}
Stellar + Trend	0.125 + 1.0	65^{f}	31^{fg}	81^{e}	70^{g}
$LSD_{0.05}$	–	9.49	5.29	4.25	5.22
Random effect interactions POST herbicide treatments x locality				*	

* Significant at the 5% level according to a Fisher's protected LSD test at P <0.05.
POST treatments were applied in the 4–6 maize leaf stage (BBCH 14–16).
Weed control efficacy was estimated at 28 DAT.
Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at P <0.05.

For optimal weed control, topramezone should be applied with a certain adjuvant, and DASH (MSO) is the most recommended (Torma *et al.*, 2011). This herbicide has good field performance when applied with the MSO adjuvant (Zhou *et al.*, 2010; Zheng *et al.*, 2011; Zhang *et al.*, 2013), because significantly increases foliar absorption by weed plants (Grossmann, Ehrhardt, 2007). Some other reports also presented that a good efficacy could be achieved when this herbicide was tank-mixed with MSO adjuvant (Young *et al.*, 2007; Zollinger, Ries, 2006). Applied as a post-emergence herbicide, it controls a wide spectrum of annual grass and broadleaf weeds (Ransom, Ishida, 2005; Porter *et al.*, 2005; Schonhammer *et al.*, 2006; Bollman *et al.*, 2007). Weed control efficacy was significantly higher with the application of topramezone 336 SC at 25.2 and 33.6 g a.i. ha^{-1} + MSO adjuvant (94.8 and 95.4% based on weed dry weight (Tiwari *et al.*, 2018). Field research conducted by Zollinger, Ries, (2006) showed that topramezone applied at a 1X rate completely controlled *A. retroflexus, C. album, S. arvensis, K. scoparia, S. sarachoides*, and *X. strumarium*, while *A. artemisiifolia* control from topramezone applied alone was 95% through the growing season. In addition, topramezone gave 100% control of *Abutilon theophrasti* in maize crops (James, Cooper, 2012). Swetha *et al.*, (2018) recorded the lowest density of grasses (4.50 m^2) and broad-leaved weeds (3.56 m^2) in a mixture of topramezone + atrazine (25.2 + 250 g a.i ha^{-1}) + MSO adjuvant. Dobbels, Kapusta (1993) reported up to 100% control of *C. album, A. retroflexus* and *Setaria viridis* with nicosulfuron plus dicamba plus atrazine plus adjuvant X–77® (a mixture of alkylarylpolyoxyethylene glycols, free fatty acids, and isopropanol) in maize. However, nicosulfuron combination with companion herbicides such as dicamba plus X–77® provided inconsistent (0–100%) control of *A. theophrasti* in maize (Dobbels, Kapusta 1993). Nicosulfuron plus dicamba provided 90–98% control of *A. theophrasti*, 99% control of *A. artemisiifolia*, 74–99% control of *C. album* and 80–94% control of *S. viridis*. The control of *C. album* improved with the addition of either Agral 90® (Nonylphenoxy phenoxyethanol 90%) or Liberate® (non-ionic surfactant) (Soltani *et al.*, 2010).

However, limited research has been conducted about the biological efficacy of reduced rates of topramezone plus dicamba (Stellar) with different adjuvants on weeds in maize crops.

Weed control of predominant weeds

Efficacy of herbicide and herbicide plus adjuvants treatments in control of prevailing weeds at 28 and 56 DAT ranged from 22 to 100% in Tetovo locality (Table 7) and 30 to 100% in Skopje locality, respectively (Table 8).

Stellar at a recommended rate (1.0 L ha^{-1}) without adjuvants excellent controlled predominant broad-leaved *P. lapathifolium* and *C. album* in both localities and years (100%), except *E. crus-galli* (<65%) in Tetovo locality and *E. crus-galli* and *S. halepense* (<63 and <60%) in Skopje locality, respectively for both estimation periods. At the recommended dose topramezone provided good control on broadleaved weeds whether it was applied at the 2–3 leaf or 4–5 leaf stage of weeds (Zhang *et al.*, 2013). Similar results were reported by Bollman *et al.* (2008). Topramezone provided greater than 90% control of *C. album, A. theophrasti* and *A. artemisiifolia*.

In Tetovo locality, 28 DAT Stellar at 0.75; 0.50; 0.25 and 0.125 L ha^{-1} with all studied adjuvants provided control of *P. lapathifolium* between 100 and 88%. At the same time, control of *E. crus-galli* with Stellar at 0.75; 0.50 and 0.25 L ha^{-1} with Dash (MSO) and Trend (NIS) adjuvants was higher than 90%, which was quite effective than Stellar applied at the recommended rate (1.0 L ha^{-1}) without adjuvants (64%). Control of *E. crus-galli* with Stellar at 0.75; 0.50 and 0.25 L ha^{-1}

with White oil (COC) adjuvant was significantly lower in comparison with other adjuvants (between 86 and 76%), but statistically higher in comparison with Stellar applied at the recommended rate (1.0 L ha^{-1}) without adjuvants. From the other side, all adjuvants with Stellar at 0.125 L ha^{-1} showed the poorest control of *E. crus-galli* (<29%). Reduced rates of Stellar (0.75 and 0.50 L ha^{-1}) with Dash (MSO) and Trend (NIS) adjuvants resulted in maximum mortality (100%) of *C. album* compared with <89% control of this weed with Stellar at 0.75 and 0.50 L ha^{-1} with White oil (COC) adjuvant. Satisfactory efficacy in the control of *C. album* (>87%) was obtained with the lowest rates of Stellar (0.25 and 0.125 L ha^{-1}) with Dash (MSO) and Trend (NIS) adjuvants, which was not the case with the same Stellar rates (0.25 and 0.125 L ha^{-1}) and White oil (COC) adjuvant (77 and 68%, respectively) (Table 7).

56 DAT full rate of Stellar without adjuvants, as well as reduced rates of Stellar with adjuvants, provided similar levels of predominant weeds control as in the previous period of weed control estimation – 28 DAT. Reduced rates of Stellar (0.75 and 0.50 L ha^{-1}) with all studied adjuvants achieved complete control of *P. lapathifolium*. On the other side, Stellar applied alone at recommended rate (1.0 L ha^{-1}) excellent controlled broadleaved weeds, including predominant *Polygonum lapathifolium* and *Chenopodium album* and shows some activity on grass weeds, but without commercially acceptable control of those grasses (Goršić *et al.*, 2008; Soltani *et al.*, 2012). Stellar at 0.25 L ha^{-1} with all adjuvants gave 88–90% control of *P. lapathifolium*, but the efficacy of Stellar at 0.125 L ha^{-1} with all adjuvants gave only marginal control of this weed (between 66 and 74%). The lack of predominant *P. lapathifolium* control because this weed recovered after application of the lowest rate of Stellar (0.125 L ha^{-1}), regardless of adjuvants. Reduced rates of Stellar (0.25; 0.50 and 0.75 L ha^{-1}) with Dash (MSO) and Trend (NIS) adjuvants effectively controlled *E. crus-galli*; control ranged from 90–98%. Opposite, the same rates of Stellar with White oil (COC) adjuvant provided control levels of *E. crus-galli* between 79 and 89%. The three COC, MSO and NIS adjuvants added to the Stellar liquid spray at the lowest reduced rate (0.125 L ha^{-1}) showed the poorest *E. crus-galli* control (<26%). Concerning *C. album*, excellent control was achieved with Stellar at 0.75 and 0.50 L ha^{-1} with Dash (MSO) and Trend (NIS) adjuvants (100%), and with Stellar at 0.25 L ha^{-1} with Dash (MSO) and Trend (NIS) adjuvants (96–97%). White oil (COC) adjuvant only with Stelar at 0.75 and 0.50 L ha^{-1} provided good control levels of *C. album* (92 and 87%, respectively). Satisfactory efficacy (83%) was obtained with the Stellar at 0.125 L ha^{-1} with Dash (MSO) and Trend (NIS) adjuvants. The lowest *C. album* efficacy 56 DAT in Tetovo locality showed Stellar at 0.25 and 0.125 L ha^{-1} rate with White oil (COC) adjuvant (77 and 62%, respectively) (Table 7).

Table 7. Control of predominant *Polygonum lapathifolium*, *Echinochloa crus-galli* and *Chenopodium album* 28 and 56 DAT in maize crop in 2017 and 2018, averaged over years in Tetovo locality

Treatments	Rate, L ha^{-1}	Weed control, %					
		28 DAT			56 DAT		
		POLLA	ECHCG	CHEAL	POLLA	ECHCG	CHEAL
Untreated control	–	0	0	0	0	0	0
Stellar	1.0	100^{a}	64^{d}	100^{a}	100^{a}	65^{d}	100^{a}
Stellar + White oil	0.75 + 0.2	100^{a}	86^{b}	89^{c}	100^{a}	89^{b}	92^{c}
Stellar + DASH	0.75 + 2.0	100^{a}	96^{a}	100^{a}	100^{a}	98^{a}	100^{a}
Stellar + Trend	0.75 + 1.0	100^{a}	95^{a}	100^{a}	100^{a}	98^{a}	100^{a}
Stellar + White oil	0.50 + 0.2	99^{a}	79^{c}	84^{d}	100^{a}	80^{c}	87^{d}
Stellar + DASH	0.50 + 2.0	100^{a}	93^{a}	100^{a}	100^{a}	93^{ab}	100^{a}
Stellar + Trend	0.50 + 1.0	99^{a}	93^{a}	100^{a}	100^{a}	94^{ab}	100^{a}
Stellar + White oil	0.25 + 0.2	92^{cd}	76^{c}	77^{e}	88^{b}	79^{c}	77^{e}
Stellar + DASH	0.25 + 2.0	95^{b}	90^{ab}	95^{b}	90^{b}	90^{b}	97^{b}
Stellar + Trend	0.25 + 1.0	94^{bc}	90^{ab}	93^{b}	90^{b}	92^{ab}	96^{bc}
Stellar + White oil	0.125 + 0.2	88^{e}	24^{e}	68^{f}	66^{d}	22^{e}	62^{f}
Stellar + DASH	0.125 + 2.0	90de	29^{e}	87^{cd}	72^{c}	25^{e}	83^{d}
Stellar + Trend	0.125 + 1.0	90de	29^{e}	88^{c}	74^{c}	26^{e}	83^{d}
$LSD_{0.05}$		2.80	6.03	3.87	3.45	6.23	4.61
Random effect interactions POST herbicide treatments x DAT		NS					

DAT – days after treatments; POLLA – *Polygonum lapathifolium*; ECHCG – *Echinochloa crus-galli*; CHEAL – *Chenopodium album.*
NS – not significant according to a Fisher's protected LSD test at P <0.05.
Weed control efficacy was estimated at 28 and 56 DAT.
Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at P <0.05.

In Skopje locality, 28 DAT Stellar at 0.75; 0.50 and 0.25 L ha^{-1} with Dash (MSO) and Trend (NIS) adjuvants provided control of *E. crus-galli* higher than 91%, significantly higher in comparison with 67% efficacy of Stellar applied at the recommended rate (1.0 L ha^{-1}) without adjuvants (Table 8). White oil (COC) adjuvant with Stellar at 0.75; 0.50 and 0.25 L ha^{-1} reduced the occurrence of *E. crus-galli* between 90 and 75%. The poorest control of *E. crus-galli* (<50%) was obtained in the lowest rate of Stellar (0.125 L ha^{-1}) with all studied adjuvants. The slightly higher efficacy of herbicide and herbicide plus adjuvants treatments was recorded in the control of *S. halepense* (Table 8). Both Dash (MSO) and Trend (NIS) adjuvants with Stellar at 0.75 and 0.50 L ha^{-1} provided nearly 100% control of *S. halepense,* while White oil (COC) adjuvant with the same rates of Stellar provided *S. halepense* control level of 95 and 91%, respectively. Reduced rates of Stellar (0.75; 0.50 and 0.25 L ha^{-1}) with COC, MSO and NIS adjuvants provided significantly higher control of *S. halepense* (between 80 and 100%) in comparison with 69% efficacy of Stellar applied at the recommended rate (1.0 L ha^{-1}) without adjuvants. Non-satisfactory efficacy in the control of *S. halepense* was recorded in the lowest rate of Stellar plus adjuvants treatments (between 55 and 67%). Stellar at 0.75; 0.50 and 0.25 L ha^{-1} with Dash (MSO) and Trend (NIS) adjuvants, as well as Stellar in full rate (1.0 L ha^{-1}) without adjuvant, resulted in nearly maximum mortality (98–100%) of *C. album* compared with 95, 93 and 89% control in Stellar at same rates with White oil (COC) adjuvant. Satisfactory control of *C. album* (90%) was obtained with the lowest rate of Stellar (0.125 L ha^{-1}) with Dash (MSO) and Trend (NIS) adjuvants, which was not the case with the same Stellar rate (0.125 L ha^{-1}) and White oil (COC) adjuvant (72%).

The trends in predominant weed control with a full rate of Stellar without adjuvant, as well as reduced rates of Stellar with adjuvants 56 DAT, were similar to weed control estimation 28 DAT. Stellar (0.75; 0.50 and 0.25 L ha^{-1}) tank-mixed with Dash (MSO) and Trend (NIS) adjuvants effectively controlled more than 92% of *E. crus-galli*. On the other side, the same rates of Stellar with White oil (COC) adjuvant provided control levels of *E. crus-galli* between 77 and 90%. Tank mixing Stellar (0.125 L ha^{-1}) with COC, MSO and NIS adjuvants, controlled *E. crus-galli* less than 42%. Stellar at 0.75 and 0.50 L ha^{-1} with Dash (MSO) and Trend (NIS) adjuvants achieved complete control of *S. halepense.* White oil (COC) adjuvant with Stellar at 0.75 and 0.50 L ha^{-1}, as well as Stellar at 0.25 L ha^{-1} with Dash (MSO) and Trend (NIS) adjuvants gave control of *S. halepense* between 88 and 92%. The lowest control of *S. halepense* (<58%) was recorded in the plots treated with Stellar at 0.125 L ha^{-1} with all studied adjuvants. Stellar at 0.75; 0.50 and 0.25 L ha^{-1} with all adjuvants achieved control of *C. album* bigger than 90%, while tank mixing Stellar (0.125 L ha^{-1}) with COC, MSO and NIS adjuvants, controlled *C. album* between 75 and 85% (Table 8).

Topramezone applied at 0.75X rate with MSO-type adjuvant completely controlled *A. retroflexus*, *C. album*, *S. arvensis, K. scoparia, S. sarachoides*, and *X. strumarium* (Zollinger, Ries, 2006). Spraying plants of *S. faberi*, *S. bicolor* and *S. nigrum* at the third leaf stage with topramezone (0.75 L ha^{-1}) and Dash HC (1.0 L ha^{-1}) caused strong photobleaching effects on shoots within 2–5 days after treatment. Consequently, the addition of an adjuvant such as Dash HC to the spray solution of topramezone was essential for excellent weed control (Grossmann, Ehrhardt, 2007).

As observations and previous experience with other herbicides suggested that most weed species could be controlled with significantly lower herbicide rates than recommended (Dogan *et al.*, 2005), a reduction in costs could be possible if effective minimum rates are determined for any herbicide.

Table 8. Control of predominant *Echinochloa crus-galli, Sorghum halepense* and *Chenopodium album* 28 and 56 DAT in maize crop in 2017 and 2018, averaged over years in Skopje locality

Treatments	Rate, L ha^{-1}	Weed control, %					
		28 DAT			56 DAT		
		ECHCG	SORHA	CHEAL	ECHCG	SORHA	CHEAL
Untreated control	–	0	0	0	0	0	0
Stellar	1.0	67^{d}	69^{f}	100^{a}	63^{f}	60^{d}	100^{a}
Stellar + White oil	0.75 + 0.2	90^{b}	95^{bc}	95^{abc}	90^{c}	92^{b}	100^{a}
Stellar + DASH	0.75 + 2.0	98^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}
Stellar + Trend	0.75 + 1.0	98^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}
Stellar + White oil	0.50 + 0.2	81^{c}	91^{d}	93^{bcd}	83^{d}	88^{b}	95^{b}
Stellar + DASH	0.50 + 2.0	95^{ab}	98^{ab}	100^{a}	98^{ab}	100^{a}	100^{a}
Stellar + Trend	0.50 + 1.0	93^{ab}	98^{ab}	100^{a}	98^{ab}	100^{a}	100^{a}
Stellar + White oil	0.25 + 0.2	75^{c}	80^{e}	89^{d}	77^{e}	75^{c}	90^{c}
Stellar + DASH	0.25 + 2.0	91^{ab}	93^{cd}	98^{ab}	92^{c}	90^{b}	95^{b}
Stellar + Trend	0.25 + 1.0	91^{ab}	91^{d}	98^{ab}	94^{bc}	90^{b}	97^{ab}
Stellar + White oil	0.125 + 0.2	38^{f}	55^{g}	72^{e}	30^{h}	44^{e}	75^{e}
Stellar + DASH	0.125 + 2.0	47^{e}	66^{f}	90^{cd}	40^{g}	58^{d}	85^{d}
Stellar + Trend	0.125 + 1.0	50^{e}	67^{f}	90^{cd}	42^{g}	58^{d}	88^{cd}
$LSD_{0.05}$		7.75	3.49	5.80	5.15	4.75	4.38
Random effect interactions POST herbicide treatments x DAT				NS			

DAT–days after treatments; ECHCG–*Echinochloa crus-galli*; SORHA–*Sorghum halepense* CHEAL–*Chenopodium album.*
NS–not significant according to a Fisher's protected LSD test at P <0.05.
Weed control efficacy was estimated at 28 and 56 DAT.
Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at P <0.05.

Maize injury and grain yield

Taking into consideration fact that all investigated herbicide and herbicide plus adjuvants treatments were applied in properly maize growth stages possesses high selectivity to maize, no visual injured were determined by any rates in both localities for both years (Table 9). Maize grain yields for each treatment in both localities for both years generally reflected overall weed control. In Tetovo locality, the highest grain yield among herbicide and herbicide plus adjuvants treatments were recorded in plots treated with Stellar + Trend at 0.75 + 1.0L ha^{-1} and Stellar + DASH at 0.75 + 2.0 L ha^{-1} (8300 and 8250 kg ha^{-1}, respectively, while in Skopje locality, same as in the previous case, the highest grain yield were observed in plots treated with Stellar + DASH at 0.75 + 2.0 L ha^{-1} and Stellar + Trend at 0.75 + 1.0 L ha^{-1} (8570 and 8510 kg ha^{-1}, respectively) (Table 9). From the other side, in Tetovo locality, the lowest grain yield were recorded in plots treated with Stellar + White oil (0.125 + 0.2 L ha^{-1}) – 4710 kg ha^{-1}, followed by Stellar + DASH (0.125 + 2.0 L ha^{-1}) – 5180 kg ha^{-1} and Stellar + Trend (0.125 + 1.0 L ha^{-1}) – 5270 kg ha^{-1}. Similar to in the Tetovo, in the Skopje locality, the lowest grain yield in herbicide and herbicide plus adjuvants treatments were observed in plots treated with Stellar + White oil (0.125 + 0.2 L ha^{-1}) – 4460 kg ha^{-1} and Stellar + Trend (0.125 + 1.0 L ha^{-1}) and Stellar + DASH (0.125 + 2.0 L ha^{-1}) – 4590 and 4630 kg ha^{-1}, respectively. In both localities, grain yield of the full rate of Stellar (5980 and 5530 kg ha^{-1}, respectively) was on the level of Stellar + White oil applied at 0.25 + 0.2 L ha^{-1} (5870 and 5440 kg ha^{-1}, respectively) (Table 9). Topramezone 336 g L^{-1} SC applied at 20.1, 25.2 and 33.6 g a.i. ha^{-1} + MSO adjuvant produce a significantly higher yield than the lowest dose 13.4 g a.i. ha^{-1}. + MSO Adjuvant (Tiwari *et al.*, 2018). Post-emergence application of topramezone at 25.20 g ha^{-1} + MSO recorded a grain yield of 47.12 g ha^{-1} which was comparable with the hand weeding at 20 and 40 DAS (49.41 g ha^{-1}) (Mahto *et al.*, 2020). Nicosulfuron plus dicamba increased yield by at least 67% compared with the untreated control. The addition of Agral 90®and Liberate®to nicosulfuron plus dicamba increased yield by 24 and 17%, respectively (Soltani *et al.*, 2010).

Table 9. Maize plant injury as influenced by POST treatments and grain yield as influenced by POST treatments in maize crop in Tetovo and Skopje localities in 2017 and 2018, averaged over years [a–d]

Treatments	Rate, L ha^{-1}	Grain yield, kg ha^{-1}	
		Tetovo	Skopje
Untreated control	–	2570	3210
Stellar	1.0	5980^{e}	5530^{e}
Stellar + White oil	0.75 + 0.2	7420^{c}	7770^{b}
Stellar + DASH	0.75 + 2.0	8250^{a}	8570^{a}
Stellar + Trend	0.75 + 1.0	8300^{a}	8510^{a}
Stellar + White oil	0.50 + 0.2	7290^{c}	6020^{d}
Stellar + DASH	0.50 + 2.0	7960^{b}	7430^{c}
Stellar + Trend	0.50 + 1.0	7730^{b}	7390^{c}
Stellar + White oil	0.25 + 0.2	5870^{e}	5440^{e}
Stellar + DASH	0.25 + 2.0	6110^{e}	5880^{d}
Stellar + Trend	0.25 + 1.0	6300^{d}	5990^{d}
Stellar + White oil	0.125 + 0.2	4710^{g}	4460^{f}
Stellar + DASH	0.125 + 2.0	5180^{f}	4630^{f}
Stellar + Trend	0.125 + 1.0	5270^{f}	4590^{f}
$LSD_{0.05}$		250.41	238.09

POST – post-emergence; DAT – days after treatments.
Maize injury estimated at 14 and 28 DAT.
Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at P <0.05.

Conclusion

Almost all reduced rates of Stellar (topremazone plus dicamba), except the lowest one 0.125 L ha^{-1} with the addition of properly chosen adjuvants, provided excellent control of all investigated weeds, including grasses, such as *Echinochloa crus-galli* and *Sorghum halepense*. The highest efficacy of 28 DAT was achieved in plots treated with herbicide Stellar + Trend applied at 0.75+1.0 L ha^{-1} 98% in Tetovo locality, while Stellar + DASH applied at 0.75+2.0 L ha^{-1} has shown slightly higher efficiencies 99% in Skopje locality. Therefore, the use of adjuvants in the spray liquid with different mechanisms of action, first, MSO and NIS, will improve Stellar efficacy even applied at the reduced rates, particularly in control of the monocotyledonous species in maize crop.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

ZP, AS, AM – study conception and design;
ZP – acquisition of data;
ZP, AS, AM – analysis and interpretation of data;
ZP, AM – drafting of the manuscript;
ZP, AS, AM – critical revision and approval of the final manuscript.

References

State Statistical Office 2020. Statistical yearbook of the Republic of the North Macedonia. – 10 Agriculture. https://www.stat.gov.mk/Publikacii/SG2020/SG2020-Pdf/10-Zemjodelstvo-Agriculture.pdf Accessed on 01/12/2021 (In Macedonian)

Bollman, J., Boerboom, C., Becker, R., Fritz, V. 2007. New weed control options for sweet corn. – Proceedings of the 2007 Wisconsin Fertilizer, Aglime and Pest Management Conference, 46:216–221.

Bollman, J.D., Boerboom, C.M., Becker, R.L., Fritz, V.A. 2008. Efficacy and tolerance to HPPD-inhibiting herbicides in weet corn. – Weed Technology, 22:666–674. DOI: 10.1614/WT-08-036.1

Caux, P.Y., Kent, R.A., Tache, M., Grande, C., Fan, G.T. MacDonald, D.D. 1993. Environmental fate and effects of dicamba: a Canadian perspective. – Reviews of Environmental Contamination and Toxicology, 133:1–58.

Chinnusamy, N., Chinnagounder, C., Krishnan, P.N. 2013. Evaluation of weed control efficacy and seed cotton yield in glyphosate tolerant transgenic cotton. – American Journal of Plant Sciences, 4(6):1159–1163. DOI: 10.4236/ajps.2013.46142

Christensen, S., Olesen, J.E. 1995. Adaptive weed control in an integrated wheat management system for winter wheat. – Proceedings of 9th EWRS (European Weed Research Society) Symposium, Budapest, Hungary, pp. 663–669.

Curran, W.S., Lingenfelter, D.D. 2009. Agronomy Facts 37: Adjuvants for enhancing herbicide performance. – Penn State Extension. The Pennsylvania State University 2009 Code UC106 05/14pod https://extension.psu.edu/ spray-adjuvants Accessed on 01/12/2022

Dobbels, A.F. Kapusta, G. 1993. Postemergence weed control in corn (*Zea mays*) with nicosulfuron combinations. – Weed Technology, 7:844–850. DOI: 10.1017/S0890037X00037866

Dogan, M.N., Boz, Ö., Ünay, A. 2005. Efficacies of reduced herbicide rates for weed control in maize (*Zea mays* L.) during critical period. – Journal of Agronomy, 4:44–48. DOI: 10.3923/ja.2005.44.48.

Dogan, M.N., Unay, A., Boz, O., Albay, F. 2004. Determination of optimum weed control timing in maize (*Zea mays* L.). – Turkish Journal of Agriculture and Forestry, 28: 349–354.

Evans, S.P., Knezevic, S.Z., Lindquist, J.L., Shapiro, C.A., Blankenship, E.E. 2003. Nitrogen application influences the critical period for weed control in corn. – Weed Science, 51:408–417. DOI: 10.1614/0043-1745(2003)051[0408:NAITCP]2.0.CO;2

Filipovski, G. 2006. Soil classification of the Republic of Macedonia, MASA, 313–323.

Frans, R.E., Talbert, R., Marx, D., Crowley H. 1986. Experimental design and techniques for measuring and analyzing plant responses to weed control practices. – In Research Methods in Weed Science (3rd ed.). N. D. Camper (Ed.) – Southern Weed Science Society Champaign, Illinoise, USA, 37–38.

Gitsopoulos, T.K., Melidis, V., Evgenidis, G. 2010. Response of maize (*Zea mays* L.) to post-emergence applications of topramezone. – Crop Protection, 29:1091–1093. DOI: 10.1016/j.cropro.2010.06.020

Gołębiowska, H., Yıldırım, İ. 2016. Optimization of herbicide doses in sustainable system of maize cultivation. – ÇOMÜ Zir. Fak. Derg. (COMU J. Agric. Fac.), 4(1):85–92.

Golijan, J. 2015. Evaluation of phytotoxicity and efficiency of dicamba in suppression of broadleaf weed in the corn. – The Serbian Journal of Agricultural Sciences, 64(3–4):206–212.

Goršić, M., Barić, K., Galzina, N., Šćepanović, M., Ostojić, Z. 2008. Weed control in maize with new herbicide topramezone. – Cereal Research Communications. Supplement: Proceedings of the VII. Alps-Adria Scientific Workshop, 28 April – 2 May 2008, Stara Lesna, Slovakia (June 2008), 36: 1627–1630.

Ghosheh, H.Z., Holshouser, D.L., Chandler, J.M. 1996. The critical period of johnsongrass (*Sorghum halepense*) control in field corn (*Zea mays*). – Weed Science, 44: 944–947. DOI: 10.1017/S00431745000 94960

Grossmann, K., Ehrhardt, T. 2007. On the mechanism of action and selectivity of the corn herbicide topramezone: a new inhibitor of 4-hydroxyphenylpyruvate dioxygenase. – Pest Management Science, 63(5):429–439. DOI: 10.1002/ps.1341

Hazen, J.L. 2000. Adjuvants - terminology, classification and chemistry. – Weed Technology, 14:773–784. DOI: 10.1614/0890-037X(2000)014% 5b0773:ATCAC%5d2.0.CO;2.

Huma, B., Hussain, M., Ning, C., Yuesuo, Y. 2019. Human benefits from maize. – Scholar Journal of Applied Sciences and Research, 2(2): 4–7.

Iderawumi, A.M., Friday, C.E. 2018. Characteristics and effects of weed on growth performance and yield of maize (*Zea mays*). – Biomed Journal Scientific & Technical Research, 7(3):5880–5883. DOI: 10.26717/ BJSTR.2018.07.001495

Idziak, R., Woznica, Z. 2013. Effect of nitrogen fertilizers and oil adjuvants on nicosulfuron efficacy. – Turkish Journal of Field Crops, 18(2):174–178.

Idziak, R., Woznica, Z. 2014. Impact of tembotrione and flufenacet plus isoxaflutole application timings, rates, and adjuvant type on weeds and yield of maize. – Chilian Journal of Agricultural Research, 74:129–134. DOI: 10.4067/S0718-58392014000200001

Imoloame, E.O., Omolaiye, J.O. 2017. Weed infestation, growth and yield of maize (*Zea mays* L.) as influenced by periods of weed interference. – Advances in Crop Science and Technology, 5(2):267. DOI: 10.4172/2329-8863.1000267

Isik, D., Mannan, H., Bukan, B., Oz, A., Ngauajiro, M. 2006. The critical period for weed control in corn in Turkey. – Weed Technology, 20:867–872.

James, T.K., Cooper, J.M. 2012. Control of the recently-introduced weed butterprint (*Abutilon theophrasti*) in maize. – New Zealand Plant Protection, 65:64–68. DOI: 10.30843/nzpp.2012.65.5426

Kage, U., Madalageri, D., Malakannavar, L., Ganagashetty P. 2013. Genetic diversity studies in newly derived inbred lines of maize (*Zea mays* L.). – Molecular Plant Breeding, 4(9):77–83.

Karavina, C., Mandumbu, R., Mukaro, R. 2014. Evaluation of three-way maize (*Zea mays* L) hybrids for yield and resistance to maize streak virus and turcicum leaf blight diseases. – The Journal of Animal & Plant Sciences, 24(1):216–220.

Kelley, K.B., Riechers, D.E. 2007. Recent developments in auxin biology and new opportunities for auxinic herbicide research. – Pestic. Biochemistry Physiology, 89(1):1–11. DOI: 10.1016/j.pestbp.2007.04.002

Kierzek, R., Paradowski, A., Kaczmarek, S. 2012. Chemical methods of weed control in maize (*Zea mays* L.) in variable weather conditions. – Acta Scientiarum Polonorum series Agricultura, 11(4):35–52.

Kir, K., Dogan, M.N. 2009. Weed control in maize (*Zea mays* L.) with effective minimum rates of foramsulfuron. – Turkish Journal of Agriculture and Forestry, 33:601–610

Kudsk, P., Streibig, J.C. 2003. Herbicides-a-two-edged sword. – Weed Research, 43:90–102. DOI: 10.5772/ 55957

Mahto, R., Kumar, C., Singh R.K. 2020. Weed management in maize (*Zea mays* L.) through 4-hydroxyphenylpyruvate dioxygenase inhibitor herbicide with or without a methylated seed oil adjuvant. – Pesticide Research Journal, 32(1):179–185. DOI:10.5958/2249-524X.2020.00004.7

Noor, M., Ashiq, M., Gaffar, A., Sattar, A., Arshad, M. 2012. Comparative efficacy of new herbicides for weed control in maize (*Zea mays* L.). – Pakistan Journal of Weed Science Research, 18(2):247–254.

Pacanoski, Z. 2010. Role of adjuvants on herbicide behavior: A review of different experiences. – Herbologia, 11(2):67–79.

Pannacci, E., Covarelli, G. 2009. Efficacy of mesotrione used at reduced doses for post-emergence weed control in maize (*Zea mays* L.). – Crop Protection, 28:57–61. DOI: 10.1016/j.cropro.2008.08.011

Peña-Asin, J., Costar, A., Alvarez, A. 2013. Effect of weeding management on the performance of local maize populations. – Spanish Journal of Agricultural Research, 11(4):1078–1084. DOI: 10.5424/sjar/2013114-4027

Penner, D. 2000. Activator adjuvants. – Weed Technology, 14(4):785–790. DOI: 10.1614/0890-037X(2000)014[0785:AA]2.0.CO;2

Porter, R.M., Vaculin, P.D., Orr, J.E., Immaraju, J.A., O'Neal, W.B. 2005. Topramezone: a new active for postemergence weed control in corn. – Proceedings of the North Central Weed Science Society, 60:93.

Praczyk, T., Adamczewski, K. 1996. The importance of adjuvants in chemical plant protection. – Progress Plant Protection, 36(1):117–121.

Raimondi, M.A., Oliveira, J-R., R.S., Constantin, J., Rios, F.A., Gemelli, A., Raimondi, R.T. 2015. Dose-response curve to soil applied herbicides and susceptibility evaluation of different *Amaranthus* species using model identity. – Planta Daninha, Viçosa-MG, 33(1):137–146. DOI: 10.1590/S0100-83582015000100016.

Ramsey, F.L., Schafer, D.W. 1997. The statistical sleuth: A course in methods of data analysis. – Belmont, CA, Duxbury, pp. 91–97.

Ransom, C.V., Ishida, J.K. 2005. Weed control and crop response with Option® and Impact® herbicides in furrow-irrigated field corn. – Malheur experiment station annual report 2005, Oregon State University, Special Report, 27–32.

Reigart, J.R., Roberts, J.R. 1999. Recognition and Management of Pesticide Poisoning (5th ed.) – U.S. Environmental Protection Agency, Office of Prevention, Pesticides and Toxic Substances, Office of Pesticide Programs, U.S. Government Printing Office: Washington, DC, USA, pp. 94–96.

Sanyal, D., Bhowmik, P.C., Reddy, K.N. 2006. Influence of leaf surface micromorphology, wax content, and surfactant on primisulfuron droplet spread on barnyardgrass (*Echinochloa crus-galli*) and green foxtail (*Setaria viridis*). – Weed Science, 54:627–633. DOI: 10.1614/WS-05-173R.1

Schonhammer, A., Freitag, J., Koch, H. 2006. Topramezone eineuer Herbizidwirkstoff zur hochselektiven Hirse-und Unkrautbekampfung im mais. – Journal of Plant Diseases and Protection, 23:1023–1031. (In German)

Soltani, N., Dille, J.A.,Burke, I.C., Everman, W.J., VanGessel, M.J., Davis, V.M., Sikkema P.H. 2016. Potential corn yield losses from weeds in North America. – Weed Technology, 30(4):979–984. DOI: 10.1614/WT-D-16-00046.1.

Soltani, N., Sikkema, P.H., Zandstra, J., O' Sullivan, J., Robinson, D.E. 2007. Response of eight sweet maize (*Zea mays* L.) hybrids to topramezone. – American Society for Horticultural Science, 42:110–112.

Soltani, N., Shropshire, C., Sikkema, P.H. 2010. Adjuvant comparison for postemergence weed control in corn. – Canadian Journal of Plant Science, 90:543–547. DOI: 10.4141/CJPS09146.

Soltani, N., Kaastra, A.C., Swanton, C.J., Sikkema, P.H. 2012. Efficacy of topramezone and mesotrione for the control of annual grasses. – International Research Journal of Agricultural Science and Soil Science, 2(1):46–50.

Sulewska, H., Koziara, W., Smiatacz, K., Szymanska, G., Panasiewicz, K. 2012. Efficacy of selected herbicides in weed control of maize. – Fragmenta Agronomica 29:144–151.

Swetha, K., Madhavi, M., Pratibha, G., Ramprakash, T. 2015. Weed management with new generation herbicides in maize. – 25th Asian-Pacific Weed Science Society Conference on "Weed Science for Sustainable Agriculture, Environment and Biodiversity", Hyderabad, India, 13-16 October, 2015, p. 255.

Swetha, K., Madhavi, M., Pratibha, G., Ramprakash, T. 2018. Efficacy of herbicide mixtures with and without adjuvants on weed control and yield of maize. – Research Journal of Agricultural Sciences, 9(3):578–583.

Thobatsi, T. 2009. Growth and yield responses of maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* L.) in an intercropping system. – MSc. Agric (Agronomy). Faculty of Natural and Agricultural Sciences, Department of Plant Production and Soil Science, University of Pretoria, South Africa, 149 p.

Tiwari, D. K., Paradkar, V.K., Dubey, R., Dwivedi R.K. 2018. Bio-efficacy of post-emergence herbicide topramezone against weed control of maize (*Zea mays* L.). – International Journal of Agriculture Sciences, 10(2):5079–5081.

Torma, M., Adamszki, T., Kazinczi, G. 2011. The role of nitrogen in the post-emergence weed control of maize. – Herbologia, 12(2):61–69.

Whitford, F., Patton, A. 2016. Adjuvants and the power of the spray droplet: Improving the Performance of Pesticide Applications – Purdue Extension (PPP-107) (PPP-107), 60 p.

Young, B.G., Zollinger, R.K., Bernards, M.L. 2007. Variability of tembotrione efficacy as influenced by commercial adjuvant products. –North Central Weed Science Society Proceedings, 62:141.

Zhang, J., Zheng, L., J. Ortrud, Yan, D., Zhang, Z., Gerhards, R., Ni, H. 2013. Efficacy of four post-emergence herbicides applied at reduced doses on weeds in summer maize (*Zea mays* L.) fields in North China plain. – Crop Protection, 52:26–32. DOI: 10.1016/j.cropro.2013.05.001.

Zheng, L., Lv, Y., Ni, H. 2011. Efficacy comparison of four post-emergence herbicides in weed control in corn. – Agrochemicals, 50:597–613.

Zhou, X., Zhu, J., Chen, Q., Zheng, S., Tu, M. 2010. Efficacy of 33.6% topramezone SC in weed control in maize field. – Phytomedicine, 23:41–44

Zollinger, R., Ries, J.L. 2006. Comparing mesotrione, tembotrione and topramezone. – North Central Weed Science Society Proceedings, 61:114.

Agraarteadus
1 • XXXIII • 2022 139–145

Journal of Agricultural Science
1 • XXXIII • 2022 139–145

EFFECT OF FUNGICIDES ON MYCOSIS PROGRESSION AND POTATO YIELDS

Oleksandr Sayuk, Natalia Plotnytska, Ruslan Troyachenko, Olga Ovezmyradova

Faculty of Agronomy, Polissia National University, 7 Staryi Blvd, Zhytomyr, UA10008, Ukraine

Saabunud: Received: 23.11.2021

Aktsepteeritud: Accepted: 08.05.2022

Avaldatud veebis: Published online: 08.05.2022

Vastutav autor: Corresponding author: Natalia Plotnytska

E-mail: plotnat@ukr.net

ORCID:
0000-0002-1355-0832 (OS)
0000-0001-7758-1307 (NP)
0000-0002-3972-2866 (RT)
0000-0001-5430-5676 (OO)

Keywords: potato, late blight, early blight, fungicides, disease spreading, disease development, technical efficiency, yield.

DOI: 10.15159/jas.22.16

ABSTRACT. The efficiency of crop cultivation technologies, including potatoes, can decrease under the influence of pests, especially in the case of untimely or low-quality protective measures. Pathogens parasitizing the vegetative surface of plants have a significant impact on the quality and yield of potato tubers. Such pathogens are fungi *Phytophthora infestans* (Mont) de Bary, *Alternaria solani* Sorauer and *Alternaria alternata* Keis, which are the causative agents of late blight and early blight. Early manifestation and significant development of these diseases during the growing season can lead to losses, which are estimated at 4 billion euros per year. Studies by many scientists reveal a significant positive result from the use of fungicides during the growing season of plants, harvesting and storage of crops. This article investigated the efficacy of fungicides against late blight and early blight and their effects on yield and tuber quality of the early maturing potato variety Bellarosa. The research was conducted from 2018 to 2020 at the PE Zherm of the Zhytomyr region Ukraine. The experiment scheme consisted of the following variants: Control – spraying of plants with water; Variant 1. Ridomil Gold MC 68 WP, (mancozeb, 640 g kg^{-1} + metalaxyl M, 40 g kg^{-1}) – 2.5 kg ha^{-1} – the reference variant; Variant 2. Infinito 61 SC, 68.75% (fluopycolide, 62.5 g L^{-1} + propamocarb hydrochloride, 625 g L^{-1}) – 1.5 L ha^{-1}; Variant 3. Quadris TOP 325 SC, 32.5% (azoxystrobin, 200 g L^{-1} + difenoconazole, 125 g L^{-1}) – 0.8 L ha^{-1}. It has been established that the application of fungicides in the potato plantings against late blight and early blight reduces the spread of the leaf spot by 1.4–2.0 times at the end of the vegetation period, and its development – by 1.8–2.9 times in comparison with the Control variant. An increase in yield of potato tubers of Bellarosa variety due to the application of fungicides against leaf spot disease was within 4.5–10.9 t ha^{-1} in comparison with the Control variant. Among the studied preparations, the best indicators were obtained when using the fungicide Infinito 61 SC, 68.75% in potato plantings against late blight and early blight. Application of this preparation helped to reduce the spread of the studied diseases by 2.0 times, the development of diseases by 2.9 times, and increase the yield by 1.4 times compared to the variant without fungicides application. Application of fungicides also contributed to the improved quality of the tubers; in particular, we observed an increase of the dry matter content in tubers by 0.1–0.6%, ascorbic acid – by 0.2–1.1 mg% 100 g^{-1} compared to the variant without using the preparations.

Introduction

The effectiveness of any crop cultivation technology, including potatoes, can be reduced due to significant damage by pests, high incidence of diseases and weeds of crops, especially if the elements of the crop protection system against pests were not observed (Andrivon *et al*., 2003; Shpaar, 2004).

Cultivation of varieties resistant to pests and pathogens is ecologically important and contributes to increasing crop yields. However, varieties with increased resistance reduce their tolerance during several growing seasons, and then it is necessary to apply additional protection measures. One of the highly effective measures contributing to the maximum elimination of pests is the use of chemical preparations (Bukolova *et al*., 1997; Holiachuk, Kosylovych, 2018).

The science and practice proved significant effectiveness of chemical preparations against pathogens in potato plantings, the use of which is based on an integrated approach to solving the problem. The pathogens developing on the vegetative surface of plants cause a significant influence on the yield and quality of tubers. Such pathogens are fungi – pathogens of late blight *Phytophthora infestans* (Mont) de Bary) and early blight (*Alternaria solani* Sorauer and *Alternaria alternata* Keis.) (Zan, 1962; van der Waals *et al*, 2001; Raichuk, 2010; Filippov, 2012). The global losses in yield due to the development of these diseases and the costs associated with protection measures against them amount to about four billion euros per year. The damage of these diseases grows by early manifestation and rapid development during the growing season. The use of fungicides in potato plantings during the growing season is aimed primarily at destroying the pathogens of late blight and early blight. Vegetative surface protection of plants against these pathogens helps to maximize the preservation of tuber yields (Wastie, 1991; Plotnytska *et al.*, 2009; Brurberg, 2011; Kalenska, Knap, 2012; Tsedaley, 2014; Holiachuk, Kosylovych, 2018).

Fungicides, which are chemical preparations against pathogens, are subdivided, depending on their purpose, into preparations for seed dressing, plant treatment during vegetation and soil treatment. Earlier studies have revealed a significant positive result from the use of fungicides in the growing season of plants, harvesting and storage of crops. The use of fungicides helps to protect potato plants from the most common diseases, in particular late blight and early blight, and increase tuber yields (Ghorbani *et al.*, 2004; Shpaar, 2004; Nielsen *et al.*, 2010).

Studies on the use of chemicals against late blight began in the XIX century in France after the invention of the Bordeaux liquid, which combined the action of compounds of copper and lime. However, the effectiveness of this preparation began to decline over time, and this contributed to the search for the most effective means of protection against pathogens. Currently, preparations with contact and systemic action can be used to protect potatoes from spot disease. Contact fungicides do not penetrate the plant and remain on its surface, and their main action is to suppress the reproductive organs of fungi so that the plants are not over-infected. The effectiveness of contact action preparations depends on the duration of contact with the treated surface and decreases with precipitation, and the protective effect lasts no longer than eight days. The effectiveness of contact fungicides against late blight and early blight pathogens is confirmed only if they are used in a timely and repeated manner (Polozhenets *et al*., 2011).

Systemic action fungicides penetrate the plant and, together with the cell sap, are transferred to the untreated parts of the plant. They have not only a protective but also a therapeutic effect. Active substances of systemic fungicides penetrate the plant within the first thirty minutes after application, and their effectiveness is not reduced by precipitation and can be stored for 10–14 days. Application of systemic phenylamide fungicides (Ridomil, Sandofan) against *Ph. infestans* pathogen initially contributed to the reduction of the disease development, but mass application led to pathogen mutation, formation of resistant strains of the pathogen, in turn, required an increase in consumption rates and multiplicity of drugs application (Schepers van Soesbergen, 1995; Lazarchuk, 2015).

Now practical application as fungicides has received about 20 active substances, of which only 15 are the most widely used. The following active substances are the most common for protection against late blight: metalaxil, mancozeb, mephenoxam, propamocarb, fluopicolide, dimethomorph, *etc.*. Previously, contact preparations based on dithiocarbamates, copper and chlorothalonil preparations and azoxystrobin were mainly used to protect against early blight. However, an increase in the disease's harmfulness brought difenoconazole- and mandipropamide-based preparations to the market (Martynenko, 2003; Holiachuk, Kosylovych, 2018).

The number of potato plantings treatments with fungcides during vegetation season may reach 10–15 times, and 4–8 times in our country. When planning protective measures and selecting fungicides, the resistance of varieties grown in specific conditions to leaf spot pathogens, such as late blight and early blight, should be taken into account primarily. Plant protection during the growing season should be planned to take into account the preventive treatments carried out before the disease emergence. The duration of preventive treatments is calculated based on the forecast and meteorological conditions of the season. Untimely preventive treatments and late application of fungicides when 3–5% of leaves are infected result in 4–5 times more yield losses (Bondarchuk *et al*., 2009).

A considerable number of scientists and practitioners in all areas of culture cultivation deal with the problem of developing effective measures to protect potatoes from leaf spots by using fungicides. Even a single application of fungicides against late blight rot and early blight spot helps to reduce the development of pathogenic agents considerably. An increase in the number of fungicides treatments of potato plantations within a season, use of growth-promoting factors and micro fertilizers help not only to decrease the development of spot diseases of potato but also reduce affection of potato tubers by fusarium dry rot (Schepers, van Soesbergen, 1995; Martynenko, 2003; Nielsen *et al*, 2010; Polozhenets *et al*., 2011; Frost *et al*., 2013).

The constant development of new, more effective chemical preparations, and adjustment of application rates for active ingredients considering the degree of affection, may partially reduce the number of treatments during the season; nevertheless, it is impossible to exclude fungicides entirely from the system of potato protection from spot diseases of leaves. The effectiveness of preparations largely depends on weather conditions and growing conditions, it is necessary to consider specific conditions of soil and climate when developing a system of potato protection from pests (Brasovean *et al.*, 2009).

The study aimed to investigate the effectiveness of fungicides against late blight, and early blight and their effect on the yield and quality of tubers of early maturing potato varieties.

Materials and Methods

Field researches in 2018–2020 were conducted in conditions of Ukraine housed by the private company Zherm in the Zhytomyr region, located in the north-western part of Ukraine (50°31′ N 28°45′ E). The climate of the region, where the research took place, is moderate continental, mild and damp. Precipitation during the spring-summer period is approximately 300 mm and in autumn-winter – over 200 mm. Average annual precipitation is within 600–670 mm. The average annual temperature is +6... +8 °C and the temperature in summer approaches +17... +20 °C.

The soil cover of the research field is presented by sod-podzolic soils that are characterized by low content of nutrients and have an acid reaction to the soil solution. In general, soil-climatic conditions of the region of the private company allow the growing of most of the crops, including potatoes.

Cultivation technology of potatoes in the experiment was generally accepted for the Polissia zone of Ukraine. The early maturing variety of potatoes Bellarosa, included in the "State Register of plant varieties suitable for distribution in Ukraine" was planted in the experiment. We investigated the effectiveness of fungicides against major mycoses (late blight and early blight). We determined the effect of chemical and biological preparations on the development of potato mycoses according to the following scheme:

Control – spraying of plants with water;

Variant 1 – Ridomil Gold MC 68 WP, (mancozeb, 640 g kg^{-1} + metalaxil M, 40 g kg^{-1}) – 2.5 kg ha^{-1} – the reference;

Variant 2 – Infinito 61 SC, 68.75% (fluopycolide, 62.5 g L^{-1} + propamocarb hydrochloride, 625 g L^{-1}) – 1.5 L ha^{-1};

Variant 3 – Quadris TOP 325 SC, 32.5% (azoxystrobin, 200 g L^{-1} + difenoconazole, 125 g L^{-1}) – 0.8 L ha^{-1}.

The area of the experimental plot was 25 m^2 in four replications. Plants were sprayed with the investigated fungicides three times: during the phase of budding, at the appearance of disease symptoms, and 14 days after the second spraying.

Spread and development of late blight and early blight spot was noted during vegetation of potato plants every 7 days starting from the seedling stage by examining 40 plants in each plot in all replicates.

The progress of diseases studied was calculated by the Formula (1).

$$R = \frac{n \times 100}{N}, \tag{1}$$

where R – progress of the disease (%);

n – number of affected plants in samples;

N – total number of accounted plants (healthy and affected).

Progress of diseases characterizing the relation of the affected leaf surface to the total area of the leaf on the field was calculated by the Formula (2).

$$P = \frac{(n \times b) \times 100}{N \times K}, \tag{2}$$

where P – progress of the disease, %;

$(a \times b)$ – figures of the sum of multipliers of the number of affected plants (n) to the corresponding grade of affection (b);

N – total number of accounted plants;

K – the highest grade on the accounting scale.

Visual inspection of the degree of affection by late blight rot and early blight spot was done according to the following scale in grades: 9 – very high resistance (absence of spots), and 1 – very low resistance (affected more than 75% of leaves of the sample) (Trybel, 2001; Kononuchenko *et al.*, 2002).

The results of the study were statistically processed by using MS Excel 2016 and Statistica 6.0. The analysis of variance was used to find statistical differences (P <0.05).

Results and Discussion

The development of pathogens *Phytophthora infestans* (Mont) de Bary and *Alternaria solani* Sorauer, causing late blight and early blight of potato, depends largely on the weather conditions of the growing season and growing conditions. The years of the study were not particularly favourable for the spread of these pathogens on potato plants. Our research suggests that the fungicides studied have sufficiently high efficiency in protecting potatoes from pathogens of late blight and early blight.

At the beginning of the growing season, the symptoms of mycosis on potato plants could be distinguished visually. However, beginning from the blossoming phase, the studied pathogens jointly began to parasitize on the vegetative surface of potato plants, and it was quite difficult to distinguish them visually by the available symptoms (Fig. 1). The common pathological process of fungi *Phytophthora infestans* (Mont) de Bary and *Alternaria solani* Sorauer led to the rapid damage of potato plants.


A


B

Figure 1. Symptoms of mycosis on potato plants: A – tillering phase; B – after blossoming (Bellarosa variety, 2019)

Visual records and calculations of the spread and development of late blight and early blight in the field conditions were carried out by assessing their joint parasitization on the vegetative surface of potato plants.

The application of investigated fungicides has allowed reducing the distribution of pathogens of late blight and early blight on potato plants. The conducted surveys showed an increase in the index of mycosis spread on potato plants during the growing season (Fig. 2). In particular, in the Control variant, this indicator ranged from 5% in the primary recording to 72.1% in recording at the end of the growing season. The use of the studied fungicides reduced the spread of leaf spot disease at the end of the growing season by 1.4–2.0 times compared with the variant without fungicides. The best result, in which the spread of the evaluated diseases was 2.0 times lower than in the Control variant and 1.5 times lower than in the reference variant, was obtained in Variant 2 with the active substances fluopicolide and propamocarb hydrochloride (Infinito 61 SC, 68.75%).

A similar dependence was obtained in the study of disease development. Starting from the third ten-day period of June, the Control variant recorded a fairly rapid increase in disease development from 5.0% in the second recording to 10.5% in the third recording (Fig. 3).

The development of late blight and early blight pathogens in potatoes during the growing season in the variant without the use of fungicides was within 73.3%.

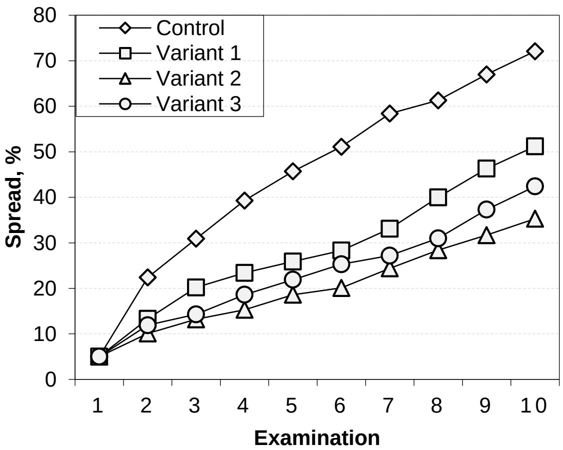


Figure 2. Dynamics of late blight and early blight spread when using fungicides, 2018–2020 (Control – spraying of plants with water; Variant 1 – Ridomil Gold MC 68 WP, (mancozeb, 640 g kg^{-1} + metalaxil M, 40 g kg^{-1}) – 2.5 kg ha^{-1} – the reference; Variant 2. Infinito 61 SC, 68.75% (fluopycolide, 62.5 g L^{-1} + propamocarb hydrochloride, 625 g L^{-1}) – 1.5 L ha^{-1}; Variant 3. Quadris TOP 325 SC, 32.5% (azoxystrobin, 200 g L^{-1} + difenoconazole, 125 g L^{-1}) – 0.8 L ha^{-1})

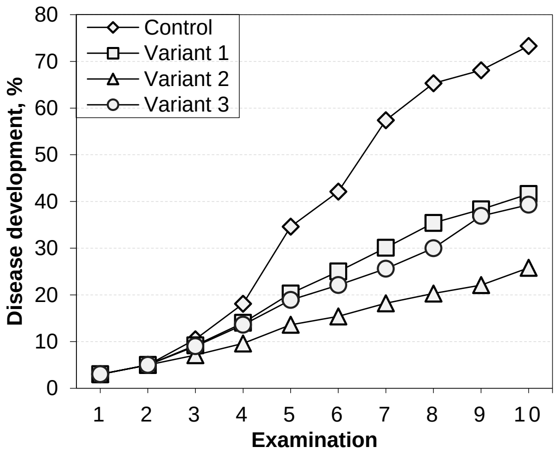


Figure 3. Dynamics of late blight and early blight development when using fungicides, 2018–2020 (Control – spraying of plants with water; Variant 1 – Ridomil Gold MC 68 WP, (mancozeb, 640 g kg^{-1} + metalaxil M, 40 g kg^{-1}) – 2.5 kg ha^{-1} – the reference; Variant 2. Infinito 61 SC, 68.75% (fluopycolide, 62.5 g L^{-1} + propamocarb hydrochloride, 625 g L^{-1}) – 1.5 L ha^{-1}; Variant 3. Quadris TOP 325 SC, 32.5% (azoxystrobin, 200 g L^{-1} + difenoconazole, 125 g L^{-1}) – 0.8 L ha^{-1})

The use of fungicides reduced the development of diseases in the variants with the use of preparations by 1.8–2.9 times compared with the control one. The development of the studied potato mycoses when using the preparation Quadris TOP 325 SC, 32.5% (Variant 3) at the end of the study was 32.5%, which was 1.9 times lower than in the Control variant. The lowest rate of disease development amounted to 25.8% at the last count was recorded in Variant 2 with the application of the preparation Infinito 61 SC, 68.75%. In this variant, we observed a decrease in the development of leaf spot disease by 2.9 times compared with the Control variant and by 1.6 times compared with the reference preparation Ridomil Gold MC 68 WP (Variant 1).

Research carried out in different soil-climatic areas showed, that use of fungicides helps to decrease the spread and development of spot diseases in potato leaves and for potato sorts with high resistance to pathogenic agents it is possible to reduce chemical preparations application rate to 30% (Nielsen *et al.*, 2010; Polozhenets *et al.*, 2011).

The technical effectiveness calculation of the investigated fungicides during the observation period confirmed the data obtained earlier (Fig. 4). Weather conditions of the growing seasons at the beginning of the observation period were not contributing to the development of diseases, and the applied preparations showed primarily a preventive effect. The effectiveness of the studied preparations was recorded starting from the third recording, and a gradual decrease in the index of technical effectiveness of fungicides was recorded throughout the observation period.

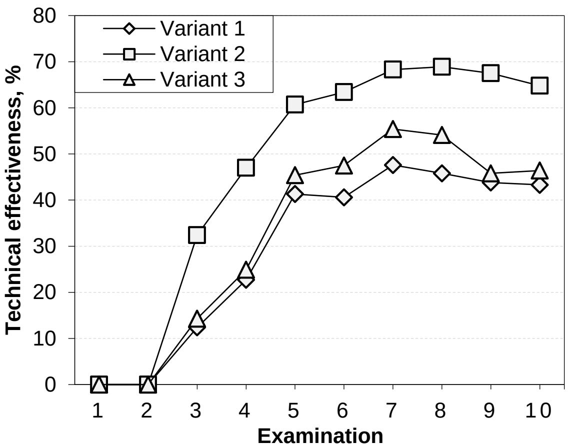


Figure 4. Technical effectiveness of fungicides against late blight and early blight, 2018–2020 (Variant 1 – Ridomil Gold MC 68 WP, (mancozeb, 640 g kg^{-1} + metalaxil M, 40 g kg^{-1}) – 2.5 kg ha^{-1} – the reference; Variant 2. Infinito 61 SC, 68.75% (fluopycolide, 62.5 g L^{-1} + propamocarb hydrochloride, 625 g L^{-1}) – 1.5 L ha^{-1}; Variant 3. Quadris TOP 325 SC, 32.5% (azoxystrobin, 200 g L^{-1} + difenoconazole, 125 g L^{-1}) – 0.8 L ha^{-1})

The efficacy of any preparations is determined by their ability to maintain the therapeutic effect over a long period. The technical efficacy of the reference preparation Ridomil Gold MC 68 WP, with mancozeb and methylaxyl at the end of the observation period was 43.3%, Quadris TOP 325 SC, 32.5% (azoxystrobin + difenoconazole) was 46.4%, and Infinito 61 SC, 68.75% (fluopycolide + propamocarb hydrochloride) – 64.8%. The highest technical efficiency indicator against late blight and early blight of potatoes during the whole period of the study was obtained when using the preparation based on active substances fluopicolide and propamocarb hydrochloride (Variant 2).

Several factors influence the degree of affection by pathogenic agents of late blight and early blight spot and harvest yield of potato tubers, in particular, the intention of potato crops rotation, application of organic and mineral fertilizers, planting sorts resistant to pathogenic agents and use of fungicides during vegetation. The researchers ascertained, that each element of potato protection against spot diseases has a positive effect, but, to achieve the maximum result it is necessary to use a complex approach to solving this problem (Garrett *et al.,* 2001; Makarov *et al.,* 2005; Plotnytska *et al.,* 2009; Frost *et al.,* 2013; Eric Mosota Rosana *et al.*, 2017*).*

Positive dynamics on reduction of spread and development of late blight and early blight of potatoes due to the use of preparations affected the yield of potato tubers (Table 1).

During the study, small fluctuations in the yield of potato tubers over the years were observed. The highest yields were obtained in 2020 for all variants of the experiment, which is primarily due to the weather conditions of the growing seasons.

Table 1. The yield of Bellarosa variety potatoes due to the use of fungicides, t ha^{-1}

Variant	Years 2018	2019	2020	average	Difference, ± Control
Control	26.0	25.8	26.8	26.2	–
Variant 1	31.4	28.9	31.8	30.7	4.5
Variant 2	36.9	36.7	37.7	37.1	10.9
Variant 3	32.4	31.4	33.1	32.3	6.1
$LSD_{0.05}$	0.7	1.2	1.1		

Control – spraying of plants with water; Variant 1 – Ridomil Gold MC 68 WP, (mancozeb, 640 g kg^{-1} + metalaxil M, 40 g kg^{-1}) – 2.5 kg ha^{-1} – the reference; Variant 2. Infinito 61 SC, 68.75% (fluopycolide, 62.5 g L^{-1} + propamocarb hydrochloride, 625 g L^{-1}) – 1.5 L ha^{-1}; Variant 3. Quadris TOP 325 SC, 32.5% (azoxystrobin, 200 g L^{-1} + difenoconazole, 125 g L^{-1}) – 0.8 L ha^{-1}

The yield of potato variety Bellarosa for 3 years of research on average in the Control variant without application of preparations was 26.2 t ha^{-1}. Applying fungicides against leaf spot in the potato plantings of this variety allowed obtaining an increase in tuber yield in the range of 4.5–10.9 t ha^{-1} compared to the Control variant. Spraying of potato plants in Variant 1 with the preparation Ridomil Gold MC 68 WP, which was the reference one, increased the tuber yield by 4.5 t ha^{-1} up to the level of 30.7 t t ha^{-1}. The highest increase in potato tuber yield was obtained in Variant 2 with the use of Infinito 61 SC, 68.75%. This variant of the experiment resulted in a yield of 37.1 t ha^{-1}, which was 1.4 times more compared to the Control variant and 1.2

times more compared to the reference Variant 1 with the preparation Ridomil Gold MC 68 WP.

It is known that the biochemical composition of potato tubers can vary depending on varietal characteristics, cultivation technology and protective measures (Bukolova *et al.*, 1997)

After harvesting, we conducted a study to determine the quality indicators of potato tubers' yield of Bellarosa variety due to the use of the fungicides (Table 2).

Table 2. Effect of fungicides on tuber quality parameters of the potato variety Bellarosa (mean, 2018–2020)

Variant	Content of		
	dry matter, %	starch, %	ascorbic acid, mg% 100 g^{-1}
Control	21.5	15.3	23.5
Variant 1	21.7	14.8	23.7
Variant 2	22.1	15.0	24.6
Variant 3	21.6	14.9	24.0

Control– spraying of plants with water; Variant 1 – Ridomil Gold MC 68 WP, (mancozeb, 640 g kg^{-1} + metalaxil M, 40 g kg^{-1}) – 2.5 kg ha^{-1} – the reference; Variant 2. Infinito 61 SC, 68.75% (fluopycolide, 62.5 g L^{-1} + propamocarb hydrochloride, 625 g L^{-1}) – 1.5 L ha^{-1}; Variant 3. Quadris TOP 325 SC, 32.5% (azoxystrobin, 200 g L^{-1} + difenoconazole, 125 g L^{-1}) – 0.8 L ha^{-1}

The content of dry matter in tubers, which was obtained in the Control variant without the use of preparations, amounted to 21.5%, starch – 15.3%, and ascorbic acid – 23.5 mg% 100 g^{-1}. Variants with fungicide use showed an increase of tubers' dry matter content by 0.1–0.6% and ascorbic acid content by 0.2–1.1 mg% 100 g^{-1} compared to the variant without fungicides. Starch content in the variants with the use of fungicides was 14.8–15.0%. The decrease in starch content due to the use of fungicides was in the range of 0.3–0.5% compared to the Control variant. The content of ascorbic acid in tubers, depending on the variant of research, was within the limit of 23.7–24.6 mg% 100 g^{-1} and was by 0.2–1.1 mg% 100 g^{-1} higher than in the Control variant.

Conclusion

Using fungicides in potato plantings against late blight and early blight reduces the spread of leaf spot disease at the end of the growing season by 1.4–2.0 times, and its development – by 1.8–2.9 times in comparison with the Control variant.

The increase in yield of potato tubers of Bellarosa variety due to the application of fungicides against leaf spot disease was within 1.2–1.4 times in comparison with the Control variant.

Among the studied preparations, the best indicators were obtained when using the fungicide Infinito 61 SC, 68.75% in potato plantings against late blight and early blight. Application of this preparation helped to reduce the spread of the studied diseases by 2.0 times, the development of diseases by 2.9 times, and to increase the yield by 1.4 times compared to the variant without fungicides application.

Application of fungicides also contributed to the improvement of quality indices of tubers; in particular, we observed an increase in the content of dry matter in tubers by 0.1–0.6% and ascorbic acid by 0.2–1.1 mg% 100 g^{-1}compared to the variant without fungicides.

Further studies will be aimed at determining the effect of preparations and their mixtures on the development of some potato mycoses during the growing season and postharvest period, yields and quality indicators of potato tubers.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author contributions

RT – a study of the concept and design, drafting the manuscript;
OS – author of the idea, who led the research;
OO – data analysis and interpretation, the corresponding author;
RT, NP – data collection, drafting the manuscript;
RT, NP – conducted analysis and discussion of data from the research literature;
OS, OO – critical revision and approval of the final manuscript.
All the authors have read and approved the final manuscript.

References

Andrivon, D., Lucas, J.M., Ellissèche, D. 2003. Development of natural late blight epidemics in pure and mixed plots of potato cultivars with different levels of partial resistance. – Plant Pathology, 52(5): 586–594. DOI: 10.1046/j.1365-3059.2003.00882.x

Bondarchuk, A.A., Koltunov, V.A., Znamenskyi, O.P. 2009. Kartoplia: vyroshchuvannia, yakist, zberezhenist [Potatoes: cultivation, quality, safety]. – Kyiv, KYT, 232 p. (In Ukrainian).

Brasovean, I., Oroian, I., Florian, V. 2009. Integrated Control of Potato Diseases. – Pro Environment 2, 83: 230–234.

Brurberg, M.B., Elameen, A., Le, V.H., Naerstad, R., Hermansen, A., Lehtinen, A., Hannukkala, A., Nielsen, B., Hansen, J., Andersson, B., Yuen, J. 2011. Genetic analysis of Phytophthora infestans populations in the Nordic countries reveals high genetic variability. – Fungal Biology, 115:335–342. DOI: 10.1016/j.funbio.2011.01.003

Bukolova, T.P., Duda, V.V., Malenko, I.M., Kravets, V.S. 1997. Biokhimichnyi sklad bulb i yoho vplyv na yakist kartopleproduktiv [Biochemical composition of tubers and its effect on the quality of potato products]. – Kyiv, Ahrarna nauka [Kyiv, Agrarian Science], 153–160 (in Ukrainian).

Filippov, A.V. 2012. Fitoftoroz kartofelya [Potato late blight]. – Zashhita i karantin rastenij [Protection and quarantine of plants], 5:62–65. (In Russian)

Frost, K.E, Groves, R.L, Charkowski, A.O. 2013. Integrated control of potato pathogens through seed potato certification and provision of clean seed potatoes. – Plant Disease, 97(10):1268–1280. DOI: 10.1094/PDIS-05-13-0477-FE

Garrett, K.A, Nelson, R.J, Mundt, C.C, Chacon, G., Jaramillo, R.E, Forbes G.A. 2001. The effects of host diversity and other management components on epidemics of potato late blight in the humid highland tropics. – Phytopathology, 91:993–1000. DOI: 10.1094/PHYTO.2001.91.10.993

Ghorbani, R., Wilcockson, S.J., Giotis, C., Leifert C. 2004. Potato late blight management in organic agriculture. – Outlooks Pest Management, 15(4): 176–180. DOI: 10.1564/15aug12

Holiachuk, Yu., Kosylovych, H. 2018. Efektyvnist funhitsydiv dlia zakhystu serednopiznikh sortiv kartopli v umovakh navchalno-naukovoho tsentru Lvivskoho NAU [The effectiveness of fungicides for the protection of mid-late varieties of potatoes in the educational and scientific center of Lviv NAU]. – Visnyk Lvivskoho Natsionalnoho Ahrarnoho Universytetu [Bulletin of the Lviv National Agrarian University], 22(2):103–106. DOI: 10.31734/ agronomy2018.02.103 (In Ukrainian)

Kalenska, S.M., Knap, N.V. 2012. Stan ta perspektyvy vyrobnytstva kartopli v sviti ta v Ukraini [Status and prospects of potato production in the world and in Ukraine]. – Zb. naukovykh prats Vinnytskoho nats. ahrar. Universytetu [Coll. scientific works of Vinnytsia National University. agrarian. University], 4(63): 41–48. (In Ukrainian).

Kononuchenko, V.V., Kutsenko, V.S., Osypchuk, A.A. 2002. Metodychni rekomendatsii shchodo provedennia doslidzhen z kartopleiu [Methodical recommendations for research with potatoes]. – Nemishaieve, 182 p. (In Ukrainian).

Lazarchuk, L.A. 2015. Efektyvnist elementiv systemy zakhystu kartopli vid khvorob i koloradskoho zhuka [The effectiveness of the elements of the system of protection of potatoes from diseases and the Colorado potato beetle]. – Visnyk ZhNAEU [Bulletin of ZhNAEU], 1(1):174–180 (In Ukrainian).

Makarov, V.I., Khlopyuk, M.S., Kalashnikov, K.G. 2005. Primenenie udobrenij i pesticzidov pod kartofel` e`konomicheski opravdano [The use of fertilizers and pesticides for potatoes is economically justified]. – Kartofel` i ovoshhi [Potatoes and vegetables], 8:22. (In Russian).

Martynenko, V.I. 2003. Fitoftoroz kartopli ta zakhody dlia obmezhennia yoho poshyrennia ta shkodochynnosti [Potato late blight and measures to limit its spread and harmfulness]. – Visnyk SNAU. Ser. Ahronomiia i biolohiia [SNAU Bulletin. Ser. Agronomy and biology], 7: 187–189. (In Ukrainian).

Nielsen, B. J., Bodker, L., Hansen, J. G. 2010. Control of potato late blight using a dose model to adjust fungicide input according to infection risk. – Proceedings of the twelfth workshop of an European network for the development of an integrated control strategy of potato late blight. Arras, France, 3–6 May, 2010, 14:187–192

Plotnytska, N.M., Matviichuk, B.V., Tymoshchuk, O.A. 2009. Urozhainist kartopli zalezhno vid urazhennia fitoftorozom [Potato yield depending on the defeat of late blight]. – Zb. naukovykh prats Nats. naukovoho tsentru «Instytut zemlerobstva UAAN» [Coll. scientific works of the Nat. Research Center "Institute of Agriculture UAAS"], 3:107–112 (In Ukrainian).

Polozhenets, V.M., Nemerytska, L.V., Plotnytska, N.M. 2011. Zakhyst kartopli vid fitoftorozu [Protection of potatoes from late blight]. – Karantyn i zakhyst roslyn [Quarantine and plant protection], 5:17–19. (In Ukrainian).

Raichuk, T.M. 2010. Zbudnyky pliamystostei kartopli. Vydovyi sklad u Pivnichnomu Lisostepu [Pathogens of potato spots. Species composition in the Northern Forest-Steppe]. – Karantyn i zakhyst roslyn [Quarantine and plant protection], 3:15–16. (In Ukrainian).

Rosana, E.M., Kange, A.M., Wati, L.N., Otaye, D.O. 2017. Effects of fertilizer and fungicide application rates on the incidence and severity of late blight (*Phytophthora infestans*) on Irish potatoes (*Solanum tuberosum* L). – World Journal of Agricultural Research, 5(3):169–176. DOI: 10.12691/wjar-5-3-7

Schepers, H.T.A.M., van Soesbergen, M.A.T. 1995. Factors affecting the occurrence and control of tuber blight. – In Phytophthora infestans 150. Dowley, L.J., Bannon, E., Cooke, L.R., Keane, T., O'Sullivan, E. (Eds.). – Boole Press Ltd., Dublin, Ireland, 171–176.

Shpaar, D. 2004. Kartofel` [Potatoes]. – Torzhok, Variant, 466 p. (In Russian).

Trybel, S. O., Siharova, D. D., Sekun, M. P., Ivashchenko, O. O., Bublyk, L. I., Chaban, V. S., Merezhynskyi, Yu. H. 2001. Metodyka vyprobuvannia i zastosuvannia pestytsydiv [Methods of testing and application of pesticides]. – Kyiv, Svit, 448 p. (In Ukrainian).

Tsedaley, B. 2014. Late blight of potato (*Phytophthora infestans*) biology, economic importance and its management approaches. – Journal of Biology, Agriculture and Healthcare, 4(25):215–225

Wastie, R.L. 1991. Breeding for resistance. – In Phytophthora infestans: The Cause of Late Blight of Potato. Advances in Plant Pathology Ingram (Vol. 7.). D.S., Williams, P.H (Eds). – Academic Press Ltd., London, UK, pp. 193–224

van der Waals, J.E., Korsten, L., Aveling, T.A.S. 2001. A review of early blight of potato. – African Plant Protection, 7(2):91–102. DOI: 10.10520/EJC87837

Zan, K. 1962. Activity of Phytophthora infestans in soil in relation to tuber infection. – Transactions of the British Mycological Society, 45:205–221. DOI: 10.1016/S0007-1536(62)80054-0

Agraarteadus
1 • XXXIII • 2022 146–153

Journal of Agricultural Science
1 • XXXIII • 2022 146–153

RETROSPECTIVE: DURATION AND EFFICIENCY OF DAIRY COWS PRODUCTIVE LIFESPAN DEPENDING ON AGE AT FIRST CALVING AND FIRST LACTATION MILK PRODUCTIVITY

Vitalii Siriak[1], Yuriy Polupan[1], Ruslana Stavetska[2]

[1]Institute of Animal Breeding and Genetics nd. a. M.V. Zubets of National Academy of Agrarian Science of Ukraine, 1 Pogrebniaka, Chubynske, Boryspilskyi rayon, Kyivska oblast, 08321, Ukraine
[2]Department of Genetics, Breeding and Selection of Animals, Bila Tserkva National Agrarian University, pl. 8/1 Soborna, Bila Tserkva, Kyivska oblast, 09117, Ukraine

Saabunud: Received: 24.02.2022

Aktsepteeritud: Accepted: 07.05.2022

Avaldatud veebis: Published online: 07.05.2022

Vastutav autor: Corresponding author: Ruslana Stavetska

E-mail: rstavetska@gmail.com

ORCID:
0000-0003-1245-9161 (VS)
0000-0001-7609-2739 (YP)
0000-0003-0149-1908 (RS)

Keywords: dairy cows, longevity, lifetime productivity, age at first calving, first lactation milk productivity.

DOI: 10.15159/jas.22.14

ABSTRACT. The retrospective analysis involved 562 Holstein cows, 545 Ukrainian Black-and-White dairy cows and 100 Ukrainian Red-and-White dairy cows in Breeding Station Terezyne, Kyiv region. The influence of age at first calving and first lactation milk yield on the duration and efficiency of the productive lifespan of cows was studied. The results showed that with the increase of age at first calving from less than 22 to more than 34 months there was a steady tendency to reduction in the longevity and lifetime productivity of cows. There was found a statistically significant ($P < 0.001$) inverse correlation between the age at first calving and indicators of duration and efficiency of productive lifespan ($r = –0.177…–0.459$). The age at first calving determines 3.0–21.2% of the phenotypic variability of the considered indicators of duration and efficiency of the productive lifespan of cows ($P < 0.001$). According to the set of features, the most rational is the planning of age at first calving before 26 months, *i.e.* heifers need to be served before 15 months of age. With the first lactation milk yield increases and the duration and efficiency of the productive lifespan of cows increase curvilinearly. Higher longevity is typical for cows with an average 305-d milk yield in the first lactation of 6 001–8 000 kg, and higher lifetime productivity – with the highest milk yield in the first lactation (over 9 000 kg). There was found a relatively low positive correlation between 305-d milk yield in the first lactation and the parity and lifespan ($r = 0.087…0.164$, $P < 0.001$) and a moderately significant relationship – with lifetime productivity and lifetime daily milk yield ($r = 0.327…0.504$, $P < 0.001$). The milk yield of primiparous cows has a relatively low impact on the variability of lifespan, productive lifetime and total lactation length ($\eta_x^2 = 3.6–5.6\%$, $P < 0.001$) and a higher impact on the indicators of lifetime milk productivity and milk productivity per one day of life, productive lifetime and lactation ($\eta_x^2 = 12.5–35.6\%$, $P < 0.001$). The productive lifespan of cows with first lactation milk yield over 6 000 kg can be considered quite effective.

Introduction

Milk is one of the best natural foods and one of the most important animal products for human consumption. Most of the milk produced in the world (about 91%) comes from cattle, although in some countries sheep, goats and buffaloes are the major producers of milk (FAO, 2022). In recent years, the emphasis on production traits, and especially the increase in production per head of livestock, has been of particular importance. Since milk is one of the most important sources of income for most livestock producers and there is also a sufficient program for recording and collecting data about milk, and on the other hand, the maximum genetic improvement is when the number of traits is considered, the choice for milk production is important (Mohammadabadi *et al.*, 2021). Moreover, high milk yields often lead to poor health and fertility of cows and, as a result, increased intensity of their culling (Adamczyk *et al.*, 2017; Dallago *et al.*, 2021). This reduces the economic efficiency of the dairy herd. Because of the above mentioned, the duration and efficiency of the productive lifespan of cows are considered indicators of the efficiency of breeding and welfare of dairy cattle (Adamczyk *et al.*, 2017; De Vries, Marcondes, 2020; Vredenberg *et al.*, 2021). In 2021, the US Net Merit (NM$) included new indicators (feed saved, heifer livability, early first calving) and updated weight coefficients for some other dairy cattle selection indicators. In particular, the share of the sub-index of productive life of cows has increased (VanRaden *et al.*, 2021; Zhang, Amer, 2021), which is an important indicator of this trait's relevance.

Longevity and lifetime productivity of cows are determined by genotypic, environmental factors and ontogenetic parameters of animal body formation (Kulak *et al.*, 1997; Sherwin *et al.*, 2016; De Vries, Marcondes, 2020; Schuster *et al.*, 2020). Important factors of ontogenetic development that affect the longevity of cows are the age at first calving and first lactation milk yield. The speed of renewal and the cost of repairing the herd depends on the age at the first calving of cows. With low heredity of age at the first calving ($h^2 = 0.086$) (Nilforooshan, Edriss, 2004) and a weak correlation between age at first calving and lifespan of cows ($r = 0.104…0.255$) (Shkurko, 2014) there was proved its significant effect on milk yield, milk fat yield, the productive lifetime of cows (Nilforooshan, Edriss, 2004), lifetime daily milk yield (Haworth *et al.*, 2008), calving interval (Kučević *et al.*, 2020).

The optimal age of the dairy cows at first calving is considered to be 23–25 months (Do *et al.*, 2013; Nilforooshan, Edriss, 2004). In the study of Froidmont *et al.* (2013) the highest total lactation length and milking days was obtained at first calving age within 22–26 months. If the age at first calving is less than 22 months, the loss of 305-d milk yield in the first lactation is 590–800 kg (Elahi Torshizi, 2016), when above 26 months – 170–600 kg (Pirlo *et al.*, 2000). The daily milk yield of cows that calved for the first time at 22–25 months of age is 2.1–2.4 kg higher than that of animals with older or younger ages at first calving (Storli *et al.*, 2017; Eastham *et al.*, 2018). Based on the analysis of 19 publications from different geographical areas and the use of different breeds, covering information on 2.4 million cows, Steele (2020) concluded that the optimal age at first calving was 22–25 months. In the study of Almasri *et al.* (2020), Syrian Shami cows with age at first calving before 25 months showed the best indicators of longevity and lifetime milk productivity. Sanova (2020) argues that the productive lifetime of cows decreases with age at first calving increase. In the population of Korean Holsteins, it was concluded that with the reduction of age at first calving from 32.8 to 22.3 months, lifetime profit increases from 727.3 to 2 363.6 US dollars (Do *et al.*, 2013). El-Awady *et al.* (2021) report that in Egyptian buffalos reducing the age at first calving from 1 670 ± 119 to 918 ± 41 days helps to prolong the longevity in the herd from 3.88 ± 1.51 to 8.43 ± 2.3 lactations, to increase lifetime milk yield from 10 271 ± 2 943 to 20 898 ± 3 546 kg, with lifetime profit increase from $ 222 to $ 3 778. At the same time, Pirlo *et al.* (2000) found slight differences in the longevity of cows, whose age at first calving ranged from 22.4 to 27.4 months. In the Australian Holstein population, the age at first calving did not affect the lifetime days in milk and the number of parities per lifetime (Haworth *et al.*, 2008).

To assess the duration and efficiency of a dairy cow's productive lifespan, the highest prognostic value have first lactation milk yield, milk fat yield and milk protein yield, and daily milk yield in the first lactation is a reliable indicator of milk yield in subsequent lactations, its lifetime productivity and longevity (Haworth *et al.*, 2008).

Most researchers have found a positive correlation between first lactation milk yield and cows' longevity (Jairath, Dekkers, 1995; du Toit *et al.*, 2009; Abdelharith *et al.*, 2019; Almasri *et al.*, 2020), first lactation milk yield and herd culling rates (Haine *et al.*, 2017). Du Toit *et al.*, (2011) concluded that direct selection by milk productivity does not lead to undesirable genetic changes in the dairy cow's longevity.

The genetic correlation between the cow survival during three lactations and their milk productivity is quite high and varies according to various data from 0.60 to 0.99 (Jairath, Dekkers, 1995; Boettcher *et al.*, 1999; du Toit *et al.*, 2009). The relationship between 305-d first lactation milk yield and the lifetime number of lactations, lifetime days in milk, lifespan and productive lifetime and lifetime milk yield varies from 0.13 to 0.49 (Abdelharith *et al.*, 2019).

According to Januś and Borkowska (2012), primiparous cows with high milk yields are more productive in subsequent lactations. Wathes *et al.* (2014) state that cows with slightly lower than average milk yield in the herd at the first lactation are characterized by higher lifetime productivity, because these animals have the good reproductive ability and are being used in the herd for a long time.

Some researchers have found a negative correlation between the milk yield and the productive lifetime of dairy cows (Haworth *et al.*, 2008; Sawa, Bogucki, 2010; Karatieieva, 2019; Levina *et al.*, 2020). According to their results, the high milk yields of primiparous cows lead to a reduction in the longevity and productive lifetime of cows (Sawa, Bogucki, 2010; Karatieieva, 2019). According to Levina *et al.* (2020), in case the first lactation milk yields are within 4 100–5 000 kg, survival of cows after the first lactation was 67–75%, for milk yields of 10 100–11 000 kg – only 10–21%.

This study aimed to investigate the effect of age at first calving and milk yield of primiparous cows on the duration and efficiency of their productive lifespan.

Materials and Methods

The study was conducted by a retrospective statistical experiment in the herd of dairy cattle in Breeding Station Terezyne, which is located in the Kyiv region, Ukraine (49°51′27″ N, 30°6′36″E). Materials of the electronic information base ORSEK have been used. The generated matrix of observations in the sta format contained information about 5 703 cows by 458 variables. Of these, 3 908 animals had information on the date of calving (1989–2016) and the first lactation milk productivity of primiparous cows (Polupan, Siriak, 2019). A comparison of group averages revealed significant differences in the level of growing and feeding (estimated indirectly by the milk yield of primiparous cows) for chronologically different years of the first calving (3 671–8 054 kg). The range of variability of group averages (4 383 kg) is by 2.6 times higher than the total standard deviation of the sample (1 684 kg), which causes probable inaccuracy of statistical and genetic estimates and conclusions for chronologically long (19 years) periods of different conditions for growing, feeding and lactation of animals in the herd (Polupan *et al.*, 2019, 2020). Analysis of average first lactation milk yield in different years at first calving identified a relatively similar cluster from 2003 to 2008, taking into account the methodical requirement for forming a retrospective sample for the year of first calving no later than eight years before the date of analysis (Polupan, 2010). During this period, the average 305-d milk yield of primiparous cows ranged from 5 521 to 7 188 kg (lim = 1 667 kg) with a standard deviation (S.D.) of 1 383 kg (1.21 S.D.), which gives reason to expect close to reliable results of comparative analysis of animals of different genetic and genealogical groups. The level of heifer growing during this period provided 618 g of average daily live weight gain up to one year of age and 613 g at 12–18 months of age. The analysis included information on the productivity of 562 Holstein cows, 545 – Ukrainian Black-and-White and 100 – Ukrainian Red-and-White dairy cows.

A retrospective analysis of the duration and efficiency of the productive lifespan of cows was carried out according to our proposed method (Polupan, 2010). In the control animal group, we took into account the lifetime number of lactations and calves born alive, lifespan (days) (L), productive lifetime (PL), total lactation length (TLL), lifetime milk yield (kg), fat yield (kg) and protein yield (kg), lifetime, productive life and total lactation daily milk yield (kg), daily milk fat (g) and daily milk protein (g) yields (Polupan, 2010). The coefficients (%) of a productive lifetime (CPL), lactation (CL) and productive use (CPU) were calculated according to the considered periods by the following formula (Pelekhatyi *et al.*, 1999; Polupan, 2010):

$C_{PL}=PL/L\times100$;

$C_{L}=TLL/PL\times100$;

$C_{PU}=TLL/L\times100$

According to age at first calving and 305-d first lactation milk yield, the control cows were divided into eight groups by age at first calving with a class interval of 60 days, by the milk yield of primiparous cows a class interval was 1 000 kg.

The calculations were performed by methods of mathematical statistics using the software package Statistica 12.0. The results reliability was compared with three standard levels of statistical significance with their designation: P <0.05, P <0.01, P <0.001.

Results and Discussion

With the increase of age at first calving on average from 647 to 1 084 days (from less than 22 to more than 34 months), there is a steady trend to reduce the longevity and lifetime productivity of cows (Table 1).

Table 1. Duration and efficiency of dairy cows' productive lifespan depending on age at first calving *($\bar{x}$ ± S.E.)*

Parameters		Group by age at first calving, months							
		<22	22–24	24.1–26	26.1–28	28.1–30	30.1–32	32.1–34	>34
Number of cows		36	116	270	311	227	148	58	26
Age at first calving, days		647 ± 2.3	708 ± 1.5	760 ± 1.0	818 ± 0.9	877 ± 1.1	937 ± 1.4	988 ± 2.1	1 084 ± 9.7
Lifetime	no. of lactations	3.83 ± 0.310[b]	4.09 ± 0.174[c]	3.88 ± 0.097[c]	3.43 ± 0.093[a]	3.02 ± 0.107	2.75 ± 0.129	2.72 ± 0.202	2.50 ± 0.356
	calves born alive	4.65 ± 0.355[b]	4.53 ± 0.209[b]	4.45 ± 0.116[c]	3.99 ± 0.111[a]	3.85 ± 0.147	3.64 ± 0.207	3.21 ± 0.359	3.58 ± 0.452
Duration, days	lifespan	2 369 ± 115.3[b]	2 299 ± 69.9[a]	2 313 ± 39.7[b]	2 205 ± 38.2[a]	2 055 ± 48.1	2 009 ± 59.0	2 008 ± 89.9	1 906 ± 141.8
	productive lifetime	1 722 ± 115.6[c]	1 591 ± 69.9[c]	1 553 ± 39.8[c]	1 387 ± 38.3[c]	1 178 ± 48.1[a]	1 072 ± 59.0	1 021 ± 89.9	822 ± 141.1
	total lactation	1 494 ± 103.1[c]	1 378 ± 60.2[c]	1 348 ± 34.2[c]	1 212 ± 33.2[c]	1 030 ± 41.4[b]	936 ± 49.0	886 ± 76.0	711 ± 115.2
Lifetime productivity, kg	milk yield	27 671±2 091[c]	27 231±1 287[c]	26 059±754[c]	22 344 ±704[c]	18 231±796	16 286±959	15 617±1 572	13 547±2 390
	milk fat + milk protein	1 949 ± 148.4[c]	1 928 ± 91.1[c]	1 866 ± 54.2[c]	1 587 ± 50.7[c]	1 286 ± 56.8	1 146 ± 69.4	1 092 ± 112.7	940 ± 174.5
Daily milk yield per cow, kg	lifespan	11.1 ± 0.28[c]	11.2 ± 0.28[c]	10.7 ± 0.18[c]	9.5 ± 0.17[c]	8.1 ± 0.21[b]	7.3 ± 0.24	7.0 ± 0.41	6.2 ± 0.60
	productive lifetime	16.1 ± 0.63	17.2 ± 0.30[a]	16.8 ± 0.21	16.1 ± 0.23	15.9 ± 0.31	15.7 ± 0.37	15.4 ± 0.69	17.9 ± 0.99[a]
	total lactation	18.4 ± 0.65	19.7 ± 0.31[b]	19.2 ± 0.23[a]	18.2 ± 0.24	17.7 ± 0.32	17.5 ± 0.38	17.4 ± 0.72	19.4 ± 0.89
Daily milk fat and protein yields per cow, g	lifespan	782 ± 37.6[c]	792 ± 20.2[c]	767 ± 12.9[c]	671 ± 12.7[c]	568 ± 14.9[b]	512 ± 17.6	488 ± 29.6	422 ± 44.8
	productive lifetime	1 132 ± 44.8	1 216 ± 22.0[b]	1 199 ± 15.8[a]	1 137 ± 16.7	1 091 ± 21.1	1 079 ± 24.9	1 064 ± 48.2	1 199 ± 64.0
	total lactation	1 296 ± 45.8	1 392 ± 22.7[c]	1 375 ± 17.4[b]	1 289 ± 17.4	1 223 ± 22.0	1 202 ± 26.1	1 201 ± 50.3	1 304 ± 59.6
Coefficient, %	productive lifetime	69.5 ± 2.12[c]	65.3 ± 1.23[c]	64.0 ± 0.73[c]	59.2 ± 0.75[c]	52.2 ± 1. 05[c]	48.0 ± 1.33[b]	46.0 ± 2.00[a]	36.6 ± 3.66
	lactation	87.4 ± 1.44	87.2 ± 0.53	87.4 ± 0.40	88.3 ± 0.43	89.5 ± 0.60[b]	89.8 ± 0.61[b]	88.4 ± 1.16	91.5 ± 1.70[a]
	productive use	60.4 ± 1.96[c]	56.7 ± 1.08[c]	55.8 ± 0.64[c]	51.9 ± 0.66[c]	46.1 ± 0.89[c]	42.5 ± 1.08[c]	40.3 ± 1.70[a]	32.3 ± 2.83

Groups' significant differences were indicated by lowercase letters, where the level of the significance was denoted: [a] – P < 0.05; [b] – P < 0.01; [c] – P < 0.001.

The most effective was the productive lifespan of cows with age at first calving within 22–24 months, which dominate the animals with age at first calving 34 months and more by lifetime number of lactations by 1.59 ± 0.396 or 63.6% ($P < 0.001$), by lifetime calves born alive – by 0.95 ± 0.498 or 26.5% ($P < 0.01$), by lifespan – 393 ± 158.1 days or 20.6% ($P < 0.05$), by productive lifetime – 769 ± 157.5 days or 93.6%, ($P < 0.001$), by total lactation length – 667 ± 130.0 days or 93.8% ($P < 0.001$), by lifetime milk yield – 13 684 ± 2 714.4 kg or 101.0% ($P < 0.001$), by lifetime milk fat and milk protein yields – 988 ± 196.8 kg or 105.1% ($P < 0.001$), by lifetime daily milk yield – 5.0 ± 0.66 kg or 80.6% ($P < 0.001$), by lifetime daily milk fat and milk protein yields – 370 ± 49.1 g or 87.7% ($P < 0.001$), by coefficients of a productive lifetime – 28.7 ± 3.86% ($P < 0.001$) and productive use – 24.4 ± 3.03% ($P < 0.001$). At a reliable level, the majority of the considered traits of the duration and efficiency of productive lifespan, compared to the late calving group, remains the advantage of caws with age at first calving from 24.1 to 28 months.

At the age at first calving less than 22 months, the efficiency of productive lifespan compared to the group with age at first calving 22–24 months does not decrease significantly, and by lifespan, lifetime calves born alive, productive lifetime and total lactation length, lifetime milk yield, milk fat yield and milk protein yields, coefficients of a productive lifetime and productive use it is even slightly increasing.

Thus, according to the set of features, the most rational is the planning of the first calving before 26 months of age, *i.e.* heifers need to be bred before 15 months of age. This coincides with several scientists' opinions (Nilforooshan, Edriss 2004; Haworth *et al.*, 2008; Do *et al.*, 2013; Froidmont *et al.*, 2013; Storli *et al.*, 2017; Eastham *et al.*, 2018; Almasri *et al*, 2020; Steele, 2020) and is slightly lower than the results, obtained by Russian scientists (Nekrasov *et al.*, 2017), who consider the optimal age at first calving for Holstein cows 25.1–27 months, for Red-and-White dairy breed – 27.1–29 months. There is no significant precaution of age at first conception even before 13 months with intensive rearing of heifers.

In our study, the coefficients of a productive lifetime and productive use confirm the tendency to reduce the duration of productive lifetime and cows' lifetime milk production by increasing their age at first calving. Nilforooshan and Edriss (2004) also found a positive effect of lowering the age of first calving on milk yield and the productive lifetime of cows.

Correlation analysis revealed a statistically significant ($P < 0.0001$) inverse correlation of age at first calving with lifetime number of lactations ($r = –0.273 \pm 0.0279$), longevity ($r = –0.177 \pm 0.0285$), lifetime milk yield ($r = –0.322 \pm 0.0274$ %), lifetime milk fat yield and milk protein yields ($r = –0.325 \pm 0.0275$), lifetime daily milk fat and daily milk protein ($r = –0.438 \pm 0.0261$) and the coefficient of a productive lifetime ($r = –0.459 \pm 0.0257$).

Dispersion analysis confirmed a significant effect of age at first calving on lifetime number of lactations ($\eta_x^2 = 7.7 \pm 0.55\%$, $F = 14.09$, $P < 0.001$), lifetime calves born alive ($\eta_x^2 = 4.5 \pm 0.90\%$, $F = 4.98$, $P < 0.001$), longevity ($\eta_x^2 = 3.3 \pm 0.57\%$, $F = 5.73$, $P < 0.001$), productive lifetime ($\eta_x^2 = 8.8 \pm 0.54\%$, $F = 16.22$, $P < 0.001$), total lactation length ($\eta_x^2 = 8.8 \pm 0.54\%$, $F = 16.35$, $P < 0.001$), lifetime milk yield ($\eta_x^2 = 10.4 \pm 0.53\%$, $F = 19.66$, $P < 0.001$), lifetime milk fat and milk protein yields ($\eta_x^2 = 10.7 \pm 0.53\%$, $F = 20.24$, $P < 0.001$), lifetime daily milk yield ($\eta_x^2 = 18.8 \pm 0.48\%$, $F = 39.21$, $P < 0.001$), total lactation daily milk yield ($\eta_x^2 = 3.0 \pm 0.57\%$, $F = 5.29$, $P < 0.001$), lifetime daily milk fat and milk protein yields ($\eta_x^2 = 19.8 \pm 0.48\%$, $F = 41.48$, $P < 0.001$), productive lifetime daily milk fat and milk protein yields ($\eta_x^2 = 3.0 \pm 0.58\%$, $F = 5.25$, $P < 0.001$) and total lactation length daily milk fat and milk protein yields ($\eta_x^2 = 4.9 \pm 0.56\%$, $F = 8.80$, $P < 0.001$), on the coefficients of productive lifetime ($\eta_x^2 = 21.2 \pm 0.47\%$, $F = 45.41$, $P < 0.001$) and productive use ($\eta_x^2 = 20.6 \pm 0.47\%$, $F = 43.89$, $P < 0.001$).

Thus, by comparison of group averages, correlation and variance analysis there was proved the feasibility of planning early age at the first conception of heifers (13–15 months), does not reduce the duration and efficiency of the productive lifespan of cows.

A comparison of group averages revealed the effect on the duration and effectiveness of the productive lifespan of dairy cows (Table 2).

Cows with the lowest 305-d first lactation milk yield (up to four tons, on average 3 364 ± 72.2 kg) are characterized by the lowest indicators of duration and effectiveness of productive lifespan. With the milk yield of primiparous cows increasing, the duration and efficiency of the productive lifespan of cows increase curvilinearly. If we do not take into account the indicators of the group with the first lactation milk yield over 10 tons due to its small number and, consequently, statistical uncertainty of assessment, the highest level of total lactations and calves, longevity, productive lifetime and total lactation length were observed in cows with 305-d first lactation milk yield 6–7 tons. Further increase in the milk yield of primiparous cows is accompanied by a gradual decrease in these indicators. However, they remain higher than in groups with low productivity of primiparous cows (up to 5 tons). From 153 cows with the first lactation milk yield up to 5 tons per there was received on average 3.70 calves, and from 799 animals with milk yield over 6 tons – 4.19 calves, which is higher by 0.49 heads or by 13.2%. The corresponding indicators of these animals within the lifetime number of lactations were 2.83 and 3.62 (+0.79 lactation or 27.9%), longevity – 1 891 and 2 302 days (+411 days or +21.7%), by productive lifetime – 1 042 and 1 483 days (+441 days or + 42.3%), by total lactation length – 920 and 1 291 days (+371 days or +40.3%).

Table 2. Duration and efficiency of dairy cows' productive lifespan depending on first lactation milk yield *($\bar{x}$ ± S.E.)*

Parameters		Group by 305-d first lactation milk yield, kg							
		<4 000	4 000–5 000	5 001–6 000	6 001–7 000	7 001–8 000	8 001–9 000	9 001–10 000	>10 000
Number of cows		50	103	225	319	293	159	25	3
305-d first lactation average milk yield, kg		3 364 ± 72.2	4 570 ± 26.5	5 556 ± 18.1	6 522 ± 15.8	7 468 ± 16.1	8 397 ± 21.6	9 311 ± 45.4	10 185 ± 122.7
Lifetime	no. of lactations	2.78 ± 0.222	2.85 ± 0.151	3.32 ± 0.121^{a}	3.85 ± 0.095^{c}	3.56 ± 0.096^{b}	3.30 ± 0.120^{a}	3.32 ± 0.325	3.67 ± 0.333^{a}
	calves born alive	3.88 ± 0.291	3.61 ± 0.241	4.03 ± 0.160	4.31 ± 0.118^{b}	4.18 ± 0.118^{a}	4.04 ± 0.153	3.94 ± 0.378	3.33 ± 0.333
Duration, days	lifespan	1 910 ± 91.4	1 882 ± 60.8	2 063 ± 48.4^{a}	2 354 ± 38.7^{c}	2 297 ± 39.7^{c}	2 210 ± 47.7^{c}	2 268 ± 156.3^{a}	2 430 ± 248.6^{a}
	productive lifetime	1 061 ± 93.8	1 033 ± 63.2	1 237 ± 49.2^{a}	1 532 ± 39.5^{c}	1 486 ± 40.2^{c}	1 389 ± 48.5^{c}	1 421 ± 164.5^{a}	1 564 ± 232.8^{a}
	total lactation	927 ± 78.7	916 ± 54.0	1 068 ± 41.3^{a}	1 321 ± 33.7^{c}	1 301 ± 35.2^{c}	1 211 ± 41.6^{c}	1 274 ± 146.4^{a}	1 419 ± 207.0^{a}
Lifetime productivity, kg	milk yield	10 833±1 265	13 966±1 069	18 435±821^{c}	24 617±697^{c}	25 484±742^{c}	24 837±842^{c}	28 439±3 075^{c}	34 169±5 030^{c}
	milk fat + milk protein	750 ± 90.1	969 ± 76.0	1 294 ± 58.7^{c}	1 747 ± 49.7^{c}	1 817 ± 53.5^{c}	1 774 ± 60.6^{c}	2 039 ± 225.5^{c}	2 427 ± 355.5^{c}
Daily milk yield per cow, kg	lifespan	5.0 ± 0.37	6.7 ± 0.31^{c}	8.1 ± 0.20^{c}	9.9 ± 0.16^{c}	10.5 ± 0.16^{c}	10.9 ± 0.20^{c}	11.8 ± 0.70^{c}	13.9 ± 0.64^{c}
	productive lifetime	9.7 ± 0.45	13.1 ± 0.38^{c}	14.8 ± 0.23^{c}	16.1 ± 0.16^{c}	17.2 ± 0.18^{c}	18.5 ± 0.30^{c}	20.9 ± 0.78^{c}	21.9 ± 0.29^{c}
	total lactation	11.0 ± 0.53	14.6 ± 0.41^{c}	16.9 ± 0.25^{c}	18.5 ± 0.17^{c}	19.6 ± 0.19^{c}	21.0 ± 0.28^{c}	23.0 ± 0.74^{c}	24.1 ± 0.24^{c}
Daily milk fat and milk protein yields per cow, g	lifespan	346 ± 26.6	465 ± 21.8^{b}	563 ± 14.5^{c}	699 ± 11.2^{c}	751 ± 12.0^{c}	778 ± 14.3^{c}	841 ± 51.8^{c}	990 ± 46.5^{c}
	productive lifetime	663 ± 31.5	899 ± 26.0^{c}	1 027 ± 16.4^{c}	1 134 ± 11.4^{c}	1 223 ± 12.9^{c}	1 323 ± 21.5^{c}	1 487 ± 53.6^{c}	1 554 ± 11.6^{c}
	total lactation	751 ± 37.1	1 006 ± 28.9^{c}	1 170 ± 17.7^{c}	1 305 ± 12.4^{c}	1 391 ± 13.7^{c}	1 497 ± 20.4^{c}	1 636 ± 53.2^{c}	1 710 ± 6.4^{c}
Coefficient, %	productive lifetime	50.9 ± 2.21	50.8 ± 1.46	54.6 ± 1.00^{a}	61.4 ± 0.76^{c}	61.4 ± 0.76^{c}	59.9 ± 1.02^{c}	57.5 ± 3.49	63.7 ± 3.30^{c}
	lactation	88.9 ± 1.04	89.6 ± 0.69^{b}	88.1 ± 0.59	87.2 ± 0.41	88.1 ± 0.43	88.2 ± 0.57	90.8 ± 1.22^{b}	90.8 ± 0.41^{c}
	productive use	44.9 ± 1.84	45.2 ± 1.23	47.6 ± 0.84	53.3 ± 0.65^{c}	53.9 ± 0.68^{c}	52.5 ± 0.87^{c}	51.8 ± 3.02^{c}	57.9 ± 2.77^{c}

Groups' significant differences were indicated by lowercase letters, where the level of the significance was denoted: ^{a} – P < 0.05; ^{b} – P < 0.01; ^{c} – P < 0.001.

Lifetime milk production increases curvilinearly with increasing first lactation milk yield of cows to more than 9–10 tons. The lifetime milk yield of cows with 305-d first lactation milk yield 9 001–10 000 kg is 2.63 times higher than that of the group with milk yield up to 4 000 kg, and the lifetime milk fat and milk protein yields – by 2.72 times. With primiparous cows' milk yield of more than 6 000 kg, the lifetime milk yield exceeds 24 tons, and the lifetime milk fat and milk protein yields – 1.7 tons, which provides sufficient efficiency for the productive lifespan of cows. The physiological stress of primiparous cows with milk yield over 9–10 tons does not lead to a decrease in lifetime milk production, but on the contrary, is accompanied by its maximum growth to 29 053 kg of milk yield and 2 081 kg of milk fat and milk protein yields.

Lifetime daily milk yield and lifetime daily milk fat and milk protein yields with increasing milk production of primiparous cows from less than 4 000 kg to more than 9 000 kg steadily increase by 140% (from 5.0 to 12.0 kg) and 148% (from 346 to 857 g), respectively. The same increase was found in productive life daily milk yield (by 116%, from 9.7 to 21.0 kg), in total lactation daily milk yield (by 110%, from 11.0 to 23.1 kg), in productive life daily milk fat and milk protein yields (by 125%, from 663 to 1 494 g), and in total lactation daily milk fat and milk protein yields (by 119%, from 751 to 1 644 g). Thus, 305-d milk yield of primiparous cows over 6 tons can be considered quite effective for their productive lifespan. Such animals have a higher lifetime daily milk yield by 4.3 kg compared to animals with 305-d first lactation milk yield less than 5 tones (10.4 *vs.* 6.1 kg) or by 70%, by lifetime daily milk fat and milk protein yields respectively by 313 g (739 *vs.* 426 g) or by 42% (P <0.001).

The coefficient of the productive lifetime of cows increases curvilinearly from 50.9 to 58.2%, and the coefficient of productive use – from 44.9 to 52.5% with increases in milk production of primiparous cows from less than 4 000 kg to more than 9 000 kg. According to the lactation coefficient, which characterizes the ratio of lactation and dry periods during the productive lifetime of cows, intergroup differentiation was less significant without a clear pattern both for age at first calving (Table 1) and first lactation milk yield (Table 2).

Correlation analysis revealed a relatively low, but statistically significant direct correlation between 305-d first lactation milk yield and lifetime number of lactations (r = 0.087 ± 0.0291, P = 0.003), longevity (r = 0.164 ± 0.0290, P <0.001) and more significant – with lifetime milk yield (r = 0.327 ± 0.0276, P <0.001), lifetime milk fat and milk protein yields (r = 0.336 ± 0.0275), P <0.001), lifetime daily milk fat and milk protein yields (r = 0.504 ± 0.0254, P <0.001) and the coefficient of a productive lifetime (r = 0.212 ± 0.0287, P <0.001). Thus, our research results refute the statements of several authors (Haworth *et al.*, 2008; Sawa, Bogucki, 2010; Wathes *et al.*, 2014; Karatieieva, 2019; Levina *et al.*, 2020; Sanova, 2020) about the inverse correlation between first lactation milk yield and longevity and a productive lifetime of cows, and confirm the results of majority researchers' on the existence of a reliable direct correlation between these traits (Jairath, Dekkers, 1995; Boettcher *et al.*, 1999; Haworth *et al.*, 2008; du Toit *et al.*, 2009; du Toit *et al.*, 2011; Januś, Borkowska, 2012; Abdelharith *et al.*, 2019; Almasri *et al.*, 2020).

Dispersion analysis confirmed a significant, albeit relatively low, effect of primiparous cows' milk yield on lifetime number of lactations (η_x^2 = 3.6 ± 0.58%, F = 6.32, P <0.001), longevity (η_x^2 = 5.3 ± 0, 57%, F = 9.17, P <0.001), productive lifetime (η_x^2 = 5.6 ± 0.57%, F = 9.85, P <0.001) and total lactation length (η_x^2 = 5.6 ± 0.57%, F = 9.88, P <0.001), on the coefficients of a productive lifetime (η_x^2 = 7.5 ± 0.56%, F = 13.32, P <0.001) and productive use (η_x^2 = 7.1 ± 0.56%, F = 12.59, P <0.001). A more significant impact of 305-d first lactation milk yield is on lifetime milk yield (η_x^2 = 12.5 ± 0.52%, F = 23.76, P <0.001), lifetime milk fat and milk protein yields ($\eta_x^2 = 13.0 \pm 0.52\%$, F = 24.95, P <0.001), lifetime daily milk yield ($\eta_x^2 = 25.1 \pm 0.45\%$, F = 55.36, P <0.001), productive life daily milk yield ($\eta_x^2 = 29.3 \pm 0.42\%$, F = 69.36, P <0.001), total lactation daily milk yield ($\eta_x^2 = 32.7 \pm 0.40\%$, F = 81.18, P <0.001), lifetime daily milk fat and daily milk protein yields ($\eta_x^2 = 26.3 \pm 0.45\%$, F = 58.59, P <0.001), productive life daily milk fat and daily milk protein yields ($\eta_x^2 = 32.7 \pm 0.40\%$, F = 80.92, P <0.001) and total lactation daily milk fat and daily milk protein yields ($\eta_x^2 = 35.6 \pm 0.39\%$, F = 91.94, P <0.001). This coincides with the statement of Poslavska *et al.* (2017), who also found the strongest effect of first lactation milk yield on productive life and total lactation daily milk yield, milk fat and milk protein yields at significantly higher values of impact strength (54.97–62.47%). The results of our research are close to the results of Haworth *et al.* (2008), who note that neither age at first calving nor first lactation milk yield have a significant effect on the lifetime number of lactations.

Thus, the comparison of group averages, the correlation and variance analysis refuted the inexpediency warning for high milk production of primiparous cows (over 6–9 tons), which does not reduce the duration and efficiency of the productive lifespan of cows.

Conclusion

With the increasing age at first calving from less than 22 to more than 34 months, there is a steady trend to reduce the longevity of dairy cows and reduce their lifetime production. There was found a statistically significant (P <0.001) inverse correlation between the age at first calving and indicators of duration and efficiency of productive lifespan (r = –0.177…–0.456). The age at first calving determines 3.0…21.2% of the phenotypic variability of the studied indicators of duration and efficiency of the productive lifespan of cows (P <0.001). The most rational is the planning of the first calving before 26 months, i.e. heifers need to be bred before 15 months of age, without the significant precaution of mating even at the age of 13 months with intensive rearing of heifers.

With the increasing milk yield of primiparous cows, the duration and efficiency of the productive lifespan of cows increase curvilinearly. Higher longevity is typical for cows with an average 305-day first lactation milk yield of 6 001–8 000 kg, and higher lifetime production is typical for cows with the highest first lactation milk yield (over 9 000 kg). A relatively low, but statistically significant (up to P <0.001) direct correlation reveals between 305-d first lactation milk yield and lifetime number of lactations and longevity (r = 0.087…0.164) and more significant – with lifetime and daily milk yield (r = 0.327…0.504). The milk yield of primiparous cow has a relatively low, but significant (P <0.001) effect on the variability of lifespan, productive lifetime and total lactation length ($\eta_x^2 = 3.6…5.6\%$), the coefficients of a productive lifetime and productive use ($\eta_x^2 = 7.1…7.5\%$) and more significant – on the indicators of a lifetime, productive life, total lactation and daily milk production ($\eta_x^2 = 12.5…35.6\%$). The productive lifespan of cows with first lactation milk yield over 6 000 kg can be considered quite effective, as long as provides a lifetime milk yield of more than 24 tons and a lifetime milk fat and milk protein yields of more than 1.7 tons.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

YP – study conception and design;
VS – acquisition of data;
RS – analysis and interpretation of data;
RS (70%), VS (30%) – drafting of the manuscript;
YP (70%), RS (30%) – critical revision and approval of the final manuscript.

References

Abdelharith, H., Abd-Elatife, M., Ghoneim, E., Abd Elhamid, M. 2019. Genetic and phenotypic relationships among first lactation traits and some longevity and lifetime traits in Friesian cattle. – Egyptian Journal of Animal Production, 56(2):55–62. DOI: 10.21608/EJAP.2019.92997.

Adamczyk, K., Makulska, J., Jagusiak, W., Węglarz, A. 2017. Associations between strain, herd size, age at first calving, culling reason and lifetime performance characteristics in Holstein-Friesian cows. – Animal, 11(2):327–334. DOI: 10.1017/S1751731116001348

Almasri, O., Abou-Bakr, S., Ibrahim, M.A.M. 2020. Effect of age at first calving and first lactation milk yield on productive life traits of Syrian Shami cows. – Egyptian Journal of Animal Production, 57(2):81–87. DOI:10.21608/ejap.2020.104022

Boettcher, P.J., Jairath, L.K., Dekkers, J.C.M. 1999. Comparison of methods for genetic evaluation of sires for survival of their daughters in the first three lactations. – Journal of Dairy Science, 82:1034–1044. DOI: 10.3168/jds.S0022-0302(99)75324-5

Dallago, G.M., Wade, K.M., Cue, R.I., McClure, J.T., Lacroix, R., Pellerin, D., Vasseur, E. 2021. Keeping dairy cows for longer: A critical literature review on dairy cow longevity in high milk-producing countries. – Animals, 11(3):808. DOI: 10.3390/ani11030808

De Vries, A., Marcondes, M.I. 2020. Review: Overview of factors affecting productive lifespan of dairy cows. – Animal, 14(1):155–164. DOI: 10.1017/S1751731119003264

Do, C., Wasana, N., Cho, Yu., Choi, K., Choi, T., Park, B., Lee, D. 2013. The effect of age at first calving and calving interval on productive life and lifetime profit in Korean Holsteins. – Asian-Australasian Journal of Animal Sciences, 26(11):1511–1517. DOI: 10.5713/ajas.2013.13105

du Toit, J., Van Wyk, J.B, Maiwashe, A. 2011.

Correlated response in longevity from direct selection for production in the South African Jersey breed. – South African Journal of Animal Science, 42(1):38–46. DOI: 10.4314/sajas.v42i1.5

du Toit, J., Van Wyk, J.B., Maiwashe, A. 2009. Genetic parameter estimates for functional herd life for the South African Jersey breed using a multiple trait linear model. – South African Journal of Animal Science, 39:40–44. DOI: 10.4314/sajas.v39i1.43544

Eastham, N.T, Coates, A., Cripps, P., Richardson, H., Smith, R., Oikonomou, G. 2018. Associations between age at first calving and subsequent lactation performance in UK Holstein and Holstein Friesian dairy cows. – PlosOne, 13(6):e0197764. DOI: 10.1371/journal.pone.0197764

Elahi Torshizi, M. 2016. Effects of season and age at first calving on genetic and phenotypic characteristics of lactation curve parameters in Holstein cows. – Journal of Animal Science and Technology, 58(8). DOI: 10.1186/s40781-016-0089-1

El-Awady, H.G., Ibrahim, A.F., El-Naser, I.A.M.A. 2021. The effect of age at first calving on productive life and lifetime profit in lactating Egyptian buffaloes. – Buffalo Bulletin, 40(1):71–85.

FAO. 2022. Food and agriculture data. – https://www.fao.org/faostat Accessed on 20.02.2022

Froidmont, E., Mayeres, P., Picron, P., Turlot, A., Planchon, V., Stilmant, D. 2013. Association between age at first calving, year and season of first calving and milk production in Holstein cows. – Animal, 7(4): 665–672. DOI: 10.1017/S1751731112001577

Haine, D., Delgado, H., Cue, R., Sewalem, A., Wade, K., Lacroix, R., Lefebvre, D., Arsenault, J., Bouchard, É., Dubuc, J. 2017. Contextual herd factors associated with cow culling risk in Québec dairy herds: a multilevel analysis. – Preventive Veterinary Medicine, 144:7–12. DOI: 10.1016/j.prevetmed.2017.05.014

Haworth, G.M., Tranter, W.P., Chuck, J.N., Cheng, Z., Wathes, D.C. 2008. Relationships between age at first calving and first lactation milk yield, and lifetime productivity and longevity in dairy cows. – Veterinary Record, 162(20): 643–647. DOI: 10.1136/vr.162.20.643

Jairath, L.K., Dekkers, J.C.M. 1995. Operational model for genetic evaluation of functional herd life of Canadian Holsteins (Abstract). – Journal of Dairy Science, 7(1):156.

Januś, E., Borkowska, D. 2012. Correlations between milk yield in primiparous PHF cows and selected lifetime performance and fertility indicators as well as reasons for culling. – Acta Scientiarum Polonorum Zootechnica, 11(2):23–32.

Karatieieva, O.I. 2019. Analysis of the culling reasons and productive lifespan of Red Steppe cows [Analiz prychyn vybuttia ta tryvalist hospodarskoho vykorystannia koriv chervonoi stepovoi porody]. – Ukrainian Black Sea region agrarian science [Visnyk ahrarnoi nauky Prychornomoria], 2:89–95. DOI: 10.31521/2313-092X/2019-2(102)-13 (In Ukrainian)

Kučević, D., Trivunović, S., Šoronja, Ž., Janković, D., Stanojević, D., Đedović, R., Papović, T. 2020. Association between age at first calving and milk production in first lactation on longevity traits in Holstein cows. – Biotechnology in Animal Husbandry, 36(1):27–35. DOI: 10.2298/BAH2001027K

Kulak, K.K., Dekkers, I.C.M., McAllister, A.J., Lee, A.J. 1997. Relationships of early performance traits to lifetime profitability in Holstein cows. – Canadian Journal of Animal Science, 77:617–624. DOI: 10.4141/A96-129.

Levina, G.N., Zelepukina, M.V., Rudneva, T.N., Litovkina, G.N. 2020. Productive longevity of Simmental cows, depending on their milk yield, method of keeping and bulls origin from different countries [Produktivnoe dolgoletie korov simmental'skoj porody v zavisimosti ot velichiny udoya, sposoba soderzhaniya i bykov-otcov iz raznyh stran]. – Dairy and Beef Cattle Farming [Molochnoe i myasnoe skotovodstvo], 3:11–16. DOI: 10.33943/MMS.2020.85.15.003 (In Russian)

Mohammadabadi, M., Bordbar, F., Jensen, J., Du, M., Guo, W. 2021. Key genes regulating skeletal muscle development and growth in farm animals. – Animals, 11:e835. DOI: 10.3390/ani11030835

Nekrasov, A.A., Popov, N.A., Fedotova, E.G. 2017. Influence of the reproductive ability of cows on the duration of productive lifespan and lifetime production [Vliyanie vosproizvoditel'noj funkcii korov na prodolzhitel'nost' produktivnogo ispol'zovaniya i pozhiznennuyu produktivnost']. – Dairy and Beef Cattle Farming [Molochnoe i myasnoe skotovodstvo], 2:17–20. (In Russian).

Nilforooshan, M.A., Edriss, M.A. 2004. Effect of age at first calving on some productive and longevity traits in Iranian Holsteins of the Isfahan province. – Journal of Dairy Science, 87:2130–2135. DOI: 10.3168/jds.S0022-0302(04)70032-6.

Pelekhatyi, M.S., Shypota, M.S., Volkivska, Z.O., Fedorenko, T.V. 1999. Reproductive ability of Black-and-White cows depending on their origin and genotypes in the conditions of Ukrainian Polissya [Vidtvoriuvalna zdatnist chorno-riabykh koriv riznoho pokhodzhennia i henotypiv v umovakh ukrainskoho Polissia]. – Animal Breeding and Genetics [Rozvedennia i henetyka tvaryn], 31–32:180–182. (In Ukrainian).

Pirlo, G., Miglior, F., Speroni, M. 2000. Effect of age at first calving on production traits and on difference between milk yield returns and rearing costs in Italian Holsteins. – Journal of Dairy Science, 83(3):603–608. DOI: 10.3168/jds.S0022-0302(00)74919-8.

Polupan, Yu.P. 2010. Methods for assessing the selection efficiency of lifelong use of dairy cows [Metodyka otsinky selektsiinoi efektyvnosti dovichnoho vykorystannia koriv molochnykh porid]. – Methodology of scientific research on breeding, genetics and biotechnology in animal husbandry [Metodolohiia naukovykh doslidzhen z pytan selektsii, henetyky ta biotekhnolohii u tvarynnytstvi]:

mater. of sci.-theoret. conf., dedicated to the memory of UAAS academician Valerii Petrovych Burkat (Chubynske, February 25, 2010). Kyiv: Agricultural Science, 93–95. (In Ukrainian).

Polupan, Yu.P., Melnik, Yu.F., Biriukova, O.D., Peredriy, M.M. 2020. Durability and efficiency of lifetime use of red-and-white dairy cattle. – Animal Breeding and Genetics [Rozvedennia i henetyka tvaryn], 59:78–91. DOI: 10.31073/abg.59.09 (In Ukrainian).

Polupan, Yu.P., Siriak V.A. 2019. Influence of intensity of formation on live weight of heifers and milk productivity of cows [Vplyv intensyvnosti formuvannia na zhyvu masu telyts i molochnu produktyvnist koriv]. – Animal Breeding and Genetics [Rozvedennia i henetyka tvaryn], 57:111–125. DOI: 10.31073/abg.57.14 (In Ukrainian)

Poslavska, Yu.V., Fedorovych, Ye.I., Bodnar, P.V. 2017. Longevity and lifetime production of cows depending on their milk yield for the first and best lactation [Tryvalist ta efektyvnist dovichnoho vykorystannia koriv zalezhno vid yikh nadoiu za pershu ta krashchu laktatsii]. – Scientific Messenger of Lviv National University of Veterinary Medicine and Biotechnologies. Series: Agricultural sciences [Naukovyi visnyk LNUVMBT imeni S. Z. Gzhytskoho. Seriia: Silskohospodarski nauky], 19(74):175–181. DOI: 10.15421/nvlvet7439 (In Ukrainian)

Sanova, Z.S. 2020. Projection of productive longevity of Holstein cows by indirect traits [Prognoz produktivnogo dolgoletiya golshtinskih korov po kosvennym priznakam]. – Dairy and Beef Cattle Farming [Molochnoe i myasnoe skotovodstvo], 4:22–25. (In Russian). DOI: 10.33943/MMS.2020.55.90.006

Sawa, A., Bogucki, M. 2010. Effect of some factors on cow longevity. – Archiv fur Tierzucht, 53(4):403–414.

Schuster, J.C., Barkema, H.W., De Vries, A., Kelton, D.F., Orsel, K. 2020. Invited review: Academic and applied approach to evaluating longevity in dairy cows. – Journal of Dairy Science, 103(12):11008–11024. DOI: 10.3168/jds.2020-19043

Sherwin, V.E., Hudson, C.D., Henderson, A., Green, M.J. 2016. The association between age at first calving and survival of first lactation heifers within dairy herds. – Animal, 10(11):1877–1882. DOI: 10.1017/S1751731116000689

Shkurko, T. 2014. Productive use of cows [Produktyvne vykorystannia koriv]. – Livestock of Ukraine [Tvarynnytstvo Ukrainy], 7:5–9. (In Ukrainian)

Steele, M. 2020. Age at first calving in dairy cows: which months do you aim for to maximise productivity? – Veterinary Evidence, 5(1):1–22. DOI: 10.18849/ve.v5i1.248

Storli, K.S., Klemetsdal, G., Volden, H., Salte, R. 2017. The relationship between Norwegian Red heifer growth and their first-lactation test-day milk yield: A field study. – Journal of Dairy Science, 100(9):7602–7612. DOI: 10.3168/jds.2016-12018

VanRaden, P.M., Cole J.B., Neupane M., Toghiani S., Gaddis K.L., Tempelman R.J. 2021. Net merit as a measure of lifetime profit: 2021 revision. – USDA – AIP Res. Rep. NM$8 (05–21), 20 p.

Vredenberg, I., Han, R., Mourits, M., Hogeveen, H. Steeneveld W. 2021. An Empirical Analysis on the Longevity of Dairy Cows in Relation to Economic Herd Performance. – Frontiers in Veterinary Science, (8):646–672. DOI: 10.3389/fvets.2021.646672

Wathes, D.C., Pollott, G.E., Johnson, K.F., Richardson, H., Cooke, J.S. 2014. Heifer fertility and carry over consequences for lifetime production in dairy and beef cattle. – Animal, 8(1):91–104. DOI: 10.1017/S1751731114000755.

Zhang, X., Amer P. 2021. A new selection index percent emphasis method using subindex weights and genetic evaluation accuracy. – Journal of Dairy Science, 104:5827–5842. DOI: 10.3168/jds.2020-19547

Agraarteadus
1 • XXXIII • 2022 154–161

Journal of Agricultural Science
1 • XXXIII • 2022 154–161

FORTIFICATION OF MEAT PRODUCTS OF GEESE FARMING WITH LITHIUM BY INTRODUCING IT INTO POULTRY MIXED FEED

Olexander Sobolev[1], Olexander O. Borshch[1], Ihor Riznychuk[2], Olena Kyshlaly[2]

[1]Bila Tserkva National Agrarian University, Department of Biotechnology, Pl 8/1, Soborna Sq, 09117 Bila Tserkva, Ukraine
[2]Odessa State Agrarian University, 99 Kanatna St, 65039 Odessa, Ukraine

Saabunud: Received: 29.12.2021

Aktsepteeritud: Accepted: 25.04.2022

Avaldatud veebis: Published online: 25.04.2022

Vastutav autor: Corresponding author: Olexander Sobolev

E-mail: sobolev_a_i@ukr.net

ORCID:
0000-0003-3239-0560 (OS)
0000-0002-8450-2109 (OOB)
0000-0002-9614-8557 (IR)
0000-0002-0748-5093 (OK)

Keywords: lithium, goslings, accumulation, meat.

DOI: 10.15159/jas.22.11

ABSTRACT. We studied the possibility of fortification of goslings' products with lithium and peculiarities of its depositing in the organs and tissues of goslings concerning lithium level in the mixed feed. Experimental studies have been conducted on the goose breed Legart. 320 one-day-old goslings were divided on the principle of analogues into four groups, 80 heads each. The goslings of the first control group did not receive the lithium supplement with the feed mix. Experimental groups were fed with the feed where additionally was supplemented with different doses of lithium by the scheme of the experiment. After 70 days of rearing, three birds were randomly selected from each group and control slaughtered. The lithium content in the representative samples of muscle tissue and organs of goslings was determined by inductively coupled plasma-atomic emission spectrometry (ICP-AES). It was established that feeding the growing goslings with mixed feed containing lithium supplements in doses of 0.05, 0.10 and 0.15 mg kg^{-1}, contributed to the increase ($P < 0.001$) of the concentration of this trace element in the muscles of the thigh and drumstick 789.5, 1589.5 and 3447.4%, in the muscles of the breast 1096.8, 2080.6 and 3948.4%, liver are 455.4, 824.6 and 1440.8% respectively, compared to goslings that did not receive lithium supplements. Significant high values of lithium accumulation factors in organs and tissues of gosling (3.21–14.44) indicated that this element has a substantial accumulating capacity. The meat of goslings enriched with lithium can be considered a natural product with bio-corrective action that can be used in human nutrition. These meat products can be particularly useful for people that are living in regions with a low environmental level of lithium.

Introduction

Currently we know more than 50 mineral elements that are constantly present in humans and animals. Recently, it has experimentally proved the vital necessity of several trace elements, which previously were considered conditionally essential. Lithium is one of these biogenic elements. The biochemical mode of action of lithium is diverse and related to the action of hormones, enzymes, vitamins, trace elements and transcription of the genes that regulate cell growth (Mikosha *et al.*, 2017).

The results of numerous scientific studies conducted on different species of animals and poultry demonstrated that lithium has anti-stress, adaptogenic (Miftahutdinov, Terman, 2014; Ostrenko *et al.*, 2017), antiviral (Ren *et al.*, 2011; Chen *et al.*, 2015; Cui *et al.*, 2015; Qian *et al.*, 2018), antibacterial (Khalid *et al.*, 2014; Stachelska, 2015), radioprotective (Antushevich *et al.*, 2013), antitumor (Kaufmann *et al.*, 2011), anti-metastatic (Maeng *et al.*, 2016), antioxidative (Khairova *et al.*, 2012; Plotnikov *et al.*, 2016) and immunomodulatory properties (Rybakowski, 1999; Maddu, Raghavendra, 2015). Experimental data indicates the positive effects of lithium on osteogenesis (Clement-Lacroix *et al.*, 2005; Wang *et al.*, 2015).

Lithium has been successfully used in medicine as an effective remedy for the prevention and treatment of many diseases, including bipolar disorder, manic and depressive phases (Machado-Vieira *et al.*, 2009; Malhi *et al.*, 2017), dementia (Mauer *et al.*, 2014; Gerhard *et al.*, 2015), Alzheimer's disease (Matsunaga *et al.*, 2015;

Nunes *et al.*, 2015), Parkinson's and Huntington's diseases (Lazzara, Kim, 2015), some types of cancers (Li *et al.*, 2015; Berk *et al.*, 2017), osteoporosis (Tang *et al.*, 2015). Low doses of lithium reduce total mortality and promote the prolongation of human life (Zarse *et al.*, 2011).

Considering all the above, the provision of the human body with lithium in optimal quantities is essential. Currently, the majority of the world's population consumes less lithium than required. The exceptions are some geographical regions such as Northern Chile and Northern Argentina (Sobolev *et al.*, 2019; Szklarska, Rzymski, 2019).

The level of lithium consumption (mg day^{-1}) by the population varies from country to country: Belgium – 0.001–0.015; Canada – 0.022; Finland – 0.035; France – 0.048; Turkey – 0.029–0.051; Spain – 0.011–0.105; England – 0.107; Austria – 0.348; Germany – 0.182–0.546; Japan – 0.812; USA – 0.429–0.821; Denmark – 1.009; Sweden – 1.09; Mexico – 1.485; China – 1.560 (Van Cauwenbergh *et al.*, 1999; Schrauzer, 2002; Kalonji *et al.*, 2015).

People with low lithium status are impaired in tissue growth and reproductive function, life expectancy is reduced due to premature ageing, and they exhibit increased aggressiveness and behavioural problems. Using correlation analysis methods, the researchers have established an inverted relationship between the level of lithium in the human body and the level of suicide among the population, as well as the level of violent crimes such as murder, rape, and robbery (Giotakos *et al.*, 2015; Kohno *et al.*, 2020).

There are two main ways of providing the organism with this microelement: 1) taking lithium supplements in form of inorganic or organic compounds and 2) consumption of lithium-enriched food. There are reports of ways to increase the concentration of lithium in vegetables and fruits, as well as products of their technological processing (Pifferi, 2017). However, the number of scientific publications on the possibility and methods of enrichment of poultry products with lithium for human consumption is scarce.

Miftakhutdinova *et al.* (2020) reported that with the introduction of lithium additives in feed for broiler chickens at a dose of 66.0 mg kg^{-1}, its concentration increased in white meat by 211.1%, in red meat by 426.4% and in the liver by 257.6%, compared with the control group, which did not receive lithium with food. In another paper, the authors argued that even with short-term feeding of broiler chickens (five days) feed mixed enriched with lithium at the rate of 47.5 mg kg^{-1}, its concentration in white meat increases by 33.6%, in red at 104.2% (Miftakhutdinov *et al.*, 2021). It should also be noted that recently the technology for the preparation of paste from poultry meat enriched with lithium has been developed (Miftakhutdinova *et al.*, 2021).

Analysis of the results of experimental studies suggests that the amount of lithium deposition in poultry meat depends on its content in the diet, the form of the drug and the duration of introduction into the diet. In addition, a significant role in the accumulation of lithium is played by species and breed characteristics of poultry, which are probably due to genetic and physiological factors. Some researchers have found that the introduction of lithium supplements in poultry diets increases the content of protein and fat in the muscles of the chest and legs, as well as their energy and biological value (Grybanova, Sobolev, 2014), improves organoleptic and technological characteristics of meat (Miftakhutdinova *et al.*, 2020).

Our research aimed to study the possibility of fortification of gosling's meat with lithium and the investigation of peculiarities of lithium deposition in organs and tissues of goslings, depending on the level of this element in the feed mix.

Materials and Methods

Birds and experimental conditions

Experimental studies were conducted on goose breed Legart. Four groups of one-day-old goslings were formed on the principle of analogues. The goslings in the first control group did not receive the lithium supplement with the feed mix. Experimental groups were fed with the feed mixed that additionally was supplemented with different doses of lithium by the scheme of the experiment (Table 1). Each group had 80 birds. The duration of the experiment was 70 days and matched the growth period of goslings for meat. At the end of the rearing period, the average live weight of goslings was 4251.0 g in the control group 1, 4309.5 g in the experimental group 2, 4324.2 g in the experimental group 3 and 4354.7 g in the experimental group 4.

Table 1. The scheme of the feeding of goslings during the experiment

Group	Lithium additive in mixed feed, mg kg^{-1}
1 control	Complete mixed feed (CMF)
2 experimental	CMF + 0.05
3 experimental	CMF + 0.10
4 experimental	CMF +0.15

During the experiment, goslings were fed with the dry mixed feed balanced on the main nutritive and biologically active substances according to the existing norms (Table 2). Feed for the goslings was supplied *ad libitum* throughout the trial period. Lithium in feed for goslings was introduced as part of the mineral premix in the nano-aquachelated form obtained from Nanomaterial and Nanotechnologie Ltd. (Ukraine).

The birds were kept on the floor with free access to food and water. Technological parameters of gosling's keeping in all groups were similar and corresponded to the existing standards, by the national recommendations for young goslings. The density of planting goslings aged 1–3 weeks was eight birds per m^2 and at the age of 4–10 weeks four birds per m^2. The feeding front of goslings at the age of 1–3 weeks was 1.5 cm per bird, and at the age of 4–10 weeks 2.5 cm per bird. The watering front of goslings at the age of 1–3 weeks was 1.5 cm per bird and at the age of 4–10 weeks 2.0 cm per bird.

Table 2. Composition and nutritional value of complete compound feeds for goslings

Component, %	Age of goslings, weeks	
	1–3	4–10
Barley	9.50	12.50
Wheat	64.70	–
Corn	–	56.20
Wheat crops	–	7 00
Sunflower meal	3.00	5.00
Sunflower oil	1.00	–
Meat and bone meal scraps	5.00	5.00
Fish meal	9.50	4.00
Feed yeast	3.00	5.20
Lysine-NSI	0.06	0.20
Methionine	0.16	0.13
Salt	0.32	0.45
Monocalcium phosphate	0.26	0.75
Limestone	2.00	2.07
Vitamin premix	0.50	0.50
Mineral premix	1.00	1.00
Content in 100 g of mixed feed		
exchange energy, kcal	280.1	277.3
crude protein, g	20.0	17.1
crude fibre, g	2.7	3.4
calcium, g	1.4	1.3
phosphorus, g	0.8	0.8
sodium, g	0.3	0.3
lysine, g	1.0	0.9
methionine + cysteine, g	0.8	0.7

Sample collection

At the end of the scientific experience, at the age of 70 days, three birds (1 male and 2 females) were randomly selected as representatives from each group and their control slaughter was carried out by the law requirements (Zakon Ukrai'ny, 2006). After the controlled slaughter of the gosling, complete anatomical disassembly of their carcasses was carried out according to the existing guidelines (Lukashenko, 2013). During anatomical dissection of goslings' carcasses, representative samples of muscles of the thigh, drumstick, breast muscles and liver were collected according to state standards. Each sample was packed in a thick, moisture-proof plastic bag. From the moment of sampling to the beginning of the analysis, samples were stored at a temperature of 0 to 2 °C for no more than 24 hours (GOST 7702.2.0-95, 2009).

Chemical analysis

The chemical analysis of muscle tissue and poultry organs for lithium content was carried out in the certified laboratory of analytical chemistry and monitoring of toxic substances of the State Institution Kundiiev Institute of Occupational Health of The National Academy of Medical Sciences of Ukraine (Kiev).

The lithium content in the muscle tissue and organs of poultry was determined by inductively coupled plasma-atomic emission spectrometry (ICP-AES) using Optima 210 DV by Perkin Elmer (USA). The operation of the spectrometer was controlled by WinLab32 software. The results were processed by the device and displayed on the monitor in the required format.

Preparation of samples for analysis was carried out according to the guidelines (Andrusyshyna *et al.*, 2014). Samples were prepared for analysis in two stages. In the first stage, the muscles of the thigh, drumstick, breast and liver were dried to a constant mass in a drying cabinet (Memmert UF55, Germany) at a temperature of 103 ± 2 °C (DSTU ISO 1442:2005, 2008). Moisture content in the muscles of the thigh and drumstick the average for the groups ranged from 71.4 to 74.3% and in the muscles of the breast – from 73.2 to 74.8%. In the second stage, 0.1g of dried muscles of the thigh, drumstick, breast and liver were added to 2.0 ml of concentrated nitric acid (HNO_3) (Merck, Germany) followed by mineralization in the microwave MWS-2 (Berghof, Germany). The resulting mineralized substance was dissolved in deionized water (18 Ω) at a volume of 10 ml and analyzed by the ICP-AES.

The intensity of the biological accumulation of lithium in the muscle tissue and liver of goslings was estimated by the accumulation coefficient (AC), which was calculated by the formula:

$$\mathrm{AC} = \frac{\mathrm{CT}}{\mathrm{D}}, \tag{1}$$

where CT – is the lithium content in the tissue of muscle or liver of goslings mg kg^{-1} of fresh tissue; D – is the dose of the introduction of lithium in the feed mix, mg kg^{-1}.

Statistical analysis

The computer program of statistical processing of Microsoft Excel 2010 was used for the mathematical processing of obtained results. To detect a statistically significant difference between the mean values in the experimental groups' analysis of variance (one-way ANOVA procedure) was used. Differences between average values were considered statistically significant at P <0.05.

Results and Discussion

The obtained data showed that with the increase of lithium levels in compound feeds for goslings, its concentration in the muscle tissue and liver of poultry probably increased (Fig. 1).

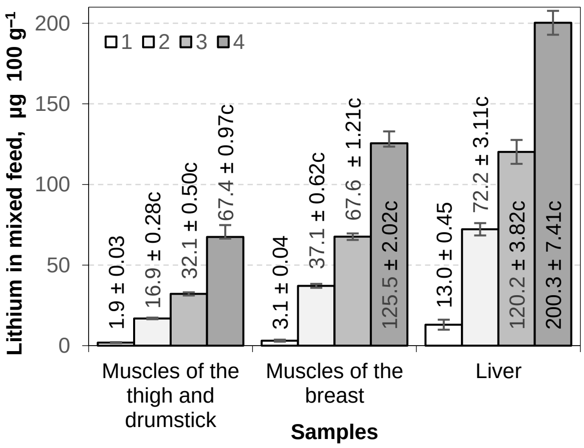


Figure 1. The concentration of lithium in muscle and liver of 70-days-old geese (± sd), µg 100 g^{-1} fresh tissue (experimental groups: 1 – control, 2 – 0.05, 3 – 0.10 and 4 – 0.15 mg kg^{-1} Li content in the mixed feed, c – similar lowercase letter indicate the statistical difference between the control group and all research groups was considered reliable at P <0.001)

Analysis of the samples of muscle tissue of goslings demonstrated that in the muscles of the thigh and drumstick of the second experimental group the concentration of lithium was 16.9 ± 0.28 μg 100 g^{-1} ($P < 0.001$), the third group was 32.1 ± 0.50 μg 100 g^{-1} ($P < 0.001$) and the fourth – 67.4 ± 0.97 μg 100 g^{-1} ($P < 0.001$) while in the control group the concentration of lithium in the same tissue was only 1.9 ± 0.03 μg 100 g^{-1}. Thus, the lithium content in these groups increased by 789.5, 1589.5 and 3447.4% correspondingly.

In the breast muscles of the control group of goslings, the concentration of lithium was 3.1 ± 0.04 μg 100 g^{-1}, while in their peers from the second experimental group it was 37.1 ± 0.62 μg 100 g^{-1} ($P < 0.001$) or 1096.8% higher than in the control group, in the third group it was 67.6 ± 1.21 μg 100 g^{-1} ($P < 0.001$) or 2080.6% of what was in the control and the fourth was 125.5 ± 2.02 μg 100 g^{-1} ($P < 0.001$) or 3948.4% higher than in control.

The liver is commonly considered the main trace elements depot in the animal and poultry bodies (Falandysz, 1991; Suttle, 2010; Counotte *et al.*, 2019). Therefore, expectedly the maximum concentrations of lithium were found in the liver tissues of goslings. Like in the muscle tissue, the concentrations of lithium in the liver also are depended on its content in the given feed mix. In particular, the concentration of lithium in the liver of goslings from the second experimental group was 72.2 μg 100 g^{-1} ($P < 0.001$), the third was 120.2 ($P < 0.001$) and the fourth 203.3 μg 100 g^{-1} ($P < 0.001$) while in the control birds the amount of lithium in the liver was 13.0 ± 0.45 μg 100 g^{-1}. Proportionally the difference in lithium concentration between the control and experimental groups was slightly less significant than in muscle tissue. Thus, in the second, third and fourth groups the liver's lithium was correspondently 455.4, 824.6, 1440.8% higher than in the control group.

The calculations of the coefficients of dose-dependent accumulation of lithium in different tissues revealed that they were not linear *i.e.* the increase in the concentration of lithium in the body of goslings was not proportional to the amount of lithium consumed with the feed mix (Fig. 2).

Thus, when the lithium was supplied at a dose of 0.05 mg per 1 kg of feed mix, the accumulation coefficient in the gosling's muscles of the thigh and drumstick of the second experimental group was 3.38, in the muscles of the breast was 7.42 and, in the liver 14.44. Although the third experimental group was fed with a feed mix enriched with lithium at a dose of 0.10 mg kg^{-1}, the corresponding coefficients were slightly lower compared to the second group and amounted to 3.21, 6.76 and 12.02 respectively. The goslings of the fourth experimental group received a feed mix enriched with lithium at a dose of 0.15 mg kg^{-1}. For them, the coefficients of accumulation of lithium in two groups of muscle and liver were 4.49, 8.37 and 13.35. Thus, the intensity of the biological accumulation of lithium in the muscle tissue and liver of the geese was undulating. High values of lithium accumulation factors in organs and tissues of gosling (3.21–14.44) indicated that this element has a substantial accumulating capacity.

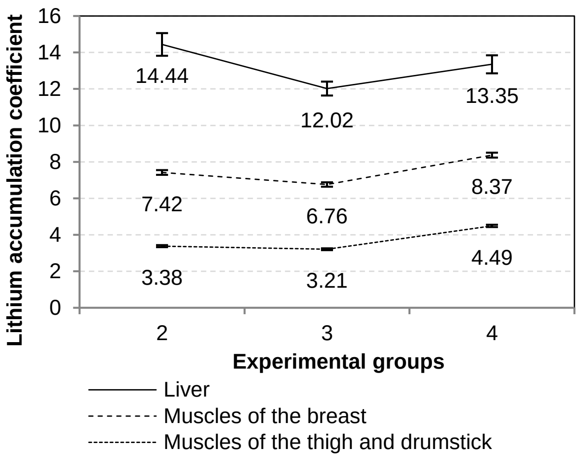


Figure 2. Lithium accumulation coefficient in the muscle tissue and liver (± sd) of the goslings from experimental groups (experimental groups: 2 – 0.05, 3 – 0.10 and 4 – 0.15 mg kg^{-1} Li content in mixed feed)

The obtained results are consistent with the findings of other scientists who in experiments on broiler chickens found that with an increase in the level of lithium in mixed feed its concentration in poultry products increases. However, data on the effect of adding different doses of lithium to mixed feed on its accumulation in the organs and tissues of broiler chickens are contradictory and do not always allow correct comparison. Miftahutdinova *et al.* (2020) reported that the introduction of lithium additives in mixed feed for broiler chickens at the rate of 66.0 mg kg^{-1} helped to increase its concentration in white meat to 4.18 mg kg^{-1}, in red meat increase up to 4.52 mg kg^{-1} and in the liver increase up to 3.40 mg kg^{-1}. The difference compared to the control group was 211.1, 426.4 and 257.6%.

In their later study, Miftakhutdinov *et al.* (2021) obtained results that prove that when feeding broiler chickens five days before slaughter with the mixed feed which was enriched with lithium at the rate of 47.5 mg kg^{-1}, lithium concentration in the white meat was 1.43 mg kg^{-1}, in red meat was 1.54 mg kg^{-1}, which is 33.6 and 104.2% more than in the control group. In broiler chickens of the control group, which were raised with the natural content of lithium in mixed feeds its concentration in white and red meat in the first research accordingly was 1.98 and 1.06 mg kg^{-1} and in the second study was 1.07 and 0.71 mg kg^{-1}.

At the same time, there is evidence in the literature that in the absence of lithium supplements in feed, the average content of lithium in the breast muscles of broiler chickens is 2.581 mg kg^{-1}, and in the leg muscles is 2.130 mg kg^{-1} (González-Weller *et al.*, 2013). Differences in the concentrations of lithium in broiler chicken meat of the control groups can be explained by differences in geochemical zones feeding conditions in which research was conducted and the composition of the diets. In general, this does not contradict previously published data that in poultry meat, lithium levels can range from 0.006 mg kg^{-1} (Leblanc *et al.*, 2005) up to 3.217 mg kg^{-1} (Mueller *et al.*, 2010).

Our experimental data once again confirmed the dependence found previously by other researchers and allows us to state with a high degree of confidence that poultry meat products can be enriched with lithium by introducing it into poultry feed. This approach will also exclude cases of toxicosis in the population, in the case of excessive consumption of individuals enriched with micronutrient meat, due to the buffer effect of animal tissues. It should be noted that the threshold of the toxic dose of lithium ranges from 90 to 200 mg day^{-1} for humans and it depends on the sex, body weight, age and physiological status of a particular individual (Shaposhnikova, Bolgova, 2012).

At present, there are no official recommendations of FAO/WHO experts on dietary standards of lithium consumption for humans (WHO/IAEA/FAO, 1996). At the same time, an adequate and upper acceptable (safe) level of lithium consumption has been established by separate countries for their citizens. For example, in Russia, these limits are set accordingly to 0.1 and 0.3 mg day^{-1} (Tutel'jan *et al.*, 2004). Existing research recommends that the suggested dose of lithium consumption with food and water for an adult weighing 70 kg be set at 1.0 mg day^{-1} (Schrauzer, 2002). Subsequently, the recommended dose of daily lithium consumption is 14.3 µg per 1 kg of human body weight (Aral, Vecchio-Sadus, 2008).

Since muscle tissue, unlike the liver, has a significantly higher portion than the edible parts of the poultry products, it can be considered the main source of lithium for humans. Our calculations show that the consumption of lithium-enriched goslings' meat within the recommended physiological norms in Ukraine (145 g day^{-1} meat and giblets) (Postanova Kabinetu Ministriv ..., 2016) on average can cover from 3.9 to 14.0% of the daily requirement of an adult in this trace element, depending on gosling's diet and hence on the concentration of lithium in gosling's products. Based on the proposed dose of daily lithium consumption at 14.3 µg per 1 kg of body weight, it is possible to estimate the level of physiological needs in this trace element in children and adolescents. Similar calculations can be made for the main social and demographic groups of the population in other countries considering the norms of consumption of meat and meat products operating in these countries.

Our experimental data allow us to assert with a high degree of confidence that gosling's meat products can be enriched with lithium by introducing it into the all mash for poultry. This approach will also exclude cases of toxicosis in the population, in the case of excessive consumption of individuals enriched with micronutrient meat, due to the buffer effect of animal tissues.

Conclusion

The amount of lithium in poultry products for human consumption and particularly in geese products can be efficiently regulated by supplementing feed mixes for birds with lithium additives. Analysis of the collected data allowed us to establish some facts and patterns: (i) lithium was found in all samples that were studied; (ii) with an increase in the level of lithium in the feed mix for geese its concentration in muscle tissue and liver of poultry was increasing correspondently; (iii) the concentration of lithium in tissues and organs increases in the following range: the muscles of the thigh and drumstick < muscles of the breast < liver. From the food hygiene point of view the introduction of lithium in the nano-aquachelated form into the feed mix for goslings at doses of 0.05, 0.10 and 0.15 mg kg^{-1}, provides an increase in the concentration of this trace element in the muscles of the thigh and drumstick respectively at 789.5, 1589.5 and at 3447.4% higher, in the muscles of the breast at 1096.8, 2080.6 and at 3948.4% higher, liver at 455.4, 824.6 and at 1440.8% higher when compared to similar indicators in goslings, which were fed with feed mix without lithium additives. Non-linear increase of lithium accumulation coefficients in the muscle tissue and liver of geese with the dose of lithium in the feed mix may indicate a stepwise biochemical mechanism of lithium metabolism in the organism. Additional research is required for the elucidation of lithium homeostasis.

Our results demonstrate that the meat of young goslings can be significantly enriched with lithium, and consequently can be considered a natural lithium fortified product that may be included in daily the diet of the human. These meat products can be particularly useful for people who are lived in regions with low levels of lithium in the natural environment.

Acknowledgements

The authors express their sincere thanks for technical assistance in the chemical analysis of poultry meat to the staff of the laboratory of analytical chemistry and monitoring of toxic substances at the State Institution Kundiiev Institute of Occupational Health of the National Academy of Medical Sciences of Ukraine.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

OS, OOB – study conception and design, drafting of the manuscript;
OS – acquisition of data;
OS, OOB, IR, OK – analysis and interpretation of data;
IR – critical revision and approval of the final manuscript.

References

Andrusyshyna, I.M., Lampeka, O.G., Golub, I.O., Lubjanova, I.P., Harchenko, T.D. 2014. Ocinka porushen' mineral'nogo obminu u profesijnyh kontyngentiv za dopomogoju metodu atomno-emisijnoi' spektroskopii' z induktyvno zv'jazanoju plazmoju: metodychni rekomendacii' [Estimation of disorders of mineral metabolism in professional contingents using the method of atomic emission spectroscopy with inductively coupled plasma: guidelines]. – Avicena: Kyi'v, Ukrai'na, 59 p. [In Ukrainian]

Antushevich, A.A., Antushevich, A.E., Grebenjuk, A.N., Tarumov, R.A., Antonov, V.G. 2013. Jeksperimental'noe izuchenie lechebnoj jeffektivnosti litievoj soli disul'fida glutationa v uslovijah ostrogo vneshnego vozdejstvija gamma-izluchenija [Experimental study of the therapeutic efficacy of the lithium salt of glutathione disulfide under conditions of acute external exposure to γ-radiation]. – Radiacionnaja biologija. Radiojekologija [Radiation biology. Radioecology], 53(5):451–458. DOI: 10.7868/S0869803113050044 [In Russian]

Aral, H., Vecchio-Sadus, A. 2008. Toxicity of lithium to humans and the environment – a literature review. – Ecotoxicology and Environmental Safety, 70(3):349–356. DOI: 10.1016/j.ecoenv.2008.02.026

Berk, M., Cowdery, S., Williams, L., Malhi G.S. 2017. Recalibrating the risks and benefits of lithium therapy. – The British Journal of Psychiatry, 211(1):1–2. DOI: 10.1192/bjp.bp.116.193789

Chen, Y., Yan, H., Zheng, H., Shi, Y., Sun, L., Wang, C., Sun, J. 2015. Antiviral effect of lithium chloride on infection of cells by porcine parvovirus. – Archives of virology, 160(4):1015–1020. DOI: 10.1007/s00705-015-2352-z

Clement-Lacroix, P., Ai, M., Morvan, F., Roman-Roman, S., Vayssiere, B., Belleville, C., Estrera, K., Warman, M.L., Baron, R., Rawadi, G. 2005. Lrp5-independent activation of Wnt signaling by lithium chloride increases bone formation and bone mass in mice. – Proceedings of the National Academy of Sciences, 102(48):17406–17411. DOI: 10.1073 / pnas.0505259102

Counotte, G., Holzhauer, M., Carp-van Dijken, S., Muskens, J., Van der Merwe, D. 2019. Levels of trace elements and potential toxic elements in bovine livers: A trend analysis from 2007 to 2018. – PLoS ONE, 14(4):e0214584. DOI:10.1371/journal.pone. 0214584

Cui, J., Xie, J., Gao, M., Zhou, H., Chen, Y., Cui, T., Bai X, Wang H, Zhang, G. 2015. Inhibitory effects of lithium chloride on replication of type II porcine reproductive and respiratory syndrome virus in vitro. – Antiviral Therapy, 20(6):565–572. DOI: 10.3851/ IMP2924

DSTU ISO 1442:2005. 2008. M`jaso ta m`jasni produkty. Metod vyznachennja vmistu vologi (kontrol'nyi metod) [Meat and meat products – Determination of moisture content (Reference method)]. – Derzhstandart Ukrai'ny: Kyi'v. 9 p. [In Ukrainian]

Falandysz, J. 1991. Manganese, copper, zinc, iron, cadmium, mercury and lead in muscle meat, liver and kidneys of poultry, rabbit and sheep slaughtered in the northern part of Poland, 1987. – Food Additives and Contaminants, 8(1):71–83. DOI: 10.1080/02652039 109373957

Gerhard, T., Devanand, D. P., Huang, C., Crystal, S., Olfson, M. 2015. Lithium treatment and risk for dementia in adults with bipolar disorder: population-based cohort study. – The British Journal of Psychiatry, 207(1):46–51. DOI: 10.1192/bjp.bp.114. 154047

Giotakos, O., Tsouvelas, G., Nisianakis, P., Giakalou, V., Lavdas, A., Tsiamitas, C., Katsaris, P., Kontaxakis, V. 2015. A negative association between lithium in drinking water and the incidences of homicides, in Greece. – Biological Trace Element Research, 164:165–168. DOI: 10.1007/s12011-014-0210-6

González-Weller, D., Rubio, C., Gutiérrez, A., Luis-González, G., Mesa, J.M., Revert, C., Ojeda, A.B., Hardisson, A. 2013. Dietary intake of barium, bismuth, chromium, lithium, and strontium in a Spanish population (Canary Islands, Spain). – Food and Chemical Toxicology, 62:856-858. DOI: 10.1016/j.fct.2013.10.026

GOST 7702.2.0-95. 2009. Mjaso pticy, subprodukty i polufabrikaty ptich'i. Metody otbora prob i podgotovka k mikrobiologicheskim issledovanijam [Poultry meat, edible, offal ready-to-cook products. Methods for sampling and preparing of microbiological examinations]. – Standartinform: Moskva, 9 p. [In Russian]

Grybanova, A.A., Sobolev, O.I. 2014. Vplyv dobavok litiju v kombikormy na jakist' m'jasa gusenjat [Influence of lithium additives in compound feed on the quality of gosling meat]. – Tehnologija vyrobnyctva i pererobky produkcii' tvarynnyctva [Technology of production and processing of livestock products], 1:36–39. [In Ukrainian]

Kalonji, E., Sirot, V., Noel, L., Guerin, T., Margaritis, I., Leblanc, J.-C. 2015. Nutritional risk assessment of eleven minerals and trace elements: prevalence of inadequate and excessive intakes from the second french total diet study. – European Journal of Nutrition and Food Safety, 5(4):281–296. DOI: 10.9734/EJNFS/2015/18193

Kaufmann, L., Marinescu, G., Nazarenko, I., Thiele, W., Oberle, C., Sleeman, J., Blattner, C. 2011. LiCl induces TNF-α and FasL production, thereby stimulating apoptosis in cancer cells. – Cell Communication and Signaling : CCS, 9:15. DOI: 10.1186/1478-811X-9-15

Khairova, R., Pawar, R., Salvadore, G., Juruena, M.F., de Sousa, R.T., Soeiro-de-Souza, M.G., Salvador, M., Zarate, C.A., Gattaz, W.F., Machado-Vieira, R. 2012. Effects of lithium on oxidative stress parameters in healthy subjects. – Molecular Medicine Reports, 5(3):680–682. DOI: 10.3892/mmr.2011.732

Khalid, A.L. Q., AlJohny, B.O., Wainwright, M. 2014. Antibacterial effects of pure metals on clinically important bacteria growing in planktonic cultures and biofilms. – African Journal of Microbiology Research, 8(10):1080–1088. DOI: 10.5897/AJMR2013.5893

Kohno, K., Ishii, N., Hirakawa, H., Terao, T. 2020. Lithium in drinking water and crime rates in Japan: Cross-sectional study. – BJPsych Open, 6(6):E122. DOI: 10.1192/bjo.2020.63

Lazzara, C.A., Kim, Y.-H. 2015. Potential application of lithium in Parkinson’s and other neurodegenerative diseases. – Frontiers in Neuroscience, 9:403. DOI: 10.3389/fnins.2015.00403

Li, L., Song, H., Zhong, L., Yang, R., Yang, X.Q., Jiang, K.L., Liu, B.Z. 2015. Lithium chloride promotes apoptosis in human leukemia NB_4 cells by inhibiting glycogen synthase kinase-3 beta. – International Journal of Medical Sciences, 12(10): 805–810. DOI: 10.7150/ijms.12429

Leblanc, J.C., Guérin, T., Noël, L., Calamassi-Tran, G., Volatier, J.L., Verger, P. 2005. Dietary exposure estimates of 18 elements from the 1st French total diet study. – Food Additives and Contaminants, 22(7): 624–641. DOI: 10.1080/02652030500135367

Lukashenko, V.S. 2013. Metodika provedenija anatomicheskoj razdelki tushek, organolepticheskoj ocenki kachestva mjasa i jaic sel'skohozjajstvennoj pticy i morfologii jaic : metodicheskoe rukovodstvo [Methodology for anatomical cutting of carcasses, organoleptic assessment of the quality of meat and eggs of poultry and morphology of eggs: guidelines]. – VNITIP: Sergiev Posad, Rossyja, 35 p. [In Russian]

Machado-Vieira, R., Manji, H.K., Zarate, C.A. 2009. The role of lithium in the treatment of bipolar disorder: convergent evidence for neurotrophic effects as a unifying hypothesis. – Bipolar Disorders, 11(2):92–109. DOI: 10.1111/j.1399-5618.2009.00714.x

Maddu, N., Raghavendra, P.B. 2015. Review of lithium effects on immune cells. – Immunopharmacology and Immunotoxicology, 37(2):111–125. DOI: 10.3109/08923973.2014.998369

Maeng, Y.S., Lee, R., Lee, B., Choi, S.I., Kim, E.K. 2016. Lithium inhibits tumor lymphangiogenesis and metastasis through the inhibition of TGFBIp expression in cancer cells. – Scientific Reports, 6:20739. DOI: 10.1038/srep20739

Malhi, G.S., Gessler, D., Outhred, T. 2017. The use of lithium for the treatment of bipolar disorder: Recommendations from clinical practice guidelines. – Journal of Affective Disorders, 217:266–280. DOI: 10.1016/j.jad.2017.03.052

Matsunaga, S., Kishi, T., Annas, P., Basun, H., Hampel, H., Iwata, N. 2015. Lithium as a treatment for Alzheimer's Disease: a systematic review and meta-analysis. – Journal of Alzheimer's Disease, 48(2):403–410. DOI: 10.3233/JAD-150437

Mauer, S., Vergne, D., Ghaemi, S.N. 2014. Standard and trace-dose lithium: a systematic review of dementia prevention and other behavioral benefits. – The Australian and New Zealand Journal of Psychiatry, 48(9):809–818. DOI: 10.1177/0004867414536932

Miftahutdinov, A.V., Terman, A.A. 2014. Farmakodinamicheskie svojstva citrata litija v modeli tehnologicheskih stressov [Pharmacodynamic properties of lithium citrate in the model of technological stress]. – Dostizhenija nauki i tehniki APK [Achievements of Science and Technology of the Agro-Industrial Complex], 6:60–62. [In Russian]

Miftahutdinova, E.A., Tikhonov, S.L., Tikhonova, N.V. 2020. Development of lithium-containing feed additive and its use for fortification of chicken broilers meat and by-products. – Theory and Practice of Meat Processing, 5(1):27–31. DOI: 10.21323/2414-438X-2020-5-1-27-31

Miftakhutdinova, E., Tikhonov, S., Tikhonova, N., Timakova, R. 2020. An effect of anti-stress feed additives on broiler productivity and meat quality. – Theory and Practice of Meat Processing, 5(2):4–11. DOI: 10.21323/2414-438X-2020-5-2-4-11

Miftakhutdinov, A., Sayfulmulukov, E., Nogovitsina, E. 2021. Safety monitoring of broiler chicken meat when correcting pre-slaughter stress using feed supplement “PIK-Antistress”. – IOP Conference Series: Earth and Environmental Science. Omsk City. Western Siberia, Russian Federation. 4–5 July 2020. 624. 012175. DOI: 10.1088/1755-1315/624/1/012175

Miftakhutdinova, E., Tikhonov, S., Diachkova, A., Miftakhutdinov, A., Tikhonova, N., Tretyakova, I., Brashko, I., Pestova, I., Saifulmuliukov, E., Nogovitsina, E. 2021. Technology optimization for the production of meat paste with lithium. – International Journal of Pharmaceutical Research and Allied Sciences, 10(1):101–108. DOI: 10.51847/Ye_NBs4

Mikosha, A.S., Kovzun, O.I., Tronko, M.D. 2017. Biological effects of lithium – fundamental and medical aspects. – Ukrainian Biochemical Journal, 89(3):5–16. DOI: 10.15407/ubj89.03.005

Mueller, R., Betz, L., Anke, M. 2010. Essentiality of the ultra trace element lithium to the nutrition of animals and man. – Proceedings of the 30. Scientific symposium of industrial toxicology, Bratislava, Slovakia. June 16–18, 2010, pp. 134–143.

Nunes, M.A., Schöwe, N.M., Monteiro-Silva, K.C., Baraldi-Tornisielo, T., Souza, S.I., Balthazar, J., Albuquerque, M.S., Caetano, A.L., Viel, T.A., Buck, H.S. 2015. Chronic microdose lithium treatment prevented memory loss and neurohistopathological changes in a transgenic mouse model of Alzheimer's Disease. – PLoS One, 10(11):e0142267. DOI: 10.1371/journal.pone.0142267

Ostrenko, K.S., Galochkina, V.P., Koloskova, E.M., Galochkin, V.A. 2017. Organicheskie soli litija – jeffektivnye antistressovye preparaty novogo pokolenija [Organic lithium salts – effective anti-stress drugs of a new generation]. – Problemy biologii produktivnyh zhivotnyh [Problems of the biology of productive animals], 2:5–28. [In Russian]

Pifferi, P.G. 2017. EP 2 794 516 B1. Composition for increasing lithium and selenium content in vegetables and their processed products and use thereof. – International Application No. PCT/EP2012/076474 – 27.06.2013, Bologna, Italy.

Plotnikov, E., Voronova, O., Linert, W., Martemianov, D., Korotkova, E., Dorozhko, E., Astashkina, A., Martemianova, I., Ivanova, S., Bokhan, N. 2016.

Antioxidant and immunotropic properties of some lithium salts. – Journal of Applied Pharmaceutical Science, 6(1):86–89. DOI: 10.7324/JAPS.2016.600115

Postanova Kabinetu Ministriv Ukrai'ny [Resolution of the Cabinet of Ministers of Ukraine]. 2016. Pro zatverdzhennja naboriv produktiv harchuvannja, naboriv neprodovol'chyh tovariv ta naboriv poslug dlja osnovnyh social'nyh i demografichnyh grup naselennja [About the statement of sets of foodstuff, sets of non-food goods and sets of services for the basic social and demographic groups of the population] (vid 11.10.2016, № 780). Kyi'v, Ukrai'na. – https://zakon2.rada.gov.ua/laws/show/780-2016-%D0%BF Accessed on 18/05/21 [In Ukrainian]

Qian, K., Cheng, X., Zhang, D., Shao, H., Yao, Y., Nair, V., Qin, A. 2018. Antiviral effect of lithium chloride on replication of avian leukosis virus subgroup J in cell culture. – Archives of Virology, 163(4):987–995. DOI: 10.1007/s00705-017-3692-7

Ren, X., Meng, F., Yin, J., Li, G., Li, X., Wang, C., Herrler, G. 2011. Action mechanisms of lithium chloride on cell infection by transmissible gastroenteritis coronavirus. – PLoS ONE, 6(5): e18669. DOI: 10.1371/journal.pone.0018669

Rybakowski, J.K. 1999. The effect of lithium on the immune system. – Human Psychopharmacology: Clinical and Experimental, 14(5):345–353. DOI: 10.1002/(SICI)1099-1077(199907)14:5<345::AID-HUP105>3.0.CO;2-T

Schrauzer, G.N. 2002. Lithium: occurrence, dietary intakes, nutritional essentiality. – Journal of the American College of Nutrition, 21(1):14–21.

Shaposhnikova, I.A., Bolgova, I.V. 2012. Tablica Mendeleeva v zhivyh organizmah : universal'noe uchebnoe posobie po biologii, himii i jekologii [Mendeleev's table in living organisms: a universal textbook on biology, chemistry and ecology]. – Binom: Moskva, Rossyja, 248 p. [In Russian]

Sobolev, O.I., Gutyj, B.V., Darmohray, L.M., Sobolieva, S.V., Ivanina, V.V., Kuzmenko, O.A., Karkach, P.M., Fesenko, V.F., Bilkevych, V.V., Mashkin, Y.O., Trofymchuk, A.M., Stavetska, R.V., Tkachenko, S.V., Babenko, O.I., Klopenko, N.I., Chernyuk, S.V. 2019. Lithium in the natural environment and its migration in the trophic chain. – Ukrainian Journal of Ecology, 9(2):195–203.

Stachelska, M.A. 2015. Inhibitory properties of lithium, sodium and potassium o-, m- and p-coumarates against Escherichia coli O157:H7. – Acta Scientiarum Polonorum. Technologia Alimentaria, 14(1):77–84. DOI: 10.17306/J.AFS.2015.1.9

Suttle, N.F. 2010. Mineral Nutrition of Livestock. (4th Ed.). – CABI, Cambridge, 579 p. DOI: 10.1079/9781845934729.0000

Szklarska, D., Rzymski, P. 2019. Is Lithium a micronutrient? From biological activity and epidemiological observation to food fortification. – Biological Trace Element Research, 189:18–27. DOI: 10.1007/s12011-018-1455-2

Tang, L., Chen, Y., Pei, F., Zhang, H. 2015. Lithium chloride modulates adipogenesis and osteogenesis of human bone marrow-derived mesenchymal stem cells. – Cell Physiol Biochem, 37(1): 143–152. DOI: 10.1159/00043034

Tutel'jan, V.A., Baturin, A.K., Vasil'ev, A.V., Vrzhesinskaja, O.A., Vysockij, V.G., Gapparov, M.M., Kodencova, V.M., Kon', I.Ja., Kravchenko, L.V., Kuvaeva, I.B., Kulakova, S.N., Lashneva, N.V., Mazo, V.K., Sokolov, A.I., Soto, S.X., Spirichev, V.B., Hotimchenko, S.A., Shatrov, G.N., Sheveleva, S.A., Jeller, K.I., Onishhenko, G.G., Petuhov, A.I., Kukes, V.G., Suhanov, B.P., Tjukavkina, N.A., Samylina, I.A., Grigor'ev, A.I., Petrov, R.V., Martynov, A.I., Bagirova, V.L., Devichenskij, V.M., Semenov, B.F., Mihajlova, N.A., Shabrov, A.V., Dadali, V.A., Tkachenko, E.I., Lesiovskaja, E.E., Bykov, V.A., Sokol'skaja, T.A., Kolhir, V.K., Skal'nyj, A.V., Nuzhnyj, V.P., Bulaev, V.M., Skal'naja, M.G. 2004. Rekomenduemye urovni potreblenija pishhevyh i biologicheski aktivnyh veshhestv: metodicheskie rekomendacii [Recommended levels of consumption of food and biologically active substances: guidelines]. – Federal'nyj centr Gossanjepidnadzora Minzdrava Rossii: Moskva, Rossyja, 47 p. [In Russian].

Van Cauwenbergh, R., Hendrix, P., Robberecht, H., Deelstra, H. 1999. Daily dietary lithium intake in Belgium using duplicate portion sampling. – Zeitschrift für Lebensmittel-Untersuchung und Forschung, 208(3):153–155. DOI: 10.1007/s002170050393

Wang, X., Zhu, S., Jiang, X., Li, Y., Song, D., Hu, J. 2015. Systemic administration of lithium improves distracted bone regeneration in rats. – Calcified Tissue Research, 96(6):534–540. DOI: 10.1007/s00223-015-0004-7

WHO/IAEA/FAO. 1996. Trace elements in human nutrition and health. – World Health Organization, Geneva, 343 p.

Zakon Ukrai'ny [Law of Ukraine]. 2006. Pro zahyst tvaryn vid zhorstokogo povodzhennja [On the Protection of Animals from Cruelty]. – https://zakononline.com.ua/documents/show/271179___677277 Accessed on 18/04/2021. [In Ukrainian]

Zarse, K.,Terao, T., Tian, J., Iwata, N., Ishii, N., Ristow, M. 2011. Low-dose lithium uptake promotes longevity in humans and metazoans. – European Journal of Nutrition, 50(5):387–389. DOI: 10.1007/s00394-011-0171-x

Agraarteadus
1 • XXXIII • 2022 162–175

Journal of Agricultural Science
1 • XXXIII • 2022 162–175

CONSUMERS' PROFILE ANALYSIS FOR CHICKEN MEAT, DURING THE FIRST WAVE OF COVID-19 PANDEMIC: CASE OF NORTHERN GREECE

Marina Stamatopoulou, Irini Tzimitra-Kalogianni

Department of Agricultural Economics, School of Agriculture, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

Saabunud: Received:	17.12.2021
Aktsepteeritud: Accepted:	31.01.2022
Avaldatud veebis: Published online:	31.01.2022
Vastutav autor: Corresponding author:	Marina Stamatopoulou

E-mail: marinastamdr@gmail.com

ORCID:
0000-0003-1695-1479 (MS)

Keywords: food-related lifestyle, chicken meat, COVID-19 pandemic.

DOI: 10.15159/jas.22.01

ABSTRACT. During the years of 2015–2016 in Greece, an increase of imports of poultry meat has been occurred on a level of 10.2%, whereas in the years of 2018–2019 the increase has only reached the level of 1.9%. On the contrary, a reduction on a level of 14.2% on poultry meat imports, in Greece, between the years of 2019–2020 have shown the possible implications of the COVID-19 pandemic to poultry meat consumption and possibly to chicken meat consumption. Moreover, the Food related lifestyle (FRL) can be defined as a system of consumers' cognitive categories and relationships that connect a set of food-related behaviours, with a set of personal values of each consumer. Hence, this paper aims to segment Greek consumers according to their food-related lifestyles values and is tried to identify the aspects that may determine consumers' behaviour towards chicken meat preference, during the first wave of the COVID-19 pandemic. Four consumer segments appeared: "Sociable and safety seekers", "Light concerned and cooks", "Unconcerned and price seekers", "Innovative and moderate concerned". Uni- and multivariate statistical techniques have been used. Consumers' profiles that demonstrated different food-related attitudes towards the pandemic were analysed with the use of variables: gender, age, marital status, educational level, monthly income and chicken meat quality cues. Significant differences were found between the four segments in terms of gender, age and income. Moreover, "Light concerned and cooks" and "Innovative and moderate concerned" consumers revealed to consider the place of purchasing as a dominant extrinsic quality cue of chicken meat. Furthermore, these consumers appeared to trust butcher in terms of the safety of chicken meat that they purchased, whereas only the consumers of the segment of "Light concerned and cooks" showed a willingness to pay a higher amount for chicken meat that is produced by animal welfare standards.

Introduction

In an ever-changing world, diverse and different consumer eating preferences are causing trends in meat consumption (Grunert, 2006). Particularly in the western world, the consumers' consumption of meat has changed in the last decade, due to their socio-economic changes, ethical concerns, religious beliefs, tradition, or dietary scandals (Font-i-Furnols, Guerrero, 2014). Since the meat market and its products are shaped through unexpected, complex and rapid changes which are caused by nutritional, economical and health events (Henchion *et al.*, 2014), meat production and consumption usually, create several controversial issues that concern consumers (Verbeke *et al.*, 2015). Thus, even though the meat has been recognized as a fundamental element of a human's diet, both from biological and social perspectives (Leroy, De Smet, 2019), nowadays, meat consumption and production have been regarded as problematic by consumers, due to health and safety issues, together with the animal welfare and environmental consumers' concerns (Vinnari, Tapio, 2009). On the other hand, the media attention to food scandals can change the time disclosure of a food incident and subsequently might affect the consumers' behavioural response (Rieger *et al.*, 2016). Consequently, consumers' preferences for meat are complex and alter due to different situations (Verbeke *et al.*, 2015).

Historically, meat was treated as a food that promotes health and gives energy to the consumer (Chong *et al.*, 2009). Moreover, western societies still consider meat as an important part of their culture (Latvala *et al.*, 2012), whereas it can be usually identified through the psychological dimension of human's habitual eating, or as a bonding effect in a community, and as a need for differentiation in the human's social hierarchical scale (Leroy, Praet, 2015). However, during the time, and especially halfway of the twentieth century, meat's positive image has been altered by negative consumers' perceptions (Leroy, De Smet, 2019) and meat consumption has been tended to be rather controversial for consumers (Latvala *et al.*, 2012). Specifically, the consumer's negative perception is focused on the consumption of red meat, which has been associated with chronic human diseases and cancer (Leroy, De Smet, 2019). In contrast, a negative health-compromising effect of white meat consumption, mainly derived from poultry meat, hasn't been reported yet, nor chronic diseases have ever been reported in the scientific literature (Marangoni *et al.*, 2015). However, there have been studies indicating a rather health-protective effect, due to white meat consumption, such as the protective effect of chicken meat consumption against age-related macular degeneration (Chong *et al.*, 2009).

Thus, human diseases related to the increasing lifestyle, such as diabetes which is associated with obesity as a function of a poor diet and a sedentary lifestyle, have led consumers to shift towards the consumption of chicken meat as a healthier option, due to its less fat and cholesterol content (Ripoll *et al.*, 2015). Moreover, chicken meat in developing markets has been considered as a value-oriented food, since it is identified as a cheap choice, has no religious restrictions and satisfies the consumer's need for new experiences through convenience packages or ready to eat meals (Michel *et al.*, 2011b). But chicken meat is also associated with foodborne illness, such as campylobacteriosis (Bearth *et al.*, 2014) and poultry diseases such as avian influenza, that may lead to a possible economic loss in the food market and more dramatic, to human losses, according to the severity of the disease infection and the immediate public response (Kraipornsak, 2010). Despite the chicken's meat safety issues, it is regarded as one of the best sources of animal protein and is usually chosen by low-income consumers, because it is an affordable and accessible source of protein with low-fat content and limited religious restrictions (Tan *et al.*, 2018).

Therefore, chicken meat could be considered as one of the most globally consumed meat (Wen *et al.*, 2019), since, according to the Food and Agriculture Organization (FAO), poultry meat represented about 39% of global meat production in 2019. The FAO recognizes China as the world's largest poultry meat producer followed by USA and Brazil. Whereas, in the European Union (EU) between the years of 2010–2018, a cumulative rise of about one quarter (3.3 million tonnes of poultry meat) has occurred despite avian influenza's cases in the several EU Member States (Eurostat, 2019). Moreover, the statistical analysis of the Hellenic Statistical Authority shows that Greek poultry meat production has increased throughout the years 2011–2019. Specifically, the total poultry meat production, in the year 2011 was 175.23 thousand tonnes and raised to 230.0 thousand tonnes in the year 2019. However, the total poultry meat production cannot satisfy the Greek domestic consumption since the self-sufficiency is on a level of 65–70%, leading to poultry meat imports. Thus, almost 84 thousand tonnes of poultry meat imported in Greece, in the year 2019, representing an increase of 1.9% in the total amount of poultry meat imports between the years 2019–2018, whereas in the years 2015–2016 in Greece, the increase of poultry meat imports was on a level of 10.2%.

All the above are witnessed the importance of chicken meat consumption in the meat sector. Therefore, there is a lot of research concerning the factors that affect chicken meat consumption. Specifically, a lot of research is focused on the evaluation of the consumer's behaviour that contributes to the understanding who is the consumer in the market area, what the decision-making process is and what influences (socio-economical and psychological) (Lantos, 2015) may lead him to the final purchase food choice. Thus, consumers can be motivated to consume chicken meat:

a) according to their perceptions of chicken meat quality, and or healthiness and nutritional value (Kennedy *et al.*, 2004; Krystallis *et al.*, 2007; Michel *et al.*, 2011b; Kuttapan *et al.*, 2012; Imran *et al.*, 2014; Naspetti *et al.*, 2015; Samant, Seo, 2016; Skunca *et al.*, 2017; Djekic *et al.*, 2018);
b) according to their perceptions of its sensory characteristics, like taste, colour, freshness (Kennedy *et al.*, 2005; Sismanoglou, Tzimitra-Kalogianni, 2011; Pirvutoiu, Popescu, 2013; Walley *et al.*, 2014; Walley *et al.*, 2015; Raimundo, Batalha, 2015; Predanocyová *et al.*, 2019);
c) according to its nutritional superiority over the red meat and that it can be treated as a health benefits food *e.g.* delay in the appearance of macular degeneration (Chong *et al.*, 2009; Jaturasitha *et al.*, 2016; Kulprachakarn *et al.*, 2017), or as functional food (Shan *et al.*, 2017);
d) according to their animal welfare concerns (Hall, Sandilands, 2006; Vukasovič, 2009; Tsakiridou *et al.*, 2010; Pouta *et al.*, 2010; Toma *et al.*, 2011; De Jonge, Van Trijp, 2014; Van Loo *et al.*, 2014; Lassoued *et al.*, 2015; Thaxton *et al.*, 2016; Vanhonacker *et al.*, 2016; Erian, Phillips, 2017; Mulder, Zomer, 2017; Vukasovič, Stanton, 2017; Otieno, Ogutu, 2019);
e) according to their perceptions of chicken rearing systems or chicken breeds, such as slow growth

chickens, that may affect the overall quality of chicken meat (Tuyttens *et al.*, 2015; Naspetti *et al.*, 2015; Jaturasitha *et al.*, 2016; Devatkal *et al.*, 2019);

f) according to their demographic characteristics and their general purchasing habits for chicken meat consumption (Kennedy *et al.*, 2005; Krystallis, Arvanitoyannis, 2006; Sismanoglou, Tzimitra-Kalogianni, 2011; Pirvutoiu, Popescu, 2013; Sahin *et al.*, 2013; Walley *et al.*, 2014; Raimundo, Batalha, 2015; Ripoll *et al.*, 2015; Walley *et al.*, 2015; Skunca *et al.*, 2017; Predanocyová *et al.*, 2019);

g) according to their perceptions of health and safety issues that are usually associated with chicken meat consumption, such as dioxins, campylobacteriosis, salmonella, avian influenza (Kraipornsak, 2010; Bearth *et al.*, 2014; Rieger *et al.*, 2016; Siettou, 2016; Zhou *et al.*, 2016; Clark *et al.*, 2019; Hessel *et al.*, 2019; Wen *et al.*, 2019; Zhang *et al.*, 2019);

h) according to their trust in the quality label, in the country of origin, or the place of sale (butcher shop) (Kennedy *et al.*, 2004; Krystallis *et al.*, 2007; Michel *et al.*, 2011a; Sismanoglou, Tzimitra-Kalogianni, 2011; De Jonge, Van Trijp, 2014; Heerwagen *et al.*, 2015; Lassoued *et al.*, 2015; Samant, Seo, 2016; Vanhonacker *et al.*, 2016; Vukasovič, Stanton, 2017; Kehagia *et al.*, 2017; Lusk, 2018);

i) according to their food-related lifestyle (Ripoll *et al.*, 2015; Escriba-Perez *et al.*, 2017; Wongprawmas *et al.*, 2018S).

Nowadays the outbreak of coronavirus 2019 (COVID-19) pandemic has caused dramatic changes in human patterns due to its health and economic problems (Safara, 2020). The consumers' purchasing power, especially after the first wave of the COVID-19 pandemic, together with the increased feeding costs and the prices of raw ingredients may affect negatively the growth of the poultry industry (Hafez, Attia, 2020) and consequently the chicken meat consumption. Specifically, in Greece between the years of 2019 and 2020, due to COVID-19 restrictions, together with the restrictions on tourism which caused a lower summer meat consumption (7.37 million tourists arrived in Greece in the year 2020 whereas, in 2019, 31.3 million tourists arrived), poultry meat imports reduced on a level 14.2% (Pramantiotis, 2021). Moreover, the European poultry meat sector has been significantly affected by the COVID-19 crisis, mainly in terms of consumption. Thus, in March 2020 an increase in demand for poultry meat in retail (+20%) has occurred while the overall consumption levels in the foodservice sector fell since this sector was forced to close down. Usually, the foodservice sector absorbs poultry meat production. Hence, European poultry slaughterhouses ordered 10–30% fewer chickens for slaughter at that period (Pramantiotis, 2021).

All the above contribute to the fact that food consumers' choice, and particularly meat choice, although it seems a simple process, has nevertheless been described as a complex consumers' behaviour which is influenced by a variety of factors that interact with each other (Hamlin, 2016). Its complexity lies in the fact that, at a given moment, the food choice is determined by an interaction of factors related: a) to the personal characteristics of the consumer, b) to the food itself (internal and external characteristics of the food) and c) to the consumer's environment (Marian, Thøgersen, 2013). Moreover, the quality evaluation of meat is considered a dominant factor influencing consumers' food purchasing intention (Papanagiotou *et al.*, 2013).

Consequently, personal influences of each consumer, together with the factors that affect meat consumption as well as the consumer's lifestyle towards the food, may contribute to shaping the consumer's behaviour towards meat (Predanocyová *et al.*, 2019) and chicken meat particular. A food-related lifestyle, FRL, is defined as a system of consumer's cognitive categories and relationships that connect a set of food-related behaviours, with a set of personal values of each consumer (Brunsø *et al.*, 2004). These consumer's cognitive structures are reflected by five dimensions, namely: a) purchase motives (*e.g.* self-realization), b) consumption situations (*e.g.* eating at home), c) cooking methods (*e.g.* cooking at home), d) ways of shopping (*e.g.* shopping in specialized stores), and quality aspects (*e.g.* healthy food, taste) (Grunert, 2006; Szakály *et al.*, 2012; Escriba-Perez *et al.*, 2017). The FRL instrument has been developed and tested in several European countries in terms of its intercultural validity, while, it has been proven stable over time and has been used for the application of Pan-European food consumer segments, particularly in meat preference (Scholderer *et al.*, 2004; Brunsø *et al.*, 2004; Grunert, 2006; Bernués *et al.*, 2012; Szakály *et al.*, 2012; Ripoll *et al.*, 2015; Buitrago-Vera *et al.*, 2016; Escriba-Perez *et al.*, 2017; Wongprawmas *et al.*, 2018). Thus, the food-related lifestyle (FRL) construct has been proposed as one of the best segmentation tools in the food sector (Grunert, 2019). Moreover, health consumers' concerns and sociodemographic features have been proved the main factors influencing consumers' behaviour towards meat consumption (Escriba-Perez *et al.*, 2017) and consequently chicken meat consumption. Furthermore, the perceived quality that is combined by intrinsic and extrinsic cues of meat is influenced by the subjectivity of the consumer and affects the final purchasing decisions (Henchion *et al.*, 2014).

Also, the Greek's market self-deficiency of poultry meat production together with the high poultry meat imports in 2019 has indicated the importance of poultry meat in the Greeks' diet. Despite the importance of poultry meat consumption, the availability of research on Greeks consumers' preferences and habits, particularly as regards chicken meat, is limited (Krystallis, Arvanitoyannis, 2006; Krystallis *et al.*, 2007; Tsakiridou *et al.*, 2010; Sismanoglou, Tzimitra-

Kalogianni, 2011; Kehagia *et al.*, 2017), and to the best of our knowledge, no published research has used the FRL approach on the meat consumption of Greeks consumers. Furthermore, the social distancing and the advice on self-isolation due to the virus pandemic may have pronounced implications to meat consumption (Nicola *et al.*, 2020) and possibly to chicken meat consumption, as the reduction of poultry meat imports in Greece between the years 2019 and 2020, has shown.

Therefore, this study aims to fill these gaps by investigating Greeks' consumers' behaviour towards chicken meat consumption on the first wave of the COVID-19 pandemic with the use of the FRL model. It is focused on the segmentation of Greek consumers based on their food-related lifestyles and is tried to identify the aspects that may determine consumers' behaviour towards chicken meat during that period. In addition, the present survey has the following objectives: a) to identify the consumers' segments, after the first wave of COVID-19 pandemic, according to their food-related lifestyle values, b) to determine the consumers' profiles by different sociodemographic variables, and c) to identify which extrinsic quality cues of chicken meat affect the consumers' segments, after the first wave of COVID-19 pandemic.

Material and Methods

Study area and data collection

The present survey was conducted in two phases, the qualitative survey and the quantitative one. The qualitative survey included 43 consumers who were interviewed by the method of in-depth interviews in the period of December 2018 to January 2019, one year before the pandemic. The motivation of the qualitative study was derived from the fact that chicken meat consumption in Greece has pointed to high demand through the years, while there was limited scientific evidence that studied chicken meat consumption in terms of consumers' behaviour. The quantitative survey was conducted after the lifting of the restrictive measures due to the pandemic, from June to September 2020, in the urban complex of Thessaloniki. The survey's sample has consisted of 689 consumers yielding an error of 2.76% with a confidence level of 95%. Besides, the least suitable size sample for consumers' behaviour research is considered 500 consumers (Zafeiropoulos, 2005). The sample size was determined by Stathakopoulos (2005) mathematical relation [$n = \frac{z^2(p(1-p))}{e^2}$, for 95% confidence level and an error of 2.76%, p = analogy of consumers (from a preliminary study) in a specific chicken attribute, *e.g.* purchasing chicken meat at least once a week, 1–p = analogy of consumers (from a preliminary study) without the specific chicken attribute, *e.g.* purchasing chicken meat less than once a week]. The aforementioned mathematical relation is used since a large number of Thessaloniki's population simplifies all other mathematical relations (Siardos, 2005) to Stathopoulos's one. The census data of 2011 by the National Statistical Service of Greece has been used for the determination of the size of consumers' sample of each Thessaloniki's region. Consumers aged from 18 to >75 years old. Random stratified, by region, sampling was used. The consumers selected from various points of chicken meat sale, such as supermarkets, butchers, restaurants, fast food outlets, at various hours during the day and all days of the week, in the city of Thessaloniki. At that period, due to the COVID-19 pandemic, there was strong advice on social distancing. Therefore, each respondent completed the questionnaire with the proper guidance, while each questionnaire was answered after the respondent's oral statement that he/she was personally responsible for purchasing chicken meat in and out of the home. Thus, the consumers in the present study were the end-users that form the final chicken meat chain.

Questionnaire and variables

The structured questionnaire was designed according to the literature mentioned in the Introduction regarding chicken meat researchers, as well as the results from the qualitative phase. Specifically, the qualitative questionnaire was divided into six thematic sections that they included: i) the attitudes of consumers towards the purchase of chicken meat, ii) the attitudes regarding the consumption of ready-cooked chicken, iii) consumers' perceptions towards the quality of chicken meat, the information and safety of the food, iv) consumers' perceptions towards price, v) consumers; beliefs towards rearing systems and vi) consumers' perceptions towards packaging and labelling.

The questionnaire of the quantitative study was structured in three parts: 1) safety and quality perception towards chicken meat 2) food-related lifestyle and 3) consumer and household characteristics. The variables that were examined to profile consumers were their sociodemographic variables, the questions of the food-related lifestyle (FRL) and the perceived quality cues of chicken meat.

As stated in the Introduction, the full version of the FRL construct with 69 questions (Brunsø *et al.*, 2004) including in its five dimensions, has already been tested for its validity in several segmentation studies. Therefore, a reduced version of the FRL model is preferred in this study to segment and profile consumers. Furthermore, its reduced version would not overload the respondents with many questions. Moreover, the FRL model can include a different number of items, so that each of them may effectively capture the various dimensions of consumer's lifestyle (Scholderer *et al.*, 2004; Buitrago-Vera *et al.*, 2016). The present FRL instrument included 20 questions regarding the aspects of food life culture (Scholderer *et al.*, 2004) and the pandemic situation.

According to previous researchers (Liang, 2014; Buitrago-Vera *et al.*, 2016; Escriba-Perez *et al.*, 2017) 5-point Likert scale has been preferred in the conduction of the FRL model. Therefore, the questions of the food-related lifestyle were measured on a 5-point Likert scale ranging from 5 "strongly agree" to 1 "strongly disagree" and there was a neutral midpoint at 3 "neither agree nor disagree". A missing data value of 16 cases, concerning the lifestyle questions, was identified after the collection of the data. Since the missing values were fewer than 10% of the total responses, we assumed that these cases were representatives of the random missing values (Buitrago-Vera *et al.*, 2016; Escriba-Perez *et al.*, 2017). Therefore, they were removed and 673 valid cases remained.

Statistical analysis

The survey's data were analysed with IBM SPSS Statistics version 25 (IBM Corp., 2017), and uni- and multivariate statistical techniques have been used. Descriptive statistics were applied for the description of Greek consumers in terms of their sociodemographic characteristics and terms of their food-related lifestyle perceptions. Then multivariate analysis was employed to reduce the 20 items related to the FRL model by the use of exploratory factor analysis. The combination of factor and cluster analysis was preferred for the definition of food-related lifestyle segments (Liang, 2014; Ripoll *et al.*, 2015; Buitrago-Vera *et al.*, 2016; Escriba-Perez *et al.*, 2017; Wongprawmas *et al.*, 2018; Kumar, Smith, 2018).

At first, principal component analysis (PCA) based on factor analysis was applied for defining the dimensions that could describe the consumers. Bartlett's sphericity test and the Kaiser-Meyer-Olkin measure of sampling adequacy (KMO) were used aiming the minimal information or item loss (Escriba-Perez *et al.*, 2017). Afterwards, a cluster analysis method was applied, to group the consumers according to the previous dimensions. The cluster analysis method was divided into hierarchical and non-hierarchical (Szakály *et al.*, 2012). The use of the two-stage clustering method has been recommended to overcome the limitations that can be occurred by hierarchical and partitioning clustering procedures (Kumar, Smith, 2018). Firstly, cluster analysis using hierarchical procedures based on Ward's method was applied to identify the number of clusters. Then, non-hierarchical K-Means cluster analysis was performed to classify the samples into clusters.

The final clusters have been evaluated according to the sociodemographic variables and tested for differences in attitudes towards using chi-square and one-way ANOVA analysis.

The reliability of the values dimensions and clusters was assessed by Cronbach's alpha. This study used 0.6 as the acceptable threshold, as suggested by Siardos (2005) together with similar food-related lifestyle studies (Liang, 2014).

Results and Discussion

Descriptive statistics of the sample

The results from the qualitative phase revealed that consumers seemed to search mainly for "nutritional value" and "convenience" on their chicken meat consumption, while the main criteria of chicken meat purchasing were the "quality" and the "country of origin". However, the purchase criteria varied according to the type of chicken meat they consumed (bulk, cooked and packaged). Moreover, the preferred quality chicken meat attributes were the "colour and the flavour" while the "butcher" is considered the main credence quality chicken meat attribute, as 37.8% of consumers stated that "the butcher supplied them with safe", "fresh" and "properly prepared for cooking meat". The price of chicken meat is considered "low" and the label that indicated the "quality control" as well as "the dates of production – slaughter" was the most important label information. It is noteworthy that the majority of the consumers argued that they are not interested in knowing the welfare conditions in which the chicken they consume has been bred, since they didn't trust the provided information label. However, the majority of the respondents trusted the information that is provided by the University and government agencies of control.

Moreover, the results of the quantitative appeared as follow:

Table 1 summarises that the gender of the consumers were 61.8% females and 38.2% males. Since the respondents have been asked whether they were purchasing chicken meat before answering the survey's questions, this imbalance was likely to have occurred. This is caused to the fact that chicken meat consumption is usually considered a female preference (Kennedy *et al.*, 2004; Sismanoglou, Tzimitra-Kalogianni, 2011; Raimundo, Batalha, 2015; Ripoll *et al.*, 2015). Moreover, food purchasing and preparation are usually regulated by women (Tsakiridou *et al.*, 2010; Liang, 2014). The most common age ranged to 46–55 years old (36.6%), followed by the age of 36–45 (26.1%) and the age of 26–35 (12.2%). Most of the consumers were married 63.2% and the majority of the respondents had no children at home, in a percentage of 44.9%, whereas the 53.0% of the consumers stated that they had two adults in their household. Moreover, the survey's results revealed that chicken meat respondents were highly educated, as the majority of them possessed at least a university degree in a percentage of 56.3%. This result may be related to the fact that these consumers were more willing to answer the questions. In addition, the most common monthly income ranged from 1001 to 1500 euro (37.1%), followed by the monthly income of 501–1000 euro (25.6%). The descriptive statistics for the sociodemographic variables of the sample are presented in Table1.

Table 1. Participants 'sociodemographic characteristics (%)

Variable	Level	Percent
Gender	Men	38.2
	Women	61.8
Age	18–25	8.9
	26–35	12.2
	36–45	26.1
	46–55	36.6
	56–65	10.6
	66–75	4.9
	>75	0.7
Marital status	Married	63.2
	Single	20.4
	Divorced	13.7
	Widow	2.7
Educational level	Primary	3.3
	Intermediate	40.4
	Advanced	56.3
Monthly respondent's income, euro	≤500	12.1
	501–1000	25.6
	1001–1500	37.1
	1501	25.2

Table 2 demonstrates the descriptive statistics for the items measuring food-related lifestyles. The majority of the items depicted the consumers' agreement. The items that received the most strongly, agreement of the consumers' perceptions were: "Eating is an enjoyment" and "I check the expiration dates of food products", followed by the items "I prefer to buy natural products without preservatives" and "I like to cook for me, my family and my friends". Some food values that appeared in Table 2 depicted a trend on efficient food purchasing as it was also supported in the study of Buitrago-Vera *et al.* (2016). Furthermore, the items that assembled the lower scores were: "After the pandemic, I don't trust the takeaway food", "I find cooking tiring", and "After the pandemic, I prefer not eating out". Hence, the food values that seemed to be associated with the pandemic revealed that consumers in cases of emergencies tend to behave with an "illusion of control" since they try to manage a world that they can't control, as Wang *et al.* (2020) noted. Moreover, cooking was found to be a pleasurable activity (Escriba-Perez *et al.*, 2017).

Table 2. Descriptive statistics for the items measuring food-related lifestyle

Item	Average	SD
I always make a list, before I go shopping for food	4.04	1.03
I like shopping for food for me or my family	4.39	0.77
I like shopping and tasting gourmet foods	3.51	1.06
Eating out with my friends or with my family is an important part of my social life	4.01	0.92
Eating is an enjoyment	4.40	0.76
I try to schedule the weekly menu, so as not to waste time and money	3.81	1.00
I like to read the labels of the food products that I buy to know what they contain	3.95	0.90
I like to cook for me, my family and my friends	4.07	1.01
I check the prices and compare them	4.01	0.93
I check the expiration dates of food	4.40	0.81
I read recipes and experiment in cooking	3.58	1.09
Members of my family like to involve in cooking	3.46	1.09
I prefer to buy products firstly for their nutritional value and then for their taste	3.53	1.11
I prefer to buy natural products without preservatives	4.16	0.91
At home, I eat take away food, at least once a month	3.49	1.28
After the pandemic, I prefer not to eat out	2.82	1.26
I find cooking tiring	2.79	1.23
After the pandemic, I pay attention to the places from where I buy food (cleanliness, without overcrowding)	3.66	1.16
After the pandemic, I don't trust the takeaway food	2.73	1.19
I use the internet to inform me and to entertain me	3.95	1.01

Multivariate analysis

Dimensions and reliability analysis

Factor analysis using principal component (PCA) was performed for the reduction of 20 items regarding the questions on FRL. PCA with varimax rotation was employed on this data.

The test KMO measures the sampling adequacy and received the value of 0.750 which is considered a good value since it was higher than an acceptable value of 0.50 (Siardos, 2005; Liang, 2014; Buitrago-Vera *et al.*, 2016; Escriba-Perez *et al.*, 2017). Moreover, in this study, Bartlett's sphericity test is considered statistical acceptable, since the adequacy of the factor analysis, was yielding a p-value of 0.000 at a significance level of 0.05 (Escriba-Perez *et al.*, 2017). Therefore, the factorability of the correlation matrix was achieved (Wongprawmas *et al.*, 2018). The reliability of the axis values was 0.746 and it was assessed by Cronbach's alpha. In this study, it is considered to be acceptable, since it was higher than the acceptable threshold of 0.6 (Siardos, 2005; Liang, 2014; Kumar, Smith, 2018). Maximum variation was employed for the examined dimensions and the extracted factors were eigenvalues larger than one, whereas items and dimensions with factor loadings lower than 0.5 (Liang, 2014) were not concerned.

The factor analysis yielded six factors that explained 59.29% of the total variance. This result is considered acceptable as according to Buitrago-Vera *et al.* (2016) a variance value of 60% or even less is considered acceptable in the social sciences. The six factors are demonstrated in Table 3 and compliance with the relevant literature (Szakály *et al.*, 2012; Buitrago-Vera *et al.*, 2016; Escriba-Perez *et al.*, 2017; Wongprawmas *et al.*, 2018) are identified as: i) "Nutritional value and innovation", ii) "Food security after the first wave of the pandemic", iii) "The role of food in social life", iv) "Ways of shopping", v) "Planned consumption and enjoyment", and vi) "Love for cooking".

Table 3. Matrix of rotated components in factor analysis

	Factors					
	Nutritional value and innovation	Food safety after the first wave of the pandemic	The role of food in social life	Ways of shopping	Planned consumption and enjoyment	Love for cooking
I prefer to buy products firstly for their nutritional value and then for their taste	0.756					
I like shopping and tasting gourmet foods	0.630		0.443			
I prefer to buy natural products without preservatives	0.621					
Members of my family like to involve in cooking	0.498					
I like to read the labels of the food that I buy to know what they contain	0.469			0.458	0.313	
After the pandemic, I don't trust the takeaway food		0.843				
After the pandemic, I prefer not to eat out		0.809				
After the pandemic, I pay attention to the places from where I buy food (cleanliness, without overcrowding)		0.702				
Eating out with my friends or with my family is an important part of my social life			0.725			
Eating is an enjoyment			0.661			
At home, I eat takeaway food, at least once a month			0.640			
I use the internet to inform me and to entertain me			0.497	0.367		
I check the prices and compare them				0.754		
I check the expiration dates of food products				0.638		
I like shopping for food for me or my family					0.741	
I always make a list, before I go shopping for food					0.737	
I try to schedule the weekly menu, so as not to waste time and money				0.361	0.539	
I find cooking tiring						–0.799
I like to cook for me, my family and my friends	0.301					0.683
I read recipes and experiment in cooking	0.397					0.680

Underlined values indicate factors loading ≥0.5

The first factor is described as "Nutritional value and innovation" and explained 21.2% of the total variance whereas high loads (over 0.621) showed three of the seven subjects. This factor contained variables regarding consumers' preferences of healthy, nutritional food as well as innovative ones, such as gourmet food (Buitrago-Vera *et al.*, 2016; Escriba-Perez *et al.*, 2017). The second factor is labelled "Food safety after the first wave of the pandemic" and explained 11.74% of the total variation with charges being over 0.702. This factor accumulated variables regarding the consumers' concerns on safe food consumption after the pandemic by selecting places that were not crowded and not trusting convenience food or eating out. The third factor is classified as "The role of food in social life" and explained 8.20% of the total variation with charges over 0.640. It is related to variables that depicted the role of food in the social life of consumers together with their enjoyment of eating. The fourth factor, which explained 6.57% of the total variance and loaded on 2 subjects over 0.638 is identified as "Ways of shopping". It collected variables that showed the consumers' interest in food pricing and food safety by the use of expiration date. The fifth factor is characterised as "Planned consumption and enjoyment", explained 6.16% of the total variance, and loaded on three subjects over 0.539. It is assembled variables that indicated the importance of planning in terms of food shopping as well as the family meals. It is also included the enjoyment from the activity of food shopping. The sixth factor is labelled "Love for cooking" and explained 5.44% of the total variation with charges at 2 issues above 0.680. The variables of this factor expressed the consumers' preference for cooking and their willingness for cooking experimentation.

Consumers' profiles after the first wave of pandemic towards chicken quality cues

The segments are estimated by the procedure of hierarchical cluster analysis. The clusters were obtained by Ward's method with the use of squared Euclidean distance that was applied to measure the similarity between the items. Four clusters were determined by the use of a non-hierarchical K-means clustering. Following the regularity test, the one-way ANOVA analysis was applied to investigate the possible differences between the four consumer segments with the six factors that are resulted from the factorial analysis of main components. These results are illustrated in Table 4. According to the items that yielded the clusters, and in compliance with the relevant literature (Krystallis, Arvanitoyannis, 2006; Krystallis *et al.*, 2007; Bernués *et al.*, 2012; Ripoll *et al.*, 2015; Buitrago-Vera *et al.*, 2016; Escriba-Perez *et al.*, 2017; Kumar, Smith, 2018; Wongprawmas *et al.*, 2018) the final food consumer segments were labelled as: "Sociable and safety seekers", "Light concerned and cooks", "Unconcerned and price seekers", "Innovative and moderate concerned". Analytically:

i) The "Sociable and safety seekers" segment represented 26.8% of the total sample size (n = 180). It is comprised of the only group of consumers that have depicted high food safety concerns due to the COVID-19 pandemic. These consumers, due to the pandemic, manifested a strong alteration in their eating habits than the other segments. Thus, they preferred not eating out, not purchasing convenience food and they avoided crowded food places after the pandemic. Although this segment was the only one that was characterised by consumers who regarded food as a dominant element in their social life, since they found eating an enjoyable activity, they preferred out of home consumption and purchasing convenience food. Furthermore, they indicated strongly preference than the segments of "Light concerned and cooks" and "Unconcerned and price seekers" for purchasing natural, innovative and nutritional food, but they showed no interest in pricing and labelling in terms of expiration dates, but greater than the segment of "Light concerned and cooks". Moreover, this segment evaluated shopping and cooking as a pleasant activity more than the segment of "Innovative and moderate concerned". Finally, this segment is determined by consumers who searched for food quality cues in terms of its nutritional value, and who have strongly switched their food consumption behaviour, due to the COVID-19 pandemic, even though the food was strongly regarded by its social aspect.

ii) The "Light concerned and cooks" segment represented 10% of the total sample size (n = 67). It included consumers who illustrated a more rational behaviour in food purchasing by planning the purchasing household food and the weekly meals and revealed light food safety concerns due to pandemics, but more than the "Unconcerned and price seekers" consumers reveal. This might have derived from the fact that this segment had less interest of all segments of eating out and purchasing convenience food. Moreover, this was the only consumers' segment that strongly evaluated shopping as a pleasant activity maybe because it involved purchasing for their family members. Thus, this segment indicated an interest in cooking as a social act and experimentation, while it showed less interest than the segment of "Innovative and moderate concerned" consumers towards the nutritional value of the food. Additionally, the occurrence of the pandemic had a light effect in this segment while food-related aspects did not comprise a social component.

iii) The "Unconcerned and price seekers" segment was the second largest one with 30.6% of the total sample size (n = 206). This segment was the only one with the least consumers' concerns on the COVID-19 pandemic. However, the consumers' values regarding food consumption by its social aspect, were higher than those of "Light concerned and cooks" and "Innovative and moderate concerned" segments. Thus, light changes in their eating habits after the pandemic might derive from the fact that food consumption is considered by these consumers a fulfilment act. Furthermore, it included consumers who illustrated a more rational behaviour in food purchasing by planning the schedule of household week meals and they indicated an interest in cooking as a social act and experimentation maybe because it involved purchasing and cooking for their family members, while they had no interest and less than the segment of "Sociable and safety seekers" towards the nutritional value of food. Finally, the minimal concerns regarding food safety aspects since the scare of a pandemic might, also, derived, from the fact that this segment was the only one in comparison to others that showed a high preference for extrinsic quality cues, such as price and food labels regarding expiration dates. Therefore, price and freshness might be strong food attributes that lead to their eating habits.

Table 4. Classification and differences of the sample's clusters

Factor	Cluster				F value	Scheffe comparison
	Sociable and safety seekers	Light concerned and cooks	Unconcerned and price seekers	Innovative and moderate concerned		
Nutritional value and innovation	0.39748	–0.66747	–0.54884	0.39198	660.376	(1) > (2), (1) > (3), (2) < (4)
Food safety after the first wave of the pandemic	0.79598	–0.06806	–0.62227	–0.04786	900.919	(1) > (2), (1) > (3), (1)> (4), (2) > (3)
The role of food in social life	0.68582	–0.65716	0.23338	–0.57952	930.622	(1) > (2), (1) > (3), (1) > (4), (2) < (3)
Ways of shopping	–0.04882	–10.7111	0.57741	0.02037	1450.523	(1) > (2), (1) < (3), (2) < (4), (2) < (3)
Planned consumption and enjoyment	0.24861	0.40843	0.35743	–0.66248	610.449	(1) > (4), (2) > (4)
Love for cooking	0.25434	0.22832	0.10534	–0.37626	170.373	(1) > (4), (2) > (4)
Cluster size	180	67	206	220		

$p < 0.001$, the cluster means are based on factor scores

iv) The "Innovative and moderate concerned" segment was the largest one and represented 32.7% of the total sample size (n = 220). It showed moderate concerns due to the pandemic. This might have derived from the fact that these consumers had no interest in food consumption in terms of social activity. Thus, as the food did not place a dominant element in their social life, the scare of pandemic did not alter many of their eating habits. These consumers showed strong concerns for nutritional value and innovative food and more interest than the segment of "Light concerned and cook". They, also, demonstrated a light preference for price and food freshness labelling, but they showed no concern about any other food-related aspects such as cooking and food shopping. This segment in comparison to the segment of "Light concerned and cooks" consumers valued more the food price and the food freshness in terms of the expiration food dates, while they demonstrated the least concerns on the COVID-19 pandemic concerning the segment of "Sociable and safety seekers".

Previous studies like Bernués *et al.* (2012), Ripoll *et al.* (2015), Buitrago-Vera *et al.* (2016), Escriba-Perez *et al.* (2017), Kumar and Smith (2018) and Wongprawmas *et al.* (2018), provided empirical support to the segments that have been obtained in the current study. This relies on the fact that similarities have been occurred among the present segments with the ones from the relevant literature, despite the different aims of the above studies. Therefore, as long as the FRL power has already been verified (Buitrago-Vera *et al.*, 2016; Escriba-Perez *et al.*, 2017), the validity of the FRL instrument across different cultures is conducted.

Furthermore, the above results appeared to be consistent with the psychological belief that consumers in extreme situations tend to behave with the illusion of control in an effort of managing their changeable world, as Wang *et al.* (2020) noted. Thus, "Unconcerned and price seekers" consumers since they considered eating as an enjoyable activity of their social life, refused to alter their food social habits, due to pandemics.

A chi-square test was performed to define the differences across the sociodemographic characteristics of the sample and the obtainable clusters, as shown in Table 5. Significant difference was found between the four clusters in terms of gender ($\chi^2 = 12.101$, $p = 0.007 < 0.01$), age ($\chi^2 = 37.065$, $p = 0.005 < 0.01$) and income ($\chi^2 = 31.526$, $p = 0.007 < 0.01$). Each segment is comprised mainly of women with a prominent range of age between 36 and 55 years old and monthly income ranging from 1001 to 1500 euro. The distinguished age group in the segment of "Sociable and safety seekers" consumers is ranged between 36 and 55 years old (18.3%), whereas the women were accounting 19.1% and the prominent monthly income was 1001 to 1500 euro (8.8%). The "Light concerned and cooks" segment is comprised mostly of women (5.8%) aged between 36 to 55 years old (5.3%) with the highest monthly income of 1001 to 1500 euro (3.7%). The "Unconcerned and price seekers" segment included mostly women (18.9%) with a notable age between 36 to 55 years old (17.8%) with the highest monthly income of 1001 to 1500 euro (13.3%). Finally, the segment of "Innovative and moderate concerned", involved mostly women (18.0%) with the highest age of 36 to 55 (21.6%) and a monthly income of 1001 to 1500 euro (11.3%).

Table 5. Sociodemographic characteristics of the four consumers' segments (%)

Variables	Sociable and safety seekers	Light concerned and cooks	Unconcerned and price seekers	Innovative and moderate concerned	Total
Age*					
18–25	1.3	0.9	3.9	2.8	8.9
26–35	3.0	1.5	5.5	2.2	12.2
36–45	8.2	2.0	7.1	8.8	26.1
46–55	10.1	3.3	10.7	12.8	36.6
56–65	3.3	1.6	1.7	4.0	10.6
66–75	1.0	1.0	1.6	1.3	4.9
>75	0.0	0.1	0.1	0.5	0.7
Gender*					
Men	7.6	4.2	11.7	14.7	38.2
Women	19.1	5.8	18.9	18.0	61.8
Marital status					
Married	17.2	5.4	18.2	22.4	63.2
Single	4.5	2.1	7.5	6.3	20.4
Divorced	3.7	2.0	3.4	4.6	13.7
Widow	0.9	0.4	1.0	0.4	2.7
Educational level					
Primary	1.0	0.5	0.6	1.2	3.3
Intermediate	9.1	4.9	14.2	12.2	40.4
Advanced	16.8	4.6	15.9	19.0	56.3
Monthly income, euro*					
≤500	2.0	1.5	4.0	4.6	12.1
501–1000	7.7	2.2	9.1	6.6	25.6
1001–1500	8.8	3.7	13.3	11.3	37.1
≥1501	8.2	2.4	4.4	10.2	25.2

* Statistically significant at 99% confidence level.

Following, Wongprawmas *et al.* (2018), the identification of the extrinsic quality attributes of chicken meat that affected consumers' segments was performed by chi-square test, as Table 6 shows. The extrinsic chicken quality attributes that were chosen to be investigated were involving consumers': a) willingness to pay a higher price for chicken meat rearing with animal welfare conditions (Pouta *et al.*, 2010; Tsakiridou *et al.*, 2010; De Jonge, Van Trijp, 2014; Vanhonacker *et al.*, 2016; Djekic *et al.*, 2018), b) trust on the information provided to them (Toma *et al.*, 2011) especially by personal contact (Verbeke *et al.*, 2015) such as the local butcher (Krystallis *et al.*, 2007), c) trust on the labelling that demonstrates the rearing system (Naspetti *et al.*, 2015; Samant, Seo, 2016; Erian, Phillips, 2017), d) purchasing place (Kennedy *et al.*, 2004; Krystallis *et al.*, 2007; Walley *et al.*, 2015; Wongprawmas *et al.*, 2018). The results showed statistically significant differences among the consumers' segments concerning the place of purchasing chicken meat and trust in local butchers in terms of purchasing safe meat. The "Innovative and moderate concerned" consumers, on an average of 54.9% considered that the place of purchasing guaranteed the quality of chicken meat while the 41.8% of the "Light concerned and cooks" consumers had the same perception. Moreover, trust in local butcher regarding chicken meat's safety revealed a percentage of 49.3% by "Light concerned and cooks" consumers, then the "Innovative and moderate concerned" consumers (35.6%). Furthermore, only one segment appeared with a statistically significant difference in consumers' willingness to purchase higher price chicken meat that was produced by animal welfare standards. Especially a rate of 32.8% was revealed on the "Light concerned and cooks" consumers. In contrast, the perception of labelling information regarding the rearing systems and the perception that local butcher provided the consumers with the desired quality of chicken meat, didn't show a statistically significant difference to all segments.

Table 6. Results of chi-square tests on consumers' segments with chicken meat attributes

Items	χ^2	Df	P-value
Willingness to pay a higher price for chicken meat that is produced by animal welfare standards	61.519	15	0.000
I do not believe the label information regarding the rearing system of the chicken	5.955	12	0.918
The place that I purchase chicken meat *e.g.* supermarket, steakhouse, *etc*., offers me quality meat	34.521	12	0.001
My butcher offers me the quality meat I desire	17.515	12	0.131
I trust my butcher for the safety of the chicken meat that I purchase	28.320	12	0.005

Additionally, the above results appeared to be consistent with the findings of other studies (Kennedy *et al.*, 2004; Krystallis *et al.*, 2007; Ripoll *et al.*, 2015; Walley *et al.*, 2015; Wongprawmas *et al.*, 2018). Analytically, consumers of the current study, especially of the segments "Innovative and moderate concerned" and "Light concerned and cooks", considered the place of purchasing as a dominant extrinsic quality cue of chicken meat. Moreover, as previous studies (Kennedy *et al.*, 2004; Krystallis *et al.* 2007; Sismanoglou, Tzimitra-Kalogianni, 2011; Raimundo, Batalha, 2015; Ripoll *et al.*, 2015) have noted the butcher as the one that provided consumers safe chicken, the consumers of this study ("Light concerned and cooks" and "Innovative and moderate concerned") appeared, also, to trust the local butcher for providing them safe chicken meat. Furthermore, inconsistent with the literature (Tsakiridou *et al.*, 2010; Van Loo *et al.*, 2014; Vanhonacker *et al.*, 2016) the consumers ("Light concerned and cooks") of the present study revealed to be a willingness to pay a higher amount for chicken meat that is produced by animal welfare standards. Although, in contrast with other studies (Pouta *et al.*, 2010; De Jonge, Van Trijp, 2014; Van Loo *et al.*, 2014; Kehagia *et al.*, 2017) consumers of this study didn't demonstrate a preference for labelling information concerning the rearing system, whereas the perceived chicken meat quality wasn't related with the butcher. These findings might have derived from the fact that as Krystallis and Arvanitoyannis (2006) and Krystallis *et al.* (2007) have noted, Greek consumers usually trust their visual chicken meat evaluation (like smell, colour, tenderness) together with their contact with the butcher, consequently, making difficult to be replaced them by trademarks and quality certifications for chicken meat.

Conclusion

The European poultry meat sector has been significantly affected by the COVID-19 crisis, mainly in terms of consumption. Specifically, in Greece, between the years 2019 and 2020, the level of reduction in poultry meat imports was 14.2%. Additionally, the socioeconomic implications of the COVID-19 pandemic may influence meat consumption (Nicola *et al.*, 2020) and possibly chicken meat consumption. Moreover, the FRL construct has been proposed as one of the best segmentation tools in the food sector (Grunert, 2019) and according to the best of our knowledge, no published research has used the FRL approach on chicken meat consumption of Greeks consumers. Thus, the current study tried to segment chicken meat from Greek consumers after the first wave of the COVID-19 pandemic. Greek consumers' segmentation was developed by the use of a food-related lifestyle model.

Exploratory factor analysis was conducted and six factors were identified: i) "Nutritional value and innovation", ii) "Food security after the first wave of the pandemic", iii) "The role of food in social life", iv) "Ways of shopping", v) "Planned consumption and enjoyment", and vi) "Love for cooking". The hierarchical cluster analysis yielded the final food consumer segments that by the relevant literature (Krystallis, Arvanitoyannis, 2006; Krystallis *et al.*, 2007; Bernués *et al.*, 2012; Ripoll *et al.*, 2015; Buitrago-Vera *et al.*, 2016; Escriba-Perez *et al.*, 2017; Kumar, Smith, 2018; Wongprawmas *et al.*, 2018) were labelled as: "Sociable and safety seekers", "Light concerned and cooks", "Unconcerned and price seekers", "Innovative and moderate concerned".

Analytically, the results revealed that only the segment that strongly switched their food consumption behaviour, due to the COVID-19 pandemic was the "Sociable and safety seekers" consumers. In contrast, the "Unconcerned and price seekers" consumers demonstrated the least concerns towards the COVID-19 pandemic, concerning all other segments. However, the segment of "Light concerned and cooks" consumers appeared to have minimal concerns regarding food safety aspects like crowded places or safe convenience food, after the first wave of the pandemic. Additionally, the segment of "Innovative and moderate concerned" showed moderate concerns, but more in comparison to the "Light concerned and cooks" consumers

Finally, "Light concerned and cooks" and "Innovative and moderate concerned" consumers appeared to consider the place of purchasing as a dominant extrinsic chicken meat quality cue. In addition, these consumers revealed to trust the butcher in terms of providing them safe chicken meat. Additionally, only "Light concerned and cooks" consumers showed a willingness to pay a higher amount for chicken meat that is produced by animal welfare standards, but there was no evidence that Greek consumers trusted the label information concerning the rearing system.

The scientific value of this study was to lead marketers to orient their marketing strategy towards the external quality attributes of chicken meat, like animal welfare standards and place of purchasing. Hence, chicken meat can be differentiated and this product can be targeted to specific Greek consumer segments like "Light concerned and cooks" and "Innovative and moderate concerned" that was identified after the first wave of the COVID-19 pandemic. The limitation of this research lay in the exclusion of analysis of types of chicken meat products on all consumers' segments as well as the analysis of intrinsic quality cues of chicken meat on all consumers' segments.

Additionally, further research might be conducted for identification of the quality cues that might dominate the Greek chicken meat food chain, whereas the results of this study might be used as a fundamental element for enhancing the knowledge of consumers' behaviour towards chicken meat after the first wave of the pandemic.

Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions

The authors contributed equally to the preparation of the manuscript.

References

Bearth, A., Cousin, M.E., Siegrist, M. 2014. Poultry consumers' behaviour, risk perception and knowledge related to campylobacteriosis and domestic food safety. – Food Control, 44:671–678. DOI: 10.1016/j.foodcont.2014.03.055

Bernués, A., Ripoll, G., Panea, B. 2012. Consumer segmentation based on convenience orientation and attitudes towards quality attributes of lamb meat. – Food Quality and Preference, 26:211–220. DOI: 10.1016/j.foodqual.2012.04.008

Buitrago-Vera, J., Escriba-Perez, C., Baviera-Puig, A., Montero-Vicente, L. 2016. Consumer segmentation based on food related lifestyles and analysis of rabbit meat consumption. – World Rabbit Science, 24:169–182. DOI:10.4995/wrs.2016.4229

Brunsø, K., Scholderer, J., Grunert, K.G. 2004. Closing the gap between values and behavior – a means – end theory of lifestyle. – Journal of Business Research, 57:665–670. DOI: 10.1016/S0148-2963(02)00310-7

Chong, E.W.T., Simpson, J.A., Robman, L.D., Hodge, A.M., Aung, K.Z., English, D.R., Giles, G.G., Guymer, R.H. 2009. Red meat and chicken consumption and its association with age-related macular degeneration. – American Journal of Epidemiology, 169(7):867–876. DOI: 10.1093/aje/kwn393

Clark, B., Panzone, L.A., Stewart, G.B., Kyriazakis, I., Niemi, J.K., Latvala, T., Tranter, R., Jones, P., Frewer, L.J. 2019. Consumer attitudes towards production diseases in intensive production systems. – PLoS ONE, 14(1):1–24. DOI: 10.1371/journal.pone.0210432

De Jonge, J., Van Trijp, H.C.M. 2014. Heterogeneity in consumer perceptions of the animal friendliness of broiler production systems. – Food Policy, 49(1):174–185. DOI: 10.1016/j.foodpol.2014.07.008

Devatkal, S.K., Naveena, B.M., Kotaiah, T. 2019. Quality, composition, and consumer evaluation of meat from slow-growing broilers relative to commercial broilers. – Poultry Science, 98:6177–6186. DOI: 10.3382/ps/pez344

Djekic, I., Skunca, D., Nastasijevic, I., Tomovic, V., Tomasevic, I. 2018. Transformation of quality aspects throughout the chicken meat supply chain. – British Food Journal, 120(5):1132–1150. DOI: 10.1108/BFJ-08-2017-0432

Erian, I., Phillips, C.J.C. 2017. Public understanding and attitudes towards meat chicken production and relations to consumption. – MDPI Animals, 7(20):1–28. DOI: 10.3390/ani7030020

Escriba-Perez, C., Baviera-Puig, A., Buitrago-Vera, J., Montero-Vicente, L. 2017. Consumer profile analysis for different types of meat in Spain. – Meat Science, 129:120–126. DOI: 10.1016/j.meatsci.2017.02.015

Eurostat. 2019. Poultry meat production in EU at new high in 2018. – https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20190325-1 Accessed on 28/01/22

Font-i-Furnols, M., Guerrero, L. 2014. Consumer preference, behavior and perception about meat and

meat products: An overview. – Meat Science, 98:361–371. DOI: 10.1016/j.meatsci.2014.06.025
Grunert, K.G. 2006. Future trends and consumer lifestyles with regard to meat consumption. – Meat Science, 74:149–160. DOI: 10.1016/j.meatsci.2006.04.016
Grunert, K.G. 2019. International segmentation in the food domain: Issues and approaches. – Food Research International, 115:311–318. DOI: 10.1016/j.foodres.2018.11.050
Hafez, M.H., Attia, Y.A. 2020. Challenges to the poultry industry: Current perspectives and strategic future after the COVID-19 outbreak. – Frontiers in Veterinary Science, 7(516):1–16. DOI: 10.3389/fvets.2020.00516
Hall, C., Sandilands, V. 2006. Public attitudes to the welfare of broiler chickens. In Land Economy and Economy Working Paper Series, 13. SAC: Edinburgh.
Hamlin, R. 2016. Functional or constructive attitudes: Which type drives consumers' evaluation of meat products? – Meat Science, 117:97–107. DOI: 10.1016/ j.meatsci.2016.02.038
Heerwagen, L.R., Mørkbak, M.R., Denver, S., Sandøe, P., Christensen, T. 2015. The role of quality labels in market-driven animal welfare. – Journal of Agricultural Environment Ethics, 28(1):67–84. DOI: 10.1007/s10806-014-9521-z.
Henchion, M., McCarthy, M., Resconi, V., Troy, D. 2014. Meat consumption: Trends and quality matters. – Meat Science, 98:561–568. DOI: 10.1016/j.meatsci.2014.06.007
Hessel, C.T., de Oliveira Eliasa, S., Pessoa, J.P., Zanin, L.M., Stedefeldt, E., Tondo, E.C. 2019. Food safety behavior and handling practices during purchase, preparation, storage and consumption of chicken meat and eggs. – Food Research International, 125(108631):1–14. DOI: 10.1016/j.foodres.2019.108631
IBM Corp. 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp. – https://www.ibm.com/support/pages/how-cite-ibm-spss-statistics-or-earlier-versions-spss
Imran, S.N., Kamarulzaman, N.H., Latif, I.A., Nawi, N.M. 2014. Enhancing poultry industry competitiveness: Consumer perspective on chicken meat quality based on sensory characteristics. – Journal of Food Products Marketing, 20(1):102–121. DOI: 10.1080/10454446.2014.921878
Jaturasitha, S., Chaiwang, N., Kreuzer, M. 2016. Thai native chicken meat: an option to meet the demands for specific meat quality by certain groups of consumers; a review. – Animal Production Science, 57(8):1582–1587. DOI: 10.1071/AN15646
Kehagia, C.O., Colmer, C., Chryssochoidis, M.G. 2017. Consumer valuation of traceability labels: a cross-cultural study in Germany and Greece. – British Food Journal, (119)4:803–816. DOI: 10.1108/BFJ-07-2016-0333
Kennedy, O.B., Stewart-Knox, B.J., Mitchell, P.C., Thurnham, D.I. 2004. Consumer perception of poultry meat: A qualitative analysis. – Nutrition & Food Science, 34(3):122–129. DOI: 10.1108/00346650410536746
Kennedy, O.B., Stewart-Knox, B.J., Mitchell, P.C., Thurnham, D.I. 2005. Flesh colour dominates consumer preference for chicken. – Appetite, 44:181–186. DOI: 10.1016/j.appet.2004.11.002
Kraipornsak, P. 2010. The outbreak of avian influenza and chicken consumption in Thailand. – Research in Business and Economics Journal, 1–11. –https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.472.9124&rep=rep1&type=pdf Accessed on 14/12/2021
Krystallis, A., Arvanitoyannis, I.S. 2006. Investigating the concept of meat quality from the consumers' perspective: The case of Greece. – Meat Science, 72(1):164–176. DOI: 10.1016/j.meatssi.2005.06.013
Krystallis, A., Chryssochoidis, G., Scholderer, J. 2007. Consumer-perceived quality in 'traditional' food chains: The case of the Greek meat supply chain. – Appetite, 48:54–68. DOI: 10.1016/j.appet.2006.06.003
Kumar, A., Smith, S. 2018. Understanding local food consumers: Theory of Planned Behavior and segmentation approach. – Journal of Food Products Marketing, 24(2):196–215. DOI: 10.1080/10454446.2017.1266553
Kuttapan, V.A., Lee, Y.S., Erf, G.F., Meullement, F.C., Mckee, S.R., Owens, C.M. 2012. Consumer acceptance of visual appearance of broiler meat with varying degrees of white striping. – Poultry Science, 91(5):1240–1247. DOI: 10.3382/ps.2011-01947
Kulprachakarn, K., Abkom, P., Pongtam, O., Ounjaijean, S., Thongkham, P., Saengyo, S., Rerkasem, K. 2017. Higher level of chicken consumption associated with less severe Venous disease. – The International Journal of Lower Extremity Wounds, 16(4):251–254. DOI: 10.1177/15347346
Lantos, G.P. 2015. Consumer behavior in action: Real-life applications for marketing managers. – Routledge Taylor & Francis Group: New York, pp. 1–17.
Lassoued, R., Hobbs, J.E., Micheels, E.T., Di Zhang, D. 2015. Consumer trust in chicken brands: A structural equation model. – Canadian Journal of Agricultural Economics, 63:621–647. DOI: 10.1111/cjag.12082
Latvala, T., Niva, M., Mäkelä, J., Pouta, E., Heikkilä, J., Kotro, J., Forsman-Hugg, S. 2012. Diversifying meat consumption patterns: Consumers' self-reported past behaviour and intentions for change. – Meat Science, 92:71–77. DOI: 10.1016/j.meatsci.2012.04.014
Leroy, F., De Smet, S. 2019. Meat in the human diet: A biosocial perspective. In More than Beef, Pork and Chicken – The Production, Processing, and Quality Traits of Other Sources of Meat for Human Diet (Eds. M. Lorenzo, P.E.S. Munekata, F.J. Barba, F. Toldrá). Springer Nature: Switzerland, pp. 1–19.

Leroy, F., Praet, I. 2015. Meat traditions. The co-evolution of humans and meat. – Appetite, 90:200–211. DOI: 10.1016/j.appet.2015.03.014
Liang, R.D.A. 2014. Enthusiastically consuming organic food. An analysis of the online organic food purchasing behaviors of consumers with different food-related lifestyles. – Internet Research, 24:587–607. DOI: 10.1108/IntR-03-2013-0050
Lusk, J.L. 2018. Consumer preferences for and beliefs about slow growth chicken. – Poultry Science, 97:4159–4166. DOI: 10.3382/ps/pey301
Marangoni, F., Corsello, G., Cricelli, C., Ferrara, N., Ghiselli, A., Lucchin, L., Poli, A. 2015. Role of poultry meat in a balanced diet aimed at maintaining health and wellbeing: an Italian consensus document. – Food & Nutrition Research, 59:1–11. DOI: 10.3402/fnr.v59.27606
Marian, L., Thøgersen, J. 2013. Direct and mediated impacts of product and process characteristics on consumers' choice of organic vs. conventional chicken. – Food Quality and Preference, 29:106–112. DOI: 10.1016/j.foodqual.2013.03.001
Michel, L.M., Anders, S., Wismer, W.V. 2011a. Consumer preferences and willingness to pay for value-added chicken product attributes. – Journal of Food Science, 76(8):S469–S477. DOI: 10.1111/j.1750-3841.2011.02354.x
Michel, L.M., Punter, P.H., Wismer, W.V. 2011b. Perceptual attributes of poultry and other meat products: A repertory grid application. – Meat Science, 87:349–355. DOI: 0.1016/j.meatsci.2010.11.010
Mulder, M., Zomer, S. 2017. Dutch consumers' willingness to pay for broiler welfare. – Journal of Applied Animal Welfare Science, 20(2):137–154. DOI: 10.1080/10888705.2017.1281134
Naspetti, S., Alberti, F., Solfanelli, F. 2015. Quality function deployment in the organic animal food sector: Application to poultry meat. – Italian Journal of Animal Science, 14(4050):544–550. DOI: 10.4081/ijas.2015.4050
Nicola, M., Alsafi, Z., Sohrabi, C., Kerwan, A., Al-Jabir, A., Iosifidis, C., Agha, M., Agha, R. 2020. The socio-economic implications of the coronavirus pandemic (COVID-19): A review. – International Journal of Surgery, 78:185–193. DOI: 10.1016/j.ijsu.2020.04.018
Otieno, D.J., Ogutu, S.O. 2019. Consumer willingness to pay for chicken welfare attributes in Kenya. – Journal of International Food & Agribusiness Marketing, 1–24. DOI: 10.1080/08974438.2019.1673275
Papanagiotou, P., Tzimitra-Kalogianni, I., Melfou, K. 2013. Consumers' expected quality and intention to purchase high quality pork meat. – Meat Science, 93:449–454. DOI: 10.1016/j.meatsci.2012.11.024
Pirvutoiu, I., Popescu, A. 2013. Research on consumer behaviour in Bucharest poultry meat market. – Animal Science and Biotechnologies, 46(1):389–396.
Pouta, E., Isoniemi, M., Makela, J., Heikkila, J., Forsman-Hugg, S. 2010. Consumer choice of broiler meat: The effects of country of origin and production methods. – Food Quality and Preference, 21(5):539–546. DOI: 10.1016/j.foodqual.2010.02.004
Pramantiotis, C. 2021. Pio ítan to apotípoma tis pandimías stis isagoyés kréatos tou 2020 (What was the impact of the pandemic on meat imports on 2020). – Periodikó Meat News, 27-05-21 (Journal Meat News, 27-05-21), 1–3. [In Greek]
Predanocyová, K., Kubicová, Ľ., Kádeková, Z., Košičiarová, I. 2019. Key factors affecting consumption of meat and meat products from perspective of Slovak consumers. – Potravinarstvo Slovak Journal of Food Sciences, 13(1):1001–1012. DOI: 10.5219/1198
Raimundo, L.M.B., Batalha, M.O. 2015. Consumption of chicken meat in Sao Paulo: market segmentation and strategies. In Conference Paper. DOI: 10.13140/RG.2.2.32113.48482, pp. 1–14.
Rieger, J., Kuhlgatz, C., Anders, S. 2016. Food scandals, media attention and habit persistence among desensitised meat consumers. – Food Policy, 64:82–92. DOI: 10.1016/j.foodpol.2016.09.005
Ripoll, G., Alberti, P., Panea, B. 2015. Consumer segmentation based on food related lifestyles and perception of chicken breast. – International Journal of Poultry Science, 14(5):262–275.
Safara, F. 2020. A computational model to predict consumer behaviour during COVID-19 pandemic – Computational Economics, 1–15. DOI: 10.1007/s10614-020-10069-3
Sahin, A., Yildirim, I., Deniz, A. 2013. Attitudes and preferences of urban and rural households towards chicken meat consumption: Case study of Hakkari, Turkey. – Journal of Food, Agriculture & Environment, 11(3–4):29–34.
Samant, S.S., Seo, H.S. 2016. Effects of label understanding level on consumers' visual attention toward sustainability and process-related label claims found on chicken meat products. – Food Quality and Preference, 50:48–56. DOI: 10.1016/j.foodqual.2016.01.002
Scholderer, J., Brunsø, K., Bredahl, L., Grunert, K.G. 2004. Cross-cultural validity of the food-related lifestyles instrument (FRL) within Western Europe. – Appetite, 42:197–211. DOI: 0.1016/j.appet.2003.11.005
Shan, L.C., Henchion, M., De Brún, A., Murrin, C., Wall, P.G., Monahan, F.J. 2017. Factors that predict consumer acceptance of enriched processed meats. – Meat Science, 133:185–193. DOI: 10.1016/j.meatsci.2017.07.006
Siardos, G. 2005. Methodoloyía kinonioloyikís érevnas (Methodology of Sociological Research). – ZITI: Thessaloniki (In Greek)
Siettou, C. 2016. Avian Influenza: outbreaks and the impact on UK consumer demand for poultry. – In 90th Annual Conference of the Agricultural

Economics Society, Discussion Paper. University of Warwick, England. April 4–6 2016.

Sismanoglou, A., Tzimitra-Kalogianni, I. 2011. Consumer perception of poultry meat in Greece. – World's Poultry Science Journal, 67(2):269–276. DOI: 10.1017/ S0043933911000298

Skunca, D., Tomasevic, I., Zdolec, N., Kolaj, R., Aleksiev, G., Djekic, I. 2017. Consumer-perceived quality characteristics of chicken meat and chicken meat products in Southeast Europe. – British Food Journal, 119(7):1525–1535. DOI: 10.1108/BFJ-11-2016-0547

Stathakopoulos, B. 2005. Méthodi érevnas agorás (Market research methods). – Stamoulis: Athens. [In Greek]

Szakály, Z., Szente, V., Kövér, G., Polereczki, Z., Szigeti, O. 2012. The influence of lifestyle on health behavior and preference for functional foods. – Appetite, 58:406–413. DOI: 10.1016/j.appet.2011. 11.003

Tan, S.M., de Kock, H.L., Dykes, G.A., Coorey, R., Buys, E.M. 2018. Enhancement of poultry meat: Trends, nutritional profile, legislation and challenges. – South African Journal of Animal Science, 48(2):199–212. DOI: 10.4314/sajas.v48i2.1

Thaxton, Y.V., Christensen, K.D., Mench, J.A., Rumley, E.R., Daugherty, C., Feinberg, B., Parker, M., Siegel, P., Scane, C.G. 2016. Symposium: Animal welfare challenges for today and tomorrow. – Poultry Science, 95:2198–2207. DOI: 10.3382/ps/pew099

Toma, L., McVittie, A., Hubbard, C., Stott, A.W. 2011. A structural equation model of the factors influencing British consumers' behaviour toward animal welfare. – Journal of Food Products Marketing, 17(2–3):261–278. DOI: 10.1080/10454446.2011.548748

Tsakiridou, E., Tsakiridou, H., Mattas, K., Arvaniti, E. 2010. Effects of animal welfare standards on consumers' food choices. – Food Economics – Acta Agricultural Scandinavica. Section C, 7(2–4):234–244. DOI: 10.1080/16507541.2010.531949

Tuyttens, F.A.M., Federici, J.F., Vanderhasselt, R.F., Goethals, K., Duchateau, L., Sans, E.C.O., Molento, C.FM. 2015. Assessment of welfare of Brazilian and Belgian broiler flocks using the Welfare Quality protocol. – Poultry Science, 94:1758–1766. DOI: 10.3382/ps/pev167

Vanhonacker, F., Tuyttens, F.A.M., Verbeke, W. 2016. Belgian citizens' and broiler producers' perceptions of broiler chicken welfare in Belgium versus Brazil. – Poultry Science, 95:1555–1563. DOI: 10.3382/ps/ pew059

Van Loo, E.J., Caputo, V., Nayga, R.M.J., Verbeke, W. 2014. Consumers' valuation of sustainability labels on meat. – Food Policy, 49:137–150. DOI: 10.1016/ j.foodpol.2014.07.002

Verbeke, W., Marcu, A., Rutsaert, P., Gaspar, R., Seibt, B., Fletcher, D., Barnett, J. 2015. Would you eat cultured meat? Consumers' reactions and attitude formation in Belgium, Portugal and the United Kingdom. – Meat Science, 102:49–58. DOI: 10.1016/j.meatsci.2014. 11.013

Vinnari, M., Tapio, P. 2009. Future images of meat consumption in 2030. – Futures, 41:269–278. DOI:10.1016/j.futures.2008.11.014

Vukasovič, T. 2009. Consumer perception of poultry meat and the importance of country of origin in a purchase making process. – World's Poultry Science Journal, 65(1):65–74. DOI: 10.1017/S0043933909 000005

Vukasovič, T., Stanton, J.L. 2017. Going local: exploring millennials preferences for locally sourced and produced fresh poultry in a developing economy. – World's Poultry Science Journal, 73:757–765. DOI: 10.1017/S0043933917000770

Walley, K., Parrott, P., Custance, P., Meledo-Abraham, P., Bourdin, A. 2014. A review of UK consumers' purchasing patterns, perceptions and decision making factors for poultry meat. – World's Poultry Science Journal, 70:493–502. DOI: 10.1017/S0043933914 000555

Walley, K., Parrott, P., Custance, P., Meledo-Abraham, P., Bourdin, A. 2015. A review of French consumers purchasing patterns, perceptions and decision factors for poultry meat. – World's Poultry Science Journal, 71(1):5–14. DOI: 10.1017/S004393391500001X

Wang, E., Ning, An., Gao, Z., Kiprop, E., Geng, X. 2020. Consumer food stockpiling behavior and willingness to pay for food reserves in COVID-19. – Food Security, 12(4):739–747. DOI: 10.1007/s1257 1-020-01092 -1

Wen, X., Sun, S., Li, L., He, Q., Tsai, F.-S. 2019. Avian influenza – Factors affecting consumers' purchase intentions toward poultry products. – International Journal of Environmental Research and Public Health, 16:1–13. DOI: 10.3390/ijerph16214139

Wongprawmas, R., Canavari, M., Imami, D., Gjonbalaj, M., Gjokaj, E. 2018. Attitudes and preferences of Kosovar consumers towards quality and origin of meat. – Studies in Agricultural Economics, 120:126–133. DOI: 10.7896/j.1802

Zafeiropoulos, K. 2005. Pós yínetai mía epistimonikí érevna? Epistimonikí érevna kai singraphí ergasión (How is scientific research done? Scientific research and writing of papers). Kritiki: Athens. [In Greek]

Zhang, Y., Yang, H., Cheng, P., Luqman, A. 2019. Predicting consumers' intention to consume poultry during an H7N9 emergency: an extension of the theory of planned behavior model. – Human and Ecological Risk Assessment: An International Journal, 1–22. DOI: 10.1080/10807039.2018.1503931

Zhou, L., Turvey, C.G., Hu, W., Ying, R. 2016. Fear and trust: How risk perceptions of avian influenza affect Chinese consumers’ demand for chicken. – China Economic Review, 40:91–104. DOI: 10.1016/ j.chieco.2016.06.003

Agraarteadus
1 • XXXIII • 2022 176–191

Journal of Agricultural Science
1 • XXXIII • 2022 176–191

ESTIMATION OF SPECIES ALLELOPATHIC SUSCEPTIBILITY TO PERENNIAL WEEDS BY DETAILING THE FORMATION PERIOD OF GERMINATED SEEDS OF OILSEED RADISH (*Raphanus sativus* L. var. *oleiformis* Pers.) AS THE TEST OBJECT

Yaroslav H. Tsytsiura

Faculty of Agronomy and Forestry, Vinnytsia National Agrarian University, 3 Sonyachna St, 21008, Vinnytsia, Ukraine

Saabunud: Received: 16.11.2021

Aktsepteeritud: Accepted: 15.04.2022

Avaldatud veebis: Published online: 15.04.2022

Vastutav autor: Corresponding author: Yaroslav H. Tsytsiura

E-mail: yaroslavtsytsyura@ukr.net

Phone: +380 675 854 008

ORCID: 0000-0002-9167-833X

Keywords: allelopathic impact, germination, growth processes, oilseed radish, weed extracts.

DOI: 10.15159/jas.22.09

ABSTRACT. The allelopathic impact of 23 perennial weed species on oilseed radish by petri dish and soil bioassays was studied. Weed extracts were prepared at concentrations of 0.25, 0.5, 1.0, 2.0, 4.0, 8.0 and 16.0%. The influence of the weed extract on germination and seedling growth of oilseed radish was analyzed according to several germination indexes. The "speed of germination", "coefficient of the velocity of germination" and the resulting levels of allelopathic potential in terms of seed germination (APG) were used to assess the allelopathic effect of the researched weed species. The application of indicators allowed determining the specific features of the influence of extracts of perennial weeds on the duration of the germination period, the effects of germination delay and the general prolongation of the period of formation of similar seeds with typification on classification groups. Conducted daily surveys for the calculation of these indices allowed to obtain a graphical interpretation of the reaction of the seeds of the test object to the extract of each weed species. This allowed identifying species of weeds for which the use of oilseed radish in the system of its biological control will be effective.

Introduction

The level of weediness of agrocenoses within their growth, development and crop formation, and the potential one due to the accumulation of weed seeds in the soil is one of the potential threats to reducing the yield of major crops and efficiency of world agricultural production (Chauan, 2020; Shahzad *et al.*, 2021). The negative impact of weeds on crops is observed in the form of competition for resources and allelopathic interaction of plants (Scavo *et al.*, 2019; Sharma *et al.*, 2019, 2021; Bachheti *et al.*, 2020; Clapp, 2021). Weeds have serious impacts on agricultural production. It is estimated that in general weeds cause a 5% loss in agricultural production in most developed countries, 10% loss in less developed countries and 25% loss in the least developed countries (Gharde *et al.*, 2018; Mesterházy *et al.*, 2020). Perennial weeds using their own high biological, adaptive and allelopathic potential (Travlos *et al.*, 2018; Ackroyd *et al.*, 2019; Romaneckas *et al.*, 2021) are rather harmful. It's have a high levels of competitiveness in relation to the main crop species (Melander *et al.*, 2016; Bergkvist *et al.*, 2017; Novak *et al.*, 2018), and demonstrate high plasticity of development (Bybee-Finley *et al.*, 2017; Somerville *et al.*, 2018). Perennial weeds are also characterized by high fertility and long-term viability of vegetative and seed germs in the soil (Haring, Flessner, 2018). These species are also characterized by rapid rates of spread (Możdżeń *et al.*, 2018), high levels of adaptation to modern climate change and levels of tillage technologies (Travlos *et al.*, 2018; Simić *et al.*, 2020). All this leads to high biological competitiveness of perennial weed species (Buddhadeb, Bhowmik, 2020; Kocira, Staniak, 2021).

The modern strategy of integrated weed control has branch combining effective phytocenological construction of agrocenosis taking into account the allelopathic interaction of species forming it (Westwood *et al.*, 2018; Anwar *et al.*, 2019; Korresa *et al.*, 2019; MacLaren *et al.*, 2020; Schandry, Becker, 2020; Muli *et al.*, 2021). It meets environmental friendliness and organicity of relevant cultivation technologies, and the ability to mobilize natural factors of plant adaptation to competition with other species due to its allelopathic potential (Jugulam *et al.*, 2019; Kumar *et al.*, 2020). Under these conditions, the use of plants with high allelopathic potential with the main species of weeds will reduce the level of herbicide load due to substances of allelochemicals with a corresponding herbicidal effect (Kaab *et al.*, 2020; Maurya *et al.*, 2022). Enhancement of the bioherbicidal effect is due to the content of complex active allelochemicals, including essential oils of different chemical structures (Mirmostafaee *et al.*, 2020; Gharibvandi *et al.*, 2022). On the other side, the allelopathic potential of cruciferous crops is widely known and successfully used in the system of greening, binary and mixed crops, biofumigation, soil remediation, and phytoremediation (Ali *et al.*, 2019; Khan *et al.*, 2019; Rehman *et al.*, 2019; Koehler-Cole *et al.*, 2020; Tsytsiura, 2020; Rasul, Ali, 2020, 2021; Liu *et al.*, 2021). However, the complex aspects of the interaction of cruciferous plant species with perennial species taking into account their allelopathic potential is an issue that requires additional scientific generalization and study. This is relevant for oilseed radish, which is widely used in agronomic practice in the system of greening and organic farming (Ferreira *et al.*, 2021). However, it should be noted that the research of plant species" allelopathic sensitivity as a basic one involves the assessment of germination under the influence of other species" extracts (Kobayashi *et al.*, 2021). According to Sothearith *et al.* (2021), germination is an informative indicator of allelopathic sensitivity, but many features require more careful research.

The working hypothesis of our research is the possibility of studying the allelopathic reaction of the test object at the stage of its germination by estimating the rate of its formation and options for prolonging the germination from the optimal dates. This detail will clarify their impact on the stages of seed germination and the nature of the biological response of the test object to aggressive allelopathic species. This version of the study of allelopathy differs from traditional methods in terms of seed germination.

Materials and Methods

Study Site: This research was performed in May-August 2020 at Vinnytsia National Agrarian University (49°11′ N, 28°22′ E), during the oilseed radish growing season of April-September (sowing date April 12–15, harvest date September 5–10). Height above sea level: 325 m. The area has a temperate continental climate. During the study period, the maximum and minimum temperatures were 18.3 °C in July and 15.8 °C in May, respectively. Mean annual relative humidity was 77% and mean annual precipitation was 480–596 mm.

Selection of the perennial weed species: the frequency of appearance (F) of perennial weeds was investigated from 2013 to 2020 in the oilseed radish fields located at the Vinnytsia National Agrarian University (Table 1).

Oilseed radish was sown at densities comprised between 0.5 and 4.0 million seeds ha^{-1} in 25 plots with a size of 1.0 x 1.0 m in two non-contiguous variants of the density of standing oilseed radish. Each year, quadrants of 1 m^2 were randomly thrown in 50 different locations in each oilseed radish plot at the starting fruiting phase BBCH (Biologische Bundesanstalt, Bundessortenamt and Chemical industry) 70–74.

Table 1. The botanical name, English name, family and economic importance of the perennial weed species involved in this study

No.	Botanical name	EPPO code	English name	Family	Frequency (F)***
1	*Achillea millefolium* L.	ACHMI	Common yarrow	Asteraceae	1.8*–4.1**
2	*Acroptilon repens* (L.) de Candolle	CENRE	Russian knapweed	Asteraceae	12.6–31.4
3	*Agropyron repens* (L.) Gould	AGRRE	Couch grass	Poaceae	50.8–71.3
4	*Arctium lappa* L.	ARFLA	Greater burdock	Asteraceae	1.3–2.9
5	*Artemisia absinthium* L.	ARTAB	Wormwood	Asteraceae	4.5–3.7
6	*Artemisia vulgaris* L.	ARTVU	Common mugwort	Asteraceae	5.4–3.6
7	*Carduus acanthoides* L.	CRUAC	Spiny plumeless thistle	Asteraceae	6.7–10.3
8	*Cichorium intybus* L.	CICIN	Common chicory	Asteraceae	1.8–3.9
9	*Cirsium arvense* (L.) Scopoli	CIRAR	Creeping thistle	Asteraceae	40.7–48.9
10	*Convolvulus arvensis* L.	CONAR	Field bindweed	Convolvulaceae	17.9–25.8
11	*Cuscuta campestris* Yuncker	CVCCA	Field dodder	Convolvulaceae	1.3–2.9
12	*Cyclachaena xanthiifolia* Nuttall	IVAXA	Giant sumpweed	Asteraceae	5.2–12.3
13	*Cynodon dactylon* (L.) Pers.	CYNDA	Bermuda grass	Poaceae	10.1–15.8
14	*Echium vulgare* L.	EHIVU	Blueweed	Boraginaceae	1.9–5.8
15	*Equisetum arvense* L.	EQUAR	Field horsetail	Equisetaceae	3.9–12.3
16	*Linaria vulgaris* Mill.	LINVU	Yellow toadflax	Plantaginaceae	4.2–7.5
17	*Onopordum acanthium* L.	ONRAC	Cotton thistle	Asteraceae	1.3–1.9
18	*Plantago lanceolata* L.	PLALA	Narrowleaf plantain	Plantaginaceae	2.6–3.1
19	*Plantago major* L.	PLAMA	Broadleaf plantain	Plantaginaceae	3.8–5.5
20	*Rumex acetosella* L.	RUMAA	Field sorrel	Polygonaceae	2.1–4.4
21	*Rumex confertus* Willdenow	RUMCF	Russian dock	Polygonaceae	1.7–2.9
22	*Sonchus arvensis* L.	SONAR	Field sowthistle	Asteraceae	27.8–36.1
23	*Taraxacum officinale* Weber	TAROF	Common dandelion	Asteraceae	9.8–24.2

* This frequency appeared in oilseed radish fields sown with 0.5 million seeds ha^{-1}; ** this frequency appeared in oilseed radish fields sown with 4.0 million seeds ha^{-1}; *** average indicators for the period 2013–2020.

Individuals of each weed species in each quadrant were identified with the aid of standard flora reference books (Veselovsky *et al.*, 1988). Then, the Frequency (F) for a weed species was yearly calculated by Eq. (1). (Rana, Rana, 2016; Rao, 2017):

$$F(\%)=\frac{TOI}{50}\cdot 100, \qquad (1)$$

where TOI is the number of squares at which a weed species appeared.

Extract preparation: The whole plants (aerial and underground parts) of 23 weed species selected according to the F values were collected at the flowering stage in Fromour University"s research fields. The collected plants were transported in air-conditioned vehicles to the laboratory. Before drying, all materials were washed with running water to remove dust and contaminants. After that, plants were partitioned into roots, stems, leaves and inflorescences and were hand cut into small pieces of 2–3 cm long. Then, they were dried in the shade at 27–30 °C for 11 days. The dried samples were powdered using a laboratory mill and stored in sealed bags in a dry place in the dark.

Extracts were prepared by immersion of each powdered sample into heated distilled water at 40 ºC for 24 h (Grodzinsky *et al.*, 1990; Grodzinsky, 1991). Weights of 0.625, 1.25, 2.5, 5, 10, 20 and 40 g of each powdered plant material were immersed in flasks containing 250 ml of distilled water to obtain concentrations of 0.25, 0.5, 1, 2, 4, 8 and 16%, respectively. The flasks were shaken by hand every two hours. After heating, extracts were recovered by centrifugation at 4000 rpm and 30 ºC for 30 s in a centrifuge Eppendorf model 5804R. Thereafter, the extracts were filtered through Whatman Filter paper No. 1.

Petri plate bioassays: they were performed in a complete randomized design with three factors which were (i) the weed species (23 species), (ii) the weed parts (root, stem, leaf and flower), and (iii) extract concentration (0.25, 0.5, 1, 2, 4, 8 and 16%). Fifty oilseed radish seeds were sown on filter paper in each petri dish. Then, 50 mL of an aqueous extract was added to each petri dish. Extract concentrations (0.25, 0.5, 1, 2, 4, 8 and 16%) were tested. Each extract concentration was replicated 4 times and the experiments were performed twice. The control consisted of distilled water added instead of the water extracts. The Petri plates were kept in a Biological Oxygen Demand (BOD) incubator at 25 °C and seed germination was recorded on the 6th day (AOSA Rules for Testing Seeds, 2011; ISTA, 2017; Jain *et al.*, 2017). Speed of germination was recorded daily until the 6th day (Duke, 2015).

Collection of rhizosphere soil: The rhizosphere soil of the 23 weed species was directly collected (Fujii *et al.*, 2005). The weed species were taken out from the soil without disturbance, then plant roots were shaken softly to remove the root-zone soil. Each soil sample was sieved through a 1 mm mesh to remove coarse particles (root hair, *etc*.). Then, the sieved soil samples were immediately used in bioassays (Williamson, Richardson, 1988; Grodzinsky *et al.*, 1990; Grodzinsky, 1991). In all cases, the collected soil samples were classified as dark grey forest Luvic Greyic Phaeozem soils (IUSS Working Group, 2015; State standard of Ukraine ISO (International Organization for Standardization) 10381-6:2015, 2017) with 2.56% organic carbon, 77.9 kg ha^{-1} lightly hydrolyzed nitrogen, 153 kg ha^{-1} mobile phosphorus, 105 mg kg^{-1} exchangeable potassium and pH$_{\text{KCl}}$ 6.0.

Soil bioassays: they also were performed in a complete randomized design with three factors. Plastic 150-well-plates were used where each well had a depth of 7 cm, an upper diameter of 4.2 cm, and a lower diameter of 1.7 cm. Each well was filled with 65 g of fresh rhizosphere soil. Then, each well was irrigated with 30 mL of distilled water. After 2 h, the seeds were sown in the centre of each well. Seeds were placed at 2 cm depth. The 20 mL aqueous extracts of weeds/water (Control treatment) per well were added on 1.5 and 10 days after germination. One treatment had 10 wells and all treatments were replicated 5-times.

Indicators such as speed of germination (S) and coefficient of the velocity of germination (CV_i) were used to determine the peculiarities of seed germination by the action of the corresponding weed extracts.

The speed of germination (S) was calculated by the Eq. (2) (Duke, 2015) taking into account (ISTA, 2017):

$$S=\frac{N_1}{1}+\frac{N_2}{2}+\frac{N_3}{3}\ldots\frac{N_n}{n}, \qquad (2)$$

where, N_1, N_2, $N_3 \ldots N_n$, ... are the number of seeds germinated on days 1, 2, 3...n.

Coefficient of the velocity of germination (CV_i (% day^{-1})) in percentage terms (own interpretation of the Abd El-Gawad formula (2014)) was recorded daily till the 9th day and was calculated by the Eq. (3):

$$CV_i=\left(\frac{\sum N_i}{T}\right)\times 100, \qquad (3)$$

where, N – number of seeds germinated on day and T – the total number of seeds laid in the variant for germination.

The traditional block of allelopathic evaluation of seed germination indicators included a number of typical indicators.

Allelopathic potential was calculated for seed germination (APG) Allelopathic potential was determined by the Eq. (4) (Rueda-Ayala *et al.*, 2015).

$$APG=((IR_a+IR_b)/2)/100, \qquad (4)$$

where, APG – allelopathic potential of gemination; IR_a and IR_b – germination inhibitions recorded at weed extract concentrations of 1 and 4%, respectively.

Per cent inhibition (IR) was calculated according to Eq. (5) (Marinov-Serafimov, Golubinova, 2015; Marinov-Serafimov *et al.*, 2017, 2019):

$$IR = \frac{C - T}{C} \times 100, \tag{5}$$

where C – germination in control and T – germination in a treatment.

The seed germination (%) was calculated after preliminary arcsin-transformation following Eq. (6) (Marinov-Serafimov *et al.*, 2017, 2019):

$$Y = arcsin\left(\sqrt{\frac{x\%}{100}}\right), \tag{6}$$

Basic statistical data analysis was done with Microsoft Office Excel 2010. Figures were constructed with Microsoft Office Excel 2010 and Tukey multiple comparisons of means 95% family-wise confidence level were performed with the R-statistica (i386 3.2.2) and the application of proven methods of biometric statistics (Sokal, James, 2012; Rumsey, 2016).

Results and Discussion

Long-term research on oil radish coenosis weediness (Tsytsiura, 2020) showed the complex nature of its formation both in terms of species composition and the nature of the individual species dominance (Table 1). The share of the Asteraceae family species accounts for 52.2%, they are dominant in the agrocenosis of oilseed radish. Other species are placed in descending order of their coenotic role, *i.e.*, Plantaginaceae (13.1%), Convolvulaceae, Poaceae, Polygonaceae (8.7%), Boraginaceae, Equisetaceae (4.3%). The species obtained ratio by biological features allows classifying the type of perennial species weedings of perennial species of oilseed radish agrocenoses as the root-sprouting and rhizome type.

The oilseed radish seeds germination in "petri dish bioassay" (Table 2) showed a specific species allelopathic sensitivity of oilseed radish. It is confirmed by laboratory germination results both in water and soil substrate already from the extract concentration level of 0.25%. For most of the studied species, the concentration of 4.0% extract was indicative. Increasing its value to 8 and 16% led to an intensive decrease in the number of similar seeds of oilseed radish by the action of extracts of 16 species of weeds and its complete absence by the action of extracts of 8 species.

According to Grodzinsky (1992), this nature of reaction indicates both high allelopathic sensitivity of the species and its adaptive vitality tactics in the formation of its cenosis in the overall cenosis of interactions between species diversity of competing plant species. In many studies (Jabran *et al.*, 2015; Kunz *et al.*, 2016; Lahdhiri, Mekki, 2016), an allelopathic reaction in the range from 0.1% to 32.0% was observed for many plant species.

Table 2. Seed germination of oilseed radish exposed to aqueous extracts prepared ("Petri dish bioassay") from whole plants of 23 perennial weed species

No.	Species of weeds	Germination, % water extracts concentration, %							APG[*]
		0.25	0.5	1.0	2.0	4.0	8.0	16.0	
1	Control (Distilled water)	92.4	92.7	92.8	93.5	91.4	92.6	93.4	–
2	*Achillea millefolium* L.	90.8^{c}	85.6^{b}	77.6^{a}	58.7^{a}	26.4^{a}	8.2	4.5	0.37
3	*Acroptilon repens* (L.) de Candolle	62.4^{a}	50.2^{a}	32.6^{a}	16.4^{a}	7.3^{a}	0.0	0.0	0.66
4	*Agropyron repens* (L.) Gould	78.9^{a}	60.9^{a}	42.2^{a}	26.2^{a}	10.4^{a}	1.8	0.0	0.60
5	*Arctium lappa* L.	89.6^{b}	84.2^{b}	72.6^{a}	56.4^{a}	10.4^{a}	1.7	0.0	0.48
6	*Artemisia absinthium* L.	86.1^{b}	70.3^{a}	57.8^{a}	27.8^{a}	11.3^{a}	2.4	0.0	0.53
7	*Artemisia vulgaris* L.	86.7^{b}	73.6^{a}	60.3^{a}	36.5^{a}	17.5^{a}	3.1	0.0	0.49
8	*Carduus acanthoides* L.	76.2^{a}	70.8^{a}	62.6^{a}	49.3^{a}	27.2^{a}	1.4	0.0	0.43
9	*Cichorium intybus* L.	80.2^{a}	60.8^{a}	42.4^{a}	34.1^{a}	19.4^{a}	2.8	1.5	0.55
10	*Cirsium arvense* (L.) Scopoli	65.9^{a}	48.2^{a}	37.3^{a}	19.1^{a}	9.2^{a}	0.0	0.0	0.63
11	*Convolvulus arvensis* L.	62.8^{a}	50.2^{a}	41.9^{a}	26.7^{a}	9.3^{a}	0.0	0.0	0.61
12	*Cuscuta campestris* Yuncker	60.9^{a}	42.5^{a}	29.3^{a}	16.7^{a}	6.5^{a}	0.0	0.0	0.68
13	*Cyclachaena xanthiifolia* Nuttall	74.1^{a}	60.2^{a}	49.6^{a}	28.6^{a}	11.7^{a}	0.0	0.0	0.56
14	*Cynodon dactylon* (L.) Pers.	82.6^{a}	73.4^{a}	67.2^{a}	29.2^{a}	14.2^{a}	2.7	0.0	0.48
15	*Echium vulgare* L.	82.6^{a}	70.9^{a}	57.8^{a}	36.4^{a}	19.3^{a}	2.7	1.2	0.49
16	*Equisetum arvense* L.	84.7^{b}	71.3^{a}	52.4^{a}	38.8^{a}	5.1^{a}	0.0	0.0	0.60
17	*Linaria vulgaris* Mill.	64.3^{a}	51.7^{a}	37.8^{a}	18.5^{a}	9.3^{a}	1.5	0.0	0.62
18	*Onopordum acanthium* L.	69.7^{a}	59.6^{a}	44.5^{a}	29.5^{a}	12.5^{a}	0.0	0.0	0.58
19	*Plantago lanceolata* L.	77.9^{a}	62.3^{a}	48.4^{a}	29.3^{a}	14.7^{a}	3.6	2.3	0.55
20	*Plantago major* L.	83.9^{b}	62.8^{a}	34.7^{a}	19.2^{a}	8.4^{a}	1.5	0.0	0.64
21	*Rumex acetosella* L.	82.9^{a}	75.3^{a}	62.5^{a}	46.2^{a}	14.7^{a}	2.5	1.4	0.49
22	*Rumex confertus* Willdenow	90.1^{c}	82.6^{a}	78.2^{a}	44.2^{a}	9.6^{a}	1.1	0.0	0.46
23	*Sonchus arvensis* L.	80.2^{a}	67.9^{a}	58.5^{a}	19.2^{a}	7.2^{a}	0.0	0.0	0.56
24	*Taraxacum officinale* Weber	89.5^{b}	84.5^{b}	77.4^{a}	31.5^{a}	18.4^{a}	6.2	2.4	0.41
Tukey multiple comparisons of means 95% family-wise confidence level (the interval of a minimum level of allowable difference for p_{adj})		0.63–0.77	0.79–1.03	0.86–1.12	0.92–1.29	0.96–1.52	–	–	–

Significance levels to control (*p*): a – 0.1%; b – 1%; c – 5%; d – no significant difference.
[*]APG is the allelopathic potential of gemination oilseed radish calculated for weed extracts concentrations of 1–4%; [**] the following classes were considered for the indicator of APG by Smith (2013): 0–0.25 Non-allelopathic (NA); 0.26–0.5 – moderately allelopathic (MA); 0.51–0.75 – highly allelopathic (HA); 0.76–1.0 – extremely allelopathic (EA).

At the same time, the reaction to an intensive decrease in seed germination is already determined from 0.5–1.5%. In some early studies (Inderjit, Keating, 1999), it is noted that the degree of the allelopathic reaction manifestation is conditioned both by the species introduction in terms of the time of its cultivation and by the proximity to typical representatives of weed vegetation. In long-term agricultural use, the species spectrum of allelopathic reaction narrows to the most aggressive species, and vice versa, with limited territorial cultivation, the allelopathic sensitivity is higher. This is confirmed in our studies, given the fact that the intensity of oilseed radish cultivation in many regions is limited. According to Grodzinsky (1991), this nature of reaction indicates both high allelopathic sensitivity of the species and its adaptive vitality tactics in the formation of its cenosis in the overall cenosis of interactions between species diversity of competing plant species. In many studies (Jabran *et al.*, 2015; Kunz *et al.*, 2016; Lahdhiri, Mekki, 2016), an allelopathic reaction in the range from 0.1% to 32.0% was observed for many plant species.

There was a decrease in seed germination at the level of extract concentration in the range of 0.5–1.5%. Some early studies (Inderjit, Keating, 1999) noted that the degree of allelopathic response to the interaction of different species depends on both the date of their introduction and the prevalence of the species in the coenosis. In long-term agricultural use, the species spectrum of allelopathic reaction narrows to the most aggressive species, and vice versa, with limited territorial cultivation, the allelopathic sensitivity is higher. This is confirmed in our studies, given the fact that the intensity of oilseed radish cultivation in many regions is limited. Thereby, the allelopathic threshold for oilseed radish at the seed germination stage for the "Petri dish bioassay" variant reaches 4% of the concentration of the researched perennials extract.

According to Scavo and Mauromicale (2021), such a threshold is identified for assessing the overall level of competition between the studied plant species. The obtained results show significant differences in the species specificity of the seed germination decreased by a multiple of two gradual increases in the weed species extract concentration. Thus, the dynamic decrease in seed germination compared to the concentration of the 0.25% extract was 26.9, 43.4, 71.0, and 86.0% to the previous concentration for *Cirsium arvense* (L.) Scopoli, it was 30.2, 51.9, 72.6 and 89.3% for *Cuscuta campestris* Yuncker and 5.7, 14.5, 35.4 and 70.9% for *Achillea millefolium* L. It should be noted that this decrease has specific features. Naturally, the species with the highest criterion of prevalence in the oilseed radish agrocenosis in terms of F (Table 1) have substantially higher rates of reduced seed germination starting from 1.0% concentration. An intensive decrease of germination is observed in the concentration range of 1.0–2.0% for species with lower occurrence in the agrocenosis, the decrease to the comparable variant of 0.25% may significantly exceed the variant of 4.0%. In our opinion, considering the research results and statements of other scholars (Inderjit, Keating, 1999; Iqbal, Fry, 2012; Melander *et al.*, 2016; Miller, 2016) this impact forms a higher level of allelopathic potential of species with a low presence in the coenosis. This leads to the lack of formation of appropriate coenotic relationships between these species and oilseed radish. On the other hand, these types of weeds belong to the specific content of active allelochemicals and essential oils. As a result, these reasons determine the specificity of the allelopathic reaction at the stage of germination of radish seeds. This specificity, given the content of active allelochemicals, has been pointed out in several recent studies (Chotsaeng *et al.*, 2017; Abd-ElGawad *et al.*, 2021; Gharibvandi *et al.*, 2022).

According to other researchers, it forms an indicator of the species abundance (Rasmussen *et al.*, 2014; Brandsæter *et al.*, 2017; Buddhadeb, Bhowmik, 2020) and provides the possibility of its distribution. If the species" dominance changes in the coenosis, their allelopathic influence on oilseed radish germination will be higher than for traditional species with a high presence in the coenosis (Tsytsiura, 2020). It should also be noted oilseed radish has a lower threshold of sensitivity to aggressive perennial weeds such as *Agropyron repens* (L.) Gould, *Acroptilon repens* (L.) de Candolle, *Carduus acanthoides* L., *Cynodon dactylon* (L.) Pers., *Sonchus arvensis* L. comparing with similar studies on other cruciferous crops (Tollsten, Bergstrom, 1988; Grodzinsky, 1992; Sarmah *et al.*, 1992; Brown, Morra, 1996; Kirkegaard, Sarwar, 1998; Norsworthy, 2003; Turk, Tawaha, 2003; Izzet *et al.*, 2004; Haramoto, Gallandt, 2005; Boydston, Al-Khatib, 2006; Lawley *et al.*, 2011; Morikawa *et al.*, 2012; Awan *et al.*, 2012; Rehman *et al.*, 2012; Takemura *et al.*, 2013; Lemerle *et al.*, 2014; Amini *et al.*, 2014; Harris *et al.*, 2015; Björkman *et al.*, 2015; Ali, 2016; Ali *et al.*, 2019; Khan *et al.*, 2019; Rehman *et al.*, 2019). This factor emphasizes the value of the application of oilseed radish as a sidereal mediator in the system of organic farming technologies.

The nature of the formation of the oilseed radish germination also differed at germination on "petri dish bioassay" and, respectively, in the variant of approximate imitation to field conditions – on "Soil bioassay" (Table 3).

Changing the germination environment of oilseed radish on the soil bioassay reduced the allelopathic effect by 0.2–2.0% depending on the type of weed. The maximum difference is noted when comparing two germination variants in the concentration range of 0.25–2%, and the minimum 1 in the range of 8–16%. Moreover, the value of such reduction is species-specific. Therefore, for the species *Agropyron repens* (L.) Gould 1.1–3.5%, and for the species *Cyclachaena xanthiifolia* Nuttall 1.0–1.8%. This nature of the allelopathic effect has also been noted in the research of several scientists (Fujii *et al.*, 2004; Sturm *et al.*, 2016, 2018; Prinsloo, Plooy, 2018). In these researches, it is explained by the absorption and adsorption of several substances extracted into the solution during the extraction process. This confirms the statement that the allelopathic potential of a particular weed species is determined both by its stage phenological development and by the edaphic conditions of its growth and development, which determine both the vegetation intensity of the species, its vitality index and the degree of influence of its root excretions, given the favourable soil fertility conditions for the species itself.

Table 3. Seed germination of oilseed radish exposed to aqueous extracts prepared (soil bioassay) from whole plants of 23 perennial weed species.

No.	Species of weeds	Germination, % water extracts concentration, %							APG*
		0.25	0.5	1.0	2.0	4.0	8.0	16.0	
1	Control (Distilled water)	91.6	90.3	89.8	90.6	89.2	88.7	90.2	–
2	*Achillea millefolium* L.	90.5[c]	85.3[b]	78.4[b]	60.3[a]	27.8[a]	8.6	5.1	0.34
3	*Acroptilon repens* (L.) de Candolle	63.8[a]	52.6[a]	33.6[a]	15.2[a]	6.8[a]	0.0	0.0	0.65
4	*Agropyron repens* (L.) Gould	82.4[a]	63.8[a]	44.6[a]	32.8[a]	12.8[a]	2.9	0.0	0.56
5	*Arctium lappa* L.	90.4[c]	85.6[b]	73.9[a]	57.8[a]	11.8[a]	2.1	0.0	0.44
6	*Artemisia absinthium* L.	87.4[c]	71.8[a]	62.1[a]	30.9[a]	12.6[a]	3.7	0.0	0.49
7	*Artemisia vulgaris* L.	87.9[c]	74.5[a]	62.4[a]	39.3[a]	19.8[a]	4.0	0.0	0.45
8	*Carduus acanthoides* L.	80.2[a]	75.3[a]	69.5[a]	51.8[a]	33.5[a]	2.1	0.0	0.35
9	*Cichorium intybus* L.	81.7[a]	62.3[a]	44.5[a]	35.6[a]	19.8[a]	3.2	1.8	0.52
10	*Cirsium arvense* (L.) Scopoli	68.9[a]	53.6[a]	44.7[a]	23.8[a]	15.2[a]	0.0	0.0	0.54
11	*Convolvulus arvensis* L.	64.8[a]	52.6[a]	43.5[a]	30.4[a]	11.6[a]	0.0	0.0	0.57
12	*Cuscuta campestris* Yuncker	56.4[a]	40.3[a]	28.4[a]	15.2[a]	5.8[a]	0.0	0.0	0.68
13	*Cyclachaena xanthiifolia* Nuttall	75.6[a]	62.3[a]	50.9[a]	29.8[a]	12.6[a]	0.0	0.0	0.53
14	*Cynodon dactylon* (L.) Pers.	83.9[b]	77.2[a]	74.3[a]	34.5[a]	19.2[a]	3.2	0.0	0.40
15	*Echium vulgare* L.	83.8[b]	72.5[a]	59.6[a]	35.6[a]	18.4[a]	2.3	1.0	0.47
16	*Equisetum arvense* L.	80.4[a]	70.6[a]	51.2[a]	37.6[a]	4.8[a]	0.0	0.0	0.59
17	*Linaria vulgaris* Mill.	66.8[a]	52.6[a]	39.3[a]	20.6[a]	11.4[a]	2.4	0.0	0.59
18	*Onopordum acanthium* L.	70.8[a]	60.3[a]	45.2[a]	28.4[a]	11.8[a]	0.7	0.0	0.56
19	*Plantago lanceolata* L.	78.2[a]	61.8[a]	50.1[a]	30.6[a]	15.5[a]	4.2	2.6	0.52
20	*Plantago major* L.	84.8[b]	63.6[a]	35.8[a]	20.6[a]	8.9[a]	2.6	0.0	0.62
21	*Rumex acetosella* L.	83.4[b]	77.5[a]	63.9[a]	42.8[a]	13.8[a]	2.0	1.2	0.47
22	*Rumex confertus* Willdenow	90.8[d]	83.9[a]	80.4[b]	45.8[a]	10.9[a]	1.8	0.0	0.42
23	*Sonchus arvensis* L.	83.6[b]	71.3[a]	60.4[a]	21.3[a]	8.6[a]	0.0	0.0	0.52
24	*Taraxacum officinale* Weber	90.4[c]	86.5[b]	79.6[b]	34.2[a]	21.3[a]	6.8	3.6	0.36
Tukey multiple comparisons of means 95% family-wise confidence level (the interval of a minimum level of allowable difference for p_{adj})		0.58–0.69	0.68–0.95	0.80–1.07	0.89–1.22	0.93–1.48	–	–	–

Significance levels to control (p): a – 0.1%; b – 1%; c – 5%;d – no significant difference.
*APG is the allelopathic potential on oilseed radish germination calculated for weed extracts concentrations of 1–4% with the same classes of allelopathic potential by Smith (2013).

In our opinion, the difference in the allelopathic impact on seed germination for the two variants is a measure of the importance of soil conditions for the manifestation of herbal competition of this species with the oilseed radish, which is confirmed in research by Meiners *et al.* (2017) and Kuht *et al.* (2016). We consider the fact that in its cycle of development, the critical period for weed control (CPWC (Knežević, Datta, 2015)) is typical for the period from 5–7 to 12–15 days of vegetation (Tsytsiura, 2020), which determines a specific competition of this species with other plant species (Lawley *et al.*, 2012). The presented averaged data show a general decrease in allelopathic effect on oilseed radish germination exactly when grown on the soil substrate by 0.2–2.0% depending on the extract concentration. The maximum difference is noted when comparing two germination variants in the concentration range of 0.25–2%, and the minimum 1 in the range of 8–16%. Moreover, the value of such reduction is species-specific. Therefore, for the species *Agropyron repens* (L.) Gould 1.1–3.5% and the species *Cyclachaena xanthiifolia* Nuttall 1.0–1.8%. This nature of the allelopathic effect has also been noted in the research of several scientists (Fujii *et al.*, 2004; Sturm *et al.*, 2016, 2018; Prinsloo, Plooy, 2018). In these researches, it is explained by the absorption and adsorption of several substances extracted into the solution during the extraction process. This confirms the statement that the allelopathic potential of a particular weed species is determined both by its stage phenological development and by the edaphic conditions of its growth and development, which determine both the vegetation intensity of the species, its vitality index and the degree of influence of its root excretions, given the favourable soil fertility conditions for the species itself. Thus, the use of two variants of seed germination provided the formation of similar features of seed germination in the dynamics of increasing the concentration of the extract while weakening the direct action of allelopathic substances of solutions due to the buffering features of the soil absorption complex in the "soil bioassay" variant (Table 4).

This conclusion is confirmed by the presented grouping. According to it some species of weeds belonged to different grouping intervals comparing both variants of germination. For *Linaria vulgaris* Mill APG interval is 0.61–0.65 for "Petri plate bioassays" and 0.56–0.60 for "soil bioassays", and for *Carduus acanthoid* L it is 0.41–0.45 and 0.31–0.35, respectively. The majority of species with the highest prevalence in the agrocenosis of oilseed radish by the criterion of frequency (F) belonged to the groups with APG> 0.50 for both germination variants.

Representatives of the families Asteraceae, Poaceae and Convolvulaceae played a dominant role in the intensity of allelopathic effects on oilseed radish. Representatives of these families had a high allelopathic activity to cruciferous and other species of agricultural plants.

The data obtained is also confirmed by the level of allelopathic effect on other cultivated plants from several weed species under study, including the representatives of the Convolvulaceae (COVF) family in the studies of Marinov-Serafimov *et al.* (2015), Dadkhah and Rassam (2016); Poaceae (1GRAF) family species in the studies of Einhellig *et al.* (1982), Awan *et al.* (2012), de Bertoldi *et al.* (2012), Anwar *et al.* (2019), Fragasso *et al.* (2013), Golubinova and Ilieva (2014); Asteraceae (1COMF) family species in the studies of Stevens (1986), Izzet *et al.* (2004), Awan *et al.* (2012), Możdżeń *et al.* (2018), Marinov-Serafimov *et al.* (2015, 2019); Polygonaceae (1POLF) family species in the studies of Anwar *et al.* (2013). According to the research results of the above-mentioned authors, the highest level of allelopathic potential was noted for the Asteraceae family representatives, and among the parasitic representatives of the Convolvulaceae family, in particular the *Cuscuta* (1CVCG) genus (Marinov-Serafimov *et al.*, 2017).

Table 4. Effect of weed extracts on seed germination of oilseed radish (BBCH 01–05*) are grouped according to their allelopathic potential (APG)

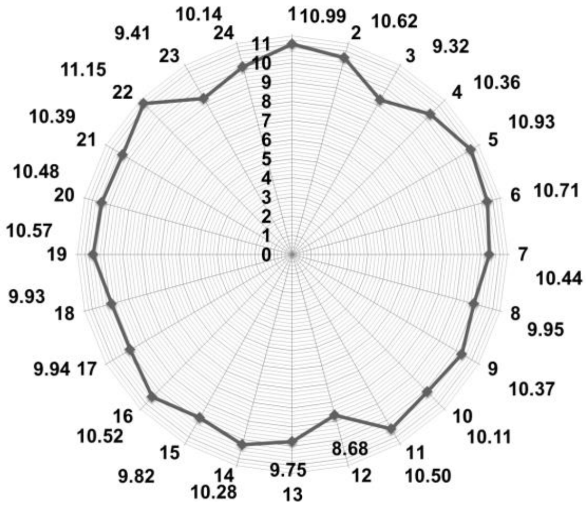
APG interval	Weed species, which belong to the interval group	
	Petri plate bioassays	soil bioassays
0.30–0.35	–	*Carduus acanthoides* L.., *Achillea millefolium* L.
0.36–0.40	*Achillea millefolium* L.	*Taraxacum officinale* Weber, *Cynodon dactylon* (L.) Pers.
0.41–0.45	*Carduus acanthoides* L., *Taraxacum officinale* Weber	*Artemisia vulgaris* L., *Rumex confertus* Willdenow, *Arctium lappa* L.
0.46–0.50	*Artemisia vulgaris* L., *Cynodon dactylon* (L.) Pers., *Rumex confertus* Willdenow, *Arctium lappa* L., *Rumex acetosella* L., *Echium vulgare* L.	*Artemisia absinthium* L., *Rumex acetosella* L., *Echium vulgare* L.
0.51–0.55	*Artemisia absinthium* L., *Cichorium intybus* L., *Plantago lanceolata* L.	*Cirsium arvense* (L.) Scopoli, *Sonchus arvensis* L., *Cichorium intybus* L., *Cyclachaena xanthiifolia* Nuttall, *Plantago lanceolata* L.
0.56–0.60	*Agropyron repens* L.) Gould, *Sonchus arvensis* L., *Equisetum arvense* L., *Cyclachaena xanthiifolia* Nuttall, *Onopordum acanthium* L.	*Agropyron repens* L.) Gould, *Convolvulus arvensis* L., *Linaria vulgaris* Mill., *Equisetum arvense* L., *Onopordum acanthium* L.
0.61–0.65	*Cirsium arvense* (L.) Scopoli, *Convolvulus arvensis* L., *Linaria vulgaris* Mill., *Plantago major* L.	*Plantago major L. Acroptilon repens* L.) de Candolle
0.66–0.70	*Acroptilon repens* L.) de Candolle, *Cuscuta campestris* Yuncker	*Cuscuta campestris* Yuncker

*Growth periodization by BBCH (Test guidelines…, 2017).

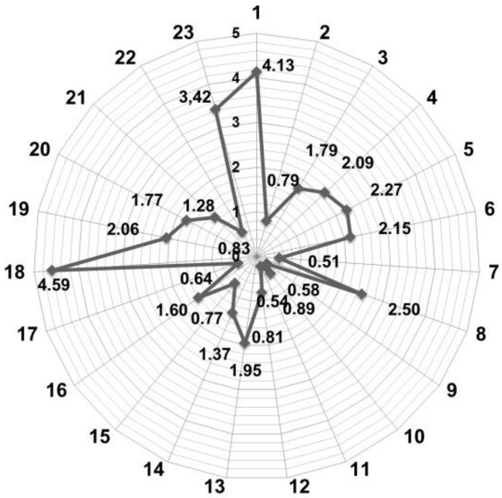
The very nature of the germination dynamics had a heterogeneous nature and species specificity from a slow-down nature to nature with leap-scopic decline, which points in favour of the biochemical causes (Reigosa *et al.*, 2006; Florence *et al.*, 2019). For a more detailed assessment of the nature of this dynamics, two indicators of the speed of germination (S) and the coefficient of the velocity of germination (CV_i) were used for the soil-free germination variant, which, as we found, is more biologically aggressive and needs to be evaluated typologically for the nature of similarity formation on an allelopathic background. These indicators are rarely applied to such research systems, but are very informative (Nasr, Mansour, 2005), as they demonstrate both the overall germination intensity and its dynamic nature for each additional day of the germination period.

The rate of seed germination (S) details the process of germinated seeds formation daily and determines the specific species" nature impact on this process considering the characteristics of the extract chemical structure. According to this indicator (Fig. 1), the researched weed species can be divided into several classification groups within each variant of the extract concentration. Thus, the specific effect of the extracts provides 10–11, 9–10 and 8–9 germinated seeds per germination day in comparison with the control variant of 10.99 germinated seeds per day in the 1.0% variant. This rate was 11.15 germinated seeds per day for *Rumex confertus* Willdenow; it was higher than the control variant; the minimum rate was 8.68 germinated seeds per day for the species *Cuscuta campestris* Yuncker. The indicator distribution by the weeds researched species changes significantly in the variant of 4.0% extract concentration and especially in the variant of 8.0%. Thus, the range of the indicator is 5.26–10.15 in the variant of 4.0% extract concentration.

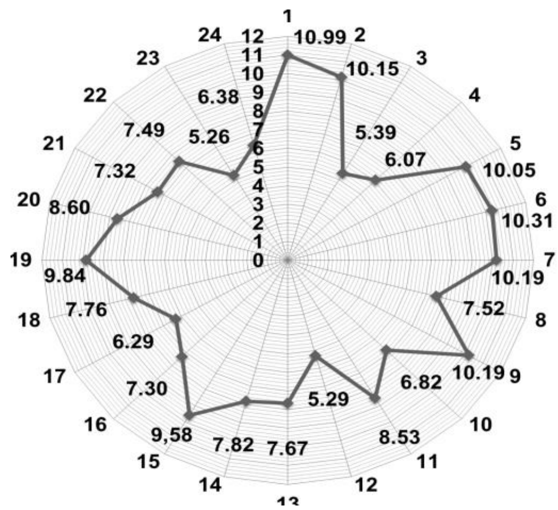
The value of this indicator decreased for species with a low presence in the cenosis of oilseed radish (*Arctium lappa* L.; *Artemisia absinthium* L.; *Artemisia vulgaris* L., *Cichorium intybus* L., *Echium vulgare* L., *Plantago lanceolata* L.) by 4.5–9.8% and was 9.58–10.31 germinated seeds per day compared to the concentration of 1.0%. The velocity interval was significantly lower and was 5.26–6.82 for the *Acroptilon repens* (L.) de Candolle, *Agropyron repens* (L.) Gould, *Cirsium arvense* (L.) Scopoli, *Sonchus arvensis* L. species with the highest precence by the frequency criterion F (Table 1) in the variant of the extract concentration of 4.0%. It should be noted that the rate of speed germination (S) in the variant of concentration of 8.0% also had certain features in the 8.0% variant concentration. Thus, the decrease was significantly higher for species with minimal presence with the same criterion of frequency (F), than for species that dominate in the agrocenosis of oilseed radish in the research area. For example, such species as *Carduus acanthoides* L. (S = 0.51), *Cichorium intybus* L. (S = 0.58), *Onopordon acanthium* L. (S = 0.64).



Weed extracts at 1%



Weed extracts at 8%



Weed extracts at 4%

Figure 1. The speed of seed germination (S) of oilseed radish growing under weed extracts at 1%, 4% and 8%. The Y-axis is scaled to indicate the number of oil radish seeds germinated per day when exposed to weed extracts.
1 – Control (Distilled water); 2 – *Achillea millefolium* L.; 3 – *Acroptilon repens* (L.) de Candolle; 4 – *Agropyron repens* (L.) Gould; 5 – *Arctium lappa* L.; 6 – *Artemisia absinthium* L.; 7 – *Artemisia vulgaris* L.; 8 – *Carduus acanthoides* L.; 9 – *Cichorium intybus* L.; 10 – *Cirsium arvense* (L.) Scopoli; 11 – *Convolvulus arvensis* L.; 12 – *Cuscuta campestris* Yuncker; 13 – *Cyclachaena xanthiifolia* Nuttall; 14 – *Cynodon dactylon* (L.) Pers.; 15 – *Echium vulgare* L.; 16 – *Equisetum arvense* L.; 17 – *Linaria vulgaris* Mill.; 18 – *Onopordon acanthium* L.; 19 – *Plantago lanceolata* L.; 20 – *Plantago major* L.; 21 – *Rumex acetosella* L.; 22 – *Rumex confertus* Willdenow; 23 – *Sonchus arvensis* L.; 24 – *Taraxacum officinale* Weber. (For the variant with an extract concentration of 8.0%, the control variant similar to the concentration of 1 and 4% was not shown on the graph while maintaining the same numbering of weed species as for the concentration of 1 and 4%).

Thus, speed of germination indicator allows for categorizing the extracts of the perennial weed into three groups: (i) 9–11 seeds day^{-1} where seed germination was completed after 3–5 days. Typical weed species in this group are *Convolvulus arvensis* L., *Artemisia vulgaris* L., *Artemisia absinthium* L., *Arctium lappa* L. and *Achillea millefolium* L.; (ii) 7–9 seeds day^{-1} at which germination of oilseed radish finished in 5 to 7 days. Typical weed species in this group are *Equisetum arvense* L., *Linaria vulgaris* Mill., *Cuscuta campestris* Yuncker; (iii) 5–7 seeds day^{-1} where full germination needed 5 to 9 days.

This group includes *Acroptilon repens* (L.) de Candolle, *Agropyron repens* (L.) Gould, *Sonchus arvensis* L., *Taraxacum officinale* Weber. This last group was characterized by the presence of "dormance seeds" which are swollen seeds with evident signs of germination initiation.

Weeds dominating the oilseed radish agrophytocoenosises in our research fields belong to both the third and the second groups mentioned. This finding suggests that the dominance of these weeds in oilseed radish fields is due, at least in part, to their allelopathic effects. This aspect is mentioned in some research (Cheng, Cheng, 2015; Arroyo *et al.*, 2018; Carvalho *et al.*, 2019).

Thus, the rate of germination rate details the gradations of allelopathic sensitivity of the species in the test-object system, *i.e.*, weeds in the early stages of germination, and allows identifying of certain typological groups of effects. It is confirmed by the Coefficient of velocity (CVi), which allowed us to assess the formation of germinated seeds of oilseed radish for each day of observation. The allelopathic effect of different weed species on radish seed germination shifts the germination pattern under appropriate standard laboratory germination conditions. Under these conditions, the germination of oilseed radish seeds is observed 6–7 days after the start of germination and some seeds had signs of germination in 3–5 days (Seeds quality ..., 2003). However, extracts of different species change the dynamics of germination. The range of CVi values by the standard deviation is significantly higher than for the treatment variant with extracts of 1.0% concentration in the case of 4.0% concentration variant in the interval from 3rd (CV3) to the 9th day (CV9) of germination (Fig. 2).

The maximum range interval for the extract concentration variant was observed on the seventh (CV7) and eighth (CV8) days of germination, and the minimum was observed on the ninth (CV9) with a steady increase in variation for the total population researched from the first to the eighth day of germination. The maximum range of values was observed mosaically on the 4th, 7th and 9th day of germination for the 1.0% concentration variant. It confirms our conclusions about the inhibition of physiological processes of germinated seeds formation with a shift of stages in 7–9 days for oilseed radish. Therefore, this effect should be expected for allelopathically aggressive species in comparison to the test object. On the other hand, the use of 1.0% extract provides a more even distribution of seed formation with signs of germination from the 3rd to 7th days. A percentage shift of normally germinated seeds from 4th to 9th days with a maximum value from 6th to 8th days of germination was observed for the variant of 4.0% concentration. That is, the effect of physiological depression and prolongation of stages of seed germination is observed.

The difference between our conclusions and similar research (Singh *et al.*, 2003; Uremis *et al.*, 2009; Toosi, Baki, 2011; Swanton *et al.*, 2015; Sturm *et al.*, 2018; Carvalho *et al.*, 2019; Ali *et al.*, 2019; Schandry, Becker, 2020) is to identify the processes of seed germination displacement beyond the biologically typical date of the species, according to the standards for germination determining.

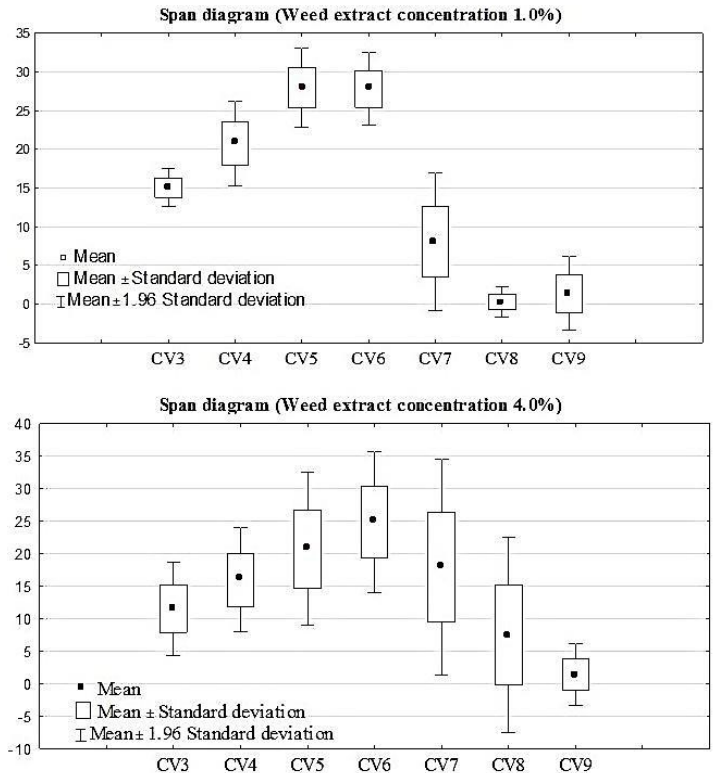


Figure 2. Span diagrams obtained for the means of the Coefficient of velocity of germination (CV_i) calculated from the third (CV3) to the nineth day (CV9) of oilseed radish germination.

According to the classical scheme, such seeds should be classified as seeds that have not germinated. The studied features require some revision using a wider interval than accepted by standard methods for estimating the value of seed germination considering oilseed radish allelopathic analysis at the stage of seed germination. Visually indicated features within the researched weed species are presented in Figure 3. Thus, most of the presented weed species provided a general decrease in the percentage of germinated seeds starting from the third day of germination with the increasing difference to 5th and 6th days for the variant of 1.0% extract concentration. The process of inhibiting germination by shifting the maximum proportion of germinated seeds on the 7th day of germination under the action of extracts for weed species such as *Acroptilon repens* (L.) de Candolle, *Cirsium arvense* (L.) Scopoli, *Plantago major* L. *Cyclachaena xanthiifolia* Nuttall was observed. It should also be noted that a germinated seed was observed on the 9th day of germination, it was not observed on the 8th day.

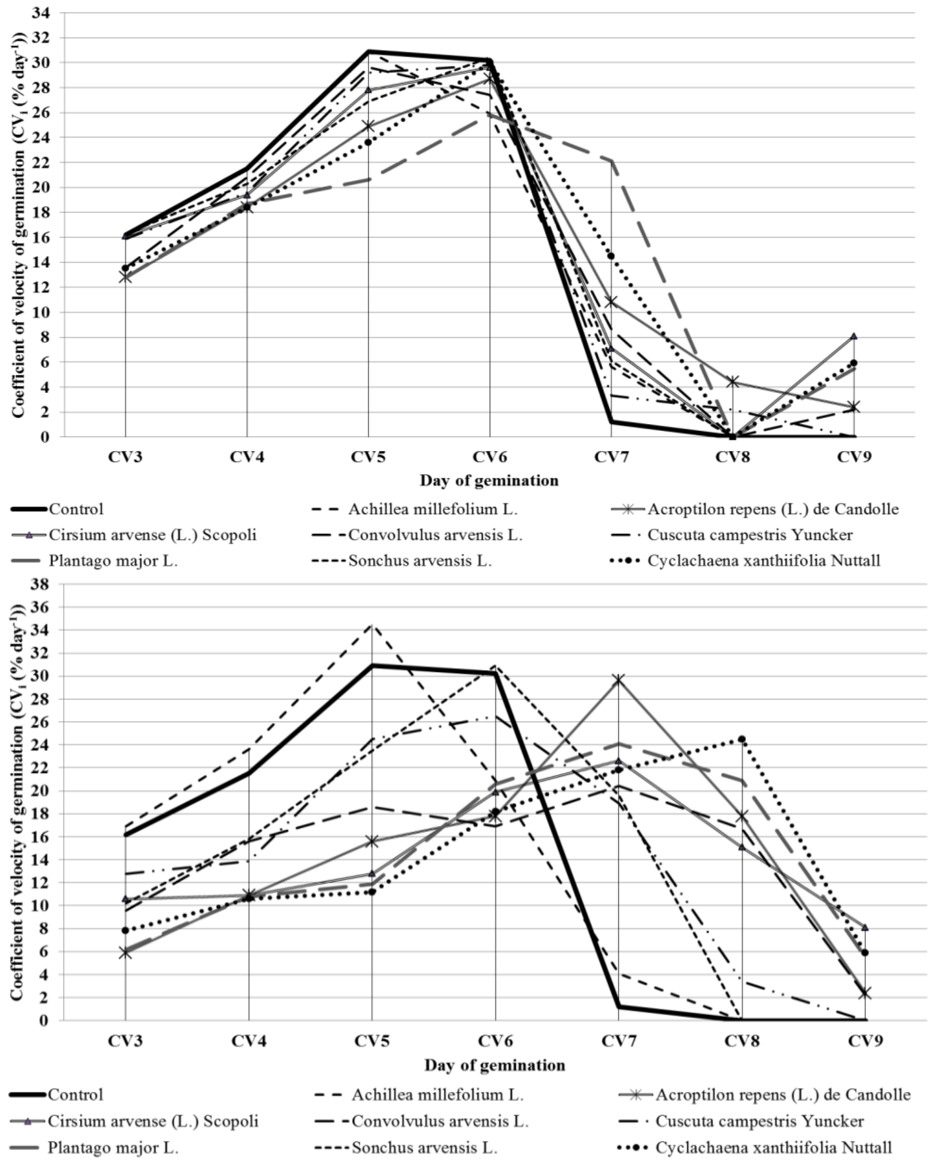


Figure 3. Coefficient of the velocity of germination (CVi (%)) calculated for oilseed radish germination exposed to distilled water (control) and some weed extracts at the concentration of 1% (upper position) and 4% (down position), from day 3rd (CV3) to day 9th (CV9). The units in the Y-axis indicate the % of germinated seeds on the ith day of germination.

The dynamic formation of the indicator had significant differences and species specificity at the variant of 4.0% extract concentration. Thus, a 4.0% concentration level is a threshold for oilseed radish (Melander *et al.*, 2016). The maximum CV index was observed on the 5th and 6th day of oil radish seeds germination of (parity at 30–31%) in the control variant. The peak values were observed in *Achillea millefolium* L. on the 5th day, in *Sonchus arvensis* L. on the 6th day, in *Acroptilon repens* (L.) de Candolle and *Convolvulus arvensis* L. on the 7th day, in *Cyclachaena xanthiifolia* Nuttall on the 8th day under the action of different species extracts. The maximum values of CV_i are achievable for oilseed radish on 6–8th days for species with higher allelopathic potential according to APG (Table 2), and on 4th–6th days of germination for species with significantly lower APG values. It should be noted that in both 1.0% and 4.0% extracted concentrations the seeds are swollen, lively, but not germinated according to the classical morphological parameters with the initial signs of germination after the 9th day.

Thus, the formation of germinated seeds in the extracts of certain species of weeds was observed (*Cuscuta campestris* Yuncker, *Equisetum arvense* L., *Cirsium arvense* (L.) Scopoli, *Acroptilon repens* (L.) de Candolle, *Carduus acanthoides* L.) on 11–12th days of germination under optimal germination conditions. The processes potential under the action of extracts of certain weed species is indicated in the studies of Marinov-Serafimov *et al.* (2017), Novak *et al.* (2018), and Khan *et al.* (2019).

Our research has confirmed this possibility and provides grounds for recommendations for changes in some approaches to the research of allelopathic effects and allelopathic sensitivity of biological test species at the stage of seed germination.

Conclusion

Oilseed radish was sensitive to water extracts of 23 perennial weed species tested in the range of concentrations of 0.25–16.0% (w/v).

The range growth of weed species allelopathic potential on their impact on seed germination according to APG averaged for two variants of germination was as follows: *Cuscuta campestris* Yuncker (APG (average for germination variants) 0.68) > *Acroptilon repens* (L.) de Candolle (0.66) > *Plantago major* L. (0.63) > *Linaria vulgaris* Mill. (0.61) > *Equisetum arvense* L. (0.60) > *Cirsium arvense* (L.) Scopoli, *Convolvulus arvensis* L. (0.59) > *Agropyron repens* (L.) Gould (0.58) > *Onopordum acanthium* L. (0.57) > *Cyclachaena xanthiifolia* Nuttall (0.55) > *Sonchus arvensis* L., *Cichorium intybus* L., *Plantago lanceolata* L. (0.54) > *Artemisia absinthium* L. (0.51) > *Echium vulgare* L., *Rumex acetosella* L. (0.48) > *Artemisia vulgaris* L. (0.47) > *Arctium lappa* L. (0.46) > *Cynodon dactylon* (L.) Pers., *Rumex confertus* Willdenow (0.44) > *Carduus acanthoides* L., *Taraxacum officinale* Weber (0.39) > *Achillea millefolium* L. (0.36).

It has been established that "speed of germination" and "coefficient of velocity of germination" can be used as effective indicators for assessing the allelopathic sensitivity of test objects. Thus, they were respectively 5–7 germinated seeds per day for the percentage of germinated seeds for 7–9 days over 30% of the total number laid for germination, and for species with weak allelopathic activity, respectively, 10–11 germinated seeds per day of germination and the percentage of germinated seeds per 7–9 days more than 4–15% of the total in the case of oilseed radish in allelopathically adhesive species at an extract concentration of 4.0%.

Taking into account the classification of allelopathic potential (Smith, 2013) with 47.8% of the researched species belonging to the Non-allelopathic (NA) class and the absence of weeds belonging to the class Highly allelopathic (HA) for the test object, radish oilseed should be considered as an effective candidate for its application in the system of weeds biological control of sidereal and mediator application in traditional rotational schemes of cultivation of major crops of the non-cruciferous group.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

YHT – drafting of the manuscript; analysis, interpretation and acquisition of data; study conception and design; critical revision and approval of the final manuscript.

References

Abd El-Gawad, A.M. 2014. Ecology and allelopathic control of Brassica tournefortii in reclaimed areas of the Nile Delta. – Egyptian Turkish Journal of Botany, 83:347–357. DOI: 10.3906/bot-1302-29

Abd-ElGawad, A.M., El Gendy, A.E.-N.G., Assaeed, A.M., Al-Rowaily, S.L., Alharthi, A.S., Mohamed, T.A., Nassar, M.I., Dewir, Y.H., Elshamy, A.I. 2021. Phytotoxic effects of plant essential oils: A systematic review and structure-activity relationship based on chemometric analyses. – Plants, 10(1):36. DOI: 10.3390/plants10010036

Ackroyd, V., Besancon, T., Bunchek J., Cahoon C., Chandran R., Curran W., Flessner M., Klodd A, Lingenfelter D., Mirsky S., Ryan M., Sandy D., VanGessel M., Vollmer K., Ward M. 2019. A practical guide for integrated weed management in mid-atlantic grain crops. – Northeastern IPM Center and USDA NIFA, USA, pp. 8–14.

Ali, K.A. 2016. Allelopathic potential of radish (*Raphanus sativus* L.) germination and growth of some crop and weed plants. – International Journal of Biosciences, 9:394–403. DOI: 10.12692/ijb/9.1.394-403

Ali, K.W., Shinwari, M.I., Khan, S. 2019. Screening of 196 medicinal plant species leaf litter for allelopathic potential. – Pakistan Journal of Botany, 51(6):2169–2177. DOI: 10.30848/PJB2019-6(43)

Amini, S., Azizi, M., Joharchi, M.R., Shafei, M.N., Moradinezhad, F., Fujii, Y. 2014. Determination of allelopathic potential in some medicinal and wild plant species of Iran by dish pack method. – Theoretical and Experimental Plant Physiology, 26:189–199. DOI: 10.1007/s40626-014-0017-z

Anwar, T., Ilyas, N., Qureshi, R., Qureshi, H., Khan, S., Khan, S. A., Fatimah, H., Waseem, M. 2019. Natural herbicidal potential of selected plants on germination and seedling growth of weeds. – Applied Ecology and Environmental Research, 17(4):9679–9689. DOI: 10.15666/aeer/1704_96799689

Anwar, T., Khalid, S., Arafat, Y., Sadia, S., Riaz, S. 2013. Allelopathic suppression of *Avena fatua L.* and *Rumex dentatus L.*, in associated crops with plant leaf powders. – Life Sciences Leaflets, 3:106–113.

Arroyo, A.I., Pueyo, Y., Giner, M.L., Foronda, A., Sanchez-Navarrete, P., Saiz, H., Alado, C.L. 2018. Evidence for chemical interference effect of an allelopathic plant on neighboring plant species: a field study. – PLoS One, 13:1–19. DOI: 10.1371/journal.pone.0193421.

AOSA Rules for Testing Seeds. 2011. Association of Official Seed Analysts. USA, 1–4:18–44.

Awan, F.K., Rasheed, M. Ashraf, M., Khurshid, M.Y. 2012. Efficacy of brassica, sorghum and sunflower aquesous extracts to control wheat weeds under rainfed conditions of Pothwar, Pakistan. – Journal of Animal and Plant Sciences, 22(3):715–721.

Bachheti, A., Sharma, A., Bachheti, R.K., Husen, A., Pandey, D. 2020. Plant Allelochemicals and Their Various Applications. – In Co-Evolution of Secondary Metabolites, Merillon, J.-M., Ramawat, K.G. (Eds.). – Springer International Publishing, pp. 10–38.

Bergkvist, G., Ringselle, B., Magnuski, E., Mangerud, K., Brandsæter, L.O. 2017. Control of *Elymus repens* by rhizome fragmentation and repeated mowing in a newly established white clover sward. – Weed Research, 57(3): 172–181. DOI: 10.1111/wre.12246

Björkman, T., Lowry, C., Shail, J.W., Brainard, D.C., Anderson, D.S., Masiunas, J.B. 2015. Mustard cover crops for biomass production and weed suppression in the Great Lakes Region. – Agronomy Journal, 107(4):1235–1249. DOI: 10.2134/agronj14.0461

Boydston, R.A., Al-Khatib, K. 2006. Utilizing Brassica cover crops for weed suppression in annual cropping systems. In Handbook Of Sustainable Weed Management. Singh, H. P., Batish, D.R., Kohli, R.K. (Eds.). – CRC Press, Binghamton, 77–94.

Brandsæter, L.O., Mangerud, K., Helgheim, M., Berge, T.W. 2017. Control of perennial weeds in spring cereals through stubble cultivation and mouldboard ploughing during autumn or spring. – Crop Protection 98:16–23. DOI: 10.1016/j.cropro.2017.03.006

Brown, P.D., Morra, M.J. 1996. Hydrolysis products of glucosinolates in Brassica napus tissues as inhibitors of seed germination. – Plant Soil, 181:307–316. DOI: 10.1007/BF0001206

Buddhadeb, D., Bhowmik 2020. Perennial weeds and their management. – In Weed Science and Management. Yaduraju, N.T., Sharma, A.R., Das, T.K. (Eds.) – Indian Society of Weed Science, ICAR–DWR, Jabalpur and Indian Society of Agronomy – ICAR–IARI, New Delhi, India, pp. 195–254.

Bybee-Finley, K.A., Mirsky, S.B., Ryan, MR. 2017. Crop biomass not species richness drives weed suppression in warm-season annual grass-legume intercrops in the Northeast. – Weed Science, 65(5):669–680. DOI: 10.1017/wsc.2017.25

Carvalho, M.S.S., Andrade-Vieira, L.F., Santos, F.E., Correa, F.F., Cardoso, M.G. and Vilela, L.R. 2019. Allelopathic potential and phytochemical screening of ethanolic extracts from five species of *Amaranthus spp*. in the plant model *Lactuca sativa*. – Scientia Horticulturae, 245:90–98. DOI: 10.1016/j.scienta. 2018.10.001

Chauan, B.S. 2020. Grand challenges in weed management. – Frontiers in Agronomy, 1:3. DOI: 10.3389/fagro.2019.00003

Cheng, F., Cheng, Z.H. 2015. Research progress on the use of plant allelopathy in agriculture and the physiological and ecological mechanisms of allelopathy. – Frontiers in Plant Science, 6:1020. DOI: 10.3389/fpls.2015.01020

Chotsaeng, N., Laosinwattana, C., Charoenying, P. 2017. Herbicidal activities of some allelochemicals and their synergistic behaviors toward *Amaranthus tricolor* L. – Molecules, 22(11):1841. DOI: 10.3390/ molecules22111841

Clapp, J. 2021. Explaining growing glyphosate use: The political economy of herbicide-dependent agriculture. – Global Environment Changing, 67(6):102239. DOI: 10.1016/j.gloenvcha.2021.102239

Dadkhah, A., Rassam, G.H. 2016. Phytotoxic effects of aqueous extract of sugar beet, ephedra and canola on seed seedlingsination, growth and photosynthesis of *Convolvulus arvensis*. – Jordan Journal of Agricultural Sciences, 12(2):667–676.

de Bertoldi, C., De Leo, M., Ercoli, L., Braca, A. 2012. Chemical profile of *Festuca arundinacea* extract showing allelochemical activity. – Chemoecology, 22(1):13–21. DOI: 10.1007/s00049-011-0092-4

Duke, S.O. 2015. Proving allelopathy in crop-weed interactions. – Weed Science, 63(Species issue):121–132. DOI: 10.1614/WS-D-13-00130.1

Einhellig, F.A., Schon, M.K., Rammussen, J.A. 1982. Synergistic effects of four cinamic acid compounds on grain sorghum. – Journal of Plant Growth Regulators, 1:251–258.

Ferreira, L.C., Moreira, B.R.A., Montagnolli, R.N., Prado, E.P., Viana, R.D.S., Tomaz, R.S., Cruz, J.M., Bidoia, E.D., Frias, Y.A., Lopes, P.R.M. 2021. Green manure species for phytoremediation of soil with Tebuthiuron and Vinasse. – Frontiers in Bioengineering and Biotechnology, 8:613–642. DOI: 10.3389/fbioe.2020.613642

Florence, A.M., Higley, L.G., Drijber, R.A., Francis, C.A., Lindquist, J.L. 2019. Cover crop mixture diversity, biomass productivity, weed suppression, and stability. – PLoS ONE, 14(3):e0206195. DOI: 10.1371/journal.pone.0206195

Fragasso, M., Iannucci, A., Papa, R. 2013. Durum wheat and allelopathy: Toward wheat breeding for natural weed management. – Frontiers in Plant Science, 4:375. DOI: 10.3389/fpls.2013.00375

Fujii, Y., Furubayashi, A., Hiradate, S. 2005. Rhizosphere soil method: a new bioassay to evaluate allelopathy in the field. – In The Fourth World Congress on Allelopathy "Establishing the scientific base", Charles Sturt University, Wagga Wagga, NSW Australia. 21–26 August 2005. Harper, J.D.I., An, M., Wu, H., Kent, J.H. (Eds.). The Regional Institute Limited, Gosford NSW, Australia, Available http://www.regional.org.au/au/allelopathy/2005/2/3/ 2535_fujiiy.htm

Fujii, Y., Shibuya, T., Nakatani, K., Itani, T., Hiradate, S., Parvez, M.M. 2004. Assessment method for allelopathic effect from leaf litter leachates. – Weed Biology and Management, 4:19–23. DOI: 10.1111/j. 1445-6664.2003.00113.x

Gharde, Y., Singh, P.K., Dubey, R.P., Gupta, P.K. 2018. Assessment of yield and economic losses in agriculture due to weeds in India. – Crop Protection, 107:12–18. DOI: 10.1016/j.cropro.2018.01.007

Gharibvandi, A., Karimmojeni, H., Ehsanzadeh, P., Rahimmalek, M., Mastinu, A. 2022. Weed management by allelopathic activity of *Foeniculum vulgare* essential oil. – Plant Biosystems: An international journal dealing with all aspects of plant biology, 8(3)193. DOI: 10.3390/horticulturae8030193

Golubinova, I., Ilieva, A. 2014. Allelopathic effect of water extracts of *Sorghum halepense* (L.) Pers., *Convolvulus arvensis* L. and *Cirsium arvense* Scop. on the early seedling growth of some legumes crops. – Pesticidi i Fitomedicina, 29(1):35–43. DOI: 10.2298/PIF1401035G

Grodzinsky, A.M. 1991. Allelopatiya rastenij i pochvoutomlenie [Plant allelopathy and soil fatigue: selected works]. – Kiev: Naukova dumka [Kyiv: Scientific opinion], pp. 52–67. (In Russian)

Grodzinsky, A.M., 1992. Allelopathic effects of cruciferous plants in crop rotation. – In Allelopathy Basic and Applied Aspects. Rizvi, S.J.H., Rizvi, V. (Eds.). – Chapman and Hall Press, London, UK, pp: 77–85.

Grodzinsky, A.M., Kostroma, E.Yu., Shrol, T.S., Khokhlova, I.G. 1990. Priami metody biotestuvannia gruntu ta metabolitiv mikroorhanizmiv [Direct methods of biotesting of soil and metabolites of microorganisms.] – Naukovyi zbirnyk Alelopatiia i produktyvnist roslyn [In Allelopathy and plant productivity]. – Kiev: Naukova dumka [Kyiv: Scientific opinion], pp. 121–124. (In Ukrainian)

Haramoto, E.R., Gallandt, E.R. 2005. Brassica cover cropping: 1. Effects on weed and crop establishment. – Weed Science, 53:695–701. DOI: 10.1614/WS-04-162R.1

Haring, S.C., Flessner, M.L. 2018. Improving soil seed bank management. – Pest Management Science, 74(11):2412–2418.

Harris, K.D., Geretharan, T., Dilsath, M.S.A., Srikrishnah, S., Nishanthi, S. 2015. Critical period of weed control in radish (*Raphinus sativus* L.) – AGRIEAST: Journal of Agricultural Sciences, 10:6–10. DOI: 10.4038/agrieast.v10i0.23

Inderjit, Keating, K.I. 1999. Allelopathy: principles, procedures, processes, and promises for biological control. – Advances in Agronomy, 67:141–231. DOI: 10.1016/S0065-2113(08)60515-5

Iqbal, A., Fry, S.C. 2012. Potent endogenous allelopathic compounds in *Lepidium sativum* seed exudate: effects on epidermal cell growth in *Amaranthus caudatus* seedlings. – Journal of Experimental Botany, 63(7):2595–2604.

ISTA. 2017. International rules for seed testing. Chapter 2; Sampling. – The International Seed Testing Association, Bassersdorf, Switzerland, pp. 5–24.

IUSS Working Group. 2015. WRB: World reference base for soil resources. – World Soil Resources Reports 106. FAO. Rome, Italy, pp. 85–90.

Izzet, K., Yanar, Y., Asav, U. 2004. Allelopathic effects of weed extracts against seed germination of some plants. – Journal of Environmental Biology, 26:169–173. DOI: 10.3923/ajps.2004.472.475.

Jabran, K., Mahajan, G., Sardana, V., Chauhan, B.S. 2015. Allelopathy for weed control in agricultural systems. – Crop Protection, 72:57–65. DOI: 10.1016/j.cropro.2015.03.004

Jain, A., Joshi, A., Joshi, N. 2017. Allelopathic potential and HPTLC analysis of *Ipomoea carnea*. – International Journal of Life-Sciences Scientific Research, 3(5):1278–1282. DOI: 10.21276/ijlssr.2017.3.5.2

Jugulam, M., Varanasi, A.K., Varanasi, V.K., Prasad, P.V.V. 2019. Climate change Influence on herbicide efficacy and weed management. – In Food security and climate change. Yadav, S.S., Redden, R.J., Hatfield, J.L., Ebert, A.W., Hunter, D. (Eds.) – John Wiley & Sons, Hoboken, New Jersey, USA, pp. 433–448.

Kaab, S.B., Rebey, I.B., Hanafi, M., Hammi, K.M., Smaoui, A., Fauconnier, M.L., De Clerck, C., Jijakli, M.H., Ksouri, R. 2020. Screening of Tunisian plant extracts for herbicidal activity and formulation of a bioherbicide based on *Cynara cardunculus.* – South African Journal of Botany, 128:67–76. DOI: 10.1016/j.sajb.2019.10.018

Kobayashi, K., Sasamoto, H., Sasamoto, Y., Sugiyama, A., Fujii, Y. 2021. Evaluation of isoflavones as allelochemicals with strong allelopathic activities of kudzu using protoplast co-culture method with digital image analysis. – American Journal of Plant Sciences, 12; 376–393. DOI: 10.4236/ajps.2021.123024

Khan, S., Shinwari, M.I., Waqar Ali, K., Rana, T., Kalsoom, S., Akbar Khan, S. 2019. Allelopathic potential of 73 weed species in Pakistan. – Revista de Biología Tropical, 67(6):1418–1430. DOI: 10.15517/rbt.v67i6.34787

Kirkegaard, J., Sarwar, M. 1998. Biofumication potential of brassicas. I. Variation in glucosinolate profiles of diverse field-grown brassicas. – Plant and Soil, 201:71–89.

Knežević, S.Z., Datta, A. 2015. The critical period for weed control: Revisiting data analysis. – Weed Science, 63(sp1):188–202. DOI: 10.1614/WS-D-14-00035.1

Kocira, A., Staniak, M. 2021. Weed ecology and new approaches for management. – Agriculture, 11(3): 262. DOI: 10.3390/agriculture11030262

Koehler-Cole, K., Elmore, R.W., Blanco-Canqui H., Francis, C.A., Shapiro, C.A., Proctor, C.A., Ruis, S.J., Heeren, D.M., Irmak, S., Ferguson, R.B. 2020. Cover crop productivity and subsequent soybean yield in the western Corn Belt. – Agronomy Journal, 112:2649–2663. DOI: 10.1002/agj2.20232

Korresa, N.E, Burgosa, N., Trovlos, I., Vurro, M., Gitsopoulos, T., Varanasi, V., Duke, S., Kudsk, P., Brabham, C., Rouse, C., Salas-Perez, R. 2019. Chapter Six - New directions for integrated weed management: Modern technologies, tools and knowledge discovery. – Advances in Agronomy, 155:243–319. DOI: 10.1016/bs.agron.2019.01.006

Kuht J., Eremeev V., Talgre L., Madsen H., Toom M., Mäeorg E., Luik, A. 2016. Soil weed seed bank and factors influencing the number of weeds at the end of conversion period to organic production. – Agronomy Research, 14(4):1372–1379.

Kumar, A. Memo, M., Mastinu, A. 2020. Plant behaviour: an evolutionary response to the environment? – Plant Biology, 22(6):961–970. DOI: 10.1111/plb.13149

Kunz, C., Sturm, D., Varnholt, D., Walker, F., Gerhards, R. 2016. Allelopathic effects and weed suppressive ability of cover crops. – Plant, Soil and Environment, 62(2):60–66. DOI: 10.17221/612/ 2015-PSE.

Lahdhiri, A., Mekki, M. 2016. Weed density assessment with crop establishment in forage crops. – Indian Journal of Weed Science, 48:309–315. DOI: 10.5958/0974-8164.2016.00076.9

Lawley, Y.E., Teasdale, J.R., Weil, R.R. 2012. The mechanism for weed suppression by a forage radish cover crop. – Agronomy Journal, 104(2):205–214. DOI: 10.2134/agronj2011.0128

Lawley, Y.E., Weil, R.R., Teasdale J.R. 2011. Forage radish cover crop suppresses winter annual weeds in fall and before corn planting. – Agronomy Journal, 103(1):137–144. DOI: 10.2134/agronj2010.0187

Lemerle, D., Luckett, D.J., Lockley, P., Koetz, E., Wu, H. 2014. Competitive ability of Australian canola (*Brassica napus*) genotypes for weed management. – Crop Pasture Science, 65(12):1300–1310. DOI: 10.1071/CP14125

Liu, Z., Wang, H., Xie, J., Lv, J., Zhang, G., Hu, L., Luo, S., Li, L., Yu, J. 2021. The roles of cruciferae glucosinolates in disease and pest resistance. – Plants, 10:1097. DOI: 10.3390/plants10061097

MacLaren, C., Storkey, J., Menegat, A., Metcalfe H., Dehnen-Schmutz K. 2020. An ecological future for weed science to sustain crop production and the environment. A review. – Agronomy for Sustainable Development, 40(4):24. DOI: 10.1007/s13593-020-00631-6

Marinov-Serafimov, P., Golubinova, I. 2015. A study of suitability of some conventional chemical preservatives and natural antimicrobial compounds in allelopathic research. – Journal Pesticides and Phytomedicine (Belgrade), 30(4):233–241. DOI: 10.2298/PIF1504233M

Marinov-Serafimov, P., Enchev, S., Golubinova, I. 2019. Allelopathic soil activity in the rotation of some forage and technical crops. – Bulgarian Journal of Agricultural Science 25(5):980–985.

Marinov-Serafimov, P., Golubinova, I., Ilieva, A., Kalinova S., Yanev, M. 2017. Allelopathic activity of some parasitic weeds. – Bulgarian Journal of Agricultural Science, 23(2):219-226. DOI: 10.5937/ AASer1743089M.

Maurya, P., Mazeed, A., Kumar, D., Zareen, I., Ahmad, Suryavanshi, P. 2022 Medicinal and aromatic plants as an emerging source of bioherbicides. – Current Science, 122(3): 258–266. DOI: 10.18520/cs/v122/ i3/258-266.

Meiners, S.J., Phipps, K.K., Pendergast, T.H., Canam, T., Carson, W.P. 2017. Soil microbial communities alter leaf chemistry and influence allelopathic potential among coexisting plant species. – Oecologia, 183(4):1155–1165. DOI: 10.1007/ s00442-017-3833-4

Melander, B., Rasmussen, I.A., Olesen, J.E. 2016. Incompatibility between fertility building measures and the management of perennial weeds in organic cropping systems. – Agriculture, Ecosystems & Environment, 220:184–192. DOI: 10.1016/J.AGEE. 2016.01.016

Mesterházy, Á., Oláh, J., Popp, J. 2020. Losses in the Grain Supply Chain: Causes and Solutions. – Sustainability, 12(6):23–42. DOI: 10.3390/ su12062342

Miller, T.W. 2016. Integrated strategies for management of perennial weeds. – Invasive Plant Science Management, 9:148–159. DOI: 10.1614/ IPSM-D-15-00037.1

Mirmostafaee, S., Azizi, M., Fujii, Y. 2020. Study of allelopathic interaction of essential oils from medicinal and aromatic plants on seed germination and seedling growth of lettuce. – Agronomy, 10(2): 163. DOI: 10.3390/agronomy10020163

Morikawa, C.I.O., Miyaura, R., Tapia, Y., Figueroa, M.D.L., Rengifo Salgado, E.L., Fujii, Y. 2012. Screening of 170 Peruvian plant species for allelopathic activity by using the Sandwich Method. – Weed Biology and Management, 12(1):1–11. DOI: 10.1111/j.1445-6664.2011.00429.x.

Możdżeń, K., Barabasz-Krasny, B., Zandi, P., Turisová, I. 2018. Influence of allelopathic activity of *Galinsoga parviflora* Cav. and *Oxalis fontana* Bunge on the early growth stages of cultivars *Raphanus sativus* L. var. *radicula* Pers. – Biologia, 73(5):1187–11. DOI: 10.2478/s11756-018-0144-0

Muli, G.K., Apori, S.O., Ssekandi, J., Murongo, M., Hanyabui, E. 2021. Effect of linear view approach of weed management in agro-ecosystem: A review. – African Journal of Agricultural Research, 17(2):238–246. DOI: 10.5897/AJAR2020.15267

Nasr, M., Mansour, S. 2005. The use of allelochemicals to delay germination of Astragalus cycluphyllus seeds. – Journal of Agronomy, 4(2):147–150. DOI: 10.3923/ja.2005.147.150

Norsworthy, J. 2003. Allelopathic Potential of Wild Radish (*Raphanus raphanistrum*). – Weed Technology, 17(2):307–313. DOI: 10.1614/0890-037X(2003)017[0307:APOWRR]2.0.CO;2

Novak, N., Novak, M., Barić, K., Šćepanović, M., Ivić, D. 2018. Allelopathic potential of segetal and ruderal invasive alien plants. – Journal of Central European Agriculture, 19(2):408–422. DOI: 10.5513/JCEA01/ 19.2.2116.

Prinsloo, G., Plooy, C.P.D. 2018. The allelopathic effects of Amaranthus on seed germination, growth and development of vegetables. – Biological Agriculture and Horticulture, 34:268–279. DOI: 10.1080/01448765.2018.1482785.

Rana, S.S., Rana, M.C. 2016. Principles and practices of weed management. – Department of Agronomy, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya. – Palampur, India, pp. 50–55.

Rao, V.S. 2017. Principles of weed science. 2nd ed. – CRC Press LLC, Boca Raton, Florida, USA, pp. 69–78.

Rasmussen, I.A., Melander, B., Askegaard, M., Kristensen, K., Olesen, J.E. 2014. *Elytrigia repens* population dynamics under different management schemes in organic cropping systems on coarse sand. – European Journal of Agronomy, 58:18–27. DOI: 10.1016/j.eja.2014.04.003

Rasul, S.A., Ali, K.A. 2021. Molecular characterization and allelopathic potential of radish species on wheat and weed species. – IOP Conference Series: Earth and Environmental Science, 761(1):012086. DOI: 10.1088/1755-1315/761/1/012086.

Rasul, S.A., Ali, K.A., 2020. Study the allelopathic effect of radish by incorporate into soil on some Poaceae species. – Plant Archives, 20(2):3624–3627.

Rehman, A.P.K., Biswas, M.S.A., Sardar, M.I.K. 2012. Allelopathic effect of Brassica biomass on yield of wheat. – Journal of Experimental Biology, 3:1.

Rehman, S., Shahzad B., Bajwa A.A., Hussain S., Rehman A., Cheemaand S.A., Li, P. 2019. Utilizing the allelopathic potential of Brassica species for sustainable crop production: a review. – Journal of Plant Growth Regulation, 38(1):343–356. DOI: 10.1007/s00344-018-9798-7

Reigosa, R.M.J., Reigosa, M.J., Nuria, P., González, L. 2006. Allelopathy: A physiological process with ecological implications. – Springer, Dordrecht, The Netherlands, 638 p. DOI: 10.1007/1-4020-4280-9

Romaneckas, K., Kimbirauskienė, R., Sinkevičienė, A., Jaskulska, I., Buragienė, S., Adamavičienė, A., Šarauskis, E. 2021. Weed diversity, abundance, and seedbank in differently tilled Faba bean (*Vicia faba* L.) cultivations. – Agronomy, 11(3):5–29. DOI: 10.3390/agronomy11030529

Rueda-Ayala, V., Jaeck, O., Gerhards, R. 2015. Investigation of biochemical and competitive effects of cover crops on crops and weeds. – Crop Protection, 71:79–87. DOI: 10.1016/j.cropro.2015.01.023

Rumsey, D.J. 2016. Statistics for Dummies (2nd ed.) – John Wiley & Sons Inc., USA, 416 p.

Sarmah, M.K., Narwal, S.S., Yadava, J.S. 1992. Smothering effect of Brassica species on weeds. – Proceeding First National Symposium Allelopathy in Agroecosystems, Haryana Agricultural University, Indian Society Allelopathy, Hisar, India, pp. 51–55.

Scavo, A., Abbate, C., Mauromicale, G. 2019. Plant allelochemicals: Agronomic, nutritional and ecological relevance in the soil system. – Plant Soil, 442:23–48. DOI: 10.1007/s11104-019-04190-y

Scavo, A.; Mauromicale, G. 2021. Crop allelopathy for sustainable weed management in agroecosystems: knowing the present with a view to the future. – Agronomy, 11: 2104. DOI: 10.3390/agronomy 11112104

Schandry, N., Becker, C. 2020. Allelopathic plants: models for studying plant-interkingdom interactions. – Trends in Plant Science, 25(2):176–185. DOI: 10.1016/j.tplants.2019.11.004.

Yakist nasinnia silskohospodarskykh ekltur [Seeds quality of agricultural crops]. 2003. Metody vyznachennia. Derzhavnyi standart Ukrainy 4138-2002 [Methods for determining: State standard of Ukraine, 4138-2002 [Valid from 2004-01-01]. – Kiev: Derzhspozhyvstandart [Kyiv: Derzhspozhivstandart], pp. 23–67. (In Ukrainian)

Shahzad, M., Jabran, K., Hussain M., Raza, M.A.S., Wijaya, L., El-Sheikh, M.A. 2021. The impact of different weed management strategies on weed flora of wheat-based cropping systems. – PLoS ONE, 16(2):e0247137. DOI: 10.1371/journal.pone.0247137

Sharma S., Kaur R., Kaur N. 2019. Allelopathy and its role in agriculture. – Journal of Pharmacognosy and Phytochemistry, 8(1S):274–277.

Sharma, G., Shrestha, S., Kunwar, S., Tseng, T.M. 2021. Crop diversification for improved weed management: A Review. – Agriculture, 11:461. DOI: 10.3390/agriculture11050461

Simić, M.S., Dragičević, V., Chachalis, D., Dolijanović, Ž., Brankov, M. 2020. Integrated weed management in long-term maize cultivation. – Zemdirbyste, 107(1):33–40. DOI: 10.13080/z-a. 2020.107.005

Singh, H.P., Batish, D.R., Kohli, R.K. 2003 Allelopathic interactions and allelochemicals: new possibilities for sustainable weed management. – Critical Reviews in Plant Sciences, 22(3):239–311. DOI: 10.1080/713610858

Smith, O.P. 2013. Allelopathic potential of the invasive alien Himalayan Balsam (*Impatiens glandulifera* Royle). – PhD thesis, Plymouth University, Plymouth, Great Britain, 388 p.

Sokal, R.R., James, R.F. 2012. Biometry: the principles and practice of statistics in biological research (4th ed.).– W.H. Freeman, New York, USA, 937 p.

Somerville, G.J., Powles, S.B., Walsh, M.J., Renton, M. 2018. Modeling the impact of harvest weed seed control on herbicide-resistance evolution. – Weed Science, 66:395–403. DOI:10.1017/wsc.2018.9

Sothearith, Y., Appiah, K.S., Mardani, H., Motobayashi, T., Yoko, S., Eang Hourt, K., Sugiyama, A., Fujii, Y. 2021. Determination of the allelopathic potential of Cambodia's medicinal plants using the dish pack method. – Sustainability, 13: 9062. DOI: 10.3390/su13169062.

Derzhavnyi standart Ukrainy [State standard of Ukraine] ISO 10381–6:2015. 2017. Instruktsii z vyboru, obrobky ta zberihannia gruntu v aerobnykh umovakh dlia laboratornoi otsinky mikrobiolohichnykh protsesiv, biomasy ta riznomanitnosti, bioindykatsii [Guidelines for Soil Selection, Treatment and Storage in Aerobic Conditions for Laboratory Assessment of Microbiological Processes, Biomass and Diversity, Bioindications] Valid from 2016–04–01. IV. – Kiev: Derzhspozhyvstandart [Kyiv: Derzhspozhivstandart]. 6, pp. 1–6. (In Ukrainian)

Stevens, K.L. 1986. Allelopathic polyacetylenes from *Centaurea repens* (Russian knapweed). – Journal of Chemical Ecology, 12:1205–1211. DOI: 10.1007/ BF01012342

Sturm, D.J., Kunz, C., Gerhards, R. 2016. Inhibitory effects of cover crop mulch on germination and growth of *Stellaria media* (L.) Vill., *Chenopodium album* L. and *Matricaria chamomilla* L. – Crop Protection, 90:125–131. DOI: 10.1016/j.cropro.2016. 08.032

Sturm, D.J., Peteinatos, G., Gerhards, R. 2018. Contribution of allelopathic effects to the overall weed suppression by different cover crops. – Weed Research, 58(5):331–337. DOI: 10.1111/wre.12316

Swanton, C., Nkoa, R., Blackshaw, R. 2015. Experimental methods for crop-weed competition studies. – Weed Science, 63(SP1):2–11. DOI: 10.1614/WS-D-13-00062.1

Takemura, T., Sakuno, E., Kamo, T., Hiradate, S., Fujii, Y. 2013. Screening of the growth-inhibitory effects of 168 plant species against lettuce seedlings. – American Journal of Plant Sciences, 4:1095–1104. DOI: 10.4236/ajps.2013.45136

Test guidelines for the conduct of tests for distinctness. uniformity and stability of Fodder Radish (*Raphanus sativus* L. var. *oleiformis* Pers.). 2017. – Geneva, pp. 10–19.

Tollsten, L., Bergstrom, G. 1988. Headscape volatiles of whole plant and macerated plant parts of Brassica and Sinapis. – Phytochemistry, 27(12):4013–4018. DOI: 10.1016/0031-9422(88)83085-1

Toosi, F., Baki, B.B. 2011. Allelopathic potential of *Brassica juncea* (L.) Czern. var. ensabi. – Pakistan Journal of Weed Science Research, 18:651–656.

Travlos, I.S., Cheimona, N., Roussis, I., Bilalis, D.J. 2018. Weed-species abundance and diversity indices in relation to tillage systems and fertilization. – Frontiers of Environmental Science, 6:11. DOI: 10.3389/fenvs.2018.00011

Tsytsiura, Y. 2020. Assessment of peculiarities of weed formation in oilseed radish agrophytocoenosis using different technological models. – Chilean Journal of Agricultural Research, 80(4):661–674. DOI: 10.4067/S0718-58392020000400661

Turk, M.A., Tawaha, A.M. 2003. Allelopathic effect of black mustard (*Brassica nigra* L.) on germination and growth of wild oat (*Avena fatua* L.). – Crop Protection, 22:673–677. DOI: 10.1046/j.1439-037X. 2003.00047.x

Uremis, I., Arslan, M., Uludag, A., Sangun, M. 2009. Allelopathic potentials of residues of 6 brassica species on johnsongrass [*Sorghum halepense* (L.) Pers.]. – African Journal of Biotechnology, 8(15):3497–3501.

Veselovsky, I.V., Lysenko, A.K., Manko, Yu.P. 1988. Atlas vyznachnyk burianiv [Atlas-determinant of the weeds]. – Kiev. Urozhay [Kyiv: Harvest], pp. 1–72. (In Ukrainian).

Westwood, J.H., Charudattan, R., Duke, S.O., Fennimore, S.A., Marrone, P., Slaughter D.C., Swanton, C., Zollinger, R. 2018. Weed Management in 2050: Perspectives on the Future of Weed Science. – Weed Science, 66:275–285. DOI: 10.1017/wsc. 2017.78

Williamson, G.B., Richardson, D. 1988. Bioassays for allelopathy: Measuring treatment responses with independent controls. – Journal of Chemical Ecology, 14(1):181–187. DOI: 10.1007/BF01022540

Agraarteadus
1 • XXXIII • 2022 192–198

Journal of Agricultural Science
1 • XXXIII • 2022 192–198

CHANGES IN THE NITROGEN COMPOUND TRANSFORMATION PROCESSES OF TYPICAL CHERNOZEM DEPENDING ON THE TILLAGE SYSTEMS AND FERTILIZERS

Oleksiy Tsyuk[1], Mykola Tkachenko[2], Andrii Butenko[3], Yurii Mishchenko[3], Iryna Kondratiuk[2], Dmytro Litvinov[1], Yuliia Tsiuk[4], Yurii Sleptsov[1]

[1]*National University of Life and Environmental Sciences of Ukraine, 15 Heroiv Oborony, Kyiv, 03041, Ukraine*
[2]*National Scientific Center, Institute of Agriculture of NAAS, Kyiv, Ukraine*
[3]*Sumy National Agrarian University, 160 H. Kondratieva St., UA40021, Sumy, Ukraine*
[4]*Central Testing State Laboratory of the State Food with Consumer Service in Kyiv region and Kyiv, 26 Balukova St., Vyshneve, Kyiv region*

Saabunud: Received: 15.12.2021

Aktsepteeritud: Accepted: 18.06.2022

Avaldatud veebis: Published online: 18.06.2022

Vastutav autor: Corresponding author: Andrii Butenko

E-mail: andb201727@ukr.net

ORCID:
0000-0001-8789-522X (OT)
0000-0001-6128-4703 (MT)
0000-0001-9639-9826 (AB)
0000-0002-5942-9288 (YM)
0000-0002-8953-8194 (IK)
0000-0001-6589-3805 (DL)
0000-0003-3240-8564 (YT)
0000-0002-3412-7320 (YS)

Keywords: typical chernozem, soil microcoenosis, fertilizers, tillage, mineralization-immobilization coefficient.

DOI: 10.15159/jas.22.23

ABSTRACT. The analysis of efficiency's research of interrelation between soil's biomass and tillage systems and fertilizers is done. The number of microorganisms responsible for the transformation of nitrogen compounds and their state in typical black soil was studied. There is evidence-based scientific and practical research on the effectiveness of these microbiological processes and the improvement of environmental performance through the various fertilizer systems and soil tillage. The use of an organic-mineral fertilizer system increases the total number of soil microorganisms and exponential mobilization processes, compared to the variant without fertilizers. This pattern is clear in the variants of shelf tillage for row crop rotation. The number of microorganisms that absorb mineral compounds of nitrogen decreased by 24%, bacteria ammonification by 1.5–5.7% compared to plough tillage. The ratio between the number of microorganisms accounted for the nutrient laboratory solutions for organic-mineral fertilizer system, compared to variants without fertilizers, is greater by 20–26% for differentiated and 14–35% for shallow tillage.

Introduction

Soil biological activity, especially soil enzymatic activity, respiration process and microbial biomass, is related to various soil factors, including pH, soil organic matter, texture and modifying factors such as climate, humidity and soil temperature. (Emmerling *et al.*, 2001; Bastida *et al.*, 2008). Microbial biomass, metabolic rate (CO_2, respiratory activity index per unit of biomass, CO_2-C/MBC) and soil enzymatic activity may be used as indicators of soil changes (Ros *et al.*, 2003; Bastida *et al.*, 2008). Enzymes are formed with soil microorganisms and, despite their relatively low number, have a crucial role in providing the nutrient cycle in soils such elements as C, N, P and S. Nutrient cycling is fundamental for the long-term functioning of ecosystems. In addition, soil microbial activities, microbial biomass, and soil AT acid content have been proven indicators of soil quality (Bending *et al.*, 2004; Goberna *et al.*, 2006; Bastida *et al.*, 2008). Soil microbial activity is a sensitive indicator of soil agricultural practices, the input of fertilizers, organic matter and crop rotation (Emmerling *et al.*, 2001; Bending *et al.*, 2004).

The application of a balanced amount of fertilizers and manures could increase enzymatic activity and soil respiration (Kanchikerimath, Singh, 2001). Organic fertilizers usually increase soil microbial biomass (Liang *et al.*, 2005; Kaur *et al.*, 2005). Organic manure-stimulated biological activity and soil microbial biomass have been proven to be positively correlated with improved soil fertility and quality as indicated by higher crop biomass and higher concentration of soil available nutrients and plant nutrient uptake (Bending *et al.*, 2004; 2005; Tu *et al.*, 2006; Kaminskyi *et al.*, 2021). Furthermore, these biological parameters can be used as sensitive bio-indicators of soil nutrient transformation, biological turnover and bio-availability (Tu *et al.*, 2006). Long-term use or overuse of organic fertilizers had a relatively less positive effect on soil microbial biomass and activities than organic fertilizers (Hopkins, Shiel, 1996; Plaza *et al.*, 2004; Hryhoriv *et al.*, 2021). Numerous studies showed that microbial biomass could be decreased by the application of mineral N fertilizer (Hopkins, Shiel, 1996; Sarathchandra *et al.*, 2001; Bittman *et al.*, 2005), which may be caused by direct toxicity and reduced pH because of ammonium-based fertilizers (Hopkins, Shiel, 1996).

In the scientific works of Ukraine's scientists (Andreyuk, 2001; Tsyuk, 2018) the theoretical bases of the formation of soil's structure and the functioning of their microbic cenoses (Patika *et al.*, 2014, 2015) are devoted to researching the elements of formation of microbic groups in agrocenoses and application of microbial solutions as well (Bilyavskaya *et al.*, 2010).

In black soils, the total number and species composition of microorganisms depend on weather and climatic conditions, crops, *e.g.* the level of application of mineral fertilizers and plant protection products and agronomic tillages. Changes in the degree of influence of these factors on the soil are affected by the activity of the microflora and the products of its metabolism (Demyanyuk, 2016, 2018a,b,c).

The information available in the scientific literature are different and indicates that the role of growing crops in the regulation of soil biodynamics has not been studied enough. It can be stated the effect of technologies for growing crops on the soil's microbial population is sophisticated. To avoid negative consequences, it's necessary to concentrate more attention on this question.

However, despite the great amount of theoretical and methodological investigations, some questions about the transformation processes of nitrogen compounds on deep typical black soil is too little studied.

Our research aimed to estimate the changes in the number of microorganisms, and the direction of the mineralization processes intensity of typical black soil for different soil's tillage and fertilizers.

Materials and Methods

The experimental part of the scientific work was performed in the research field of the National University of Life and Environmental Sciences of Ukraine (2014–2020).

Table 1. Soil's capacities (mechanical, chemical)

Soil's type	Content					
	Humus, %	Light hydrolyzed nitrogen (by Cornfield), mg 100 g^{-1} soil	P (by Chirikov), mg 100 g^{-1} soil	Cationic-change K, mg 100 g^{-1} soil	Soil's density, g $cm^{3\,-1}$	pH
Black soil typical, deep big cloggy medium-loam on the loess	4.6–4.8	14.4	15.2	15.2	1.24	6.4

The scheme of crop rotation in the field was 1–2. Alfalfa, 3. Winter wheat, 4. Sugar beets, 5. Barley, 6. Soybeans, 7. Winter wheat, 8. Corn for silage, 9. Winter wheat, 10. Sunflower. This crop rotation uses three levels of fertilizer per 1 ha of crop rotation area:

- for the mineral system – compost 4.5 tonnes + $N_{80}P_{96}K_{108}$;
- organic-mineral system – compost 4.5 tonnes + $N_{40}P_{48}K_{54}$ + 3.5 tone by-products and green manure and organic-compost 4.5 t + 3.0 tone of secondary products and green mass.

The experiment used fertilizers: compost, ammonium nitrate, granular superphosphate and potassium chloride. The second factor studied was the system of basic tillage: 1) differentiated tillage (control), which is recommended in the Forest-Steppe zone. It provides five ploughs for crop rotation, two surface tillage for winter wheat at 10–12 cm after soybeans and corn for silage and one chisel tillage under barley at 20–22 cm; 2) Plough with unplough system that provides two ploughs for crop rotation under sugar beets at 28–30 cm and sunflower at 25–27 cm and unplough cultivation for other crops; 3) surface unplough tillage at 10–12 cm for all crops. Our investigations were held in the biocenosis of winter wheat after alfalfa.

The plot area was 240 m^2 with four times repetitions. Soil samples were taken up to deep 20 cm. The number of microorganisms was determined by the methods of sowing soil suspension on solid nutrient solutions (Iutinskaya, 2006). Meat-peptone agar was used to account for the number of nitrogen-absorbing bacteria in organic compounds; on starch-ammonia agar – the number of bacteria that assimilate mineral forms of nitrogen (Zvyagintsev, 1991). The direction of microbiological processes in the soil was determined by the methods described by Volkogon (2010b).

Statistical analysis of the results was performed using Statistica 6 software.

Results and Discussion

The functioning of microbial complexes in the soil provides continuous processes of transformation of organic matter in terrestrial ecosystems. The study of the dynamics of their numbers makes it possible to reveal the mechanisms that determine the general directions of the soil's matter transformation and the state of ecosystems in general (Patika *et al.,* 2010; Loboda *et al.,* 2019).

The number of soil microorganisms of different ecological and trophic groups in typical black soils and their ratio varies depending on the system of tillage and fertilizer.

It was found that in variants with different tillage systems, independently of the applied mineral fertilizers, a biologically different tillage layer of the soil is formed, in some parts of the arable layer the microorganisms are unevenly distributed. There is a decrease in the number of all groups of microorganisms down the soil profile, which is associated with changes in thermal, air and nutrient regimes, as well as an increase in soil density with depth.

The influence of the systems of the basic autumn processing of the soil on the microbiocenosis of the typical black soil showed itself differently. Unplough processing stimulates the rapid development of soil microorganisms in the upper 0–10 cm soil layer compared with plough processing, but not in the deeper layers.

Intensive technologies for growing crops, based on plough cultivation with the use of high rates of mineral fertilizers and plant protection chemicals, significantly change the taxonomic structure of microbial associations and their functional activity. The biological cycle of substances and energy are increased with soil's biological activity, increasing the mineralization of organic matter according to maintaining the level of humification processes (Sherstoboeva, 2017; Rieznik *et al.*, 2021). So in modern agrocenoses, there is a degradation of humus and a decrease in soil fertility (Saiko, 2002). The use of unplowed tillage with the saving of stubble and plant remains on the soil surface in combination with organic and mineral fertilizers, is accompanied by the formation of favourable conditions for microbiological processes and especially humus accumulation. According to (Balaev, Tonhka, 2013; Manko *et al.,* 2019), the humification coefficients of plant residues are increased by 20–30% together with unplowed cultivation and the processes of their mineralization are attenuated compared to ploughed cultivation.

Another approach is held Nikiforenko (1982), who believes that unploughed tillage reduces microbiological activity in the soil, changes the group composition of microorganisms, reduces the number of nitrifications organisms and deteriorates the conditions of plant's mineral nutrition.

Thus, in the variants without fertilizers, the number of microorganisms using mineral forms of nitrogen (potassium ammonium nitrate) increased by 27%, and on the organic-mineral by 1.6 times (Fig. 1).

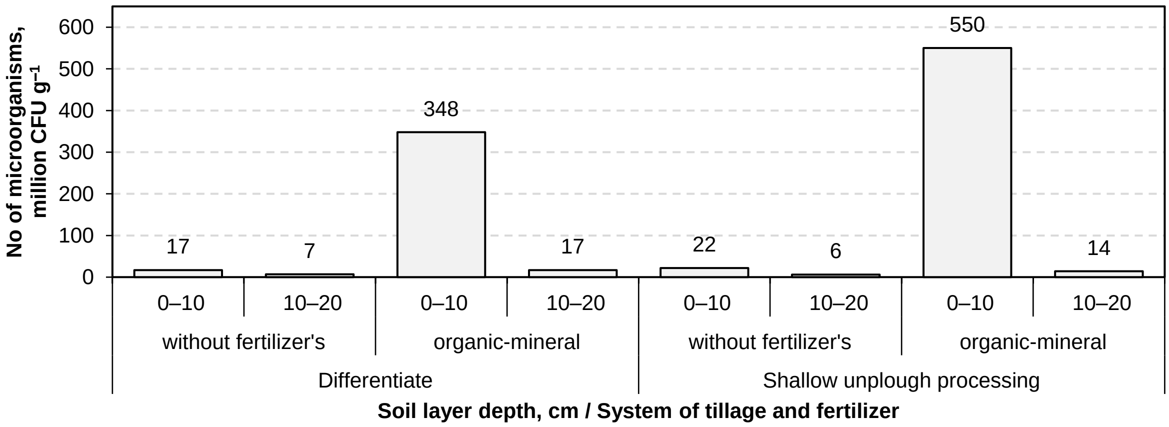


Figure 1. The number of microorganisms (million CFU g^{-1} of absolutely dry soil) of the main ecological and trophic groups in terms of application of the system of tillage and fertilizer (2014–2020 years) ($LSD_{0.05}$ for tillage – $F_f<F_{0.05}$; $LSD_{0.05}$ for fertilizers – 0.1; $LSD_{0.05}$ for soil's layer – 0.15)

Similar indicators were obtained for bacteria using nitrogen of organic compounds. The increase in their number, depending on the ground of fertilizer, was, respectively 1.5 and 1.7 times. In the case of unplough small tillage, the 0–10 cm layer remained richer in microorganisms throughout the growing season, due to the dominance of the plant residues on it, organic and mineral fertilizers, as well as better temperature conditions, higher moisture supply and good access to oxygen (Fig. 2).

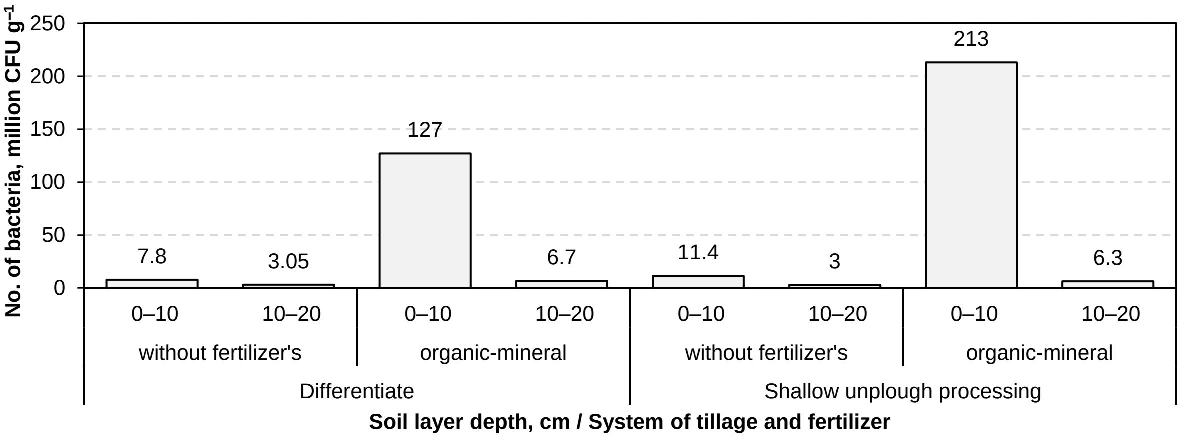


Figure 2. The number of bacteria (million CFU g^{-1} of absolutely dry soil) of the main ecological and trophic groups in terms of application of the system of tillage and fertilizer on 2014–2020 years ($LSD_{0.05}$ for tillage – $F_f<F_{0.05}$; $LSD_{0.05}$ for fertilizers – 1.12; $LSD_{0.05}$ – 1.14 for soil's layer)

It's necessary to note in terms of unploughed system the lower part of the treated layer is somewhat more microflora. Our research has shown a decrease in the number of microorganisms that absorb nitrogen mineral compounds by 9–24% and ammonifying bacteria – by 1.5–5.7% compared to plough processing.

The effect of fertilizers on the soil's microbial grouping was much stronger than the effect of soil's tillage. Their effect both during ploughing and unploughed tillage was observed in all parts of the treated layer, with a maximum at a depth of 0–10 cm. Under the influence of organo-mineral fertilizers, the number of microorganisms using mineral forms of nitrogen changed most significantly (1.5–2.0 times). As for bacteria using nitrogen of organic compounds, their number has decreased.

The organic-mineral fertilizer system increases the number of microorganisms in the soil and creates favourable mobilization processes compared to the variant without fertilizers. This is clear to both variants for processing at the depth of the treated layer.

The dynamics of the number of microorganisms in the main groups indicate the direction of microbiological processes toward degradation or restoring soil fertility. Microbiological processes occurring in black soils typical of the coefficient of mineralization-immobilization of nitrogen compounds were evaluated (Table 2). This coefficient characterizes their intensity and direction (Andreyuk, 2001; Parkhomenko *et al.*, 2021*)*.

Table 2. The intensity of mineralization processes of typical deep black soil

System of soil's tillage	Fertilizer systems	Soil layer, cm	Nitrogen mineralization-immobilization coefficient
Differentiate (control)	Without fertilizer	0–10	2.18
		10–20	2.04
	Organic-mineral	0–10	2.74
		10–20	2.44
Shallow unplough processing	Without fertilizer	0–10	1.91
		10–20	1.87
	Organic-mineral	0–10	2.57
		10–20	2.15

The enhancement of mobilization processes on fertilized variants can also be judged from the ratio between the number of microorganisms recorded on potassium ammonium nitrate and MPA. According to our data, on fertilized variants, compared to variants without fertilizers, its value is higher by 20–26% for shelf cultivation and by 14–35% for shallow cultivation. According to our investigations, on fertilized variants, compared to variants without fertilizers, its value is higher by 20–26% for shelf cultivation and by 14–35% for shallow cultivation.

As for the absolute values of mineralization-immobilization coefficients, their value, independently of the agrochemical ground, is 3–13% less than shallow tillage.

Microbiocenosis, formations in black soil typical for the variant from differentiated processing is increased the process of mineralization, due to the mineralization of organic matter, and a small unploughed processing is inhibit this process. It pleases with the thought (Andreetta *et al.*, 2011) obtained results on the content and reserves of total humus.

On typical deep soils with a low buffering capacity, it is impractical to apply high rates of mineral fertilizers, which causes a significant imbalance of microbiocenosis and does not contribute to the preservation of organic matter (Volkogon *et al.*, 2010a).

Conclusion

A study of the impact of the transformation of nitrogen compounds of chernozem typical of tillage and fertilizer systems showed that without the use of fertilizers microorganisms that use mineral forms of nitrogen, their number increased by 27%, and the organo-mineral system – by 1.6 times. There was a decrease in ammonifying bacteria in non-shelf tillage by 1.5–5.7% compared to shelf tillage. The coefficient of mineralization – immobilization of nitrogen is significantly reduced by 3–13% with shallow tillage compared to differentiated.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contributions

OT – writing a manuscript, analysis and interpretation of data;
MT, YM – acquisition of data, author of the idea, guided the research;
AB, DL, YS – analysis and interpretation of data and is the corresponding author, guided the research;
IK, YT – critical revision and approval of the final manuscript, guided the research.

References

Andreetta, A., Ciampalini, R., Moretti, P., Vingiani, S., Poggio, G., Matteucci, G., Tescari, F., Carnicelli, S., 2011. Forest humus forms as potential indicators of soil carbon storage in Mediterranean environments. – Biology and Fertility of Soils, 47:31–40. DOI: 10.1007/s00374-010-0499-z

Andreyuk, K.I., Iutinskaya, G.O., Antipchuk, A.F., Valagurova, O.V., Kozyrytska, V.E. 2001. Funktsionuvannya mikrobnykh tsenoziv gruntu v umovakh antropohennoho navantazhennya [Functioning of microbial coenoses of soil in the conditions of anthropogenic loading]. – Kyiv, Chary [Kyiv, Charms], 239 p. [In Ukrainian]

Balaev, A.D., Tonhka, O.L. 2013. Pochvozashchitnaya biologicheskaya sistema zemledeliya i vosproizvodstva plodorodiya pochv [Soil-protective biological system of agriculture and reproduction of soil fertility]. – Vestnik Natsional'nogo universiteta vodnogo khozyaystva i prirodopol'zovaniya [Bulletin of the National University of Water Management and Nature Management], 3(63):3–13. [In Russian]

Bastida, F., Zsolnay, A., Hernández, T., García, C. 2008. Past, present and future of soil quality indices: a biological perspective. – Geoderma, 147(3–4):159–171. DOI: 10.1016/j.geoderma.2008.08.007

Bending, G.D., Turner, M.K., Rayns, F., Marx, M.C., Wood, M. 2004. Microbial and biochemical soil quality indicators and their potential for differentiating areas under contrasting agricultural management regimes. – Soil Biology & Biochemistry, 36(11):1785–1792. DOI: 10.1016/j.soilbio.2004.04.035

Bilyavskaya, L.G., Sherstoboeva, O.V., Bilyavskaya, Y.V. 2010. Reaktsiya sortiv soyi na bakteryzatsiyu nasinnya za riznykh pohodnykh umov [Reaction of soybean varieties to bacterization of seeds under different weather conditions]. – Visnyk Poltavs′koyi derzhavnoyi ahrarnoyi akademiyi [Bulletin of the Poltava State Agrarian Academy], 4:47–49. [In Ukrainian]

Bittman, B., Forge, T.A., Kowalenko, C.G. 2005. Response of the bacterial and fungal biomass in a grassland soil to multi year applications of dairy manure slurry and fertilizer. – Soil Biology & Biochemistry, 37(4):613–623. DOI: 10.1016/j.soilbio.2004.07.038

Demyanyuk, O.S., Patyka, V.P., Sherstoboeva, O.V., Bunas, A.A. 2018a. Formuvannya struktury mikrobiotsenoziv gruntovykh ahroekosystem zalezhno vid trofichnykh i hidrotermichnykh faktoriv [Formation of the structure of microbiocenoses of soils agroecosystems depending on trophic and hydrothermic factors]. – Riznomanitnist′ biosystem [Biosystems diversity], 26(2):103–110. DOI: 10.15421/011816 [In Ukrainian]

Demyanyuk, O.S., Sherstoboeva, O.V., Tchaikovsky, V.V., Demidov, O.A. 2016. Spryamuvannya biolohichnykh protsesiv u grunti za riznykh system udobrennya ozymoyi pshenytsi ta pohodnykh umov [The direction of biological processes in the soil under different systems of winter wheat fertilization and weather conditions]. – Zbalansovane pryrodokorystuvannya [Balanced nature management], 2:146–151. [In Ukrainian]

Demyanyuk, O.S., Sherstoboeva, O.V., Tkach, E.D. 2018b. Funktsional′na struktura mikrobnykh uhrupovan′ hlybokoho chornozemu pid vplyvom hidrotermal′nykh ta trofichnykh faktoriv [Functional structure of microbial groups of deep chernozem under the influence of hydrothermal and trophic factors]. – Mikrobiolohichnyy zhurnal [Microbiological Journal], 80(6):94–108. DOI: 10.15407/microbiolj80.06.094 [In Ukrainian]

Demyanyuk, O.S., Sherstoboeva, O.V., Bunas, A.A., Dmitrenko, O.V. 2018c. Effects of different fertilizer systems and hydrothermal factors on microbial activity in the chernozem in Ukraine. – Biosystems Diversity, 26(4):309–315. DOI: 10.15421/011846

Emmerling, C, Udelhoven, T, Schröder, D. 2001. Response of soil microbial biomass and activity to agriculture deintensification over a 10 year period. – Soil Biology & Biochemistry, 33(15):2105–2114. DOI: 10.1016/S0038-0717(01)00143-2

Goberna, M., Sánchez, J., Pascual, J.A, Carcía, C. 2006. Surface and subsurface organic carbon, microbial biomass and activity in a forest soil sequence. – Soil Biology & Biochemistry, 38(8):2233–2243. DOI: 10.1016/j.soilbio.2006.02.003

Hopkins, D.W., Shiel, R.S. 1996. Size and activity of soil microbial communities in long-term experimental grassland plots treated with manure and inorganic fertilizers. – Biology and Fertility of Soils, 22:66–70. DOI: 10.1007/BF00384434

Hryhoriv, Y., Butenko, A., Nechyporenko, V., Lyshenko, M., Ustik, T., Zubko, V., Makarenko, N., Mushtai, V. 2021. Economic efficiency of *Camelina sativa* growing with nutrition optimization under conditions of Precarpathians of Ukraine. – Agraarteadus, 32(2):232–238. DOI: 10.15159/jas.21.33

Iutinskaya, G.O. 2006. Mikrobiolohiya gruntu [Soil microbiology]. – Kyiv, Aristey [Kyiv, Aristei], 284 p. [In Ukrainian]

Kaminskyi, V., Tkachenko, M., Malynovska, I., Kondratiuk, I., Pyndus, V., Asanishvili, N., Tkachenko, A. 2021. Preservation of acid Haplic Luvisols fertility and agrocenosis productivity increase under organic farming conditions. – Ukrainian Journal of Ecology, 11(3):328–335. DOI: 10.15421/2021_180

Kanchikerimath, M., Singh, D. 2001. Soil organic matter and biological properties after 26 years of maize–wheat– cowpea cropping as affected by manure and fertilization in a Cambisol in semiarid region of India. – Agriculture, Ecosystems & Environment, 86(2):155–162. DOI: 10.1016/S0167-8809(00)00280-2

Kaur, K., Kapoor, K.K., Gupta, A.P. 2005. Impact of organic manures with and without mineral fertilizers on soil chemical and biological properties under tropical conditions. – Journal of Plant Nutrition and Soil Science, 168(1):117–122. DOI: 10.1002/jpln.200421442

Liang, Y.C, Si, J., Nikolic, M., Peng, Y., Chen, W., Jiang, Y. 2005. Organic manure stimulates biological activity and barley growth in soil subject to secondary salinization. – Soil Biology & Biochemistry, 37(6):1185–1195. DOI: 10.1016/j.soilbio.2004.11.017

Loboda, M.I., Voichuk, S.I., Biliavska, L.O. 2019. Korelyatsiyna zalezhnistʹ biosyntezu antybiotychnykh spoluk ta inshykh biolohichno aktyvnykh rechovyn u gruntovykh streptomitsetakh [Correlation dependence between the antibiotic compounds biosynthesis and other biologically active substances in soil streptomycetes]. – Mikrobiolohichnyy zhurnal [Microbiological Journal], 81(5):36–47. DOI: 10.15407/microbiolj81.05.036 [In Ukrainian]

Manko, Yu, P., Tsyuk, O.A., Tsentulo, L.V., Shemetun, O. 2019. The methodology resource suggestion with environmental criteria for rationality agricultural systems estimation. – Ukrainian Journal of Ecology, 9(1):121–126.

Zvyagintsev, D.G. 1991. Metody mikrobiolohiyi ta biokhimiyi gruntu [Methods of soil microbiology and biochemistry]. – Moskva, MGU [Moscow, MSU], 303 p. [In Russia]

Nikiforenko, L.I. 1982. Rozpodil humusu v ornomu shari erodovanoho chornozemu zalezhno vid sposobiv obrobky [Distribution of humus in the arable layer of eroded chernozem depending on the methods of processing]. – Silʹsʹke hospodarstvo. Kyyiv, Urozhay [Agriculture. Kyiv, Urozhay], 55:76–81. [In Ukrainian]

Parkhomenko, M.M., Lychuk, A.I., Butenko, A.O., Karpenko, O.Yu., Rozhko, V.M., Tsyz, O.M., Chernega, T.O., Tymoshenko, O.P., Chmel, O.P. 2021. Nitrogen balance in short crop rotations under various systems for restoring sod-podzolic soil fertility. – Ukrainian Journal of Ecology, 11(2):72–76. DOI: 10.15421/2021_79

Patika, N.V., Kruglov, Y.V., Mazirov, M.A. 2010. Vyvchennya bioriznomanittya mikrobnoho kompleksu dernovo-pidzolystoho gruntu v umovakh bahatorichnoho silʹsʹkohospodarsʹkoho vykorystannya. Mizhvidomcha tema [Study of biodiversity of the microbial complex of sod-podzolic soil in the conditions of long-term agricultural use. Interdepartmental topic]. – Zhytomyr, 329–331. [In Ukrainian]

Patika, V.F. 2014. Biolohichnyy azot i nova stratehiya roslynnytstva v Ukrayini [Biological nitrogen and a new strategy for crop production in Ukraine]. – Naukovi zapysky Ternopilʹsʹkoho natsionalʹnoho pedahohichnoho universytetu. Seriya: Biolohiya [Scientific notes of Ternopil National Pedagogical University. Series: Biology], 3(60):10–15. [In Ukrainian]

Patika, V.P., Hnatyuk, T.G., Butsela, N.M., Kirilenko, L.V. 2015. Biolohichnyy azot v systemi silʹsʹkoho hospodarstva [Biological nitrogen in the system of agriculture]. – Silʹsʹke hospodarstvo [Agriculture], 2:12–20. [In Ukrainian]

Plaza, C., Hernandez, D., Garcia-Gil, J.C., Polo, A. 2004. Microbial activity in pig slurry-amended soils under semiarid conditions. – Soil Biology & Biochemistry, 36(10):1577–1585. DOI: 10.1016/j.soilbio.2004.07.017

Rieznik, S., Havva, D., Butenko, A., Novosad, K. 2021. Biological activity of chernozems typical of different farming practices. – Agraarteadus, 32(2):307–313. DOI: 10.15159/jas.21.34

Ros, M., Hernández, M.T., García, C. 2003. Soil microbial activity after restoration of a semiarid soil by organic amendments. – Soil Biology & Biochemistry, 35(3):463–469. DOI: 10.1016/S0038-0717(02)00298-5

Saiko, V.F. 2002. Silʹsʹke hospodarstvo v suchasnykh umovakh [Agriculture in modern conditions]. – Visnyk silʹsʹkohospodarsʹkoyi nauky [Bulletin of Agricultural Science], 5:5–10. [In Ukrainian]

Sarathchandra, S.U, Ghani, A., Yeates, G.W., Burch, G., Cox, N.R. 2001. Effect of nitrogen and phosphate fertilizers on microbial and nematode diversity in pasture soils. – Soil Biology & Biochemistry, 33(7–8):953–964. DOI: 10.1016/S0038-0717(00)00245-5

Sherstoboeva, O.V., Demyanyuk, O.S., Chabanyuk, Y.V. 2017. Biodiahnostyka ta biobezpeka gruntiv ahroekosystem [Biodiagnostics and biosafety of soils of agroecosystems]. – Ahroekolohichnyy zhurnal [Agroecological journal], 2:142–149. [In Ukrainian]

Tsyuk, O.A., Tanchyk, S.P., Kyrylyuk, V.I., Shevchenko, T.V. 2018. Biolohichna aktyvnistʹ gruntu u svynomatok ozymoyi pshenytsi zalezhno vid osnovnoyi obrobky gruntu v poslidovnosti [Biological activity of the soil in sows of winter wheats depending on the main soil treatment in sequence]. – Ukrayinsʹkyy ekolohichnyy zhurnal [Ukrainian Journal of Ecology], 8(3):37–40. [In Ukrainian]

Tu, C., Rustaino, J.B., Hu, S. 2006. Soil microbial biomass and activity in organic tomato farming systems: effects of organic inputs and straw mulching. – Soil Biology & Biochemistry, 38(2):247–255. DOI: 10.1016/j.soilbio.2005.05.002

Volkogon V., Dimova S., Volkogon K. 2010a. Vplyv mikrobnykh dobryv na zasvoyennya pozhyvnykh rechovyn kulʹturnymy roslynamy [Influence of microbial fertilizers on the assimilation of nutrients by cultivated plants]. – Visnyk silʹsʹkohospodarsʹkoyi nauky [Bulletin of Agricultural Science], 5:25–28. [In Ukrainian]

Volkogon, V.V., Nadkernicna, O.V., Tokmakova, L.M. 2010b. Eksperymentalʹna mikrobiolohiya gruntu [Experimental soil microbiology]. – Kyiv, Agrarna nauka [Kyiv, Agrarian Science], 464 p. [In Ukrainian]

Agraarteadus
1 • XXXIII • 2022 199–208

Journal of Agricultural Science
1 • XXXIII • 2022 199–208

THE MODEL FOR RANDOM PACKAGING OF SMALL-SEEDED CROPS' SEEDS IN THE RESERVOIR OF SELECTION SEEDERS SOWING UNIT

Vitalii Yaropud[1], Inna Honcharuk[1], Dmytro Datsiuk[1], Elchyn Aliiev[2]

[1]Vinnytsia National Agrarian University, 3 Sonyachna St, Vinnytsia, 21008, Ukraine
[2]Institute of Oilseed Crops of the National Academy of Agrarian Sciences of Ukraine, 1 Institutskaya St, v. Sonyachne, Zaporozhye region, 69093, Ukraine

Saabunud: Received: 08.12.2021

Aktsepteeritud: Accepted: 09.04.2022

Avaldatud veebis: Published online: 09.04.2022

Vastutav autor: Corresponding author: Vitalii Yaropud

E-mail: yaropud77@gmail.com

ORCID:
0000-0003-0502-1356 (VY)
0000-0002-1599-5720 (IH)
0000-0002-4614-2245 (DD)
0000-0003-4006-8803 (EA)

Keywords: seeds, sowing unit, model, random packing, parameters, efficiency.

DOI: 10.15159/jas.22.08

ABSTRACT. The sowing unit is one of the most important working bodies of the drill. It is used to select from the total mass of a certain number of seeds and the formation of their output flow with the specified parameters. Therefore, the advantages and disadvantages of seeders, in terms of the quality of seed distribution in a row and general in the sown field, are mainly determined by the work of sowing machines. The research was carried out to develop a model of random packing of seeds of small-seeded crops in the tank of the sowing apparatus of the selection drill. The research was conducted based on numerical simulation in the software package of the CAE-system Simcenter STAR-CCM +. Because of research, the mathematical model of casual packing of seeds of small-seeded cultures in the capacity of the sowing device of a selection seeder is developed that allowed defining the equation of regression of its density from the effective diameter of seeds and coefficient of variation of this diameter. As a result of research of process of work of the batcher of the sowing device of a selection seeder regularity of change of its throughput from an angle of inclination of a gate, type of a form of executions (triangle, semicircle, rectangle) in the form of a polynomial of the third degree are received. It is established that the choice of the triangular shape of the dispenser allows for ensuring the highest accuracy of seed dosing.

Introduction

In the sphere of selective production of small-seeded crops' seeds, the interest in sowing problems has grown significantly in recent times. This is due to the significance of obtaining high-quality crops at the initial point of research and preliminary propagation of new varieties and hybrids of small-seeded crops (Molotsky *et al.*, 2006; Hakansson *et al.*, 2013; Shepelev *et al.*, 2016; Vasylkivsky, Kochmarsky, 2016; Shackley *et al.*, 2019; Mazur *et al.*, 2021). By the conditions required for the normal development of plants, high agrotechnical requirements are put forward to the quality of crops sown on selection sites for preliminary reproduction and variety testing, since more expensive sowing material is used. Important agronomic requirements have to ensure uniform distribution of seeds along the row at a level not lower than 95% (Kryuchin, 2009).

The sowing method depends on soil and climatic conditions and the sowing qualities of small-seeded crops' seeds. The task of sowing is to create favourable conditions for the germination of seeds and plants, as well as to ensure their required density with uniform placement in rows. The required density of crops and the order of seeds placement in the field is the basis for choosing the method of sowing the seeds of small-seeded crops. On this basis, the row spacing and the interval between seeds are selected (Khalansky, Gorbachev, 2004; Kryuchin, 2009).

Technical-operational and production-technological indicators make an integral part of agro-technical requirements to seeders. They determine the main parameters of the sowing unit: capture width, operational speeds, power consumption, output, service life, coefficients of technological process's preparedness and reliability, occupational safety conditions and operational convenience, the quantity of service personnel, *etc.* (Alhassan *et al.*, 2018; Ovtov, Abrosimov, 2020; Hrushetskyi *et al.*, 2021). In addition, the seeds should be aligned in size and free from pubescence, hooks and similar roughness, characterized by high germination (Aliiev *et al.*, 2019; Aliiev, 2020; Paziuk *et al.*, 2021; Shevchenko *et al.*, 2021).

Thus, the main qualitative, quantitative and operational characteristics of sowing and other machines are determined based on agrotechnical requirements, the perfection and exact execution of which ensure the development of efficient and cost-effective sowing units.

The sowing unit is one of the most important working bodies of the seeder. It is used to select the particular number of seeds from the total mass and to form an output stream from them with specified parameters (Pankov *et al.*, 2016; Shevchenko *et al.*, 2018). Therefore, the advantages and disadvantages of seeders, in terms of quality of seed distribution in rows and sown fields in general, are mainly determined by the seeder's operation.

When sowing small-seeded crops in varietal testing and pre-propagation areas, electromechanical seeders have become widespread. However, the problem with their use lies in an insufficient uniformity of seed distribution along the row, which is due to random processes that occur during sowing. As a result, crops appear to be uneven – with thickening or rarefying of plants in a row, which ultimately leads to a decrease in yields of selection-valuable small-seeded crops.

In this regard, studies aimed at improving the process of seed dosing by sowing units of selection seeders are of great scientific and practical significance.

Methods

Sowing of small-seeded crops' seeds in the electromechanical sowing unit is reduced to the process of their dosing and transportation to the seed pipeline. In most designs of electromechanical seeders, the seeds are unloaded into the seeders reservoir, wherein mathematical terms are formed into random packages. Further, using a valve through dosing holes so formed, seeds enter the distributor, being supplied to the seed pipeline. Given the fact that the said study was conducted to develop the model for random packaging of small-seeded crops' seeds in the reservoir of selection seeders sowing unit.

Recent theoretical studies of mechanical and technological processes of seed movement under the action of the machines' working bodies are reduced to analytical methods, this leading to the compilation of complex systems of differential equations with boundary and initial conditions (Aliev *et al.*, 2018). In practical terms, these systems cannot be solved in conventional ways, so the need exists for their numerical solution using computer simulation.

Among up-to-date methods of computer simulation of mechanical and technological processes of bulk medium's (seed mixture's) movement, particular emphasis is put on the methods based on the concept of discrete representation of matter – the method of particle dynamics and the method of discrete elements (Rutkevych *et al.*, 2022). The method of particle dynamics is represented by media in the form of sets of interacting particles – material points or solids. Their motion is described by equations of classical mechanics. When simulating the motion of particles using the method of particle dynamics at each step, iterative methods solve the Cauchy problem – differential equations are integrated under given initial conditions. The best-known programs for calculations using the particle dynamics method are AMBER, CHARMM, GROMACS, GROMOS and NAMD. The discrete element method may be deemed the generalization of the finite element method. When simulating the process, this method sets particles' initial positions and velocities. Then, based on these initial data of given physical laws of particles' interaction, forces acting on each particle are calculated. At the same time, it is possible to consider various laws of interaction themselves; the existence of solvable equations to describe them is sufficient. For each particle, the resultant force is calculated and the Cauchy problem is solved at a selected time interval. The result is initial data for the next step. The following programs implementing the method of discrete elements are the best-known ones: Chute Maven (Hustrulid Technologies Inc.), PFC2D and PFC3D, EDEM (DEM Solutions Ltd.), GROMOS 96, ELFEN, MIMES, PASSAGE and Star CCM +. The discrete element method is based on the laws of momentum conservation and impulse-momentum for Lagrange models of multiphase medium (Aliev *et al.*, 2018). However, to generate a physical-mathematical model, one should assume that particles of components are represented by balls with particular density and effective diameter.

Therefore, further theoretical research was conducted based on numerical simulation in Simcenter STAR-CCM + CAE-system software package.

The first stage of theoretical research lies in the development of the model for random packaging of small-seeded crops' seeds in the reservoir of selection seeders sowing apparatus and substantiation of its dispenser's geometrical parameters.

Let us approximate the geometrical shape of small-seeded crops' (rapeseed, mustard, camelina, millet, *etc.*) seeds in the form of balls with the effective diameter of D. According to previous studies (Shevchenko *et al.*, 2018; Aliiev *et al.*, 2019; Aliiev, 2020) even calibrated seed mixtures contain seeds with different effective diameters. Therefore, let us assume that seeds' effective diameters are subject to normal distribution and characterized by the probability density of:

$$f\left(D, D_{\mu}, \sigma_{D}\right) = \frac{1}{\sigma_{D}\sqrt{2\pi}} \exp\left(-\frac{\left(D - D_{\mu}\right)^{2}}{2\sigma_{\mu}^{2}}\right), \qquad (1)$$

where D_μ is the average value of the effective seed diameter, m; σ_D is the standard deviation of the effective seed diameter, m

That said, the seeds may have the effective diameter being in the range of $D \in [D_{min}; D_{max}]$, where D_{min} is the minimum value of the effective diameter, m; D_{max} is the maximum value of the effective diameter, m

Assuming that the seeds' density is the same and equals ρ, the weight of 1000 seeds is determined using the formula:

$$m_{1000} = \frac{500}{3}\rho\pi D^3, \qquad (2)$$

where ρ is the seeds' density, kg m^{3-1}.

The reservoir of selection seeders seed sowing unit has the form of a rectangular parallelepiped with the height of h, the base of which being a square with the side of a.

Generation of random packaging consists of the consecutive launch of spherically shaped seeds with randomly chosen coordinate at the top face of the reservoir of the selection seeders seed-sowing unit (Fig. 1) in its bottom direction. The initial sedimentation rate for all particles is set as the same. For the random generation of seeds, let us assume that the upper plane of the selection seeders seed sowing unit reservoir is divided into $N_G = 4a^2/(\pi D^2)$ cells of equal size. In these cells, seeds are generated (1) or not generated (0). The probability of seed generation in each cell equals 0.5.

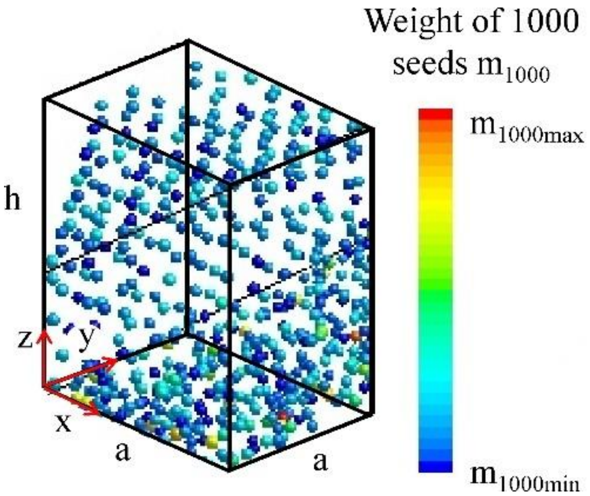


Figure 1. Simulation of filling the selection seeders seed sowing unit reservoir with spherical seeds

The movement of launched seeds is subsequently monitored. To exclude the calculation of the seed's movement from the reservoir's upper limit to its first contact with the already formed package, the seed is launched from some point inside the reservoir above the package, in which such moving seed is close enough to the level of the package. z` coordinate of controlled seed acquires z`value = z + D_1/2 + D_2/2, where z is the coordinate of the centre of the highest seed from among the seeds that settled at the bottom of the reservoir; D_1 is the diameter of the moving seed and D_2 is the diameter of the seed in the package centred in z. x` and y` coordinates are determined by a random number generator, which with equal probability acquires the values from 0.5a - (λ - D_1/2) to 0.5a + (λ - D_1/2), where λ is the predetermined number between D_{min}/2 and D_{max}/2. Setting λ number allows us to set the size of the seed launch source. With λ = D_1/2, launched seeds are on x` line = 0.5a and y` line = 0.5a.

When the seed collides with a seed in the package, the spring/dash-pot contact occurs. One can assume that the following forces can act on seeds:

- gravity (Dinesh, 2009):

$$\overline{F_g} = \pi D^3 \rho \overline{g} / 6, \qquad (3)$$

where $\overline{F_g}$ is gravity vector, N.

- the total force of seeds' contact interaction between themselves and the wall, which is based on Hertz-Mindlin's spring/dash-pot contact model (Di Renzo, Di Maio, 2004; Komiwes *et al.*, 2006):

$$\overline{F_{contact}} = \overline{F_n} + \overline{F_t}, \qquad (4)$$

where $\overline{F_{contact}}$ is the interaction effort between the seeds and the wall, H; $\overline{F_n}$ is a normal effort component, H; $\overline{F_t}$ is a tangential effort component, N.

The normal force component is determined using the following equation:

$$\overline{F_n} = -K_n \overline{d_n} - N_n \overline{V_n}, \qquad (5)$$

where K_n is the elastic component's normal stiffness factor, kg s^{2-1};

$$K_n = \frac{4}{3} E_{eq} \sqrt{d_n R_{eq}}, \qquad (6)$$

where N_n is the damping component's normal damping ratio, kg s^{-1};

$$N_n = \sqrt{(5K_n M_{eq})} N_{n\ damp}. \qquad (7)$$

According to researches (Di Renzo, Di Maio, 2004; Komiwes *et al.*, 2006), the tangential component of force is defined as:

$$\overline{F_t} = -K_t \overline{d_t} - N_t \overline{V_t} \qquad (8)$$

if $|K_t \overline{d_t}| < |K_n \overline{d_n}| C_{fs}$, where C_{fs} is the statistical coefficient of friction between the seeds or with the wall. Otherwise, the tangential component of force is determined using the following equation:

$$\overline{F_t} = |K_n \overline{d_n}| C_{fs} \overline{d_t} / |\overline{d_t}|, \qquad (9)$$

where K_t is the elastic component's tangential stiffness factor, kg s^{2-1};

$$K_t = 8G_{eq}\sqrt{d_t R_{eq}}\ , \qquad (10)$$

N_t is the damping component's tangential damping ratio, kg s^{-1};

$$N_t = \sqrt{\left(5K_t M_{eq}\right)} N_{t\ damp}\ , \qquad (11)$$

N_{damp} is the attenuation factor

$$N_{damp} = -\ln\left(C_{n\ rest}\right) \Big/ \sqrt{\pi^2 + \ln\left(C_{n\ rest}\right)^2}\ , \qquad (12)$$

R_{eq} is the equivalent radius of two seeds A and B, m;

$$R_{eq} = \left(\frac{2}{D_A} + \frac{2}{D_B}\right)^{-1}, \qquad (13)$$

M_{eq} is the equivalent weight of two seeds A and B, kg;

$$M_{eq} = \left(\frac{1}{M_A} + \frac{1}{M_B}\right)^{-1}, \qquad (14)$$

E_{eq} is the two seeds' equivalent Young's modulus ' A and B, Pa;

$$E_{eq} = \left(\frac{1-\nu_A^2}{E_A} + \frac{1-\nu_B^2}{E_B}\right)^{-1}, \qquad (15)$$

G_{eq} is the equivalent shear modulus of two seeds A and B, PA;

$$G_{eq} = \left(\frac{2\left(2-\nu_A\right)\left(1+\nu_A\right)}{E_A} + \frac{2\left(2-\nu_B\right)\left(1+\nu_B\right)}{E_B}\right)^{-1} \qquad (16)$$

M_A, M_B are weights of seeds A and B, kg; d_n, d_t, being virtual overlaps of seeds A and B in normal and tangential directions, m; D_A, D_B are effective diameters of seeds A and B, m; E_A, E_B are Young's modules of seeds A and B, Pa; ν_A, ν_B are Poisson's ratios of seeds A and B; $\overline{V_n}$, $\overline{V_t}$ are normal and tangential components of seed surface's relative velocity at the point of contact, m s^{-1}.

For the process of interaction between seeds and the wall, (2.5) – (2.16) dependencies are adequate, however D_{wall} radius = ∞ and M_{wall} wall mass = ∞ are assumed for the wall. As a result, (2.13) and (2.14) expressions transform into

$$R_{eq} = D_p/2,\ M_{eq} = M_p. \qquad (17)$$

Given the above-mentioned forces, let us write the system of differential equations of motion of one spherical seed in the reservoir of the selection seeder's sowing unit:

$$\begin{cases} \frac{1}{6}\pi D^3 \rho \frac{d_p \overline{V_p}}{dt} = \frac{1}{6}\pi D^3 \rho \overline{g} + \overline{F_n} + \overline{F_t}, \\ \frac{d_p \overline{S_p}}{dt} = \overline{V_p}, \\ \frac{d_p}{dt} = \frac{\partial}{\partial t} + \overline{V_p} \cdot \overline{\nabla}, \end{cases} \qquad (17)$$

where $\overline{V_p}$ is seed velocity vector, m s^{-1}; $\overline{S_p}$ is seed movement vector, m.

To determine the position of each seed in the reservoir of the selection seeders seed sowing unit, one should solve the system of differential equations (17) taking into account formulas (3)–(16), which is analytically quite difficult to do. Therefore, we will subsequently use Star CCM + software package, which is based on the presented mathematical apparatus.

Numerical simulation factors are represented by the average value of effective seed diameter D_μ (0.001; 0.002; 0.003 m) and variation coefficient δ_D (0.1; 0.2; 0.3), which is calculated as the ratio of the standard deviation of effective seed diameter σ_D to its average value (Table 1). The simulation was performed for a full-factor experiment concerning two factors with nine experiments in five repetitions.

The evaluation criterion is represented by package density, which is determined as follows:

$$\varphi = \frac{\sum_{i=1}^{N} \frac{1}{6}\pi D_i^3}{a^2 h} \qquad (18)$$

where *i* is seed No.; N is the total number of seeds.

Table 1. Factors and levels of numerical simulation of random packaging of seeds in the seeders reservoir

No.	Effective seed diameter D_μ, m	Variation factor δ	Standard deviation of effective seed diameter σ_D, m	Minimum seed diameter value D_{min}, m	Maximum seed diameter value D_{max}, m
1	0.001	0.1	0.0001	0.0007	0.0013
2	0.001	0.2	0.0002	0.0004	0.0016
3	0.001	0.3	0.0003	0.0001	0.0019
4	0.002	0.1	0.0002	0.0014	0.0026
5	0.002	0.2	0.0004	0.0008	0.0032
6	0.002	0.3	0.0006	0.0002	0.0038
7	0.003	0.1	0.0003	0.0021	0.0039
8	0.003	0.2	0.0006	0.0012	0.0048
9	0.003	0.3	0.0009	0.0003	0.0057

Please note that for one-dimensional spheres, the densest package in space is represented by a regular icosahedron, which contains 12 vertices (Fig. 2a). Centres of spheres are located at the vertices of this three-dimensional figure. As noted in studies (Conway, Sloane, 1999; Aste, Weaire, 2008), the average density of such packaging is 0.7405. For simple packages (4 spheres): cubic (Fig. 2b) and hexagonal (Fig. 2c) the density is 0.5236 and 0.6043, respectively. Given the above, one can state that for uniform-sized spheres in space, packaging density may range from 0.5236 to 0.7405.

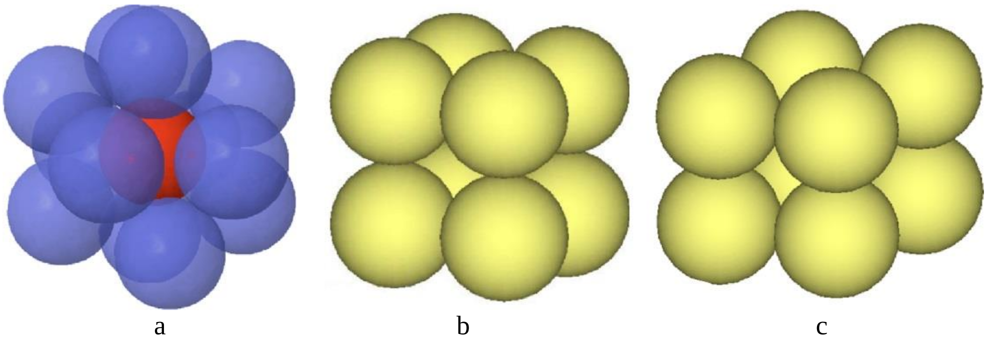


Figure 2. Examples of packages of uniform-sized spheres in space

The next step is to determine the patterns of the dispenser's operation, which is presented in the form of a valve that opens holes of different shapes. Holes of the cylindrical dispenser are made in three designs (Fig. 3): I – as a triangle, II – as a semicircle, and III – as a rectangle. Dependencies between the area of the dispenser's one hole S and valve rotation angle α for different designs are shown in Fig. 3.

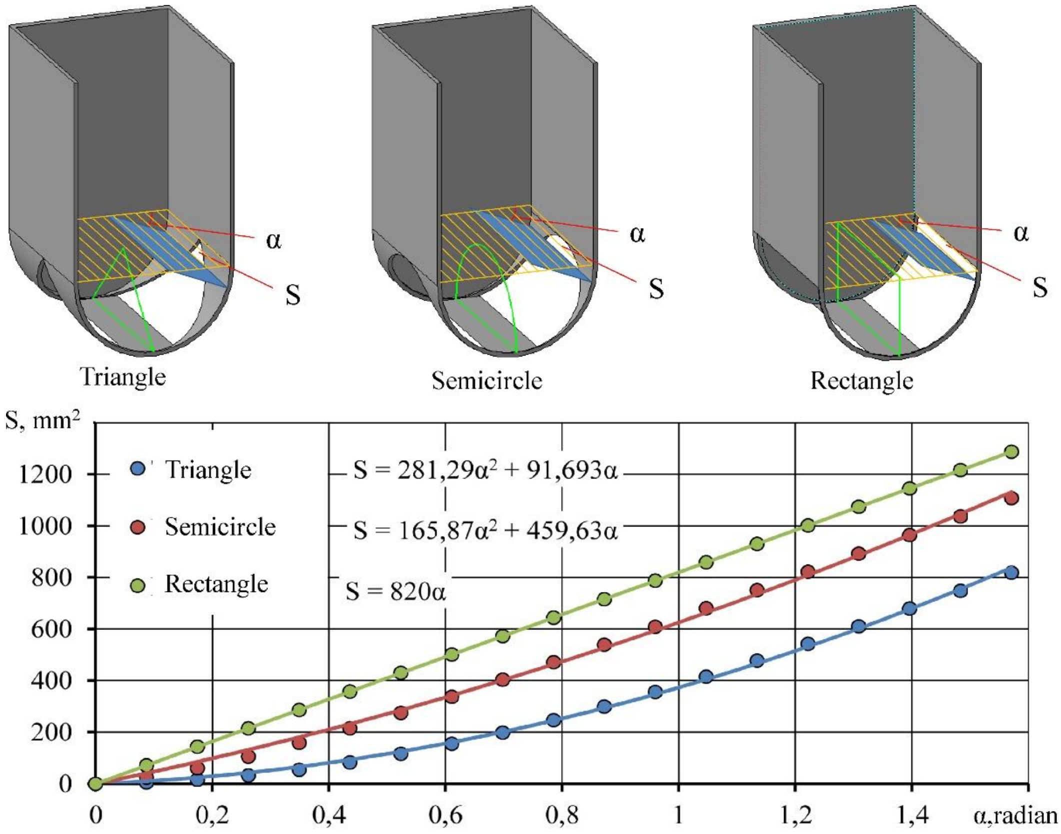


Figure 3. Dependencies between the area of the dispenser's one hole S and valve rotation angle α for different designs

The factors of numerical simulation are represented by package density φ (0.550; 0.575; 0.600) and valve rotation angle α (0.1–1.5 through 0.1).

The evaluation criterion is represented by the reservoir dispenser's throughput Q_d, which is determined using the formula:

$$Q_d = \frac{n}{t} \quad (19)$$

where t is time, s; n is the number of seeds.

Physical models for dosing process simulation using Star CCM + software package are as follows: three-dimensional model, nonstationary implicit model, the mathematical model of one-component gas (air), model of an ideal gas (air), model of turbulent airflow, k-ε model of air turbulence, isothermal equation of fluid energy, Reynolds-averaged Navier-Stokes equation (Gunko *et al.*, 2021), separate flow, gradient and boundary methods, Lagrangian model of the multi-phase medium (Solona *et al.*, 2020; Kovbasa *et al.*, 2021), multiphase interaction model, discrete elements model (DEM), gravity field (Kubicki, Lo, 2012; Satish *et al.*, 2013; Iguchi, Ilegbusi, 2014; Yaropud *et al.*, 2021; Rutkevych *et al.*, 2022).

The seeds are presented in the form of the Lagrange phase according to the following models: constant density, pressure gradient force, particle resistance force, spherical particles, single-component solid particles, and DEM particles. For example, rapeseed was selected as the seed, which according to the analysis of literature has the following physical and mechanical properties: Poisson's ratio – 0.2; Young's modulus – 0.2 MPa; density – 700 kg m^{3-1}; coefficient of static friction – 0.58; normal recovery factor – 0.5; tangential recovery factor – 0.5; rolling resistance coefficient – 0.3 (Aliiev, 2019; Paziuk *et al.*, 2019).

Results

According to numerical modelling results, visualization of random packaging of small-seeded crops' seeds in the reservoir of the selection seeders sowing unit with different geometrical sizes of seeds was obtained (Fig. 4). For each numerical experiment, packaging density is calculated, and the results are summarized in Table 2.

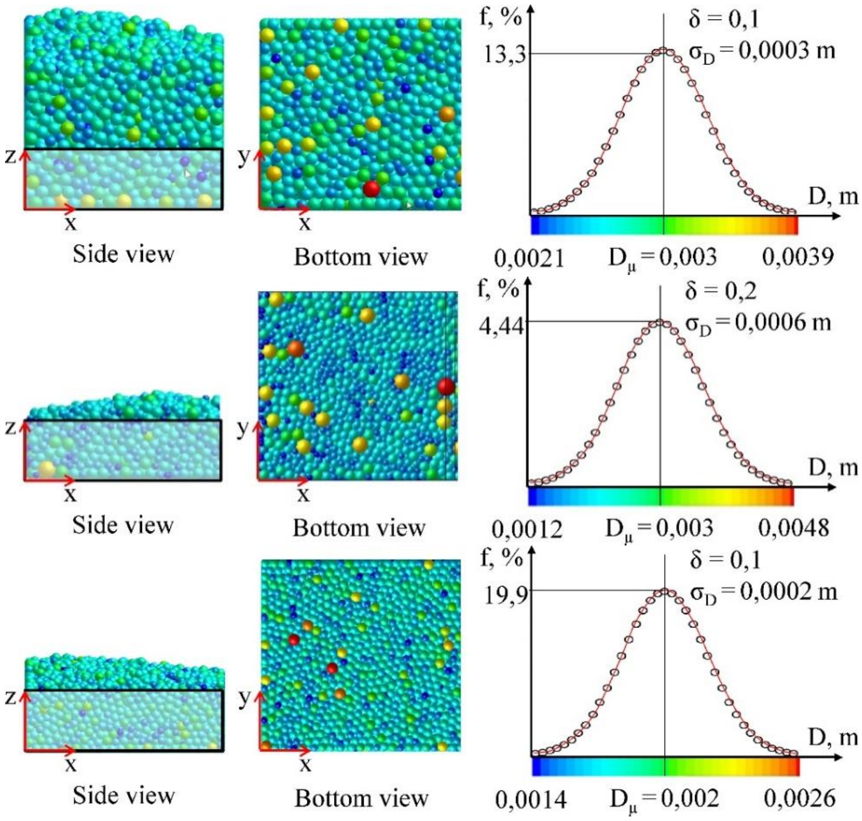


Figure 4. Visualization of random packaging of small-seeded crops' seeds in the reservoir of selection seeders sowing unit

Table 2. Results of simulation of random packaging of small-seeded crops' seeds in the reservoir of selection seeders sowing unit

Effective seed diameter		Diameter variation ratio		Packaging density φ					$\bar{\varphi}$	σ_φ	δ_φ
				Repeatability							
D_μ, mm	x_1	δ	x_2	1	2	3	4	5			
0.001	–1	0.1	–1	0.5628	0.5684	0.5552	0.5611	0.5594	0.5614	0.0048	0.0086
0.001	–1	0.2	0	0.5991	0.6024	0.5955	0.5970	0.5969	0.5982	0.0027	0.0045
0.001	–1	0.3	1	0.6164	0.6227	0.6112	0.6192	0.6130	0.6165	0.0046	0.0075
0.002	0	0.1	–1	0.5587	0.5611	0.5524	0.5585	0.5559	0.5573	0.0033	0.0059
0.002	0	0.2	0	0.5944	0.5977	0.5912	0.5930	0.5939	0.5940	0.0024	0.0040
0.002	0	0.3	1	0.6041	0.6063	0.5975	0.6048	0.6010	0.6027	0.0035	0.0058
0.003	1	0.1	–1	0.5532	0.5564	0.5496	0.5546	0.5522	0.5532	0.0026	0.0046
0.003	1	0.2	0	0.5884	0.5938	0.5842	0.5923	0.5857	0.5889	0.0041	0.0070
0.003	1	0.3	1	0.5995	0.6048	0.5952	0.6032	0.5990	0.6003	0.0038	0.0063

$\bar{\varphi}$ is the average value of packaging density; σ_φ is the standard deviation of packaging density; δ_φ is the coefficient of packaging density variation

Using the Wolfram Mathematica software package, let us present the obtained table data in the form of a second-order regression equation in coded form:

$$\varphi = 0.592558 - 0.00560667\, x_1 + 0.00171333\, {x_1}^2 + 0.0246133\, x_2 - - 0.001995\, x_1\, x_2 - 0.0117867\, {x_2}^2. \qquad (20)$$

Statistical processing of the obtained equation (20) is presented in table 3. Taking into account the number of degrees of freedom of obtained results matrix, the Student's tabular criterion is t(0.05; 36) = 2.03. Comparing the Student's tabular criterion with the one calculated in Table 3, we could discard insignificant coefficients of a regression equation (20) and finally obtain:

$$\varphi = 0.592558 - 0.00560667\, D_\mu + 0.0246133\, \delta - - 0.001995\, D_\mu\, \delta - 0.0117867\, \delta^2. \qquad (21)$$

Table 3. Statistical processing of equation (20)

Ratio	Value	Student's criterion
a_{00}	0.592558	465.7
a_{10}	–0.00560667	–8.04488
a_{20}	0.0246133	35.3171
a_{12}	–0.001995	–2.33729
a_{11}	0.00171333	1.41937
a_{22}	–0.0117867	–9.76439

A graphical representation of equation (21) is shown in Fig. 5. With the decrease in effective seed diameter D_μ and increase in variation coefficient δ, the increase in random packaging density φ of small-seeded crops' spherical seeds in the reservoir of the selection seeders sowing unit is observed. This is because seeds of smaller diameter fill the voids between the seeds of larger diameter. Increasing the density of random seed packaging can lead to the formation of arches, which renders dosing impossible. Let us test this hypothesis by determining the regular patterns of dispenser operation.

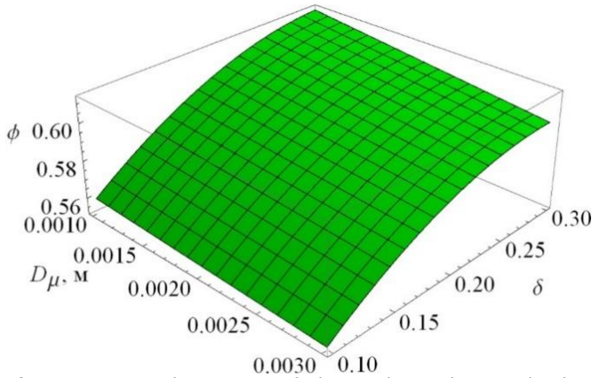


Figure 5. A regular pattern of change in random packaging density φ of small-seeded crops' seeds in the reservoir of selection seeders sowing unit in terms of effective seed diameter D_μ and its δ factor

The results of dispenser operation modelling, obtained was a visualization of the process shown in Fig. 6, while numerical data were summarized in Table 4.

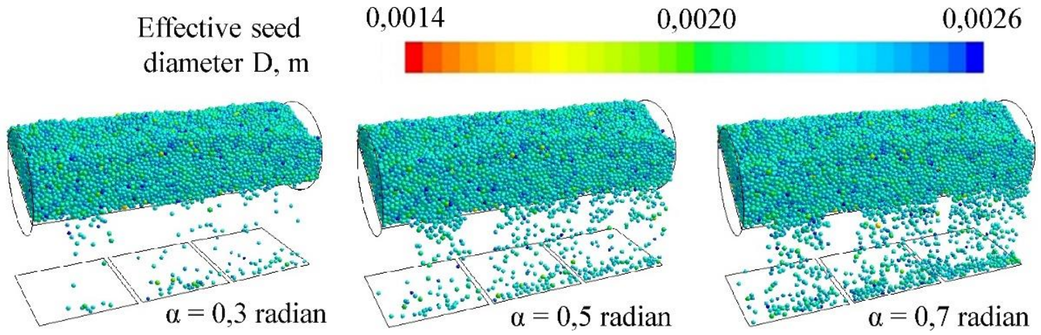


Figure 6. Visualization of dispenser operation process in selection seeders sowing unit

Table 4. Throughput Q_d of selection seeders seed sowing unit (pcs s^{-1})

φ	Hole option	Valve rotation angle α, rad														
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
0.550	I	0	0	0	6	18	35	63	103	155	227	319	438	584	764	985
	II	0	0	16	38	69	109	161	227	307	403	516	648	802	978	1179
	III	0	1	30	71	124	187	263	351	450	562	685	819	965	1124	1293
0.575 most common	I	0	0	0	3	13	32	60	99	151	224	316	434	580	761	981
	II	0	0	13	35	66	107	160	224	305	399	513	646	800	976	1176
	III	0	0	11	52	105	169	246	333	432	544	667	801	947	1105	1275
0.600	I	0	0	0	1	12	30	58	97	149	222	314	432	579	760	979
	II	0	0	0	30	61	101	154	219	299	395	508	641	794	971	1172
	III	0	0	0	36	89	153	229	318	417	528	650	786	932	1090	1259
Avg.	I	0	0	0	3	14	33	60	99	152	224	316	435	581	762	981
	II	0	0	10	34	65	106	158	224	303	399	513	645	799	975	1176
	III	0	0	14	53	106	170	246	334	433	545	667	802	948	1106	1276

And – a triangle; II – semicircle; III - a rectangle

It follows from Table 4 that the throughput of dispenser Q_d of the selection seeders sowing unit does not depend on the density of random packaging φ of small-seeded crops' seeds in the reservoir. However, one can see that at the valve's inclination angle of α = 0–0.3 rad, the throughput of metering unit $Q_d = 0$. This is due to the formation of arches in the seeders reservoir. Having found the average value of dispenser's throughput Q_d for three values of density of seeds' random packaging φ, let us approximate the obtained data in the form of a third-degree polynomial (Fig. 7):

- for an option I (triangle):

$$Q_d = = 494.05\,\alpha^3 - 387.74\,\alpha^2 + 130.04\,\alpha - 13.729;\ R^2 = 0.9998, \quad (22)$$

- for the II variant (semicircle):

$$Q_d = 220.92\,\alpha^3 + 213.26\,\alpha^2 - 34.755\,\alpha;\ R^2 = 0.9999, \quad (23)$$

- for option III (rectangle):

$$Q_d = -57.688\,\alpha^3 + 753.18\,\alpha^2 - 150.99\,\alpha;\ R^2 = 0.9998. \quad (24)$$

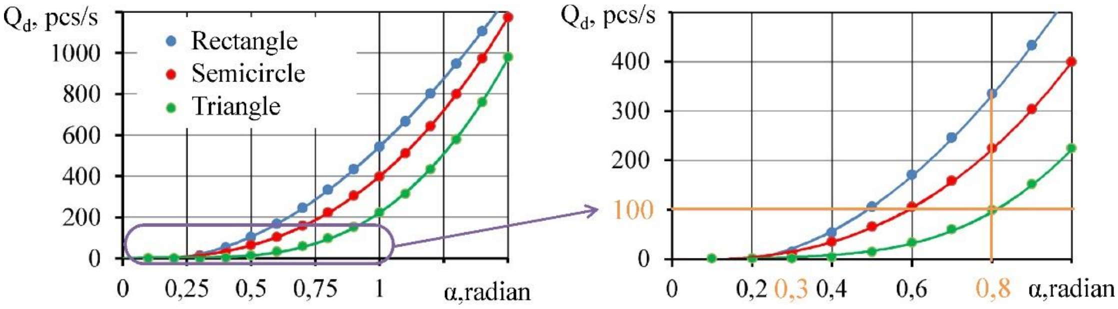


Figure 7. A regular pattern of change in the throughput of dispenser Q_d of selection seeders sowing unit depending on gate α inclination angle

Discussion

Analysis of presented studies (Molotsky *et al.*, 2006; Hakansson *et al.*, 2013; Vakhnenko, Poliakov, 2010; Makhova, Polyakov, 2012; Poliakov, Vakhnenko, 2012) and selection operation patterns (Alhassan *et al.*, 2018; Ovtov, Abrosimov, 2020) depending on biological characteristics of small-seeded crops suggests the need to create such a small seeder that can ensure sowing at all stages of the selection process (creating populations for selection; selection of desired genotypes – original elite plants; progeny testing, reproduction to production-significant volumes).

According to studies (Vakhnenko, Poliakov, 2010; Makhova, Polyakov, 2012; Poliakov, Vakhnenko, 2012; Khalansky, Gorbachev, 2004; Kryuchin, 2009) and the conditions required for normal development of vegetation, before sowing in select areas of preliminary propagation and varietal testing, significant agronomical requirements mean ensuring a uniform distribution of seeds along rows at the level not lower than 95 % (Kryuchin, 2009). Compliance with this requirement contributes to the best possible supply of nutrients to all plants.

As a result of patent data analysis (Pankov *et al.*, 2016; Shevchenko *et al.*, 2018), it has been established that electromechanical seeders are the most expedient for the selection of small-seeded crops, as they ensure high enough accuracy of sowing and have perspective opportunities for management of changes in varietal samples directly during sowing in different areas.

As a result of theoretical studies of seed movement in the reservoir of the selection seeders sowing unit, a respective system of differential equations (17) was compiled taking into account formulas (3) to (16) forming the basis of the mathematical apparatus of Star CCM + software package. According to the results of numerical simulation, obtained was the visualization of random packaging of small-seeded crops' seeds in the reservoir of selection seeders sowing unit and equation of its regression φ (21) between density and effective seed diameter D_μ, as well as coefficient of this diameter's variation δ. According to the results of numerical simulations, it has been established that the throughput of dispenser Q_d of selection seeders sowing unit does not depend on the density of random packaging φ of small-seeded crops' seeds in the reservoir. Because of data approximation, the regular pattern between the change in the throughput of dispenser Q_d of selection seeders seeds sowing unit and valve α inclination angle in the form of a third-degree polynomial (22)–(24) has been obtained. Analysis of Figure 7 and dependencies (22)–(24) allows us to the state where it is necessary to ensure the throughput of dispenser Q_d from 1 pc s^{-1} to 100 pcs s^{-1}, the angle of valve α should vary from 0.3 rad to 0.8 rad. At the seeders movement speed of 1 m s^{-1} (4 m s^{-1}), the dispenser's throughput of 1 pc s^{-1} and 100 pcs s^{-1} corresponds to the sowing rate of 50 000 pcs ha^{-1} (12 500 pcs ha^{-1}) and 5 million pcs ha^{-1} (1.25 million units ha^{-1}). To clarify this relationship, it is necessary to conduct additional research to be implemented in the future. In addition to the foregoing, graphs Q_d (α) show that the graph angle for an option I of the dispenser hole (triangle) is the smallest one. That is, the selection of the triangular shape of the dispenser allows for ensuring the greatest accuracy of seed dosing.

Conclusion

Because of research, the mathematical model of casual packing of seeds of small-seeded cultures incapacity of the sowing device of a selection seeder is developed that allowed defining the equation of regression of its density from an effective diameter of seeds and coefficient of variation of this diameter. As a result of research of process of work of the batcher of the sowing device of a selection seeder regularity of change of its throughput from an angle of inclination of a gate, type of a form of executions (triangle, semicircle, rectangle) in the form of a polynomial of the third degree are received. It is established that the choice of the triangular shape of the dispenser allows for ensuring the highest accuracy of seed dosing.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

IH – drafting of the manuscript;
DD – analysis, interpretation and acquisition of data;
VY – study conception and design;
EA –critical revision and approval of the final manuscript.

References

Aliev, E.B., Bandura, V.M., Pryshliak, V.M., Yaropud, V.M., Trukhanska, O.O. 2018. Modeling of mechanical and technological processes of the agricultural industry. – INMATEH – Agricultural Engineering, 54 (1):95−104.

Alhassan, E.A., Adewumi, A.D., Okpodjah B. 2018. Development of a self-propelled multi-crop two rows precision planter: a new design concept for the metering mechanism. – International Journal of Mechanical Engineering and Technology (IJMET), 9(10):349–358.

Aliiev, E.B. 2020. Automatic phenotyping test of sunflower seeds. – Helia, 43(72):51–66. DOI: 10.1515/helia-2019-0019

Aliiev, E. 2019. Obgruntuvannya konstruktyvno-rezhymnykh parametriv fotoelektronnoho separatora nasinnya sonyashnyka [Justification of constructive-mode parameters of a photo-electron separator of sunflower seeds]. – Scientific Horizons, 5(78):23–30. DOI: 10.33249/2663-2144-2019-78-5-23-30 [In Ukrainian]

Aliiev, E., Gavrilchenko, A., Tesliuk, H., Tolstenko, A., Koshul'ko, V. 2019. Improvement of the sunflower seed separation process efficiency on the vibrating surface. – Acta Periodica Technologica, APTEFF, 50:12–22. DOI: 10.2298/APT1950012A

Aste, T., Weaire, D. 2008. The pursuit of perfect packing. (2nf ed.) – Taylor and Francis, CRC Press, Boca Raton, 216 p. DOI: 10.1201/9781420068184

Conway, J.H., Sloane, N.J.A. 1999. Sphere packings, lattices and groups. – Springer-Verlag, New York, 706 p. DOI: 10.1007/978-1-4757-6568-7

Dinesh, J. 2009. Modelling and simulation of a single particle in laminar flow regime of a newtonian liquid. – Excerpt from the Proceedings of the COMSOL Conference. Bangalore, pp. 1–9.

Di Renzo, A., Di Maio, F.P. 2004. Comparison of contact-force models for the simulation of collisions in DEM-based granular flow codes. – Chemical Engineering Science, 59(1):525–541. DOI: 10.1016/j.ces.2003.09.037

Gunko, I., Babyn, I., Aliiev, E., Yaropud, V., Hrytsun, A. 2021. Research into operating modes of the air injector of the milking parlor flushing system. – UPB Scientific Bulletin, Series D: Mechanical Engineering, 83(2):297–310.

Hakansson, I., Arvidsson, J., Etana, A., Rydberg, T., Keller, T. 2013. Effects of seedbed properties on crop emergence. 6. Requirements of crops with small seeds. – Acta Agriculturae Scandinavica, Section B – Soil & Plant Science, 63 (6). DOI: 10.1080/09064710.2013.822540

Hrushetskyi, S., Yaropud, V., Kupchuk, I., Semenyshena, R. 2021. The heap parts movement on the shareboard surface of the potato harvesting machine. – Bulletin of the Transilvania University of Braşov. Series II: Forestry, Wood Industry, Agricultural Food Engineering, 14 (63):127–140. DOI: 10.31926/but.fwiafe.2021.14.63.1.12

Iguchi, M., Ilegbusi, O.J. 2014. Basic transport phenomena in materials engineering. (1st ed.) – Springer, Tokyo, 260 p. DOI: 10.1007/978-4-431-54020-5

Khalansky, V.M., Gorbachev, I.V. 2004. Sel'skokhozyaystvennyye mashiny [Agricultural machinery]. – Moskva: Izdatel'stvo «Kolos» [Moscow: Publishing house «Kolos»], 624 p. [In Russian]

Kryuchin, N.P. 2009. Posevnyye mashiny. Osobennosti konstruktsiy i tendentsii razvitiya: Uchebnoye posobiye [Sowing machines. Design features and development trends: Study guide]. – Samara, Russia, 176 p. [In Russian]

Komiwes, V., Mege P., Meimon, Y., Herrmann, H. 2006. Simulation of granular flow in a fluid applied to sedimentation. – Granular Matter, 8(1):41–54. DOI: 10.1007/s10035-005-0220-3

Kovbasa, V., Solona, O., Deikun, V., Kupchuk, I. 2021. Functions derivation of stresses in the soil and resistance forces to the motion of a plough share for cavity creation. – UPB Scientific Bulletin, Series D: Mechanical Engineering, 83(3): 305–318.

Kubicki, D., Lo, S. 2012. Slurry transport in a pipeline – Comparison of CFD and DEM models. – Ninth International Conference on CFD in the Minerals and

Process Industries. CSIRO, Melbourne, Australia (10-12 December 2012), 1–6.

Kupchuk, I., Yaropud, V., Hraniak, V., Poberezhets, Ju., Tokarchuk, O., Hontar, V., Didyk, A. 2021. Multicriteria compromise optimization of feed grain grinding process. – Przegląd Elektrotechniczny, 97 (11):179–183. DOI: 10.15199/48.2021.11.33

Makhova, T.V., Polyakov, A.I. 2012. Vrozhaynistʹ lʹonu oliynoho v umovakh pivdennoho stepu ukrayiny v zalezhnosti vid strokiv sivby ta norm vysivu [Productivity in oil flax in southern steppe of Ukraine conditions depending on terms of sowing and quantity of seeds per hectare]. – Naukovo-tekhnichnyy byuletenʹ Instytutu oliynykh kulʹtur NAAN [Scientific and technical bulletin of the Institute of oilseed crops NAAS], 17:116–120. [In Ukrainian]

Mazur, V., Tkachuk, O., Pantsyreva, H., Kupchuk, I., Mordvaniuk, M., Chynchyk, O. 2021. Ecological suitability peas (*Pisum Sativum*) varieties to climate change in Ukraine. – Agraarteadus, 32 (2):276–283. DOI: 10.15159/jas.21.26

Molotsky, M.Ya., Vasylkivsky, S.P., Knyazyuk, V.I., Vlasenko, V.A. 2006. Selektsiya i nasinnytstvo silʹsʹkohospodarsʹkykh roslyn: Pidruchnyk [Breeding and seed production of agricultural plants: Textbook]. – Kyyiv: Vydavnytstvo «Vyshcha osvita» [Kiev: Publishing House «Higher Education»], 463 p. [In Ukrainian]

Ovtov, V.A., Abrosimov, M.Y. 2020. Substantiation of the opener construction for sowing small seed crops. – The Agrarian Scientific Journal, 8:89–92. DOI: 10.28983/asj.y2020i8pp89-92

Pankov, A.A., Aulin, V.V., Chernovol, M.I. 2016. Tekhnicheskiye sredstva protsessa vyseva na osnove elementov pnevmoniki: Monografiya [Technical means of the seeding process based on pneumatic elements: Monograph]. – Kirovograd, Ukraine, 243 p. [In Russian]

Paziuk, V., Petrova, Z., Tokarchuk, O., Yaropud, V. 2019. Research of rational modes of drying rape seed. – INMATEH – Agricultural Engineering, 58(2):303–310.

Paziuk, V., Vyshnevskiy, V., Tokarchuk, O., Kupchuk, I. 2021. Substantiation of the energy efficient schedules of drying grain seeds. – Bulletin of the Transilvania University of Braşov. Series II: Forestry, Wood Industry, Agricultural Food Engineering, 14(63):137–146. DOI: 10.31926/but.fwiafe.2021.14.63.2.13

Poliakov, A.I., Vakhnenko, S.V. 2012. Vodospozhyvannya ripaka yaroho v zalezhnosti vid strokiv, sposobiv sivby ta norm vysivu nasinnya [Water consumption of spring rape depending on terms, methods of sowing and quantity of seeds per hectare]. – Naukovo-tekhnichnyy byuletenʹ Instytutu oliynykh kulʹtur NAAN [Scientific and technical bulletin of the Institute of oilseed crops NAAS], 17: 130–133. [In Ukrainian]

Rutkevych, V., Kupchuk, I., Yaropud, V., Hraniak, V., Burlaka, S. 2022. Numerical simulation of the liquid distribution problem by an adaptive flow distributor. – Przegląd Elektrotechniczny, 98(2):64–69. DOI: 10.15199/48.2022.02.13

Satish, G., Ashok Kumar, K., Vara Prasad, V., Pasha Sk.M. 2013. Comparison of flow analysis of a sudden and gradual change of pipe diameter using fluent software. – IJRET: International Journal of Research in Engineering and Technology, 2(12):41–45.

Shackley, B., Paynter, B., Troup, G., Bucat, J., Seymour, M., Blake, A. 2019. 2020 Western Australian crop sowing guide. – Grains Research and Development Corporation, Australia, 70 p.

Shepelev, S., Shepelev, V., Almetova, Z. 2016. Optimization of technical equipment for crop sowing processes. – Procedia Engineering, 150:1258–1262. DOI: 10.1016/j.proeng.2016.07.142

Shevchenko, I., Aliiev, E., Viselga, G., Kaminski, J.R. 2021. Modeling separation process for sunflower seed mixture on vibro-pneumatic separators. – Mechanika, 27(4):311−320. DOI: 10.5755/j02.mech. 27647

Shevchenko, I.A., Aliev, E.B. 2018. Research on the photoelectronic separator seed supply block for oil crops. – INMATEH – Agricultural Engineering, 54 (1):129−138.

Solona, O., Kovbasa, V., Kupchuk, I. 2020. Analytical study of soil strain rate with a ploughshare for uncovering slit. – Agraarteadus, 31(2):212–218. DOI: 10.15159/jas.20.22

Vakhnenko, S.V., Poliakov, A.I. 2010. Formuvannya vrozhaynosti ripakom yarym v zalezhnosti vid strokiv sivby ta norm vysivu v umovakh pivdennoho stepu Ukrayiny [Forming productivity of brassica napus annua depending on sowing date and quantity of seeds under Ukrainian south steppe conditions]. – Naukovo-tekhnichnyy byuletenʹ Instytutu oliynykh kulʹtur NAAN [Scientific and technical bulletin of the Institute of oilseed crops NAAS], 15:73–77. [In Ukrainian]

Vasylkivsky, S.P., Kochmarsky, V.S. 2016. Selektsiya i nasinnytstvo polʹovykh kulʹtur: pidruchnyk [Selection and seed production of field crops: textbook]. – Bila Tserkva, Ukraine, 376 p. [In Ukrainian]

Yaropud, V., Hunko, I., Aliiev, E., Kupchuk, I. 2021. Justification of the mechatronic system for pigsty microclimate maintenance. – Agraarteadus, 32(2): 212–218. DOI: 10.15159/jas.21.21

Agraarteadus
1 • XXXIII • 2022 209–221

Journal of Agricultural Science
1 • XXXIII • 2022 209–221

THE EFFECT OF SUPERABSORBENT AND DIFFERENT RATES OF THE LOCAL FERTILIZER ON GARLIC PRODUCTIVITY IN THE FOREST-STEPPE OF UKRAINE

Viacheslav Yatsenko, Serhii Poltoretskyi, Ivan Mostoviak, Nataliia Vorobiova, Oleh Lazariev, Vitalii Kravchenko

Uman National University of Horticulture, Instytutska 1, 20301, Uman, Ukraine

Saabunud: Received: 25.02.2022

Aktsepteeritud: Accepted: 06.06.2022

Avaldatudveebis: Published online: 06.06.2022

Vastutavautor: Corresponding author: Viacheslav Yatsenko

E-mail: slaviksklavin16@gmail.com

ORCID:
0000-0003-2989-0564 (VY)
0000-0003-3334-0880 (SP)
0000-0003-4585-3480 (IM)
0000-0003-3752-314X (NV)
0000-0003-0557-3919 (OL)
0000-0003-4873-5367 (VK)

Keywords: bulb weight, enzymes, nutritional value, pigments, plant growth, yield.

DOI: 10.15159/jas.22.21

ABSTRACT. This study aimed to determine the effect of different rates of topical fertilizers on the background of superabsorbent polymers (absorbents; SAP) on plant growth, pigments content in leaves and activity of antioxidant enzymes in leaves and soil, yield and nutritional value of products. For this purpose, an absorbent at the rate of 15 kg ha^{-1} and fertilizers were applied, spread on the soil surface 100% (control), and locally in the furrows when planting at the rate of 25, 50, 75, and 100% of the recommended rate were applied. The results showed that the use of superabsorbent polymers (SAP) and the local application of fertilizers with increasing their rate, a significant increase in chlorophyll b and the number of chlorophylls. However, the use of SAP reduced the activity of antioxidant enzymes in the leaf (superoxide dismutase by 9.5–23.2%; glutathione S-transferase by 7.4–13.4%; peroxidase by 8.4–19.0%). The bulb's weight with the absorbent increased by 31.2–45.4% compared to similar options without the introduction of absorbent. The local fertilizer without absorbent increased garlic yield by 3.5–13.9% relative to control. With the introduction of the absorbent, the local application of fertilizers contributed to the increase of yield by 4.2–25.4%. The application of fertilizers at the rate of 50 and 75% separately and together with the absorbent contributed to the improvement of nutritional value (dry matter, ash, proteins and carbohydrates, fat and caloric content of products). In conclusion, the combination of SAP with local fertilization in crop production technology can be used in today's dynamic climate conditions, due to their beneficial effects on plant productivity and savings and efficient use of water and fertilizers. Further research consists of a more detailed study of the rate of application of absorbents, the duration of their effective action, and the rate and ratio of nutrients.

Introduction

Worldwide, drought stress is one of the most important factors reducing crop production (Beigi *et al.*, 2020). The presence of water in the soil is one of the most important factors in increasing crop yields. Therefore, the priority is to increase the efficiency and optimal use of water resources as one of the main axes of stable agriculture in unstable conditions of moisture. Accordingly, one way to increase the soil water supply is to use a superabsorbent polymer that provides water for plants (Dehkordi *et al.*, 2018).

Superabsorbent polymers (SAP) can also be identified as absorbent polymers, absorbent gels, aqueous gels, or hydrogels. They are synthetic high molecular materials that can hyperaccumulate water up to 100% of its weight (insert reference). In addition, SAPs are mainly used to improve soil properties and they usually consist of sugar-like hygroscopic materials that turn into a transparent gel when added to the water (Hüttermann *et al.*, 2009).

Superabsorbents, depending on their source and structure, are divided into two main groups: natural and synthetic. Synthetic superabsorbent polymers, depending on the type of use of monomer in their synthesis, usually are divided into three groups: 1 – cross-linked polyacrylates and lyacrylamides; 2 – hydrolyzed cellulose-polyacrylonitrile (PAN) or starch PAN graft copolymers; 3 – cross-linked copolymers of maleic anhydride. The SAPs used in agriculture are poly-electrolyte gels often composed of acrylamide (AM), acrylic acid (AA), and potassium acrylate (Zohuriaan-Mehr, Kabiri, 2008). They are used in gardens, land-scapes, and agriculture to protect and preserve soil moisture and slow the release of water through the soil (Orzeszyna *et al.*, 2006; Thombare *et al.*, 2018). Super-absorbent polymers promote better growth and higher yields by increasing the water storage capacity in the soil (El-Hady *et al.*, 2006; Sarvas *et al.*, 2007), reducing the consumption of the water and soil nutrients (Adams, Lockaby, 1987), reducing the water evapora-tion from the soil surface (Sivapalan, 2001) and increasing the soil aeration (Orzeszyna, 2006). These materials increase the interval between watering which saves water and energy.

The use of absorbent polymers, especially the super-absorbent ones, has several benefits such as conser-vation of the water, lowering the surface of runoff, avoiding soil erosion, and improving the performance of different soil fertilizers (Scott, Blair, 1988; Xi, Zhang, 2021).

The yield of garlic is quite low and is 10–14 t ha^{-1} (in Ukraine), which is 30–50% of the theoretically possib-le. This leads to the need for the development and improvement of the elements of cultivation technology for each soil-climatic zone to significantly increase the yields. It is impossible to achieve this without the use of mineral fertilizers (Bondarchuk, 2008; Chaithra, Sridhara, 2018; Mao *et al.*, 2021). In addition, the use of fertilizers significantly affects biochemical compo-sition, nutritional value and taste, and shelf life. Mine-ral fertilizers have a high cost, they should be used with the greatest efficiency and payback. One of the most rational ways to apply fertilizers that can significantly increase their efficiency and reduce their costs per unit of yield is local. Studies examining the comparative effectiveness of spreading and local fertilization meth-ods have shown the advantage of the latter in growing different crops (Trapeznikov, Tavilskaya, 1980; Jing *et al.*, 2012).

Intensive agriculture indicates that fertilizers are the material basis for the quantity and quality of crop pro-ducts and a source of nutrients for plants. It is known that with this method of application it is possible to obtain a higher return from a much lower rate of ferti-lizer (Kubareva, 1980; Islam *et al.*, 2011; Fernando *et al.*, 2017). The influence of the local method of ferti-lizer application on physiological processes is mani-fested not only in the early stages of plant development but also in the period of crop formation, that is this method affects the size of the crop and its quality (Kardinalovskaya, 1980; Fomenko *et al.*, 2015; Vasiliev *et al.*, 2022).

Intensive technology, unbalanced mineral nutrition, and less or no organic fertilizers lead to depletion of soil fertility (Palm *et al.*, 1997). The local use of mineral fertilizers is of great importance today for their efficient use and optimization of crop productivity (Shalini *et al.*, 2002; Belousov *et al.*, 2020).

After analyzing the above provisions, an experimen-tal study was conducted to identify the impact of local application of mineral fertilizers in combination with the absorbent on the level of realization of the biologi-cal potential of the winter garlic cultivar 'Lubasha' which has special relevance and practical significance in the dynamic climate conditions.

Materials and Methods

Research on the technology of growing the winter garlic variety 'Lubasha' in the Right Bank Forest-Steppe of Ukraine using spreading and local methods of application and different rates of fertilizers to opti-mize mineral nutrition of the winter garlic plants and rational use of fertilizers, conducted in 2019–2021 Uman National University of Horticulture.

The soil was black, puddle, heavy loam with a well-developed humus horizon (about 2.9% of humus) (Krupskiy, Polupan, 2018), (Table 1), in the depth of 40–45 cm. Soil pH was determined in the water (soil to water ratio 1:1). The electrical conductivity (EC_e) of the soil suspension was measured using the conductivity of the meter. The P and K were determined by the am-monium bicarbonate-diethylenetriaminepentaacetic acid (ABDTPA) method (Ryan *et al.*, 2001).

Total N, including nitrate and nitrite, was determined by distillation after digestion of the sample with a mixture of salicylic acid and sulfuric acid plus sodium thiosulfate (Bremner, Mulvaney, 1982). Nitrate N (including nitrite-N) was extracted with 1.0 mol L−1 N hydrochloric acid (HCl) solution (Blacquiere *et al.*, 1987), reduced with zinc powder (Broaddus *et al.*, 1965) and then determined using the Griess-Ilosvay nitrite method (Keeney, Nelson 1982).

The organic matter contents of compost and soil were determined by the loss of weight at 450 °C (Gagnon *et al.*, 1997).

Table 1. Physical and chemical parameters of the soil of the experimental field (X ± SD)

Indicator	Actual content before fertilizer application		
	2018/19	2019/20	2020/21
Organic carbon%	1.48 ± 0.11	1.40 ± 0.08	1.43 ± 0.10
Acidity (pH)	6.0 ± 0.09	6.2 ± 0.13	6.2 ± 0.12
EC , µS cm^{-}	24.6 ± 0.48	25.1 ± 0.50	26.2 ± 0.54
Extractable P (ABDTPA), mg kg^{-1}	4.2 ± 0.10	5.5 ± 0.12	4.7 ± 0.12
Extractable K (ABDTPA), mg kg^{-1}	4.9 ± 0.12	6.3 ± 0.15	5.9 ± 0.15
NO_3N, mg kg^{-1}	3.5 ± 0.06	4.2 ± 0.08	4.4 ± 0.11

The establishment of experiments was performed by randomized design. Repetition of the experiment – four times. The accounting area one variant of the research land is 100 m^2. Garlic planting was carried out on October, 10–15 according to the 45×6 cm scheme. The scheme of the experiment included the method of cultivation (factor A – without absorbent (control) and with absorbent at the rate of 25 kg ha^{-1}) and mineral rates (25, 50, 75 and 100% of the recommended rate) of fertilizers (urea (46% nitrogen content), double superphosphate (50% phosphorus content) and potassium sulfate (50% potassium content) with spreading and local application in rows before planting. The option with 100% by the application of fertilizers is taken as a control (Table 2).

Table 2. The lack of nutrients for the formation of the planned harvest and the rate of application of mineral fertilizers (X ± SD)

Variant	Fertilizer need, kg ha^{-1}	Fertilizers, kg ha^{-1} were applied		
		2019	2020	2021
Control*	$N_{240}P_{120}K_{120}$ (spreading 100%)	$N_{236,5}P_{115,8}K_{115,1}$	$N_{235,8}P_{114,5}K_{113,7}$	$N_{235,6}P_{115,3}K_{114.1}$
100%	$N_{240}P_{120}K_{120}$ (locally)	$N_{236,5}P_{115,8}K_{115,1}$	$N_{235,8}P_{114,5}K_{113,7}$	$N_{235,6}P_{115,3}K_{114.1}$
75%	$N_{180}P_{90}K_{90}$ (locally)	$N_{176,5}P_{85,8}K_{85,1}$	$N_{175,8}P_{84,5}K_{83,7}$	$N_{175,6}P_{85.3}K_{84,1}$
50%	$N_{120}P_{60}K_{60}$ (locally)	$N_{116,5}P_{55,8}K_{55,1}$	$N_{115,8}P_{54,5}K_{53,7}$	$N_{115.6}P_{55.3}K_{54.1}$
25%	$N_{60}P_{30}K_{30}$ (locally)	$N_{56,5}P_{25,8}K_{28,8}$	$N_{55,8}P_{24,5}K_{23,7}$	$N_{55.6}P_{25.3}K_{24.1}$

* – control (100% of the recommended rate of NPK scatter)

Analysis of the above data on air temperature and precipitation from October 2018 to September 2020, compared to average long-term data (for 30 years – from 1961 to 1990), indicates a characteristic feature of this agricultural year was increased temperature background, an insufficient amount of precipitation in summer and autumn. The average air temperature of the agricultural year during the growing season of garlic plants was significantly higher in 2019 (May–June) was 17 and 23.4 °C, which was 1.6 and 4.4 °C higher than the long-term average (Fig. 1).

The total amount of precipitation during the growing season of garlic plants significantly exceeded the average long-term mark in May 2020 and June, July, and August 2021, which reduced the variation in growth and productivity in 2021. The long-term summer deficit of precipitation was noted in 2019 and 2020 which was a limiting factor for the growth and development of garlic (Fig. 2).

MaxiMarin granules: 1 kg of absorbent can accumulate up to 400 litres of water. The information provided by the manufacturer prevents soil compaction, it is safe, neutral, non-toxic, and inert to pesticides. The term of efficiency of the absorbent in the soil is up to 10 years. Because it is based on potassium, it decomposes into nitrogenous compounds, carbon dioxide, and water after decomposition.

Characteristics of the absorbent:

Basis: crosslinked copolymer of polyacrylamide and potassium polyacrylate.

Form: white granules.

Particles size: from 70 to 2000 microns.

Density: 0.5–0.6 g cm$^{3\ -1}$.

pH: 6.0–6.8.

Moisture content: 5% (± 2%)

The powder (granules) of the absorbent before the application was thoroughly mixed with fertilizers. The local application of absorbent and mineral fertilizers was applied before planting by a cultivator with fertilizer spreaders to a depth of 20–25 cm.

The scheme of the experiment was based on the results of chemical analysis of the soil that the content of nutrients was brought to the optimum level.

Biometric research. The leaf length and width, leaf blade area, and total leaf area per plant on the BBCH 53 were determined; the number of leaves per plant was calculated, and the leaf blade area was determined by a calculated (linear) method (Nichiporovich, 1969), using the parameters of length and width of the leaf by the formula:

$$Sn = 0.74 \times ab, \tag{1}$$

where:

Sn – single leaf area, cm²;

a – the largest leaf width, cm;

b – leaf length, cm;

0.74 is the leaf configuration coefficient.

Leaf index is the ratio of the total leaf area of plants to the area of soil on which they are located and was determined by the formula (Nichiporovich, 1969):

$$LAI = \frac{S_{total}}{0.1\ ha^{-1}}, \tag{2}$$

where

LAI – the leaf index;

S_{total} – total leaf area (thousand m^2 ha^{-1}).

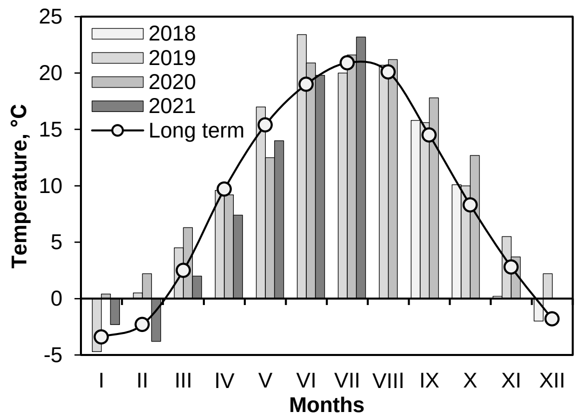


Figure 1. The average air temperature, °C (2019–2021)

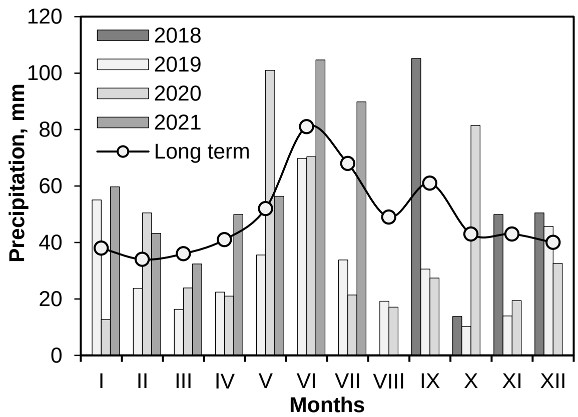


Figure 2. The amount of precipitation, mm (2019–2021)

We studied the effect of superabsorbent and local application of fertilizers on the garlic plant (enzymes activity, the productivity of plants, pigments contents in leaf; protein, fats, carbohydrate, and ash in cloves and enzymatic activity of soil). All analyzes were performed in four replicates.

Plant material. Garlic (*Allium sativum* L.) cv. 'Lubasha'.

Determination of chlorophylls

The plant material was washed with distilled water and air-dried in a shady, well-ventilated room at the temperature of 22–25°C. Then, 0.10–0.05 g of the sample was weighed and triturated with 5 mL of the solvent (ethanol) for 15 min. The obtained suspension was filtered into a volumetric flask (capacity of 10 mL) and supplemented with ethanol. Concentrations (µg mL^{-1}) of chlorophylls *a* and *b*, were determined using equations published by Lichtenthaler and Buschmann (2001):

$$\text{Chlorophyll } a = 13.36A_{664.1} - 5.19A_{648.6} \quad (3)$$

$$\text{Chlorophyll } b = 27.43\mathrm{A}_{648.6} - 8.12\mathrm{A}_{664.1} \quad (4)$$

The activity measurements of antioxidant enzymes. Enzyme activities were determined: A 1 g of plant tissue from control and treated plants was homogenized on ice in 4 ml extraction buffer (50 mM^{-1} phosphate buffer pH 7.0, containing 1 mM EDTA, 1 mM phenylmethylsulfonyl fluoride, and 1% polyvinylpolypyrrolidone). The homogenate was centrifuged for 25 min at 15 000 and 4 °C. The supernatant was used for enzyme activity assays. The means ± SD were calculated from the data of at least three independent measurements. SOD (superoxide dismutase) activity was determined spectrophotometrically by measuring the ability of the enzyme to inhibit the photochemical reduction of nitro blue tetrazolium (NBT) in the presence of riboflavin in light (Dhindsa *et al.,* 1981). One unit (U^{-1}) of SOD was the amount that causes 50% inhibition of NBT reduction in light. The enzyme activity was expressed in terms of specific activity (U mg $protein^{-1}$). POD (peroxidase) activity was determined by monitoring the increase in absorbance at 470 nm during the oxidation of guaiacol (Upadhyaya *et al.,* 1985). The amount of enzyme-producing 1 µmol min^{-1} of oxidized guaiacol was defined as 1 U-1. GST (glutathione S-transferase) activity was determined spectrophotometrically by using an artificial substrate, 1-chloro-2.4-dinitrobenzene (CDNB), according to Habig *et al.* (1974). One U is the amount of enzyme-producing 1 µmol conjugated product in 1 min, ε_{340}=9.6 mM cm^{-1}. The protein contents of the extracts were determined by the method of Bradford (1976).

The enzymatic activity of soil. Samples for soil enzymatic activity testing were collected from 20 random locations, from the topsoil (0–25 cm) from each fertilization variant, once after the crop was harvested. Tests covered the activity of dehydrogenases, urease, and protease. The enzyme activity was determined by the following methods: the activity of dehydrogenases was expressed in cm^3 H_2, required to reduce triphenyltetrazole chloride (TTC) to TFP (triphenyl formazan) (Thalmann *et al.*, 1968); urease, in mg N-NH4+, obtainned from hydrolyzed urea (Ladd, Butler, 1972); proteases, in mg of tyrosine developed from sodium caseinate (Von Mersi *et al.*, 1991; Wolinska *et al.*, 2010). The activity of tested enzymes was analyzed in soil with natural humidity, and the results were converted into absolutely dry soil mass. Dehydrogenases, by the Thalmann method, using a 1% solution of TTC as a substrate and 96-h incubation at 37 ºC, expressing their activity in cm^3 H_2 kg^{-1} d^{-1} (for 1 kg of soil in 24 h). Urease (AU), by the method of Zantu (Zantua, 1976), using a 2.5% urea solution as a substrate and an 18-h incubation at 37 ºC, expressing the enzyme activity in mg N-NH_4 + kg^{-1} h^{-1} N-NH_4 + (for 1 kg of soil in 1 h). Proteases (AP), by the method of Ladd and Butler (1972), using a 1% solution of sodium caseinate as a substrate and using a 1 h incubation at 50 ºC, expressing the enzyme activity in mg of tyrosine kg h^{-1} (per 1 kg of soil in 1 h).

The bulb dry matter (%). The average dry matter weight (g) of bulbs after curing was measured by drying 10 randomly sampled bulbs in an oven with a forced hot air circulation at 70 °C until a constant weight was obtained. The percentage of bulb dry matter was calculated by taking the ratio of the dry weight to the fresh weight of the sampled bulbs and multiplying it by 100.

The nutritional value. Proteins, fats, carbohydrates and ash content were determined by using standard methods described in the procedures of the American Organization of Analytical Chemists (International Organization of International, AOAC International) (Horwitz, Latimer, 2005). The crude fat was determined using a Soxhlet apparatus (Behr R 106 S, Germany) with petroleum ether, according to the AOAC 920.85 methodology (Horwitz, Latimer, 2016). The content of ash was determined by burning at 600 °C to constant mass following procedures AOAS 923.03 (Horwitz, Latimer, 2016). The energy was calculated by the formula:

$$Energy, kcal = 4 \times (protein) + 4 \times (carbohydrate) + 9 \times (fat) \quad (5)$$

Statistical analysis

Statistical processing of the obtained results was performed with the calculation of the arithmetic mean (x) standard deviation (SD), calculated using Microsoft Excel 2016 and Statistica 10. The obtained data were compared using an analysis of variance. The validity of the research and the significance of the differences between the mean values of the variables examined were evaluated by the dispersion and correlation analysis.

Results

The formation and proper functioning of the leaf apparatus is a determining factor in the productivity of the plant and its crops. The chlorophyll content increased with increasing the concentration of fertilizers. The content of chlorophyll a decreased with the introduction of SAP, while the content of chlorophyll b and total chlorophyll increased. The highest content of chlorophyll b (0.78% d.w.$^{-1}$) and total chlorophyll (2.01% d.w.$^{-1}$) was obtained in plants grown using absorbent and local application of 100% fertilizer (Table 3).

Table 3. Pigment and leaf complex of garlic plants of the winter cultivar 'Lubasha' depending on absorbent and fertilizer (2019–2021) (X ± SD)

Growing method (factor A)	Fertilizer rate,% of recommended (factor B)	Chlorophyll content in the leaves,% d.w.$^{-1}$ Chl. a	Chl. b	∑ Chl. a+b	No. of leaves, pcs plant^{-1}	Leaf area, cm^2	Leaf index
Without absorbent	Control (100% NPK spreading)*	1.26 ± 0.032	0.57 ± 0.015	1.83 ± 0.225	8.1 ± 0.7	60.6 ± 3.2	1.09 ± 0,04
	25% NPK locally	0.98 ± 0.027	0.47 ± 0.010	1.45 ± 0.147	7.7 ± 1.1	53.3 ± 0.4	0.92 ± 0,13
	50% NPK locally	1.21 ± 0.005	0.57 ± 0.007	1.77 ± 0.200	7.7 ± 1.1	57.2 ± 1.4	0.98 ± 0,11
	75% NPK locally	1.32 ± 0.036	0.58 ± 0.019	1.90 ± 0.200	8.2 ± 1.1	60.8 ± 1.0	1.11 ± 0,13
	100% NPK locally	1.34 ± 0.012	0.61 ± 0.019	1.94 ± 0.155	8.4 ± 0.8	63.8 ± 0.8	1.19 ± 0,13
Application of absorbent 25 kg ha^{-1}	Control (100% NPK spreading)*	1.21 ± 0.025	0.70 ± 0.011	1.91 ± 0.079	8.4 ± 0.5	74.4 ± 3.3	1.39 ± 0,02
	25% NPK locally	0.91 ± 0.020	0.62 ± 0.011	1.53 ± 0.045	8.5 ± 0.5	67.1 ± 2.4	1.26 ± 0,03
	50% NPK locally	1.11 ± 0.012	0.73 ± 0.017	1.84 ± 0.034	8.8 ± 0.4	71.8 ± 2.8	1.40 ± 0,01
	75% NPK locally	1.14 ± 0.014	0.77 ± 0.016	1.91 ± 0.032	9.0 ± 0.6	75.6 ± 3.3	1.51 ± 0,03
	100% NPK locally	1.17 ± 0.013	0.84 ± 0.023	2.01 ± 0.050	9.3 ± 0.6	80.1 ± 2.9	1.65 ± 0,04
$LSD_{0.05}$	A	0.029	0.017	0.010	0.10	0.88	0,02
	B	0.046	0.027	0.016	0.15	1.39	0,02
	A×B	0.065	0.038	0.023	0.22	1.96	0,03
Years	2019	1.21 ± 0.152	0.51 ± 0.108	1.72 ± 0.158	7.8 ± 0.64	65.2 ± 10.77	1.15 ± 0.28
	2020	1.17 ± 0.142	0.59 ± 0.112	1.89 ± 0.179	8.8 ± 0.43	63.1 ± 8.77	1.24 ± 0.23
	2021	1.15 ± 0.115	0.64 ± 0.119	2.00 ± 0.183	8.3 ± 0.51	64.1 ± 9.74	1.20 ± 0.25
	$LSD_{0.05}$	0.047	0.023	0.075	0.41	2.56	0.059

* – control (100% of the recommended rate of NPK scatter)

The indicator "number of leaves, pcs plant^{-1}" with the introduction of the absorbent increased on average, compared to the options without absorbent by 0.7–1.1 ($LSD_{0.05}$ – 0.22). The local application of fertilizers at the rate of 25 and 50% of the recommended contributed to an increase in the number of leaves against control by 0.1 pcs plant^{-1}. With the application of 75 and 100% of fertilizers locally, this figure increased by 0.6 and 0.8 pieces. (8.6 and 10.5%). When using an absorbent with local application of fertilizers, garlic plants increased the number of leaves by 0.2; 0.5; 0.8 and 1.1 pcs plant^{-1}. (+2.4...+12.7% relative to control).

The indicator of leaf area increased with the use of absorbent by 14.8–26.1% compared to similar options without absorbent. The local application of fertilizers without absorbent contributed to the increase of this indicator by 8.9–30.4%, with the introduction of absorbent the difference increased to 19.6–42.7%. The use of absorbents contributed to an increase in the leaf area of plants by 24.4–42.5% compared to similar options without absorbents. Moreover, the difference was the most significant for the application of 50% of fertilizers locally. The increase in the number of leaves and their area in total contributed to the formation of the leaf area of the plant and the leaf index greater than the control without the introduction of absorbent by 11.0–44.1%; for the use of absorbent by 22.4–60.8, which significantly affected the performance indicators, (Table 3). Our results are similar to those obtained by Ulianych *et al.* (2020) using absorbents in the cultivation of spinach, Havrilyuk *et al.* (2021) with basil.

Besides the direct effect of SAP application on plant growth and development, the increases in amino acid contents of plants make them more tolerant to the stress conditions during the vegetation period, as an indirect positive effect of SAP. The present results show that the SAP application does not cause any oxidative stress in plants. On the contrary, it reduces the formation of free oxygen radicals causing cellular damage.

Plants that were under stress with water deficiency showed a significant increase in the activity of SOD, GST and POD in the leaf compared to the versions without absorbent. The use of superabsorbents reduced the activity of antioxidant enzymes (SOD by 9.5–23.2%; GST by 7.4–13.4%; POD by 8.4–19.0%), (Table 4).

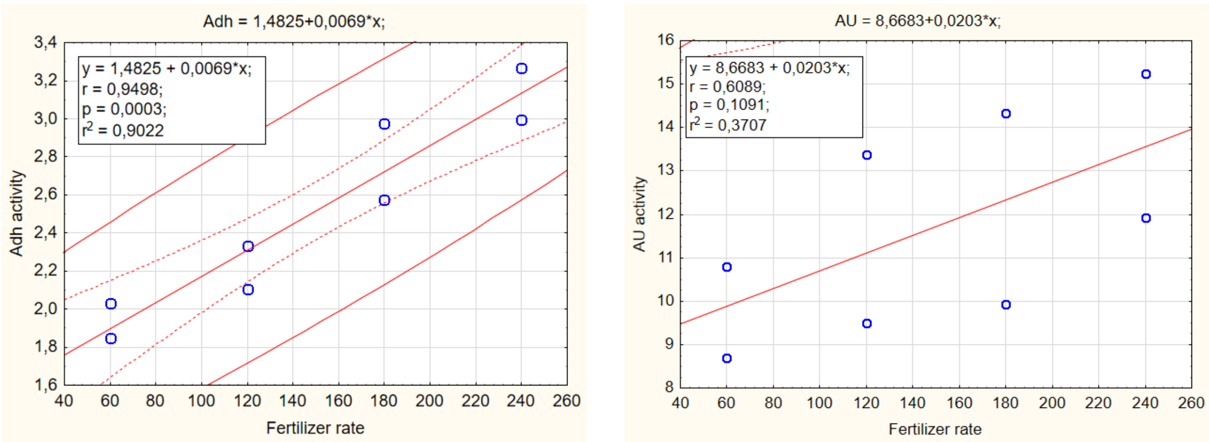
The regression analysis shown in Figure 2 showed a close dependence of dehydrogenase activity on the level of nitrogen fertilization (R^2 = 0.90); the weak relationship between urease activity and nitrogen level (R^2 = 0.37) and did not show the dependence of protease activity on the level of nitrogen fertilizer application.

The activity of soil enzymes reflects the general range of the oxidative activity of soil microflora, and therefore is used as an indicator of microbial activity (Perucci, 1992; Masciandaro *et al.*, 1994). The results of the research indicate obvious changes in the enzymatic activity of the soil under the influence of absorbent and differentiated fertilizer. In the variants fertilized locally in the norm of 50% or more, the activity of the analyzed enzymes was significantly higher than in the control variant (100% of the spreading norm). The activity of enzymes during the growing season depended mainly on the individual characteristics of the studied enzyme. The impact of years of research on enzymatic activity was high, especially in 2021, due to the different responses of enzymes to atmospheric conditions during the years of study. The data show that the absorbent significantly reduced the activity of enzymes.

Table 4. The activity of enzymes in the leaves and rhizosphere of garlic depends on the absorbent and fertilizer (2019–2021) (X ± SD)

Growing method (factor A)	Fertilizer rate,% of recommended (factor B)	Enzyme activity					
		In the leaves			In the rhizosphere		
		SOD, U mg^{-1} protein	GST, U mg^{-1} protein	POD, U mg^{-1} protein	Adh, cm^3 H_2 kg^{-1} d^{-1}	AU, mg NH_4NO_3 + kg^{-1} h^{-1}	AP, mg tyrosine kg^{-1} h^{-1}
Without absorbent	Control (100% NPK spreading)*	8.36 ± 1.34	21.73 ± 3.84	73.14 ± 14.45	2.19 ± 0.14	12.35 ± 0.42	15.35 ± 0.95
	25% NPK locally	8.50 ± 1.59	21.90 ± 4.12	75.53 ± 18.39	2.03 ± 0.14	10.79 ± 0.61	15.19 ± 0.50
	50% NPK locally	8.65 ± 1.61	22.53 ± 3.92	80.00 ± 18.24	2.33 ± 0.19	13.38 ± 0.49	15.90 ± 0.59
	75% NPK locally	8.82 ± 1.66	23.80 ± 4.10	86.04 ± 18.28	2.98 ± 0.15	14.33 ± 0.49	16.44 ± 0.66
	100% NPK locally	10.32 ± 0.76	26.74 ± 2.07	99.33 ± 7.92	3.27 ± 0.24	15.24 ± 0.85	17.18 ± 0.54
Application of absorbent 25 kg ha^{-1}	Control (100% NPK spreading)*	6.54 ± 0.25	18.87 ± 1.03	67.01 ± 2.50	1.97 ± 0.10	8.87 ± 0.15	14.24 ± 0.20
	25% NPK locally	6.62 ± 0.34	18.97 ± 1.86	61.20 ± 1.63	1.85 ± 0.13	8.69 ± 0.10	13.56 ± 0.21
	50% NPK locally	6.69 ± 0.36	19.60 ± 1.84	65.63 ± 2.10	2.11 ± 0.13	9.49 ± 0.09	14.62 ± 0.12
	75% NPK locally	6.77 ± 0.40	20.40 ± 1.70	69.73 ± 1.18	2.57 ± 0.10	9.93 ± 0.10	15.47 ± 0.11
	100% NPK locally	9.33 ± 0.17	24.77 ± 1.03	82.13 ± 1.72	3.00 ± 0.10	11.92 ± 0.37	15.81 ± 0.15
$LSD_{0.05}$	A	0.141	1.30	5.33	0.070	0.221	0.209
	B	0.224	2.06	8.43	0.110	0.350	0.331
	A×B	0.317	2.92	11.93	0.156	0.496	0.468
Years	2019	8,97 ± 1.66	25.03 ± 3.05	84.82 ± 16.07	2.62 ± 0.53	11.97 ± 2.62	15.84 ± 1.24
	2020	8.20 ± 1.53	21.77 ± 3.28	78.50 ± 12.92	2.38 ± 0.48	11.43 ± 2.23	15.41 ± 1.06
	2021	7.02 ± 1.27	18.99 ± 2.57	64.60 ± 12.37	2.28 ± 0.48	11.09 ± 2.11	14.88 ± 0.97
	$LSD_{0.05}$	0.40	1.09	3.79	0.12	0.45	0.76

* – control (100% of the recommended rate of NPK scatter); SOD – superoxide dismutas; GST – glutathione S-transferase; POD – peroxidase; Adh – dehydrogenases; AU – urease; AP – proteases.



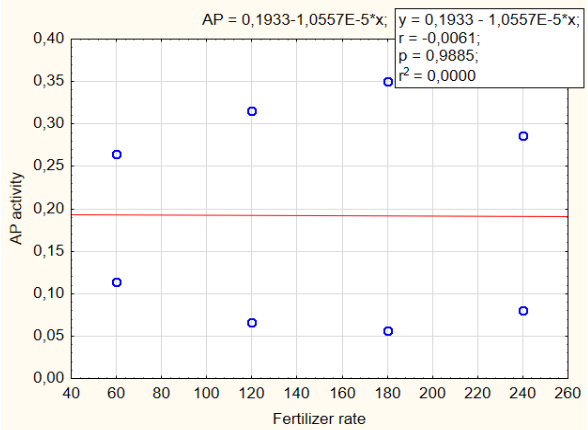


Figure 2. Spot graphs and theoretical regression line at rectilinear correlation with enzyme activity indicators and N fertilizer rate (Adh – dehydrogenases; AU – urease; AP – proteases)

The bulb weight on average with the use of absorbent increased by 8.3–21.9 g (31.2–45.4%) compared to similar options without absorbent. Local application of fertilizers without absorbent contributed to an increase in the bulb weight by 3.1–13.0 g (18.4–22.6%) relative to control, at $LSD_{0.05}$–0.90 (A), garlic plants of similar variants with the application of absorbent, increased the bulb weight by 1.2–12.3 g (2.1–21.2%) which indicates that the presence of sufficient moisture increases the efficiency of fertilizers and the level of realization of the biological potential. However, this figure in both versions of the experiment with 25% of the fertilizer rate was lower than the control by 8.1% in the version without absorbent and 6.8% with absorbent.

Garlic growing with the introduction of absorbent contributed to an increase in yield by 2.4–7.1 t ha^{-1} compared to similar options without absorbent. The local application of fertilizer without absorbent contributed to the increase in garlic yield by 0.4–1.5 t ha^{-1} (3.5–13.9%) relative to the control at the level of $LSD_{0.05}$–0.37 t ha^{-1}. With the application of the absorbent, the local application of fertilizers contributed to the increase in yield by 0.6–3.9 t ha^{-1} (4.2–25.4%) relative to the production control with 100% application of spreading fertilizers (Table 5).

Similar results of seed yield were obtained with rapeseed (Shekari *et al.*, 2015), green mass of spinach (Ulianych *et al.*, 2020) and basil (Havrilyuk *et al.*, 2021), hay (Jnanesha *et al.*, 2021).

The level of realization of biological potential was quite low. This phenomenon can be explained by the fact that in the years of research, during the rooting period, there was a fairly small amount of precipitation, especially in the 2019/20 agricultural year. At the same time, a sufficient amount of precipitation during the period of intensive growth contributed to the formation of a larger mass of bulbs, relative to 2018/19, which affected the yield, but in 2019/20 and 2020/21 increased the rate of rot by plants, which reduced yields.

Without the use of the absorbent, the yield is reduced, but the biochemical characteristics of garlic are significantly improved and the caloric content of the product is generally increased (Table 6).

Depending on the application of absorbent, the content of absolutely dry matter in garlic bulbs decreased by 2.0–4.1% compared to similar variants without absorbent. Thus, when growing garlic without absorbent, the dry matter content decreased from 30.9% in the control to 27.7% in the variant with 100% topical fertilization. With the application of absorbents, this figure decreased from 26.8% in the control to 24.3% in the version with 100% application of fertilizers locally. The maximum dry matter content was observed in the variants with the application of 25 and 50% of fertilizers.

Table 5. Bulb weight and yield of garlic depending on the absorbent and fertilizer (2019–2021) (X ± SD)

Growing method (factor A)	Fertilizer rate,% of recommended (factor B)	Mass of bulbs, g	CV, %	Yield, t ha^{-1}	CV, %
Without absorbent	Control (100% NPK spreading)*	44.6 ± 9.2	21	11.7 ± 2.4	20
	25% NPK locally	37.1 ± 7.3	20	8.8 ± 1.2	14
	50% NPK locally	46.1 ± 10.1	22	11.8 ± 2.3	19
	75% NPK locally	47.5 ± 9.9	21	12.4 ± 2.4	19
	100% NPK locally	50.0 ± 10.3	21	13.1 ± 2.6	20
Application of absorbent 25 kg ha^{-1}	Control (100% NPK spreading)*	54.8 ± 7.3	13	15.0 ± 0.8	6
	25% NPK locally	47.5 ± 5.0	10	11.9 ± 1.6	13
	50% NPK locally	56.2 ± 6.4	11	15.0 ± 0.9	6
	75% NPK locally	60.2 ± 8.1	13	15.6 ± 0.8	5
	100% NPK locally	65.2 ± 9.3	14	17.0 ± 1.0	6
	$LSD_{0.05}$ A	4.11		0.83	
	$LSD_{0.05}$ B	6.50		1.31	
	$LSD_{0.05}$ A×B	9.19		1.86	
Years	2019	43.0 ± 11.87	28	11.6 ± 3.30	28
	2020	60.2 ± 9.58	16	14.5 ± 2.32	16
	2021	49.6 ± 3.76	8	13.6 ± 2.09	15
	$LSD_{0.05}$	2.54		0.66	

* – control (100% of the recommended rate of NPK scatter)

Table 6. The content indicators of the components of biochemical composition and nutritional value of garlic depending on the absorbent and fertilizer rate (X ± SD)

Growing method (factor A)	Fertilizer rate,% of recommended (factor B)	Nitrates, mg kg^{-1}	Dry matter, %	Ash, g 100 g f. w.$^{-1}$	Protein, g 100 g f. w.$^{-1}$	Carbohydrates, g 100 g f. w.$^{-1}$	Fat, g 100 g f. w.$^{-1}$	Energy, kcal 100 g f. w.$^{-1}$
Without absorbent	Control (100% NPK spreading)*	68.5 ± 2.50	30.9 ± 3.25	1.16 ± 0.02	5.84 ± 0.49	27.40 ± 0.20	0.28 ± 0.02	135.48 ± 1.02
	25% NPK locally	66.4 ± 3.10	32.8 ± 2.66	1.10 ± 0.02	5.69 ± 0.48	25.18 ± 0.18	0.24 ± 0.03	125.68 ± 0.99
	50% NPK locally	85.0 ± 4.75	30.9 ± 2.96	1.22 ± 0.03	5.90 ± 0.53	27.84 ± 0.25	0.41 ± 0.02	138.61 ± 1.29
	75% NPK locally	105.0 ± 7.75	29.3 ± 3.82	1.27 ± 0.02	6.43 ± 0.70	26.68 ± 0.19	0.45 ± 0.03	136.49 ± 1.90
	100% NPK locally	113.5 ± 6.03	27.7 ± 3.89	1.33 ± 0.04	6.61 ± 0.60	24.21 ± 0.16	0.38 ± 0.04	126.70 ± 1.46
Application of absorbent 25 kg ha^{-1}	Control (100% NPK spreading)*	61.5 ± 1.63	26.8 ± 2.12	1.21 ± 0.01	5.29 ± 0.20	28.04 ± 0.10	0.31 ± 0.03	136.11 ± 1.18
	25% NPK locally	58.9 ± 0.90	30.9 ± 2.35	1.15 ± 0.01	5.18 ± 0.19	25.80 ± 0.16	0.26 ± 0.03	126.29 ± 0.37
	50% NPK locally	78.7 ± 3.45	28.3 ± 2.20	1.30 ± 0.03	5.48 ± 0.27	28.57 ± 0.29	0.46 ± 0.03	140.37 ± 0.62
	75% NPK locally	97.7 ± 8.0	25.8 ± 2.35	1.34 ± 0.04	5.67 ± 0.21	27.23 ± 0.17	0.50 ± 0.04	136.10 ± 0.44
	100% NPK locally	103.0 ± 8.94	24.3 ± 2.35	1.38 ± 0.02	5.89 ± 0.16	25.05 ± 0.04	0.41 ± 0.03	127.45 ± 0.17
$LSD_{0.05}$	A	1.62	0.53	0.013	0.14	0.08	0.017	0.31
	B	2.57	0.85	0.021	0.22	0.13	0.027	0.49
	A×B	3.63	1.20	0.030	0.32	0.18	0.038	0.69
Years	2019	83.8 ± 19.94	31.99 ± 3.58	1.22 ± 0.09	6.16 ± 0.57	26.38 ± 1.41	0.33 ± 0.08	133.17 ± 5.46
	2020	80.5 ± 34.20	29.34 ± 3.82	1.26 ± 0.10	5.96 ± 0.59	26.61 ± 1.48	0.37 ± 0.10	133.58 ± 6.00
	2021	71.9 ± 28.99	26.69 ± 3.63	1.25 ± 0.09	5.29 ± 0.28	26.80 ± 1.49	0.41 ± 0.09	132.04 ± 5.79
	$LSD_{0.05}$	3.93	1.47	0.061	0.29	1.06	0.018	6.64

* – control (100% of the recommended rate of NPK scatter)

The use of absorbent and local application of fertilizers increased the ash content from 1.16 g 100 g f. w.$^{-1}$ in the control without absorbent up to 1.38 g 100 g f. w.$^{-1}$ with the introduction of absorbent and 100% fertilizer.

The content of nitrates and protein decreased with the use of the absorbent but increased with the local application of fertilizers. These findings may be because protein is considered a good indicator of plant resistance to water deficiency, as the water intake causes hydrolysis and catabolism of proteins, releasing free amino acids and ammonia, as well as proline (Fayed *et al.*, 2018; Mayer *et al.*, 2021). Moreover, fertilizer application rate and soil moisture have been reported to significantly affect protein content in garlic bulbs (Diriba-Shiferaw *et al.*, 2014). The local application of fertilizers contributes to a greater accumulation of nitrates in the bulbs, so it is advisable to use these products for processing. The maximum permissible concentration of nitrates is 80 mg kg^{-1}, while in our studies their content exceeded the permissible level at 50% of fertilizers application locally without absorbent and 75% with absorbent.

The nutritional value of the studied garlic genotypes is presented in Table 6 and is within the range of the values suggested by Brewster (2008) regarding proteins, carbohydrates, fat, and energy content, and Haciseferogullari *et al.* (2005) for crude protein and ash.

The concentration of carbohydrates and fats also increased which indicates the greater efficiency of fertilizers using absorbents. However, within the framework of factor A, the maximum values of carbohydrate content were reached with the application of 50% of fertilizers, with the application of 100% a significant decrease in their content was observed. The maximum fat content was observed for the application of 75% of fertilizers and a significant decrease for the application of 100%. The same trend is observed with the caloric content of products where the energy value of the product is highest in the options with 50% of fertilizers and decreases significantly with the introduction of 100%.

Discussion

Scientific substantiation of the local application of fertilizers in combination with the absorbent is an important tool for improving the productivity and sustainability of agriculture (Li *et al.*, 2019a,b).

The chlorophyll content is an important biochemical indicator of stress tolerance in plants (Percival *et al.*, 2003). Therefore, the increase in chlorophyll levels of SAP treated plants can be considered an indication that plants are not experienced with water and nutrient stress. In other words, these plants take water and nutrients sufficiently. SAP treatment increased, especially, N and Mg uptakes, allowing to form the central ion of chlorophyll and, consequently, building a darker green leaf colour (Buehner, 1956). Similar to our findings, SAP addition significantly increased the amounts of chlorophyll in cucumber (Li *et al.*, 2019a) and pepper (Sayyari, Ghanbari, 2012) plants. Moghadam (2017) reported that total chlorophyll content in the wheat plant was increased by SAP application doses (5 and 10 g per kg soil).

Our results are consistent with those of other scientists who show a decrease in the enzymatic activity with the introduction of absorbent in rapeseed (Foyer, Halliwell, 1976), corn (Habibi *et al.*, 2009), basil (Havrilyuk *et al.*, 2021). The lack of moisture (drought stress) directly or indirectly leads to the formation of oxygen radicals which leads to increased peroxidation of lipids which, in turn, can increase the formation of free radicals and cause oxidative stress (Johnson *et al.*, 2003). In our study, the superabsorbent polymer reduced the activity of these enzymes, possibly by eliminating free radicals.

The use of hydrolytic enzymes in the soil is a common approach to assessing soil quality. Enzyme activity in the soil depends on several factors. They include, for example, the content of organic matter, soil pH, the content of biogenic elements, and the quantity and condition of microorganism species (Wolinska, 2010; Bielinska, Mocek-Plociniak, 2012). According to Koper *et al.* (2004), Bielinska and Mocek-Plociniak (2012), Natywa *et al.* (2014) and Wang *et al.* (2020), the cultivation system, as well as various agrotechnical procedures, such as the correct crop rotation, the amount and type of fertilization, and the species and cultivar of crops, also have a great influence of the enzymatic activity and thus the fertility of the soil. As shown in Table 4 and Figure 2, the activity of enzymes in the soil with increasing fertilizer rate increased from 50% relative to the control with 100% scatter, but decreased significantly with the application of absorbents, which can be explained by improved water regime and soil stabilization. High activity of dehydrogenases in objects with higher nitrogen fertilization might have resulted from higher concentration of root exudates secreted by the root system of garlic.

Consistent with our findings the positive effects of SAPs applications on plant weight, height, and yield in cucumber, pepper, tomato, and soya bean are shown (Maboko, 2006; Yazdani *et al.*, 2007; Sayyari, Ghanbari, 2012; Başak *et al.*, 2016; Li *et al.*, 2019b). The increases in plant growth and yield by SAP treatment can be attributed to the presence of a sufficient amount of water and nutrients which can be easily taken with low pressure in the root area.

The local application of fertilizers improves the availability of NPK in the root zone which increases the absorption of nutrients by the plant. The studies show that such an increase in nutrients contributes to the accumulation of plant biomass due to greater intensity of photosynthesis (Chen *et al.*, 2018). However, excess fertilizers can lead to low water availability for plants due to high osmotic conditions in the soil (Studer *et al.*, 2007), but this can be compensated by absorbents that will help evenly provide plants with easily accessible moisture and nutrients.

The use of superabsorbent polymer improves plant growth. For example, the total amount of raw cucumber biomass (*Cucumis sativus L.*) and fruit biomass increased with the addition of 2% absorbent to the substrate mixture by 840 and 494 g^{-1} per plant, by Montesano *et al.* (2015). Another study with different varieties of potatoes (*Solanum tuberosum L.*) found an increase in tuber yield using superabsorbents locally in the furrows to a depth of 25 cm^{-1} (Salavati *et al.*, 2018). A similar result was found with the application of 60 and 90 kg ha^{-1}, which increased the yield of potatoes by 38.2 and 50.5% relative to the control when applying superabsorbents to a depth of 20 cm (Hou *et al.*, 2017). Although the use of superabsorbents can improve plant growth, the depth of its use can significantly affect its effectiveness.

In conditions of insufficient moisture, superabsorbents have a greater impact on plant productivity (Fazeli Rostampour *et al.*, 2013; Eneji *et al.*, 2013). The dry matter of sorghum (*Sorghum bicolor L.* Moench) increased only when there was a shortage of water in the sandy loamy soil (Fazeli Rostampour *et al.*, 2013). Similar results were obtained with beans (*Phaseolus vulgaris L.*) grown with superabsorbents (Satriani *et al.*, 2018). The use of absorbent materials has increased the yield of Citrus limon (Pattanaaik *et al.*, 2015), and coffee plants (Pieve *et al.*, 2013).

Conclusion

In the variants with local application and increasing fertilizer rate, the activity of the analyzed enzymes increased relative to control. The intensity of biochemical processes in the soil depended on the type of enzyme which is associated with the individual sensitivity of the enzyme to environmental factors and the content of minerals for the enzymatic reaction in the soil. The activity of dehydrogenase increased with increasing levels of fertilizers, including nitrogen. However, the use of absorbents contributed to the stabilization of the soil environment, increasing the availability of nutrients and, accordingly, reducing the activity of enzymes of one variant without absorbent.

To use fertilizers more efficiently and improve soil fertility it is advisable to apply fertilizers locally in rows immediately before or during the planting of garlic.

When growing garlic for food purposes (with or without absorbent) and saving fertilizers up to 50% they should be applied in the norm $N_{120}P_{60}K_{60}$ kg ha^{-1} which will ensure the formation of garlic yield at 11.8 t ha^{-1} (without absorbent) and 15.0 t (with absorbent).

To grow garlic for processing and to obtain the maximum yield in the Right-Bank Forest-Steppe of Ukraine the fertilizers should be applied locally at the rate ($N_{240}P_{120}K_{120}$ kg ha^{-1}) which will ensure crop yield of 13.1 t ha^{-1} (without absorbent) and 17.0 t ha^{-1} (with absorbent).

SAP application increased growth, yield, leaf chlorophyll, and nutrient composition contents. This increase did not only have a positive effect on plant development but also made plants more tolerant to the stress conditions.

Acknowledgements

I would like to thank the staff of the Laboratory of Mass Analysis of Uman National University of Horticulture for the help provided during the experiment

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

VY, NV, SP – study conception and design;
VY, NV, OL, VK – acquisition, analysis, and interpretation of data;
VY, SP, IM – revision, and approval of the final manuscript.

References

Adams, J. C., Lockaby, B. G., 1987. Commercial produced superabsorbent material increases water-holding capacity of soil medium. – Tree Planters Notes, 38(1):24–25.

Başak, H., Şahin, E., Kıymaz, S. 2016. Effect of water holding polymers and water restriction on growth of tomato cultivated in different soilless cultures. – VII International Scientific Agriculture Symposium “Agrosym 2016”, Jahorina, Bosnia and Herzegovina, 6–9 October, pp. 2101–2109.

Beigi, S, Azizi, M, Iriti, M. 2020. Application of super absorbent polymer and plant mucilage improved essential oil quantity and quality of *Ocimum basilicum* var. Keshkeni Luvelou. – Molecules. 25(11):2503. DOI: 10.3390/molecules25112503

Belousov, S., Khanin, Y., Zhadko, V. 2020. Methods and means of concentrated fertilizers application. – IOP Conference Series: Materials Science and Engineering, 971:052050. DOI: 10.1088/1757-899X/971/5/052050

Bielinska, E.J., Mocek-Płóciniak, A. 2012. Impact of the tillage system on the soil enzymatic activity. – Archives of Environmental Protection, 38(1):75–82. DOI: 10.2478/v10265-012-0006-8

Blacquiere, T., Hofstra, R., Stulen I. 1987. Ammonium and nitrate nutrition in *Plantago lanceolata* and *Plantago major L.* ssp. major. I. Aspects of growth, chemical composition and root respiration. – Plant Soil, 104:129–141.

Bondarchuk, A.A. 2008. State and priority directions of development of the potato growing industry in Ukraine. – Potato growing, 37:7–13.

Bradford, M.M. 1976. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. – Analytical Biochemistry, 72(1–2):248–254. DOI: 10.1016/0003-2697(76)90527-3

Bremner, J. M., Mulvaney, C. S. 1982: Salicylic acid-thiosulfate modification on Kjeldahl method to include nitrate and nitrite. – In Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. Page, A.L. (Ed.). – Academic Press, New York, pp. 621–622.

Brewster, J. L. 2008. Onions and other vegetable Alliums (2nd ed.) – CABI:Wallingford, UK, 432 p.

Broaddus, G.M., York, J.E., Hoseley, J.M. 1965. Factors affecting the levels of nitrate nitrogen in cured tobacco leaves. – Tobacco Science, 9:149–157.

Buehner, A. 1956. Grundsaetzlisches zur Düngung der Weinberg. – Weinberg und Keller, 3:453–462.

Chaithra, G., Sridhara, S. 2018. Growth and yield of rainfed maize as influenced by application of super absorbent polymer and Pongamia leaf mulching. – International Journal of Chemical Studies, 6(5):426–430.

Chen, Z, Tao, X, Khan, A, Tan, D.K.Y., Luo, H. 2018. Biomass accumulation, photosynthetic traits and root development of cotton as affected by irrigation and nitrogen-fertilization. – Frontiers in Plant Science, 9:173. DOI: 10.3389/fpls.2018.00173

Dehkordi, D.K. 2018. Effect of superabsorbent polymer on soil and plants on steep surfaces. – Water and Environment Journal, 32(2):9158–163. DOI: 10.1111/wej.12309

Dhindsa, R.S., Plumb-Dhindsa, P., Thorpe, T.A. 1981. Leaf senescence: correlated with increased levels of membrane permeability and lipid peroxidation, and decreased levels of superoxide dismutase and catalase. – Journal of Experimental Botany, 32(1): 93–101. DOI: 10.1093/jxb/32.1.93

Diriba-Shiferaw, G., Nigussie-Dechassa, R., Woldetsadik, K., Tabor, G., Sharma, J.J. 2014. Bulb quality of Garlic (*Allium sativum* L.) as influenced by the application of inorganic fertilizers. – African Journal of Agricultural Research, 9(8):778–790. DOI: 10.5897/AJAR2013.7723

El-Hady, O.A., Wanas S.A. 2006. Water and fertilizer use efficiency by cucumber grown under stress on sandy soil treated with acrylamide hydrogels. – Journal of Applied Sciences Research, 2(12):1293–1297.

Eneji, A., Islam, R., An, P., Amalu, U.C. 2013. Nitrate retention and physiological adjustment of maize to soil amendment with superabsorbent polymers. – Journal of Cleaner Production, 52:474–480. DOI: 10.1016/j.jclepro.2013.02.027

Fayed, T.B., Abdrabbo, M.A A., Maha, M., Hamada, A., Hashem, F.A., Hegab, A.S. 2018. Irrigation requirements of faba-bean under two climatic locations in Egypt. – Journal of General Virology, 6(2):85–94. DOI: 10.21608/ejar.2018.135777

Fazeli Rostampour, M., Yarnia, M., Rahimzadeh Khoee, F., Seghatoleslami, M.J., Moosavi, G.R. 2013. Physiological response of forage sorghum to polymer under water deficit conditions. – Agronomy Journal, 105:951–959. DOI: 10.2134/agronj2012.0071

Fernando, T.N., Ariadurai, S.A., Disanayaka, C.K., Kulathunge, S., Aruggoda, A. 2017. Development of radiation grafted super absorbent polymers for agricultural applications. – Energy Procedia, 127:163–177. DOI: 10.1016/j.egypro.2017.08.106

Fomenko, T., Popova, V.P., Pestova, N. 2015. Effect of local fertilization and water reclamation on soil parameters of orchard cenoses. – Russian Agricultural Sciences, 41:247–251. DOI: 10.3103/S1068367415040060

Foyer, C.H., Halliwell, B. 1976. The presence of glutathione and glutathione reductase in chloroplasts: A proposed role in ascorbic acid metabolism. – Planta, 133:21–25. DOI: 10.1007/BF00386001

Gagnon, B., Simard, R. R., Robitaille. R., Goulet, M., Rioux, R. 1997. Effect of composts and inorganic fertilizers on spring wheat growth and N uptake. – Canadian Journal of Soil Science, 77:487–495. DOI: 10.4141/S96-093

Habibi, D., Mashhadi-Akbar-Boojar, M. 2009. The effects of Zeolite and foliar applications of selenium on growth, yield and yield components of three canola cultivars under drought stress. – World Applied Sciences Journal, 7(2):255–262.

Habig, W.H., Pabst, M.J., Jakoby, W.B. 1974. Glutathione S-transferases. The first enzymatic step in mercapturic acid formation. – The Journal of Biological Chemistry, 246(22):7130–7139.

Haciseferogullari, H., Özcan, M., Demir, F., Çalisir, S. 2005. Some nutritional and technological properties of garlic (*Allium sativum* L.). – Journal of Food Engineering, 68(4):463–469. DOI: 10.1016/j.jfoodeng.2004.06.024

Havrilyuk, M., Fedorenko, V., Ulianych, O., Kucher, I., Yatsenko, V., Vorobiova, N., Lazariev, O. 2021. Effect of superabsorbent on soil moisture, productivity and some physiological and biochemical characteristics of basil. – Agronomy Research, 19(2): 394–407, 2021. DOI: 10.15159/AR.21.080

Horwitz, W., Latimer, G. 2005. Official Methods of Analysis of AOAC International (18th ed.). – AOAC International, USA.

Horwitz, W., Latimer, G. 2016. Official Methods of Analysis of AOAC International (20th ed.). – AOAC International, USA, 3172 p.

Hou, X., Li, R., He, W., Dai, X., Ma, K., Liang, Y. 2017. Superabsorbent polymers influence soil physical properties and increase potato tuber yield in adry-farming region. – Journal of Soils and Sediments, 18:816–826. DOI: 10.1007/s11368-017–1818-x

Hüttermann, A.; Orikiriza, L. J. B.; Agaba, H. 2009. Application of superabsorbent polymers for improving the ecological chemistry of degraded or polluted lands. – Clean Soil Air Water. 37(7):517–526. DOI: 10.1002/clen.200900048

Islam, M.R., Hu, Y., Mao, S., Mao, J., Eneji, A.E., Xue, X. 2011. Effectiveness of a water-saving super-absorbent polymer in soil water conservation for corn (*Zea mays* L.) based on eco-physiological parameters. – Journal of the Science of Food and Agriculture, 91(11):1998–2005. DOI: 10.1002/jsfa.4408

Jing, J., Zhang, F., Rengel, Z., Shen, J. 2012. Localized fertilization with P plus N elicits an ammonium-dependent enhancement of maize root growth and nutrient uptake. – Field Crops Research, 133:176–185. DOI: 10.1016/j.fcr.2012.04.009.

Jnanesha, C., Ashish, K., Lal, R.K. 2021. Hydrogel application improved growth and yield in Senna (*Cassia angustifolia* Vahl.). – Industrial Crops and Products, 174:114175. 10.1016/j.indcrop.2021.114175

Johnson, S.M., Doherty, S.J., Croy, R.R.D. 2003. Biphasic superoxide generation in potato tubers: A self amplifying response to stress. – Plant Physiology, 131(3):1440–1449. DOI: 10.1104/pp.013300

Kardinalovskaya, R. I. 1980. Effektivnost' lokal'nogo vneseniya osnovnogo mineral'nogo udobreniya pod sel'skokhozyaystvennyye kul'tury [Efficiency of local application of the main mineral fertilizer for agricultural crops]. Kiev, 42 p. [In Russian]

Keeney, D. R., Nelson, D. W. 1982: Modified Griess–Ilosvay method. – In Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. Page, A.L. (Ed.). – Academic Press, New York, USA, pp. 684–687.

Koper, J., Lemanowicz, J., Igras, J. 2004. Wplyw nawozenia na aktywnosc fosfatazy i zawartosc wybranych frakcji fosforu [The effect of fertilization on the phosphatase activity and the content of some phosphorus forms]. – Annales Universitatis Mariae Curie-Sklodowska. Sectio E Agricultura, 49:679–686. [In Polish]

Krupskiy, N.K., Polupan, N.I. 2018. Atlas monitoringa kompleksnoj ocenki plodorodija pochv Lesostepi i Stepi Ukrainy [Atlas of monitoring of a comprehensive assessment of soil fertility in the Forest-steppe and Steppe of Ukraine]. Urozhaj, Kyiv, 159 s. [In Russian].

Kubareva, L.S. 1980. Lokal'noe vnesenie udobrenij – odin iz putej po-vyshenija ih jeffektivnosti [Local application of fertilizers is one of the ways to increase their efficiency]. – Vestnik Nauchno-issledovatel'skij Institut Udobrenij i Agropochvovedenija Imeni V.I.D.N. Prjanishnikova [Bulletin Research Institute of Fertilizers and Agrosoil Science named after V. I. D. N. Pryanishnikov]. 53:3–9. [In Russian].

Ladd, J.N.; Butler, J.H.A. 1972. Short-term assays of soil proteolytic enzyme activities using proteins and dipeptide derivatives as substrates. – Soil Biology and Biochemistry, 4(1):19–30

Li, Y., Shi, H., Zhang, H., Chen, S. 2019a. Amelioration of drought effects in wheat and cucumber by the combined application of super absorbent polymer and potential biofertilizer. – The Journal of Life and Environmental Sciences, 7:e6073. DOI: 10.7717/peerj.6073

Li, Y.K., Xue, X.Z., Guo, W.Z., Wang, L.C., Duan, M.J., Chen, H. 2019b. Soil moisture and nitrate-nitrogen dynamics and economic yield in the greenhouse cultivation of tomato and cucumber under negative pressure irrigation in the North China Plain. – Scientific Reports, 9(1):4439. DOI: 10.1038/s41598-019-38695-4

Lichtenthaler, H.K., Buschmann, C. 2001. Chlorophylls and carotenoids: Measurement and characterization by UV-VIS spectroscopy. – In Current protocols in food analytical chemistry. – New York, NY, USA: Wiley pp. F4–F4.3.8. DOI: 10.1002/0471142913.faf0403s01

Maboko, M.M. 2006. Growth, yield and quality of tomatoes (*Lycopersicon esculentum* Mill.) and lettuce (*Lactuca sativa* L.) as affected by gel-polymer soil amendment and irrigation management. – Master's Dissertation, Natural and Agricultural Sciences University of Pretoria, South Africa, 104 p.

Mao, L., Zha, R., Chen, S., Zhang, J., Jie, L., Zha, X. 2021. Mixture compound fertilizer and super absorbent polymer application significantly promoted growth and increased nutrient levels in *Pinus massoniana* seedlings and soil in seriously eroded degradation region of southern China. – Frontiers in Plant Science, 12:763175. DOI: 10.3389/fpls.2021.763175

Masciandaro, G., Ceccanti, B., Garcia, C. 1994. Anaerobic digestion of straw and piggery wastewaters: II. Optimization of the process. – Agrochimica, 38:195–203.

Mayer, L., Inger, C., Frokiær, H., Sandberg, A. S. 2021. Nutritional and antinutritional composition of fava bean (*Vicia faba* L., *var. minor*) cultivars. – Food Research International, 140:110038. DOI: 10.1016/j.foodres.2020.110038.

Moghadam, H.R.T. 2017. Super absorbent polymer mitigates deleterious effects of arsenic in wheat. – Rhizosphere 3(1):40–43. DOI: 10.1016/j.rhisph.2016.12.003

Montesano, F.F., Parente, A., Santamaria, P., Sannino, A., Serio, F. 2015. Biodegradable superabsorben thydrogel increases water retention properties of growing media and plant growth. – Agriculture and Agricultural Science Procedia, 4:451–458. DOI: 10.1016/j.aaspro.2015.03.052

Natywa, M., Selwet, M., Maciejewski, T. 2014. Effect of some agrotechnical factors on the number and activity soil microorganisms. Fragmenta Agronomica, 31:56–63.

Nichiporovich, A.A. 1969. Metodicheskie ukazanija po uchetu i kontrolju vazhnejshih pokazatelej processov fotosinteticheskoj dejatel'nosti rastenij v posevah [Methodical instructions on the accounting and control of the most important indicators of the processes of photosynthetic activity of plants in crops]. – VASKhNIL, Moscow, Russia, 93 p. [In Russian].

Orzeszyna, H., Garlikowski, D., Pawlowski, A. 2006. Using of geocomposite with superabsorbent synthetic polymers as water retention element in vegetative laters. – International of Agrophysics, 20(3):201–206.

Palm, C.A., Myers, R.J.K., Nandwa, S.M. 1997. Combined use of organic and inorganic nutrient source for soil fertility maintenance and replenishment. – In Replenishing soil fertility in Africa. Bruesh, R.J., Sanchez, P.A., Calhoun, F. (Eds.). – SSSA Special Publications, 51:193–217. DOI: 10.2136/sssaspecpub51.c8

Pattanaaik, S.K., Singh, B., Wangchu, L., Debnath, P., Hazarika, B.N., Pandey, A.K. 2015. Effect of hydrogel on water and nutrient management of *Citrus limon*. – International Journal of Agriculture Innovations and Research, 3(5):1555–1558.

Percival, G.C., Fraser, G.A., Oxenham, G. 2003. Foliar salt tolerance of Acer genotypes using chlorophyll fluorescence. – Journal of Arboriculture, 29:61–65.

Perucci, P. 1992. Enzyme activity and microbial biomass in a field soil amended with municipal refuse. – Biology and Fertility of Soils, 14:54–60. DOI: 10.1007/BF00336303

Pieve, L.M., Guimares, R.J., Assis, G.A., Amato, G.A.S., Correa, J.M. 2013. Use of water retention polymers during implementation of coffee plantations. – Coffee Science, 8(3):314–323.

Ryan, J., Estefan, G., Rashid, A. 2001. Soil and plant analysis laboratory manual (2nd ed.). ─ International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria, 172 p.

Salavati, S., Valadabadi, S.A., Parvizi, K.H., Sayfzadeh, S., Hadidi Masouleh, E. 2018. The effect of super-absorbent polymer and sowing depth on growth and yield indices of potato (*Solanum tuberosum* L.) in Hamedan Province, Iran. – Applied Ecology and Environmental Research, 16:7063–7078. DOI: 10.15666/aeer/1605_70637078

Sarvas, M., Pavlenda, P., Takacova, E. 2007. Effect of hydrogel application on survival and growth of pine grainling in reclamations. – J. Forest Sci., 53(5):204–209.

Satriani, A., Catalano, M., Scalcione, E. 2018. The role of superabsorbent hydrogel in bean crop cultivation under deficit irrigation conditions: Acase-studyin Southern Italy. – Agricultural Water Management, 195:114–119. DOI: 10.1016/j.agwat.2017.10.008

Sayyari, M., Ghanbari, F. 2012. Effects of super absorbent polymer A200 on the growth, yield and some physiological responses in sweet pepper (*Capsicum annuum* L.) under various ırrigation regimes. – International Journal of Agricultural and Food Research, 1(1):1–11.

Scott, J.; Blair, G. 1988. Phosphorus seed coatings for pasture species. I. Effect of source and rate of phosphorus on emergence and early growth of phalaris (*Phalaris aquatica* L.) and lucerne (*Medicago sativa* L.). – Australian Journal of Agricultural Research, 39(3):437–445.

Shalini, S.B., Channal, H.T., Hebsur, N.S., Dharmatti, P.R., Srangamath, P.A. 2002. Effect of integrated nitrogen management on nutrient uptake in Knolkhol, yield and nutrient availability in the soil. – Karnataka Journal of Agricultural Sciences, 15(1):43–46

Shekari, F., Javanmard, A., Abbasi, A. 2015. Effects of super-absorbent polymer application on yield and yield components of rapeseed (*Brassica napus* L.). – Notulae Scientia Biologicae, 7(3):361–366. DOI: 10.15835/nsb.7.3.9554

Sivapalan, S. 2001. Effect of a polymer on growth and yield of soybeans (*Glycine max*) grown in a coarse textured soil. – Proceedings Irrigation 2001. Regional Conference, Toowoomba, Queensland, Australia, pp. 93–99.

Studer, C, Hu, Y.C., Schmidhalter, U. 2007. Evaluation of the differential osmotic adjustments between roots and leaves of maize seedlings with single or combined NPK-nutrient supply. – Functional Plant Biology, 34:228–236. DOI: 10.1071/FP06294

Thalmann, A. 1968. Zur Methodik der Bestimmung der Dehydrogenase Aktivität in Boden Mittels Triphenyltetrazoliumchlorid (TTC). – Landwirtschaft. Forsh, 21:249–258. [In German]

Thombare, N., Mishra, S., Siddiqui, M., Jha, U., Singh, D., Mahajan, G. R. 2018. Design and development of guar gum based novel, superabsorbent, and moisture retaining hydrogels for agricultural applications. – Carbohydrate Polymers, 185:169–178. DOI: 10.1016/j.carbpol.2018.01.018

Trapeznikov, V.K., Tavilskaya, N.G. 1980. Fiziologicheskiye osobennosti formirovaniya urozhaya yarovoy pshenitsy i kukuruzy pri razbrosnom i lokal'nom vnesenii udobreniy. [Physiological features of the formation of the yield of spring wheat and maize with widespread and local application of fertilizers]. – Bulgarian Research Institute of Fertilizers and Agrosoil Science named after V.I. D.N. Pryanishnikov. 53:16. [In Russian].

Ulianych, O., Kostetska, K., Vorobiova, N., Shchetyna, S., Slobodyanyk, G., Shevchuk, K. 2020. Growth and yield of spinach depending on absorbents'action. – Agronomy Research, 18(2):619–627. DOI: 10.15159/AR.20.012

Upadhyaya A., Sankhla D., Davis T.D., Sankhla N., Smith B. N. 1985. Effect of paclobutrazol on the activities of some enzymes of activated oxygen metabolism and lipid peroxidation in senescing soybean leaves. – Journal of Plant Physiology, 121: 453–461.

Vasiliev, A., Oleynikova, E., Lisunov, O., Boginya, M. 2022. Efficiency of local application of mineral fertilizers simultaneously with pre-sowing tillage. – IOP Conference Series: Earth and Environmental Science, 981:042041. DOI: 10.1088/1755-1315/981/4/042041.

Von Mersi, W., Schinner, F. 1991. An improved and accurate method for determining the dehydrogenase activity of soil with iodonitrotetrazolium chloride. – Biology and Fertility of Soils, 11:216–220. DOI: 10.1007/BF00335770

Wang, L., Zhao, Y., Al-Kaisi, M., Yang, J., Chen, Y., Sui, P. 2020. Effects of seven diversified crop rotations on selected indicators of soil condition and wheat productivity. – Agronomy, 10(2):235. DOI: 10.3390/agronomy10020235

Wolinska, A. 2010. Dehydrogenase activity of soil enzymes and oxygen availability in the reoxidation process of selected mineral Polish soils. Dissertations and Monographs. – Acta Agroph, 180:1234–4125.

Xi, J., Zhang, P. 2021. Application of super absorbent polymer in the research of water-retaining and slow-release fertilizer. – IOP Conference Series: Earth and Environmental Science, 651:042066. DOI: 10.1088/1755-1315/651/4/042066

Yazdani, F., Allahdadi, I., Akbari, G. A. 2007. Impact of süper absorbent polymer on yield and growth analysis of soybean (*Glycine max* L.) under drought stress condition. – Pakistan Journal of Biological Sciences 10(23): 4190–4196.

Zantua, M.I. 1976. Urease activity in soils. – PhD Dissertation. Iowa State University, Ames, IA, USA, 110 p.

Zohuriaan-Mehr, M.J. K. Kabiri. 2008. Superabsorbent polymer materials: a review. – Iranian Polymer Journal, 17(6):451–477.

AKADEEMILISE PÕLLUMAJANDUSE SELTSI 2021. AASTA TEGEVUSARUANNE

Mittetulundusühingu, Akadeemiline Põllumajanduse Selts (APS) tegevuse eesmärk on kaasa aidata Eesti maaelu, põllumajanduse ning põllumajandus- ja keskkonnateaduste arengule. APSi liikmeteks on isikud, kes on tasunud sisseastumismaksu ning täidavad seltsi põhikirjast tulenevaid kohustusi. Selts asutati 1920. aastal. Tartu Ülikooli juures, mil kandis nime Akadeemiline Põllumajanduslik Selts; seega on APS eelpool nimetatud seltsi tegevuse jätkaja.

Akadeemilise Põllumajanduse Seltsi tööd korraldab eestseisus (juhatus), kuhu kuulub kuni 13 liiget. Eestseisusesse kuulusid 2021. aastal tehn-dr Arvo Leola, pm-knd Peep Piirsalu, *PhD* Ingrid Bender, pm-dr Ülle Tamm, tehn-mag Katrin Laikoja, pm-dr Jaan Kuht, *PhD* Evelin Loit (asepresident), pm-mag Avo Toomsoo, prof Marina Aunapuu, *PhD* Matti Piirsalu ja *PhD* Marko Kass (president). Seltsi eestseisusesse kuulub veel ka ametist tulenevalt Agraarteaduse peatoimetaja pm-dr Alo Tänavots. Seltsi sekretäri ametis jätkab pm-dr Heli Kiiman.

Seltsi ridades oli aruandeperioodi lõpul 210 liiget, kellest koosolekutel ja sündmustel osaleb aktiivselt ligi 30. Seltsi võeti 2021. aastal kaks liiget (*PhD* Reelika Rätsep, tehn-mag Kristi Kerner). Seltsil on 31 auliiget, sh kolm aupresidenti.

Traditsiooni kohaselt annab president aasta lõpus ühele seltsiliikmele tiitli „AASTA TEGIJA", mille juurde kuulub presidendi rändkarikas. 2021. aastal pälvis tiitli Arvo Leola, silmapaistva panuse eest seltsi sündmuste korraldamise ja pikaajalise tulemusliku õppetöö eest (anti üle 2022. aasta üldkoosolekul).

Toimus neli eestseisuse koosolekut (19.01., 19.03., 28.10. ja 10.11.) ning kuus ettekandekoosolekut (kaheksa ettekannet). Eestseisuse koosolekutel on peamisteks aruteluteemadeks ürituste korraldamine, seltsi ajakirja väljaandmine, seltsi eelarve, liikmete tunnustamine ja tegevuskava jooksvaks aastaks. Üheks teemaks on koostöö Eesti Taimekasvatuse Instituudiga ning seltsi visioonikonverentsi korraldamine koos instituudiga. Eestseisus on võtnud eesmärgiks korraldada igas kuus ühe sündmuse. Seltsi juubeliraamatu kokku panemine on takerdunud, kuna muud tööülesanded on pärssinud korraldustoimkonna tegevust.

Seoses COVID pandeemiaga jäi ära seltsiliikmetele mõeldud traditsiooniline aastalõpu koosviibimine. Ent samas toimusid mitmed sündmused veebi vahendusel.

3. veebruaril toimus seltsi ettekandekoosolek videosilla vahendusel, kus ettekande tegi taimekasvatuse instituudi teadur Anne Ingver teemal "Viljelussüsteemi eelvilja ja ilmastikutingimuste mõju suvinisu saagile ja kvaliteedile" ning EMÜ põllumajandus- ja keskkonnainstituudi peaspetsialist Uko Bleive kõneles teemal "Tehnoloogilised katsetused astelpajuga". Osales 28 liiget.

22. veebruaril toimus veebikeskkonnas Eesti Vabariigi 103. aastapäevale pühendatud loeng, kus külalisena esines Tallinna Ülikooli vanemteadur Marju Kõivupuu, kes kõneles teemal "Meie pühad ja tähtpäevad". Osales 31 liiget.

14. aprillil said seltsiliikmed osa ettekandekoosolekust, mis toimus videosilla vahendusel, kus esinesid Tervise Arengu Instituudi analüütik Marit Priinits teemal "Taimetoitluse head ja vead" ning seltsiliige Reelika Rätsep teemal "Aiandusalane teadustöö Polli aiandusuuringute keskuses". Osales 23 liiget.

12. mail kõnelesid seltsi ettekandekoosolekul (videosillas) ETKI vaneminsener Edvin Nugis teemal "Kuivõrd võivad maakonniti ohustada raskemad traktorid meie põllumulda" ning ETKI teadur Ingrid Bender teemal "Soovitusi tomatikasvatuseks". Osales 18 liiget.

18. juunil toimus veebis seltsi aastakonverents teemal "Kliima, süsinikuringe ja põllumajandus". Pärast presidendi avasõnu kõnelesid maaülikooli põllumajandus- ja keskkonnainstituudi vanemteadur Karin Kauer "Süsinikuvaru muutused Eesti põllumuldades", HKScan Estonia kvaliteedijuht Priit Dreimann "Suund süsinikuneutraalsele toidule", maaülikooli põllumajandus- ja keskkonnainstituudi magister ja maaeluministeeriumi maakasutuspoliitika osakonna valdkonnajuht Merje Põlma "Põllumajandustootjate kogemus rohestamise tavade rakendamisel", maaeluministeeriumi põllumajanduskeskkonna büroo juhataja Martti Mandel "Mida tähendab kliimaneutraalsus põllumajandusele?", Eesti Põllumajandus-Kaubanduskoja arendusnõunik Triin Hallap "Arendusnõunikud erialaliitudes" ning maaülikooli metsandus- ja maaehitusinstituudi vanemteadur Jürgen Aosaar "Ülevaade Eesti metsasüsiniku uuringutest". Teaduskonverentsile järgnes seltsi üldkoosolek koos presidendi aruande ja revisjonikomisjoni hinnanguga. Osales 37 liiget.

8. juulil toimus seltsi 100. juubelile pühendatud väljasõit lõunapiirile egiidi all "Valga – üks linn, kaks riiki". Päev algas peatusega Valga külje all, kus avaldati austust sõjasangaritele Paju lahingu ausamba juures, süüdates küünlad ja pidades vaikuseminutit. Edasi suunduti Isamaalise kasvatuse muuseumisse, kus ülevaate muuseumi tegemistest andis kapten Valdeko Nielson. Muuseumist lühikese jalutuskäigus kaugusel, linnapargis peatuti Vabadussõja mälestusmärgi juures, kus major Meelis Kivi meenutas leitnant Julius Kuperjanovit. Väljasõidu pidulik osa leidis aset restoranis Metsis, kus hea ja parema maitsmise kõrval peeti kõnesid ja tunti hääd meelt seltsi kuulsusrikka ajaloo üle. Seejärel liikus reisiseltskond kesklinna linnamuuseumi õuele, kus algas giidiga ekskursioon piirilinna vaatamisväärsuste juurde. Osales 19 liiget.

26. augustil osales seltsi delegatsioon koosseisus Marko Kass ja Evelin Loit Viljandis Ugala teatrimajas toimunud Eesti Põllumajandus-Kaubanduskoja 25. juubeli pidulikul vastuvõtul.

15. septembril toimus Tehnikamajas aadressil Fr. R. Kreutzwaldi 56/2 Malle Järvani raamatu "Üle poole sajandi põllumajandusteaduses" esitlus. Autori lühiülevaatele järgnesid seltsi presidendi tervitus, kolleegide Erika Vesiku ning Heli Meripõllu meenutused ühiselt käidud aastatest ja aupresidendi Heldur Petersoni sõnavõtt "Kaasteelised seltsipäevilt". Osales 23 liiget.

6. oktoobril tegi seltsi aupresident Arvo Leola Tehnikamajas, Vambola Veinla auditooriumis ettekande teemal "101. ülikoolisemester loomakasvatuse mehhaniseerimist" ja kõneles värskelt ilmunud kõrgkooliõpikust "Karjandustehnika". Osales 19 liiget.

4. detsembril toimus Akadeemilise Põllumajanduse Seltsi ja Eesti Taimekasvatuse Instituudi ühine (hübriid) visioonikonverents "Säilitades vana loome uut". Pärast seltsi presidendi tervitussõnu kõnelevad Mattias Lepp (Click & Grow), Argo Peepson (Maaeluministeerium), Mariliis Holm (Sustainable Food Ventures USA-st), Lea Narits (ETKI), Toomas Kevvai (Eesti Kalatootjate Keskühistu) ja Laura Valli (Washington State University, USA). Konverentsi modereeris ETKI direktor Andre Veskioja. Konverentsi lõpetas paneeldiskussioon kooseisus Andre Veskioja, Anu Hellenurme (Anu Ait, EPKK, ETSAÜ) ja Toomas Kevvai ning arutelu juhtisid Marko Kass ja Evelin Loit. Osales 57 liiget.

Seltsi teadusajakirjal Agraarteadus, ilmus 2021. aastal kaks põhinumbrit, vastavalt juunis ja detsembris. Aasta esimeses numbris avaldati vastavalt 19 ning teises numbris 24 teadusartiklit. Esimeses numbris oli kaks ning teises üks eestikeelne teadusartikkel. Ajakirjas ilmunud teadusartiklid on leitavad ka SCOPUS® andmebaasis.

Liikmed osalevad Eesti Teaduste Akadeemia ja teiste seltside (Jaan Tõnissoni Selts) poolt korraldatud sündmustel.

Selts kasutab teabe edastamiseks meililisti ja sotsiaalmeediakontot Facebookis. Seltsi sissetulekuallikateks on Eesti Teaduste Akadeemia iga-aastane toetus ning seltsikaaslastelt kogutud liikmemaksud ja annetused. Seltsil palgalisi ametikohti ei ole. Võlgnevusi pole.

Presidendi tegevusaruanne 2022. aasta seltsi üldkoosolekul.

Marko Kass, president
Heli Kiiman, sekretär

AKADEEMILISE PÕLLUMAJANDUSE SELTSI LIIKMETE JUUBELID

60

ANDRES ANNUK	–	29.05.1961

65

LEMBIT NEI	–	19.07.1957
HELI NÕMMSALU	–	21.10.1957

70

JEVGENI KURÕKIN	–	01.04.1952
AARNE PÕLDVERE	–	12.10.1952
MIHHAIL SUDAKOV	–	09.10.1952
ALVAR TIMMI	–	12.09.1952

75

HELGI KALDMÄE	–	10.04.1947
MATTI PIIRSALU	–	05.07.1947
VÄINO POIKALAINEN	–	06.04.1947
ELLI PÄRNA	–	29.10.1947
AIDE TSAHKNA	–	15.07.1947

80

MALLE KÄRNER	–	26.04.1942
AO PAE	–	29.01.1942
REGINA PÄLLIN	–	15.10.1942
MAIA RAUDSEPING	–	13.02.1942
BORIS REPPO	–	28.02.1937
ENNO SIIBER	–	13.07.1937
REIN VIIRALT	–	29.01.1942

85

HANS KÜÜTS	–	20.12.1932

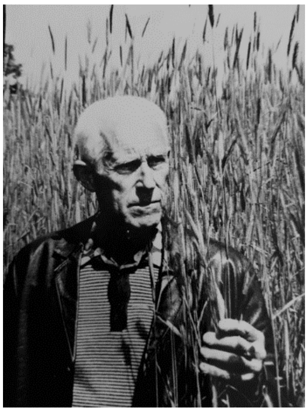
90

HEINO KASESALU	–	01.04.1932

95

HARRI PIHO	–	10.11.1927

AIN-ILMAR LEESMENT – 100



Eesti Maakarja Kasvatajate Seltsi taasasutajal Ain-Ilmar Leesmentil täitus 22. dets 2021. a 100 aastat sünnist. Siinkohal oleks paslik meenutada tema elukäiku, sest kes minevikku ei mäleta, see elab tulevikuta.

Ain-Ilmar Leesment, eesti maakarja aretuse entusiast, sündis 22. detsembril 1921. a Pärnumaal Tali vallas Lanksaare suurtalu seitsmelapselises peres. Tema elutee oli käänakuterohke. Isa Karl oli ettevõtlik põllumees ja eesti maakarja kasvataja, ema Emma Mälberg-Leesment koolitas end Soomes kodumajanduse asjatundjaks ja töötas enne abiellumist Põhja-Liivimaa Põllumeeste Keskseltsi instruktorina, olles esimene taoline ametnik kogu tollasel Eesti- ja Liivimaal. Seejuures andis ta välja Eesti esimese kokaraamatu.

Juba 1914. a oli Lanksaare talus maakarja katsekari ja hiljem maakarja sugulava. Peremees Karl Leesment astus EK Seltsi liikmeks selle asutamiskoosolekul 20. aprillil 1920. a ja kuulus EK Seltsi esimesse juhatusse aastatel 1921–1924.

Ain-Ilmar sai alghariduse Jäärja algkoolis, seejärel õppis Pärnu Poeglaste Gümnaasiumis ja Vändra Keskkoolis. Viimase lõpetas ta 1941. aastal ja astus seejärel (1942) Tartu Ülikooli põllumajandusteaduskonda. Üsna pea aga õpingud katkesid, tuli sõdurimunder selga tõmmata ja hakata Narva all rebenenud rinnet koos hoidma. Õnneks pääses ta sellest möllust eluga ja üsna pea – küll läbi rohkete katsumuste – oli ta uuesti ülikoolis.

Vahepealsed sõja-aastad ja raske majanduslik olukord – kodutalu natsionaliseeriti, ema suri kodukaotuse valu tõttu ja isa küüditati Siberisse, kus kuklalasuga mõrvati, vennad pillutati mööda ilma laiali – ei suutnud aga ”purupaljast” noort meest murda. Ülikoolidiplomini jõudis ta 1949. aastal. Küüditamise hirmus tuli tihti elukohti vahetada. Pärast ülikooli lõpetamist töötas Ain-Ilmar zootehnikuna Harjumaal Kostiveres (1949–1950), Niinja sovhoosis Haapsalu rajoonis (1950–1953) ja Sootaga sovhoosis Tartu rajoonis (1953–1957).

Vahepeal abiellus Ain kursusekaaslase Esmeralda Rattasepaga. Perre sündis kaks tütart. Mõlemad jätkasid isa poolelijäänud tööd: Ädu Leesment Lanksaare talu perenaisena ja Käde (Leesment) Kalamees EK Seltsi tegevjuhi ja teadussekretärina alates 1995. aastast kuni maini 2021. Ajavahemikus 1957–1960 oli Ain-Ilmar EPAs aspirantuuris, uurimistöö teemaks ”Eesti punase karja eksterjöör ja konstitutsioon”. Töö jäi enne kaitsmist pooleli, sest teema oli vastumeelne: südamel olevat eesti maakarja, mida oleks tahtnud uurida, peeti surnuks ja hääbuvaks tõuks.

1960–1961 oli Ain-Ilmar Leesment Tartu rajooni Sootaga sovhoosis EPA üliõpilaste praktikajuhendaja loomakasvatuse alal. Siis tuli paras juhus ja ta asus tööle kodukanti Pärnu rajooni Pärivere näidissovhoosi tõuaretuszootehnikuna, 1962. a aga Pärnu Kolhoosi- ja Sovhoositootmise Valitsusse (hilisem Pärnu Rajooni Põllumajandusliku Tootmise Valitsus). Ajavahemikul 1973–1989 töötas ta Pärnus Eesti Mustakirju Karja Tõulava zootehnikuna, võttes oma hoole alla ka eesti maakarja tõuaretuse ja tõuraamatusse võtmise.

Eesti taasiseseisvumisega avanes Ain-Ilmaril võimalus ka eesti maatõug iseseisvaks tõuks kuulutada, tema eestvedamisel taastati 14. okt 1989. aastal Eesti Maakarja Kasvatajate Selts. Seltsi asjaajajana töötas ta kuni 1995. aastani, paaril viimasel aastal küll talutöö kõrvalt. Lühikese ajaga (1993. aastast kuni 1996. a veebruarini) suutis A.-I. Leesment oma kodutalus Lanksaares palju ära teha: valmis uus ait-kuivati, käima lükati maaparandus-kuivendustööd, lüpsilaudas oli vabariigi parim maakarja tõufarm (1994, 1995). 1992. a tunnustati A.-I. Leesmenti tööd Pärnumaal C. R. Jakobsoni nimelise põllumajandusmedaliga.

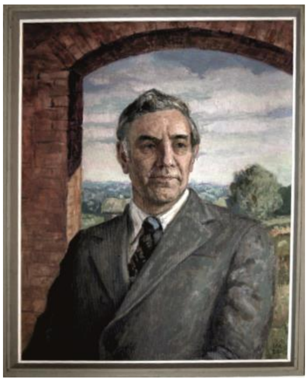
Saanud Lanksaare talu peremeheks, oli Ain-Ilmari esimeseks mureks maakari talulauta tagasi tuua. Kunagine Lanksaare maakari paigutati talu võõrandamise järel Pärivere sovhoosi, kust tuli hakata lehmi (küll kunagiste Lanksaare omade järglasi) koju kutsuma. Tagasi ei antud kogu võõrandatud vara, vaid pisku, tuli leppida 19 lehmaga. Juurde osteti veel 16 mullikat ja 1994. a oktoobris veel 7 lehmikut. Eesmärk oli saada 50 lehma, nagu vanasti talus oli. Unistused ja soovide täitumised aga katkesid ootamatult – Ain-Ilmar Leesmenti elutee lõpetas 8. veebruaril 1996 tuleõnnetuse ajal laudast lahti lastud pull Muku.

Jätkasin suure pühendumuse ja kohusetundega isa elutööd eesti maatõu säilitamisel ja aretamisel ning võin nüüd öelda, et meie suguvõsa on andnud suure panuse oma kohaliku tõu – eesti maatõu aretus- ja säilitustöösse. Mida vanemaks ma saan, seda rohkem oskan hinnata isa südameheadust, tarkust ja suurt elukogemust. Pea 27 aastat pärast tema surma meenutan teda ikka ja jälle suure südamesoojusega ja olen õnnelik, et mul on olnud eeskujuks selline isa.

Käde Kalamees

[Foto. A.-I. Leesment Lanksaare talu rukkipõllul H. Soodla]

PROFESSOR JÜRI KUUM – 100



Avades tänapäevase Vikipeedia, leiame professor Jüri Kuuma kohta väga tagasihoidliku refereeringu. Tegelikult on ta Eesti suurmees lausa mitmeski mõttes – nii teadlase ja õppejõuna, kui ühiskonnategelase ning perekonnapeana.

Jüri Kuum sündis 16. mail 1922. aastal Viljandimaal Rulli talus, Suure-Jaani kihelkonnas, Sürgavere vallas, Tällevere külas. Koheselt, peale algkooli lõpetamist kavatses ta 14-aastaselt astuda Olustvere Kõrgemasse Põllutöökooli, selleks oli ta tollal veel liiga noor. Pärast kaheaastast tööd isatalus sai ta unistus teoks. Pärast Olustveret jätkusid õpingud Tallinna tehnikumi maaparanduse- ja maamõõdu osakonnas direktor Richard Tiitso juures. Tiitso näpunäidetel jäi ta eemale nii 1941. aasta sundmobilisatsioonist Venemaale kui ka "kauples" saksa sõjaväest välja peale Jüri veel mõned teisedki noored mehed. Pärast diplomi omandamist sai Jüri töökoha Maardus markšreiderina, siin aitas teda lell Aleksander Kuum. Jüril oli 1944–45 järjekordselt õnne Kuramaale kahurilihaks saatmisest, sest oli veel Maardus ja pärastpoole veel Viljandimaal turbainspektor. Mis parata, andis ju tollal sünniaasta templi otsaette.

Jüri Kuuma Tartu periood algas 1945. aastal õpingutega Tartu riikliku ülikooli põllumajandusteaduskonnas, jällegi R. Tiitso juures. Ülikoolikursuse läbis ta kiirkorras, sest juba kahe aastaga, s.t 1947. aastal oli ta noor õppejõud. Siinjuures ei jätnud juhust ta kasutamata, tehes noorele, Vastse-Kuustest pärit tudengineiule konkreetse ettepaneku. Ning 3. septembril 1948. oligi 19-aastase Elliga abielu sõlmitud. Mis sellest, et elu tuli alustada Rüütli ehk tollal 21. juuni tänava neljanda korruse ühisköögis kahe vene perekonnaga. Tänu õigele otsusele jätkus abikaasadena teineteise toetamine nii tööl, koduehitusel, laste kasvatuses kui seltsielus. Jüril töö jätkus 1951. aastal äsja asutatud maaparandusosakonna loomisel avatud Eesti põllumajanduse akadeemias (EPA). Sealt alates järjest tõustes ametiredelil, millest aastatel 1971–92 oli tegev professorina.

Abikaasa Elli töötas Eesti Loomakasvatuse ja Veterinaaria Teadusliku Uurimise Instituudi söötmis- ja söödatehnoloogia osakonnas. Koos abikaasa Elliga algasid ühised huvid haritud põllumajandusteadlaste kaasahaaramiseks. Aktiivselt osaleti aastatel 1957–58 C. R. Jakobsoni talumuuseumi töö korraldamisel jt ettevõtmistes. Üheks isiklikuks suuremaks ettevõtmiseks oli koos isa, äia ja lellaga 1960. aastal valminud maja ehitamine Vikerkaare tänavale. Tagasilöögiks sai kollatõbi ja seetõttu pikemaajaline viibimine haiglas Lina tänaval. Samal ajal tulid Jüri Kuumal esimesed mõtted ka põllumajandusmuuseumist, kuid isa surm 1964. aastal, ema tulek Tartusse ja kohustused Rulli taluhoonete eest, lükkasid unistuse edasi. Olgu siinjuures allakirjutanu poolt lisatud, et mind köitis alati Kuumade elutoa seinal olnud õlimaal Rulli talust – eespool vanatüübilised mesitarud, taamal klassikaline taluhäärber. Hiljem olen külastanud seda ilusat talu juba tema tütre ja tubli väimehe, Kõvatoomase pidamise aegu.

Professor Kuuma isikupäraks oli peast kõnelemine, oma kirjalikke töid esitas ta väga põhjalikult. Tema 1965. aastal kaitstud kandidaadiväitekiri oli "Eesti kultuurrohumaade taimkate ja selle eri taimeliikide majanduslik väärtus". Näiteks oma doktoritööga "Maaparanduse osa Eesti põllumajanduse arengus ja selle mõju taimekasvatusele" läks ta ülimalt põhjalikuks, esitades selle kolmes osas, kuueköitelise kogumikuna, kokku 1088 leheküljel. Kaitses ta selle 26. veebruaril 1969. aastal, mille järel omistatigi professori kutse.

Jüri Kuuma isikupäraks oli tema ülimalt lai huvi ja tegutsemine Eesti põllumajandusajaloo valdkonnas. Nimelt kuulub temale idee Eesti põllumajandusmuuseumi loomisest Ülenurmele, mille teadusnõukogu esimees ja aseesimees oli ta alates 1968. aastast. Sellele järgnes C. R. Jakobsoni talumuuseumi teadusnõukogu esimehe, hiljem aseesimehe ülesanded 1977. aastast. Ta oli Eesti NSV teaduste akadeemia põllumajandusteaduste väitekirjade kaitsmise nõukogu liige 1970–76, EPA agronoomialaste väitekirjade kaitsmise nõukogu liige 1982–92, Eesti etnograafiamuuseumi teadusnõukogu liige 1968. aastast. Eesti aianduse- ja mesinduse seltsi presiidiumi liige ja Tartu osakonna esimees 1977. aastast oli ta suuresti tänu abikaasa Ellile. Professor Kuum on päris mitme põllumajandusalase telefilmi autor või režissöör, mis vändati aastatel 1970–76. Nendel kujutati viljalõikust ja rehepeksu käsitsi kootidega kuni hobuse, aurukatla ja traktoriga ringiaetavateni välja. Samuti ka leivategemist ja koduõlle valmistamist. Palju tegi professor Kuum Aleksandrikooli, Kõo ja Olustvere põllutöökoolide ajaloo jäädvustamisel.

Ka 35 aastat tagasi uuemal, nn laulva revolutsiooni ajal, ei jäänud professor Kuum kõrvalseisjaks kui kutsusin teda ning mitmeid teisi vanemaid ja väärikaid õppejõude Tartu Eesti põllumeeste seltsi (TEPS) taasavamisele 12. märtsil 1988. aastal EPA aulasse. Meie taastatud seltsi akadeemilises toimkonnas oli Jüri üks aktiivsemaid taasärkavate talupidajate toetajaid. Aasta hiljem, 4. aprillil 1989 aastal, pidasime Tartu maavalitsuse saalis maha TEPS-i esimese konverentsi "Kellele kuulub maa Eestimaal?", kus Jüri Kuum esines teemal "Maareformist ja asundustalude rajamisest Eestis". Samal päeval taastati EPA aulas akadeemiline põllumajanduse selts (APS), kus ka Kuum pealelõunal taasasutamiskoosolekust alates aktiivselt kaasa lõi. Jüri Kuuma koostamisel ja kaasautorlusel ilmusid APS-i seni mahukamad teosed "Teadus Eesti põllumajanduse arenguloos I osa, kuni 1918. aastani", ilmus 1998. ja "II osa, 1918 kuni 1940" 2003. a. Kahjuks kolmas osa ei ole seni ilmavalgust näinud.

Kokkuvõtteks oli professor Jüri Kuum aastatel 1949–2007 avaldanud ligi 500 artiklit ja ta on lugenud erialaseid loenguid ligi kümnele tuhandele tudengile. Kümneid kordi suurem on tema üldrahvalik missioon ja üleriigiline auditoorium. Omaette suurim ajaloolis-poliitiline poolehoid oli professor Kuumal Jakobsoni suuna toetajana, kirjutades 2002. aastal isegi kirjandus-teadlaste arvates ühe sellealase mahukaima raamatu "Carl Robert Jakobson – talurahva õpetaja ja põllumees". Lubatagu siinkohal ka ainuke väike kõrvalekalle professor Kuuma seisukohast, mida ma ühisel raamatu esitlemiskäigul Kurgjal temale ka isiklikult mainisin ja võrdselt pakkusin kõrvale Johann Voldemar Jannseni. Siinkohal ei oma tähtsust, et Jannseni esimeseks akadeemiliseks isaks oli kuulsa Palermo jutluse pidaja, Vändra pastori Carl Eduard Körberi Võnnu päritolu, kust ka allakirjutanu ja meie seltsi ajakirja peatoimetaja on pärit. Lihtsalt ajadistants võimaldab enamat kui meie esimese iseseisvuseaegne rahvuslik-romantiline meelsus.

Üks parimaid ja võimsamaid professor Jüri Kuuma kõnesid on säilinud Eesti raadio fonoteegis Kaljo Jaagura 14.08.1988 saatest „Tere hommikust, maarahvas“, kus Kuum ütles:

"*Kõiki Kaarlimõisa, Kõo ja Olustvere koolide õpilasi, õpetajaid ja lõpetajaid on ühendanud ja saatnud nn Aleksandrikooli vaim, mis on pikkamisi kasvanud üle Olustvere vaimuks. See tunne mõjutab kõiki õppijaid, õpetajaid ja lõpetanuid. Sisendab kõikidesse püüet aidata kaasa kodumaa põllumajandusele ning sotsiaalsele ja kultuurilisele arengule. See on suur nõudlikkus enda ja teiste vastu, on üldine arusaamiste kogum, mis peegeldab siinset maad, loodust ja Eesti ühiskonda ning Olustvere kooliga seotud inimeste kohta nendes. See vaimsus on kujunenud põhiliselt siinses kollektiivis salvestunud teadmistes ning väärtusnormides, stiihilise või teadliku omaksvõtmise läbi. Selle mõjul tunnevad kõik sõnad, et siinsete koolimajade seinte vahel peab sirguma, kasvama ja arenema omalaadne Eesti maad ja rahvast armastav Eesti tamm –* Quercus Estonica. *Selle vaimu on loonud siinsed õpetajad, kuid selle tekkelugu on siiski palju laialdasem ja keerukam. See on sisuliselt ka üks osa põllumajanduskultuuri arenguloost, selle vaimu teket on põhjustanud omaaegne rahvuslik ärkamisaeg, parimad haridusasutused, põllumeeste seltsid, meie põllumeeste esimene juht ja president Carl Robert Jakobson oma ideedega, siinsed õpetajad. See kõik on eriliselt seotud Sakalamaaga. Põllumeeste rahvusliku liikumise juured Viljandimaal ulatavad kaugesse minevikku, selle liikumise möödanik on nii võimas ja kangelaslik, et juubelipäevadel võime soovida – olgu tulevik ja olevik mineviku vääriline*."

Nimetatud saatest võtsid osa veel mitmed nimekad, nüüdseks manalateele läinud mehed nagu Jüri Liivak, Ilmar Jõesoo jt.

2001. aasta vabariigi aastapäeva eel annetas president Eesti põllumajandusülikooli emeriitprofessor Jüri Kuumale Valgetähe III klassi teenetemärgi.

Emeriitprofessor Jüri Kuum lahkus meie hulgast 30. juunil 2009. aastal ja puhkab väärika tammena oma esivanemate hauaplatsil Suure-Jaani kalmistul koos paljude meie Eestimaa kuulsuste seltsis.

Heldur Peterson

[Foto. Jüri Kuum. EPM TR 1770:2 K 76. Eesti Maaelumuuseumid SA, Eesti Põllumajandusmuuseum]

Kasutatud kirjandus

Jaagura, K. 1988. Eesti Raadio fonoteek. Saade: Tere hommikust, maarahvas. 14.08.1988.

Joandi, A. 2007. Emeriitprofessor tähistas juubelit. Sakala, 29. mai, lk 7.

Karelson, M. 1997. Jüri Kuum – 75. Agraarteadus, nr 2, lk 196–197.

Kuum, J. 1989. Maareformist ja asundustalude rajamisest Eestis. Vastutav toim. Ü. Oll, TEPS-i aastapäevakonverents "Kellele kuulub maa Eestimaal?", Tartu, lk 6–8.

Peterson, H. 2012. Prof Jüri Kuum – 90. sünniaastapäev. Ettekanne Eesti põllumajandusmuuseumis, 24. mai 2012.

ERRATA: 70 AASTAT EESTI PÕLLUMAJANDUSE AKADEEMIA MOODUSTAMISEST. ARENGUD ÕPPETEGEVUSES

Lk. 355 teise lõigu esimese rida palun lugeda "1991. aasta 1. **septembrist** reorganiseeriti teaduskonnad.".

Anne Lüpsik