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Peatoimetaja:	pm-dr Alo Tänavots
Tehniline toimetaja:	pm-mag Irje Nutt
Aadress:	Fr. R. Kreutzwaldi 1, 51006 Tartu
e-post:	jas@emu.ee
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ACCELERATED BIOTHERMAL COMPOSTING OF MANURE-COMPOST MIXTURE

Elchyn Aliiev[1], Sergey Pavlenko[2], Olga Aliieva[1], Olesia Morhun[3]

[1]Institute of Oilseed Crops of the National Academy of Agrarian Sciences of Ukraine, 1 Institutskaya St, v. Sonyachne, 69093 Zaporozhye region
[2]National University of Life and Environmental Sciences of Ukraine, 11 Heroyiv Oborony St, 03041 Kyiv
[3]National Academy of Agrarian Sciences of Ukraine, 9 Mikhail Omelyanovich-Pavlenko St, 01010 Kyiv

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Vastutav autor: Corresponding author: Elchyn Aliiev

E-mail: aliev@meta.ua

ORCID:
0000-0003-4006-8803 (EA)
0000-0003-3352-5797 (SP)
0000-0002-2766-7548 (OA)
0000-0001-5399-0309 (OM)

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ABSTRACT. The aim of the research was to observe the technological processes of accelerated biothermal composting of manure-compost mixture and to determine the dynamics of its temperature regime. Because of experimental research of conditions of biothermal processes of composting of manure-compost mix the mathematical laws describing dynamics of change of a temperature field in the composting pad of a different configuration for various mechanized conditions are received. It is established that mechanized composting of raw materials provides growth of internal temperatures to the maximum temperature of 65–71 °C (at height of the composting pad of 1.5 m) for 2–3 days after laying of the composting pad. In 15–17 days, the temperature is up to 50 °C, which does not correspond to the thermophilic mode of bacterial activity and the processes gradually pass into the mesophilic mode – up to 40 °C. As a result of experimental studies of biothermal processes of composting manure, it was found that during the fermentation of raw materials in the composting pad without treatment (36 days) the weight of the composting pad (at the composting pad height of 1.5 m) decreased by 20% (raw material moisture decreased by 5%). In the composting pad with mechanical treatment and addition of water, the weight of the composting pad varied from the amount of water introduced, which led to an increase in the moisture content of the raw material. There was a significant decrease in organic matter from 47–50 to 32–35% in the raw material against 50–52 to 40–41%.

Introduction

Global trends in agricultural production indicate significant changes in the technological use of organic raw materials of crop and livestock (straw, manure, droppings) for organic fertilizers. The main challenges: increasing social requirements for the ecological state of the environment (odours, pollution of water bodies, soils), restoring soil fertility, production of raw materials for organic products. One way to solve the problem is to use better organic fertilizers – compost – a mixture of animal manure or poultry droppings with plant biomass, which is produced in a shorter time of aerobic fermentation (Samarin *et al.*, 2020).

The purpose of accelerated composting is to control the processes of fermentation-decomposition of organic matter, reducing the loss of nutrients by maintaining rational living conditions of microorganisms, which reduces the time of the readiness of the product. The positive result of the measures is the reduction of environmental risks, improvement of the environment, resource conservation using non-commodity crops and processing, reduction of storage and accumulation of manure and droppings, improving the quality of fertilizers (Malik *et al.*, 2020).

Today, many organic waste composting systems are known, they have found their use in various industries for processing and further use as organic fertilizers (Huzaifah *et al.*, 2001; Rajkhowa *et al.*, 2019). Ecological and agrotechnical precautions on the release of unpleasant and greenhouse gases, phytotoxicity of components (presence of harmful substances and toxins), increase in nutrients, weed seed disposal, reduction of cultivation time, reduction of areas under sites, cost of structures and equipment, environmental

factors environments (temperature, precipitation, wind, *etc.*) at the present stage have led to the development of various composting methods, which differ in shape and size, degree of perfection, use of additional components, etc. (Diacono *et al.*, 2019).

Methods of composting agricultural waste can be broadly divided into three main types, based on methods of aeration of compost materials, mechanical mixing and shovelling (Aliev *et al.*, 2018; Shevchenko *et al.*, 2021), as well as control over the release of odours and harmful gases (Sayara *et al.*, 2020).

Analysis of the state of research of bioenergetic fermentation processes of compostable raw materials allowed us to conclude that the simultaneous solution of several theoretical issues regarding changes in heat and mass balances as a function of time, and in some cases (from the point of view of practical application main states of idea) environment, shape, structure and total mass of compost material are an integral basis in the construction of most models of composting processes (Seki, 2000). In theoretical studies, most scientists use the following generalized formula for heat balance (Mason, 2006):

$$E = \Sigma E_{in} \pm \Sigma E_{trans} - \Sigma E_{out}\,, \qquad (1)$$

where

E – the accumulated energy of the compost system, MJ;
ΣE_{in} – total energy at the entrance to the system, MJ;
ΣE_{trans} – total energy of biochemical transformations, MJ;
ΣE_{out} – total energy at the output of the system (lost energy), MJ.

That is, the dynamics of the composting process depends on and changes under the influence of its input and output parameters, as well as several parameters that characterize the biochemical transformations (endogenous and exogenous) of organic matter in compost materials. Many model developers relied on deterministic approaches, *i.e.*, those that precluded the possibility of accidental influence on the studied parameters. However, some stochastic blocks are reflected in at least two of the analyzed models that have emerged in recent years (Scholwin, Bidlingmaier, 2003; Edsel, Grant, 2006).

The research (Hamelers, 2004) considers the main elements of process modelling (relative to the smallest structural component of the mixture – a single compost particle), based on the possibilities and different perspectives on the application of models.

Model developers consider a composting system at the macro level, in which attention to its analytical justification was based on the bioreactor (mainly for closed composting systems). However, several authors (Kaiser, 1996; Stombaugh, Nokes, 1996; Ndegwa *et al.*, 2000; Seki, 2000; Higgins *et al.*, 2001) have considered modelling problems based directly on the microbiological point of view of the composting process.

In some cases, the simulation was applied directly to processes occurring in the horizontal layers of the substrate (Stani, 2012; Seng *et al.*, 2016; Zhao *et al.*, 2017; Sokač *et al.*, 2021). Depending on the technological approaches to waste composting, the processes that take place in rectangular or triangular compost piles (Kim *et al.*, 2000; Petric, 2008), or concerned only individual areas of the compost substrate with uniform temperature fields (Bari *et al.*, 2000; Robinzon *et al.*, 2000; Straatsma *et al.*, 2000; Agnew, Leonard, 2003; Mironov, 2006).

The thermal balance of components in composting models was based on the rationalization of thermal energy consumption for heating the structural elements of the system, taking into account the input and output heat fluxes (thermal energy of incoming air and its water vapour, as well as any additional inputs of water vapour), losses due to heat transfer and convection losses, incoming heat fluxes and losses due to radiation, latent heat due to water evaporation and thermal energy of biological and chemical origin.

The heat released because of microbiological processes and latent heat of water evaporation were considered as the most influential parameters in the heat balance of full-scale composting systems (Weppen, 2001) and were taken into account in almost all developed models. Regression models of specific heat release were obtained from research (Kuznetsov, 2001). Simplified models for determining the specific heat of biothermal processes based on the a priori established depth of decomposition of organic matter and specific heat release based on chemical oxygen demand (HSC) have also been proposed. The proposed model (Golub, 2007; Golub *et al.*, 2017a) predicted a functional relationship between temperature and the sum of heat fluxes overtime under the conditions of heating the substrate with water vapour and heat productivity of biochemical reactions based on glucose decomposition rather than decomposition of available organic matter in general. In most cases, the latent heat of water evaporation was considered in the physical equations of gas motion due to the enthalpy of exhaust gases saturated with water vapour.

Heat loss parameters due to convection, heat transfer and radiation can be calculated using well-known dependencies and information on heat transfer processes or by heat transfer parameters determined experimentally (Weppen, 2001).

Many of the authors-developers of the models considered "mc" as a constant value (Bari *et al.*, 2000; Robinzon *et al.*, 2000; Straatsma *et al.*, 2000), which allowed to obtain the equation as follows:

$$mc\frac{dT}{dt} = GH_i + U\frac{d(BVS)}{dt}H_c - GH_o - A(T - T_a)\,, \qquad (2)$$

from which the expression for determining the rate of temperature change is as follows:

$$\frac{dT}{dt} = \frac{GH_i + U\frac{d(BVS)}{dt}H_c - GH_o - A(T - T_a)}{mc}, \quad (3)$$

where
T – the temperature, K;
H – entropy, J K^{-1};
t – time, s;
B, V, S – geometric sizes, m;
m – mass kg;
c – specific heat, J $(kg \cdot K)^{-1}$;
G – empirical coefficients, K s^{-1};
U – empirical coefficients, K m^{-3};
A – empirical coefficients, J $(s \cdot K)^{-1}$.

The presented models are theoretical and cannot fully characterize the process of bioconversion of manure-compost mixture during solid-phase composting. Therefore, the research aims to observe the technological processes of accelerated biothermal composting of manure-compost mixture and to determine the dynamics of its temperature regime.

Material and Methods

The program of experimental research provided:
– substantiation on results of research of technological and mode parameters and the basic provisions of management of processes of biothermal composting of manure-compost mix in full-scale composting pad;
– research of regularities of dynamics of a temperature mode in a full-size composting pad with their various geometrical parameters;
– study of the influence of the periodicity of mechanical aeration of manure-compost mixture in full-scale composting pads on the course of the composting process.

A closed hangar with a concrete surface, size 90 × 18 m, was used as a platform. Fresh (unloaded from the premises) litter based on sunflower husk is unloaded in tight piles onto the prepared site using a modified PRT-10 organic fertilizer spreader. Further research was conducted on four full-scale composting pads:

- composting pad №1 – composting pad 1.5 m high without further mechanical aeration and additional humidification;
- composting pad №2 – composting pad height of 1.0 m without further mechanical aeration and additional humidification;
- composting pad №3 – composting pad 1.5 m high with subsequent mechanical aerations and with additional humidification;
- composting pad №4 – composting pad 1.0 m high with subsequent mechanical aerations and with additional humidification.

Directly the process of formation of full-scale composting pads with the use of the modified spreader of organic fertilizers PRT-10 is presented in Figure 1. Further planned mechanical aeration and formation of composting pads were performed using a bucket loader T-156 and a modified spreader of organic fertilizers PRT-10.

Humidification is performed to bring the compost mixture to the technologically necessary humidity. The technical means of water delivery was a specialized car based on GAZ-53 with a capacity of 4 m^3. The amount of water (effluent) M_{water} was required to bring the manure-compost mixture to the technologically specified humidity $M_{mixture}$ and was calculated by the formula:

$$M_{water} = M_{manure}\frac{W_{mixture} - W_{manure}}{100 - W_{mixture}} \quad (4)$$

where
M_{water} – the mass of water (sewage) that must be added to the manure-compost mixture, kg;
M_{manure} – the weight of manure, kg;
W_{manure} – humidity of manure, %;
$W_{mixture}$ – humidity of manure-compost mixture, %.

Moisturizing water is supplied during mechanical aeration by spraying.

During research composting pads 3 and 4 were mechanical aerating with time intervals that are presented in Figure 2.

without additional hydration with additional hydration

Figure 1. The process of forming full-scale composting pads using a modified spreader of organic fertilizers PRT-10

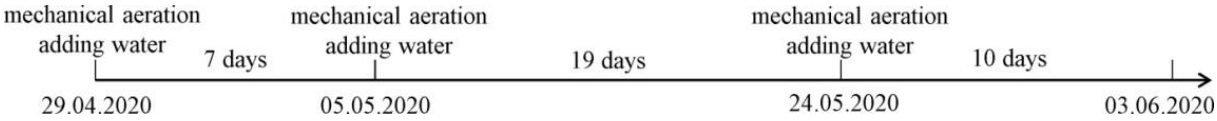

Figure 2. Time intervals of technological operations in the process of accelerated biothermal composting

During research the following parameters of technological process of the accelerated biothermal composting of litter manure on the basis of sunflower husk were defined:

- geometrical sizes of composting pads and their vertical subsidence;
- bulk density, weight, humidity;
- dynamics of temperatures in the cross section of the composting pads;
- the temperature field of the composting pads and the homogeneity of the distribution of the components of the manure-compost mixture in the composting pads.

All measurements were performed upon completion of the technological operation according to the set time interval in three repetitions.

Measurement of the geometric sizes of the composting pads and their vertical subsidence was performed using a construction tape measure (50 m) and a ruler (1.5 m) with an absolute measurement error of 1 cm. The height, width and length of the formed composting pads were determined. The vertical subsidence of the sides was measured by installing a laboratory bar in three places along their length, followed by fixing the position of the upper point of the sides.

The bulk density was determined by determining the ratio of the net weight of the manure-compost mixture poured into the tank to the volume of the specified tank (the volume of the tank was specified by the manufacturers 0.01 m^3). The mass was determined by electronic scales with an absolute measurement error of 0.001 kg.

Calculations are carried out according to the formula:

$$\gamma = \frac{m_i}{V_i} \quad (5)$$

where

γ – is the bulk density, kg·m^{3-1};

m_i – a mass of the bulk sample, kg;

V_i – the volume occupied by the sample of the material in bulk, m^3.

Measurement of the mass of manure-compost mixture in the composting pad was performed using SMART Life REXANT (Lin'an CF Co., Ltd, Hangzhou, Zhejiang, China) scales with an absolute measurement error of 0.1 kg.

Humidity measurement of manure-compost mixture was performed using a calibrated moisture meter VLK-01 (TOV NVF Standard-M, Zaporozhye, Ukraine). Calibration of the moisture meter was performed in the laboratory of the State Institution "State Soil Protection" (Dnipropetrovsk branch) by comparing with the results of chemical analysis according to standard methods according to GOST 26713-85, based on determining moisture loss from the mass of compost by drying it to constant weight. The absolute measurement error of the VLK-01 moisture meter for the manure-compost mixture was 0.2%.

The most important criterion for evaluating the effectiveness of the composting process is the control and maintenance of temperature. The dynamics of temperatures in the sides was studied using a personal computer to which an electronic thermometer TM-32/H-5T (TOV UKRRELE, Dnipro, Ukraine) with a system of temperature probes based on temperature sensors DS18B20 ("Dallas Manufacturing Co", Dallas, USA) was connected (Fig. 3). The absolute measurement error of the thermometer TM-32/H-5T is 0.1 °C. Temperature monitoring using the TM-32/H-5T electronic thermometer was performed every 10 minutes, and the data were recorded on a personal computer in the appropriate database file.

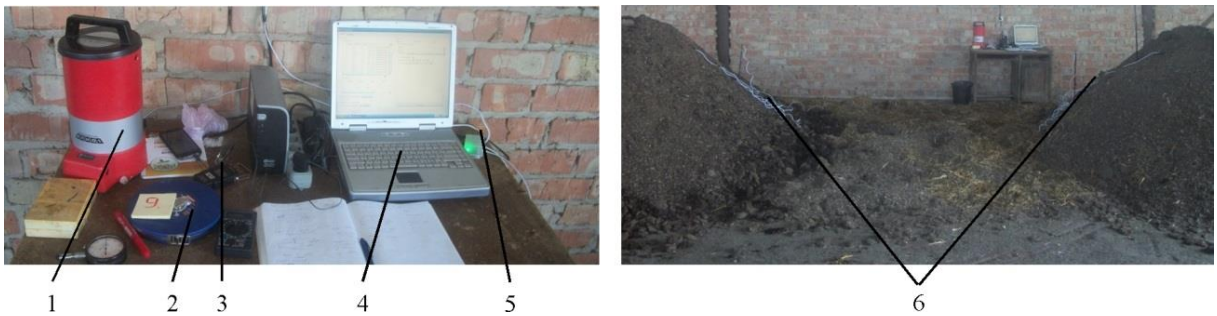

Figure 3. Measuring instruments and equipment (1 – moisture meter VLK-01; 2 – construction roulette; 3 – electronic manual scales; 4 – personal computer; 5 – electronic thermometer TM-32/H-5T; 6 – DS18B20 temperature sensors)

The scheme of arrangement of temperature probes in composting pads 1.5 m and 1.0 m high is presented in Figure 4.

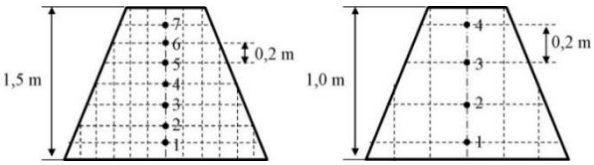

Figure 4. The layout of temperature probes

The temperature field of the surface or section of the sides was determined using a thermal imager Testo-875 (Testo SE & Co. KgaA, Lenzkirch, Germany), which allows the analysis of temperature fields with an absolute measurement error of 0.01 °C. Using the additional Testo IRSoft v. 4.1 software (Testo SE & Co. KgaA, Lenzkirch, Germany), the maximum, minimum and average values of the temperature field; build histograms and graphs of temperature distribution over a certain area and line of the temperature field was determined. The general view of the specified thermal imager and the corresponding software is presented in Figure 5.

The least Significant Difference (LSD) indicator was used for statistical evaluation of research results. LSD is a critical value that is expressed in absolute numbers and shows the limit of random deviations between the compared averages, which corresponds to a reliable interval for the absolute difference of the sample arithmetic means. If it was less than the LSD, then the samples do not differ, and if more, they are statistically different. Determine the LSD by the formula (Kiselyov *et al.*, 2017):

$$LSD_{\alpha(v)} = t_{\alpha} \cdot S_{d}\,, \qquad (6)$$

where

S_d – standard error of the difference between the arithmetic means;

$t_{\alpha(v)}$ – theoretical (critical) value of Student's criterion for the level of significance α and degrees of freedom of error.

Figure 5. General view of the Testo-875 thermal imager (a), Testo IRSoft software (b) and the temperature measurement process (c)

Results

During the study, four composting pads (cross-section – triangle) were formed, the geometric sizes of which were:

- composting pad №1 – height 1.4–1.5 m, length 5.7–6.3 m, width 3.8–4.4 m;
- composting pad №2 – height 0.9–1.0 m, length 8.7–9.0 m, width 3.1–3.6 m;
- composting pad №3 – height 1.4–1.5 m, length 5.8–6.1 m, width 3.3–4.1 m;
- composting pad №4 – height 0.9–1.0 m, length 6.8–7.1 m, width 3.5–3.8 m.

Considering the time intervals of technological operations during the process of accelerated biothermal composting of full-scale composting pads, measurements of their vertical subsidence were carried out. The histogram of the above dependence is presented in Figure 6. As can be seen from the histogram, the greatest value of subsidence of the composting pad was observed in the first 7 days, which was due to the more intense process of biothermal composting. In the future, the absolute value of vertical subsidence decreases by 25–30%. $LSD_{0.5}$ for the value of the vertical subsidence of the full sides was 4.3 mm, which is lower than the difference observed in the dynamics.

By the time intervals of technological operations in the process of accelerated biothermal composting of full-scale composting pads were measured changes in their mass, taking into account the addition of water. The histogram of change of weight of full-size composting pads is presented in Figure 7. For values of weight of composting pads $LSD_{0.5}$ makes 56 kg. This figure is lower than the difference observed in the dynamics, which confirms the adequacy of the results.

The bulk density changed according to the graph in Figure 8, which shows its reduction during biothermal composting. This decrease is due to the evaporation of moisture and the chemical reaction with the release of gaseous substances. $LSD_{0.5}$ for the volume volumetric mass of full-scale composting pads was 21.3 kg·m$^{3\ -1}$, which is lower than the difference observed in the dynamics.

During the observation period on the composting pads without treatment (36 days) the weight of the composting pad №1 (H = 1.5 m) decreased by 22% (moisture content of raw materials decreased by 6%), and composting pad №2 by 26% (moisture content of raw materials by 5%). In liquids with the addition of liquid – water, the weight of the composting pad №3 and the composting pad №4 varied depending on the amount of introduced water, which led to an increase in the moisture content of the raw material. For the values of moisture content in full-sized composting pads $LSD_{0.5}$ is 2.1%. Since this figure is lower than the difference observed in the dynamics, the adequacy of the results is confirmed.

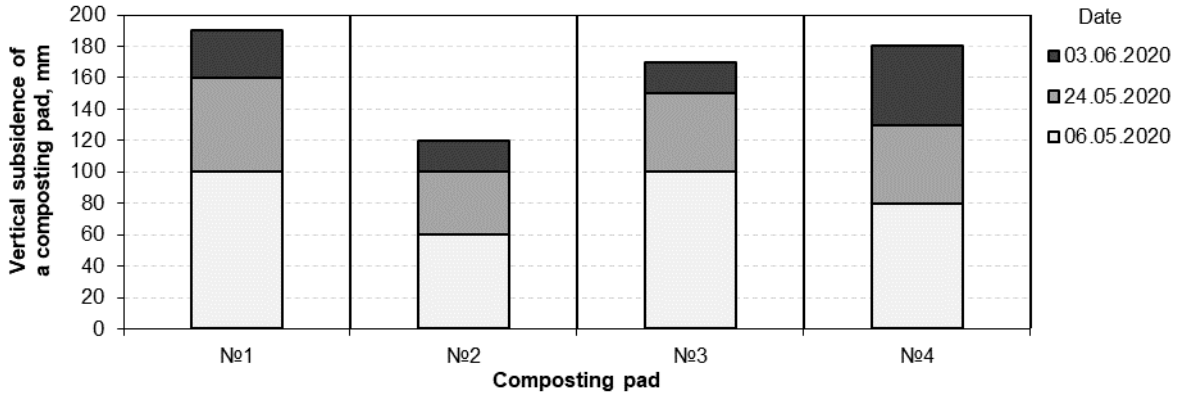

Figure 6. The dynamics of changes in the absolute value of the vertical subsidence of the full-scale composting pads

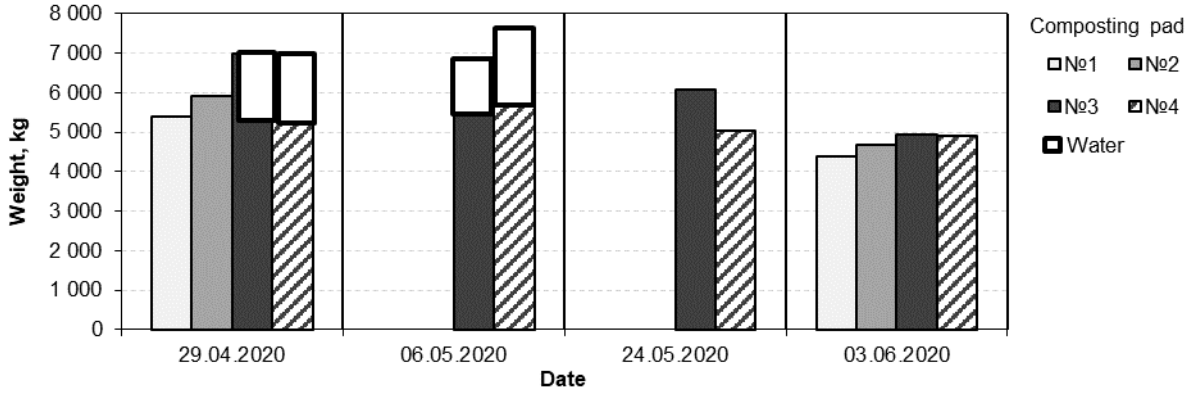

Figure 7. Changes in the mass of full-scale composting pads

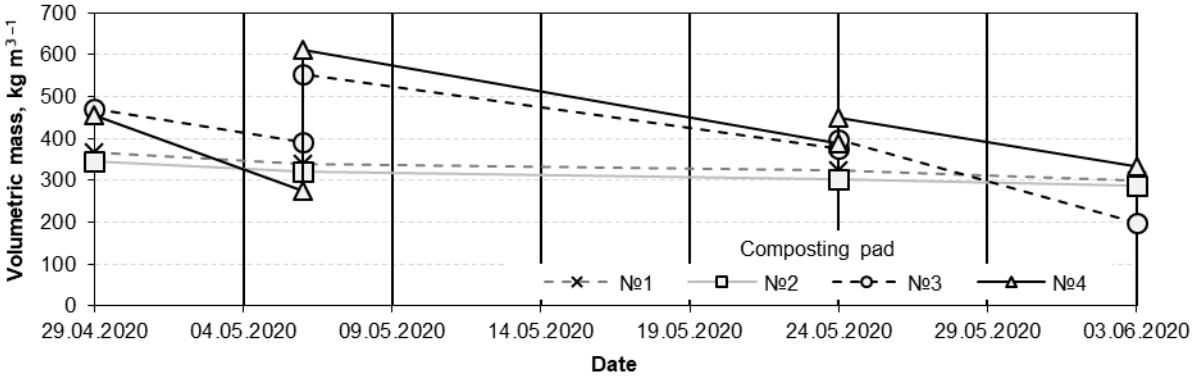

Figure 8. Changes in the volumetric mass of full-scale composting pads

Indicators of moisture content when considering changes over time relative to untreated compost has significant variations in the respective composting pads at the height of the composting pads of 1.5 m and 1.0 m (Fig. 9). It should be noted that there is a characteristic increase in moisture content and a further decline with the resumption of the rise (*i.e.*, there is an oscillating relationship).

The corresponding tendency is present also with the processed raw materials with that difference concerning discrepancy of fluctuations, which are a result of the addition of liquid – water to these composts. It should also be noted that the levels at which the values of moisture content for 36 days in untreated and treated materials are quite close to each other. The presence of fluctuations in moisture content should be considered because of the process of mineralization of organic matter: burning of carbon and oxidation of hydrogen with subsequent evaporation of moisture.

As a result of research, the dynamics of change of temperature in each point of a full-scale composting pad according to the developed technique (Figs. 10–13) is received. For the presented results of research $LSD_{0,5}$ for temperature makes 0,51 °C, that is sufficient for the statement of adequacy of the received data.

Mechanical shovelling of raw materials – aeration provides growth of internal temperatures (7 points of measurement on the height of the composting pad H = 1.5 m) to the maximum temperature of 65–71 °C and 50–58 °C at height of the composting pad of H = 1.0 on 2–3 the day after laying the composting pad. In 15–17 days, the temperature is up to 50 °C, which does not correspond to the thermophilic mode of bacterial activity and the processes gradually pass into the mesophilic mode – up to 40 °C.

By the end of the observation period (up to 36 days), the internal temperature in the composting pad №1 (H = 1.5 m), according to Figure 10, was 39–45 °C, and in the lower layers up to 30 °C.

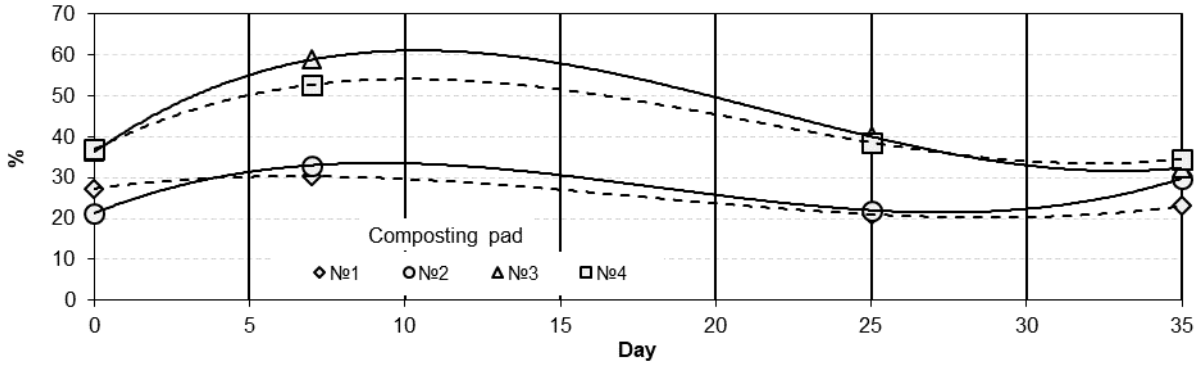

Figure 9. Dynamics of moisture content in full-sized composting pads

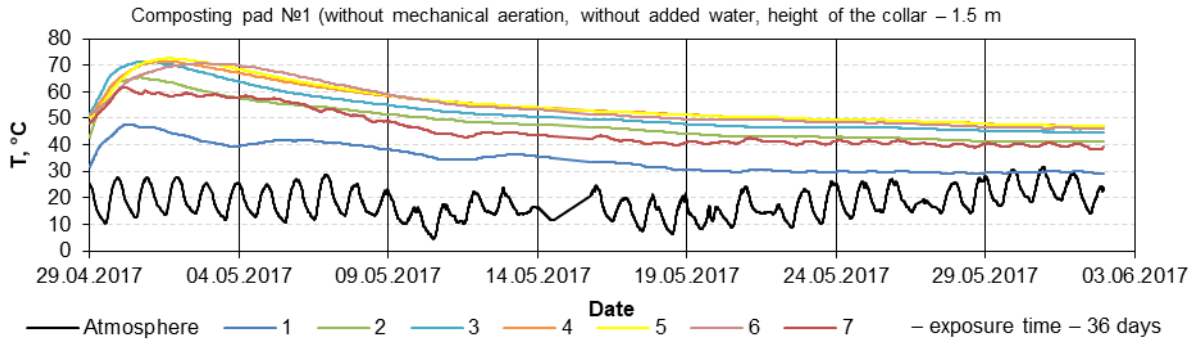

Figure 10. Dynamics of the temperature field of the composting pad №1

In the composting pad №2 (H = 1.0 m), according to Figure 11, the temperature was 5–8 °C lower in the corresponding periods. The change in ambient temperature during the day from 10 to 25 °C, during the observation period there were no significant fluctuations in the internal temperature.

In the composting pad, №3 (fig. 12) with mechanical shovelling and the addition of liquid – water, the temperature rose to 61–65 °C (H = 1.5 m) for 2–3 days at all seven measuring points, decreased by 3–5 °C and remained stable during the observation. Shovelling of raw materials without the addition of liquid for 20 days showed an increase in temperature to 70–72 °C with a gradual attenuation of thermal processes for 10 days and a decrease in temperature to 50 °C.

In the composting pad, №4 (at H = 1.0 m) and similar treatments as in the composting pad №3, thermal processes are 5–10 °C lower (Fig. 13). During aeration, the temperature of the raw material decreases to 38–44 °C, the effect of fluctuations in external temperature (10–25 °C) on the change in internal temperatures was statistically insignificant.

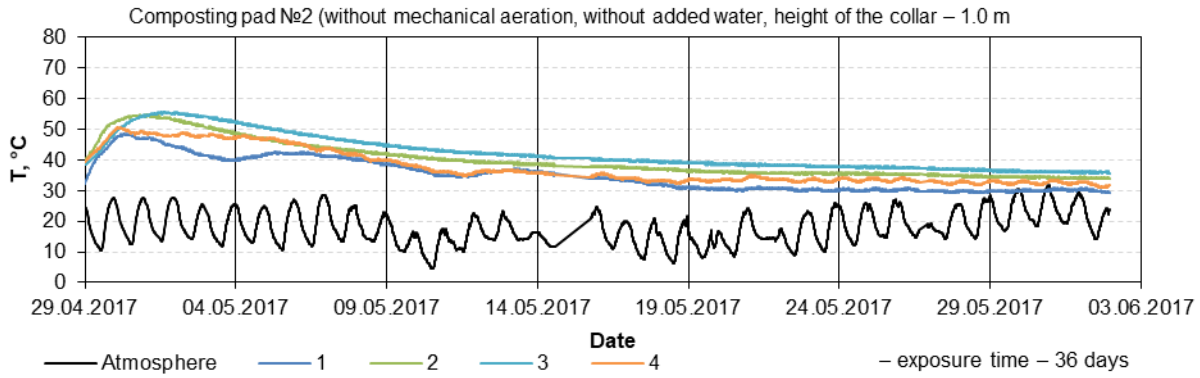

Figure 11. Dynamics of the temperature field of the composting pad №2

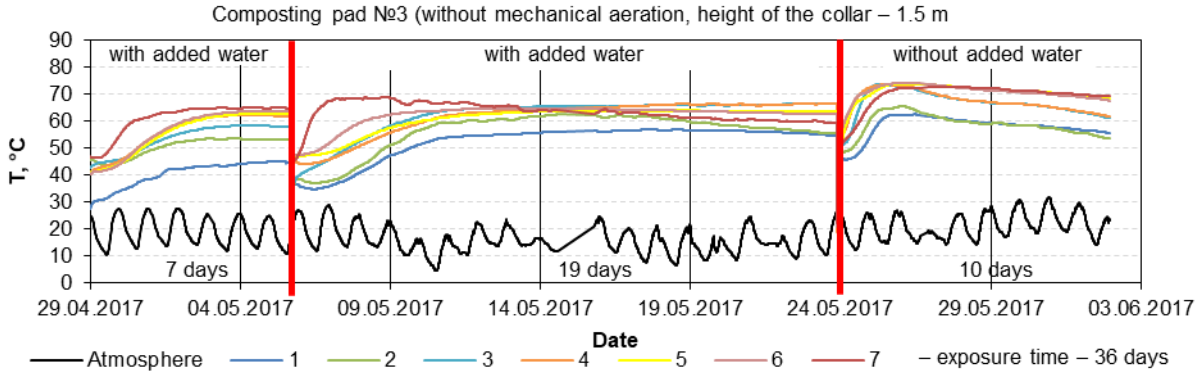

Figure 12. Dynamics of the temperature field of the composting pad №3

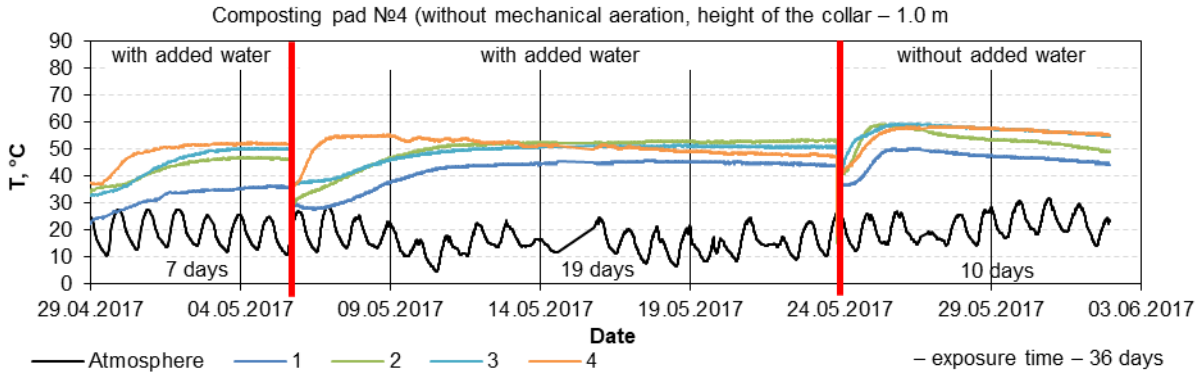

Figure 13. Dynamics of the temperature field of the composting pad №4

The results of monitoring the static temperature field of the surface of the sides with a thermal imager and a pyrometer are presented in Figs. 14–17. As can be seen from Figure 14, for the composting pad №1 there is a temperature range from 19.6 to 23.5 °C, which is practically determined by the ambient temperature, while the average value is 21.5 °C.

For composting pad №2 (Fig. 15) the temperature on the outer surface varies from 18.3 to 21.1 °C, which coincides with the ambient temperature. The average temperature is 19.9 °C, and its standard deviation is 1.2 °C.

The outer surface of the composting pad №3 (Fig. 16) is 19.0–22.3 °C. The mean value is 20.8 °C, and its standard deviation is 1.3 °C.

The composting pad №4 (Fig. 17) is quite homogeneous in terms of surface temperature, which is confirmed by the small value of the standard deviation – 0.9 °C. The average temperature is 20.9 °C.

Longitudinal and transverse sections of the composting pads №3 and №4 (Figs. 18–19) and the determination of temperatures using the above equipment indicate uniform heating of the sides within the above temperatures.

In this case, for the composting pad №3 at the cross section, the minimum and maximum temperature values are 22.7 °C and 59.4 °C, respectively, and the average value is 40.8 °C. Analysis of Figure 17 shows that in the center of the collar is a warmer mixture than outside. The standard deviation of the temperature is 8.2 °C.

A similar situation is observed for the composting pad №4: the minimum and maximum values of temperatures are 23.7 °C and 52.9 °C, respectively, and the mean value is 40.6 °C, the standard deviation is 9.1 °C.

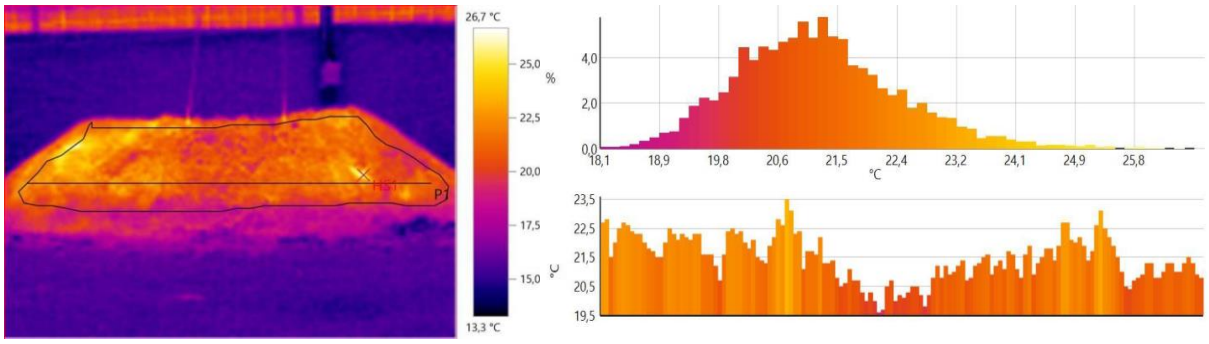

Figure 14. Static temperature field of the surface of the composting pad №1 (composting pad height of 1.5 m without further mechanical aeration and additional humidification)

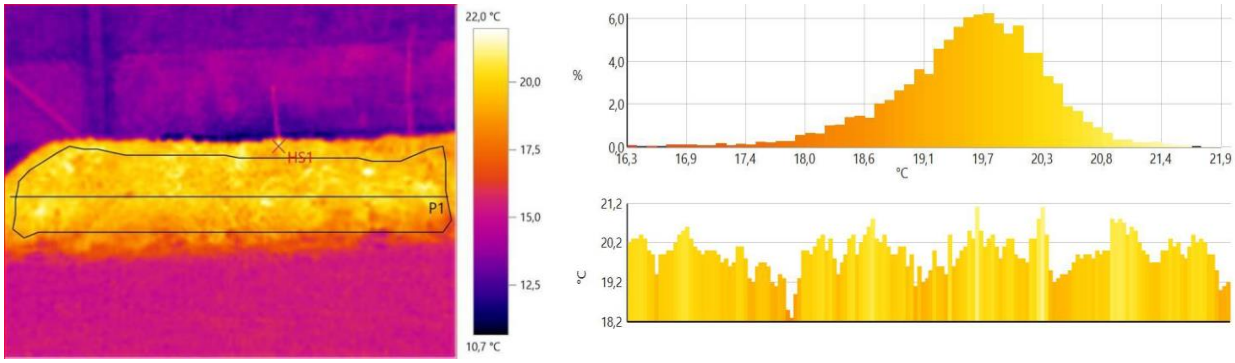

Figure 15. Static temperature field of the surface of the composting pad №2 (composting pad height of 1.0 m without further mechanical aeration and additional humidification)

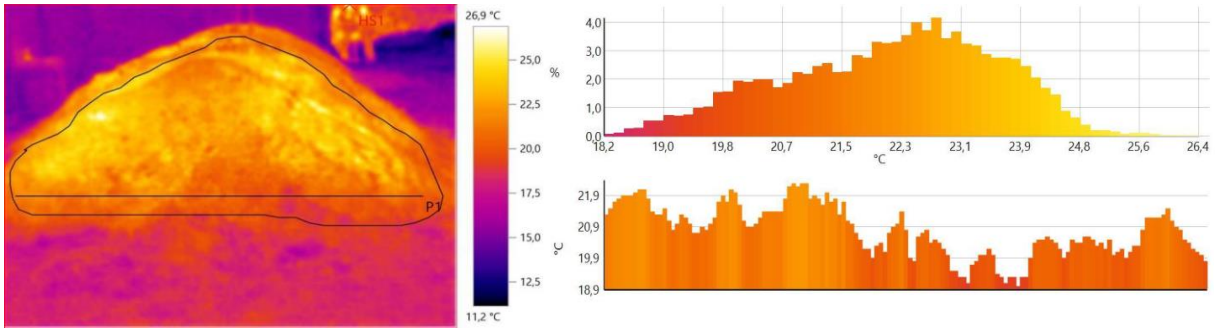

Figure 16. Static temperature field of the surface of the composting pad №3 (composting pad 1.5 m high with subsequent mechanical aeration and with additional humidification)

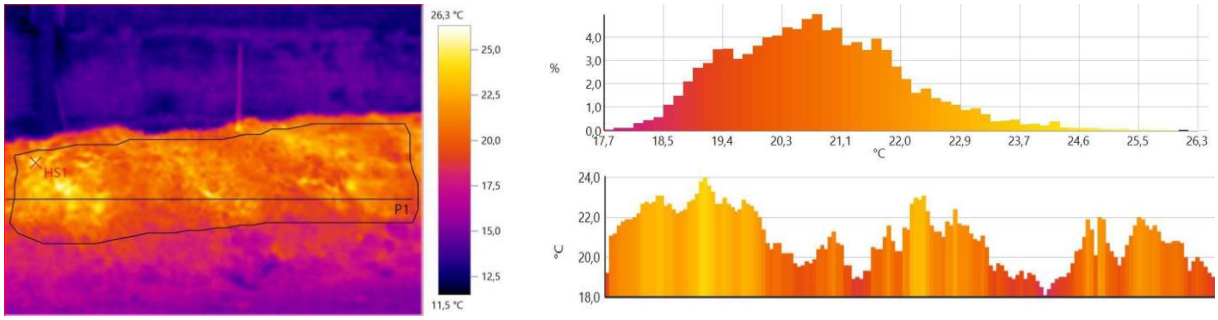

Figure 17. Static temperature field of the surface of the composting pad №4 (composting pad 1.5 m high with subsequent mechanical aeration and with additional humidification)

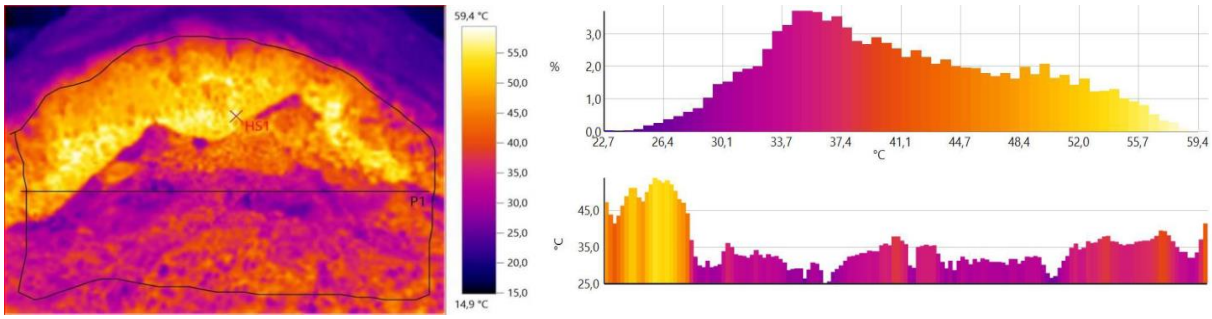

Figure 18. Static temperature field of the cross-section of the composting pad №3 (composting pad 1.5 m high with subsequent mechanical aerations and with additional humidification)

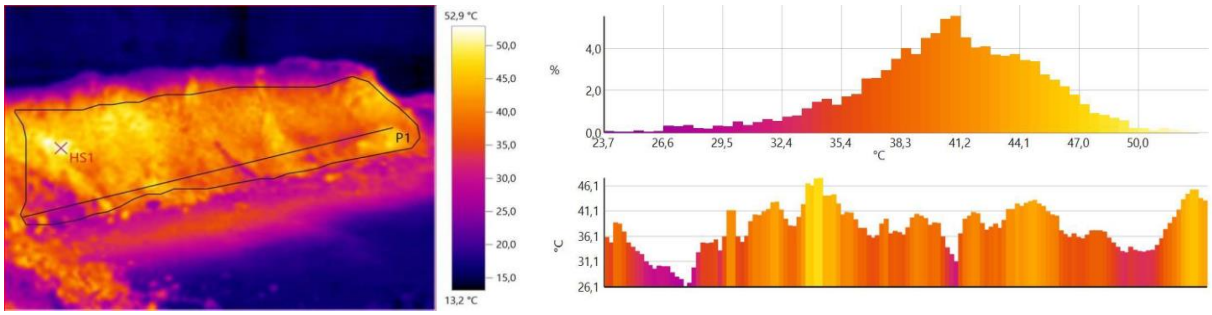

Figure 19. Static temperature field of the longitudinal section of the composting pad №4 (composting pad 1.5 m high with subsequent mechanical aeration and with additional humidification)

Discussion

As a result of the analysis of previously published sources research (Huzaifah *et al.*, 2001; Mironov, 2006; Zhao *et al.*, 2017; Diacono *et al.*, 2019; Rajkhowa *et al.*, 2019; Malik *et al.*, 2020; Samarin *et al.*, 2020; Sayara *et al.*, 2020) it was established that reduction of the negative influence of organic biomass of plant growing and animal husbandry at their accumulation on an ecological condition of environment can be reached at the expense of compost production by the accelerated fermentation technology, which is disinfected from harmful microflora and have an increased concentration of nutrients compared to the original. It was found that a multi-stage composting system with mechanized operations of mixing components, shovelling compost mixtures and simultaneous aeration is the most effective because the decomposition of the organic component of the compost mixture and water evaporation due to released heat energy leads to changes in relative water content (40–70%), ash (20–40%) and organic matter (10–40%) in the finished compost. This significantly improves its agronomic properties: the level of dry matter content increases to 40% (400 kg·t^{-1}) and the specific content of nutrients.

The state of theoretical research of bioenergetic processes of fermentation of compostable raw materials based on analytical dependences on the release of biological energy and use and preservation of the saved energy, which was applied in models of decomposition of organic matter (Bari *et al.*, 2000; Robinzon *et al.*, 2000; Straatsma *et al.*, 2000), is generalized.

The relative weight loss (due to carbon oxidation) in the storage of nutrients improves the logistics component and productivity of machine-tractor units when applying organic fertilizers. There is a significant decrease in organic matter from 47–50 to 32–35% in the raw material against 50–52 to 40–41%.

It is established that mechanical shovelling of raw materials – aeration provides growth of internal temperatures (7 measuring points on the height of the composting pad H = 1.5 m) to the maximum temperature of 65–71 and 50–58 °C at height of the composting pad H = 1.0 m on 2–3 days after laying the composting pad. In 15–17 days, the temperature is up to 50 °C, which does not correspond to the thermophilic mode of bacterial activity and the processes gradually pass into the mesophilic mode – up to 40 °C. Comparing the obtained regularities with the research data (Weppen, 2001), similar stages of biothermal composting regimes of manure-compost mixture are traced. However, our studies are more accurate and show, in addition to the dynamics of temperature change, its distribution in the composting pad. That is, we have determined the dynamics of changes in the temperature field of the composting pad as a whole.

It was found that by the end of the observation period (up to 36 days) the internal temperature in the composting pad №1 (H = 1.5 m) was 39–45 °C, and in the lower layers up to 30 °C, in the composting pad №2 (H = 1.0 m) in the corresponding periods the temperature was 5–8 °C less. Due to the changes in ambient temperature during the day from 10 to 25 °C during the observation period, no significant fluctuations in internal temperature occurred. In the composting pad №3 with mechanical shovelling and addition of liquid – water, the temperature rose to 61–65 °C (H = 1.5 m) for 2–3 days at all 7 measurement points, then decreased by 3–5 °C and remained stable during observation. Shovelling of raw materials without the addition of

liquid for 20 days showed an increase in temperature to 70–72 °C with a gradual attenuation of thermal processes for 10 days and a decrease in temperature to 50 °C. In the composting pad №4 (at H = 1.0 m) and similar treatments as in the composting pad №3, thermal processes are 5–10 °C lower. During aeration, the temperature of the raw material decreases to 38–44 °C. The influence of external temperature fluctuations (10–25 °C) on the change of internal temperatures is statistically insignificant. Comparing the revealed experimental dependences of temperature dynamics with theoretical models (Golub, 2007; Golub *et al.*, 2017b) it is possible to assert their adequacy due to the similar nature of the regularities. However, the proposed theoretical models need to be clarified through the introduction of appropriate empirical coefficients.

As a result of experimental studies of biothermal processes of manure composting, it was found that during the observation period on the composting pads without treatment (36 days) the weight of the composting pad №1 (H = 1.5 m) decreased by 20% (moisture content decreased by 5%), and the composting pad № 2 on – 15% (humidity of raw materials on 5%). In liquids with the addition of liquid – water, the weight of the composting pad №3 and the composting pad №4 varied depending on the amount of introduced water, which led to an increase in the moisture content of the raw material. The change in the mass of the composting pad confirms the model proposed (Bari *et al.*, 2000; Robinson *et al.*, 2000; Straatsma *et al.*, 2000). From this we can conclude that the mass of the composting pad during the biothermal process, logarithmically changes with temperature.

Conclusion

Because of experimental research of conditions of biothermal processes of composting of manure-compost mix the mathematical laws describing dynamics of change of a temperature field in the composting pad of a different configuration for various mechanized conditions are received. It was established that mechanized composting of raw materials provides growth of internal temperatures to the maximum temperature of 65–71 °C (at height of the composting pad of 1.5 m) for 2–3 days after laying of the composting pad. In 15–17 days, the temperature is up to 50 °C, which does not correspond to the thermophilic mode of bacterial activity and the processes gradually pass into the mesophilic mode – up to 40 °C. As a result of experimental studies of biothermal processes of composting manure, it was found that during the fermentation of raw materials in the composting pad without treatment (36 days) the weight of the composting pad (at the composting pad height of 1.5 m) decreased by 20% (raw material moisture decreased by 5%). In the composting pad with mechanical treatment and addition of water, the weight of the composting pad varied from the amount of water introduced, which led to an increase in the moisture content of the raw material. There was a significant decrease in organic matter from 47–50 to 32–35% in the raw material against 50–52 to 40–41%. At the same time, the structure of the treated compost has changed significantly: small and dusty parts under the action of moisture, temperatures have turned into an aggregate medium of particles from 5 to 10 mm with a significant reduction in the number of lumps and layers.

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;
OA – study conception and design;
OM – drafting of the manuscript.

References

Agnew, J.M., Leonard, J.J. 2003. The physical properties of compost. – Compost Science & Utilisation, 11(3):238–264. DOI: 10.1080/1065657X.2003.10702132

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. http://aliev.in.ua/doc/stat/ 2018/ stat_2.pdf

Bari, Q.H., Koenig, A., Guihe, T. 2000. Kinetic analysis of forced aeration composting: I. Reaction rates and temperature. – Waste Management & Research, 18(4):303–312. DOI: 10.1034/j.1399-3070.2000.00114.x

Diacono, M., Persiani, A., Testani, E., Montemurro, F., Ciaccia, C. 2019. Recycling agricultural wastes and by-products in organic farming: Biofertilizer production, yield performance and carbon footprint analysis. – Sustainability, 11(14):3824. DOI: 10.3390/su11143824

Edsel, P., Grant, C. 2006. A Pilot-scale compost reactor for the study of gaseous emissions from compost. – Paper presented at ASABE Annual International Meeting. Reno, Nevada, June 21–24. DOI: 10.13031/2013.27202

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 Ukraine]

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 Ukraine]

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

Hamelers, H.V.M. 2004. Modeling composting kinetics: A review of approaches. – Reviews in Environmental Science and Bio / Technology, 3(4):331–342. DOI: 10.1007/s11157-004-2335-0

Higgins, C., Walker, L. 2001. Validation of a new model for aerobic organic solids decomposition: simulations with substrate specific kinetics. – Process Biochemistry, 36(8–9):875–884. http://pbil.univ-lyon1.fr/members/lobry/articles/JTB_1993_162_447.kim/HigginsCW2001.pdf

Huzaifah M.R. M., Ismail S., Umor N.A., Johar Z., Ang S.Y., Mehedi I.M. 2021. Bio-compost production from organic waste: A brief review. – I Natural Food Products and Waste Recovery. 1st Edition: 10 p. https://www.taylorfrancis.com/chapters/edit/10.1201/9781003144748-19/bio-compost-production-organic-waste-brief-review-huzaifah-ismail-umor-johar-ang-mehedi

Kaiser, J. 1996. Modelling composting as a microbial ecosystem: A simulation approach. – Ecological Modelling, 91(1–3):25–37. DOI: 10.1016/0304-3800(95)00157-3

Kim, D.S., Kim, J.O., Lee, J.J. 2000. Aerobic composting performance and simulation of mixed sludges. – Bioprocess Engineering, 22(6):533–537. DOI: 10.1007/s004499900102

Kiselyov, O.V., Komarova, I.B., Milko, D.O., Bakardzhiev, R.O. 2017. Statystychna obrobka i oformlennya rezul′tativ eksperymen-tal′nykh doslidzhen′ (iz dosvidu napysannya dysertatsiynykh robit) [Statistical processing and design of the results of experimental research (from the experience of writing dissertations): Textbook]. – Electronic analogue of the printed edition (electronic book). – Zaporozhye: STATUS: 1181 p. [In Ukraine]

Kuznetsov, V.I. 2001. Intensifikatsiya protsessa aerobnoy biofermentatsii navozosolomennoy smesi [Intensification of the process of aerobic biofermentation of the manure-straw mixture]. – Avtoreferat dissertatsii doktora tekhnicheskikh nauk: 05.05.11. NNTS "ÍMESG" [Abstract of the dissertation of Doctor of Technical Sciences: 05.05.11. NSC "IMESG"]: 21 p. [In Russian]

Malik, K., Rani, S., Ahlawat, S., Kumari, N., Singh, D. 2020. Bioconversion process for compost production from agricultural residue. – International Journal of Chemical Engineering 9(2):827–830. https://www.researchgate.net/publication/350191108_Bioconversion_process_for_compost_production_from_agricultural_residue/references.

Mason, I.G. 2006. Mathematical modelling of the composting process: A review. – Waste Management, 26:3–21. DOI: 10.1016/j.wasman.2005.01.021

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]

Ndegwa, P.M., Thompson, S.A., Merka, W.C. 2000. A dynamic simulation model of in-situ composting of caged layer manur. – Compost Science & Utilisation, 8(3):190–202. DOI: 10.1080/1065657X.2000.10701991

Petric, I. 2008. Aerobic Composting of Poultry Manure and Wheat Straw-Kinetic and Reactor Model. – International Journal of Chemical Reactor Engineering, 6(1): 1–40. DOI: 10.2202/1542-6580. 1647

Rajkhowa, D.J., Sarma, A.K., Bhattacharyya, P.N., Mahanta, K. 2019. Bioconversion of agricultural waste and its efficient utilization in the hilly ecosystem of Northeast India. – International Journal of Recycling of Organic Waste in Agriculture, 8:11–20. DOI: 10.1007/s40093-019-0253-y

Robinzon, R., Kimmel, E., Avnimelech, Y. 2000. Energy and mass balances of windrow composting system. – Transactions of ASAE, 43(5):1253–1259. DOI: 10.13031/2013.3019

Samarin, G.N., Kokunova, I.V., Vasilyev, A.N., Kudryavtsev, A.A., Normov, D.A. 2020. Optimization of compost production technology. – International Conference on Intelligent Computing & Optimization. ICO 2020. Advances in Intelligent Systems and Computing, vol. 1324. Springer, Cham: 1319–1327. DOI: 10.1007/978-3-030-68154-8_113.

Sayara, T., Basheer-Salimia, R., Hawamde, F., Sánchez, A. 2020. Recycling of organic wastes through composting: Process performance and compost application in agriculture. – Agronomy, 10:1838. DOI: 10.3390/agronomy10111838

Scholwin, F., Bidlingmaier, W. 2003. Fuzzifying the composting process: a new model based control strategy as a device for achieving a high grade and consistent product quality. – Proceedings of the Fourth International Conference of ORBIT Association on Biological Processing of Organics: Advances for a Sustainable Society, 30 April – 2 May, 2003, Perth, Australia. ORBIT Association, Weimar, Germany, pp. 739–751.

Seki, H. 2000. Stochastic modeling of composting process with batch operation by the Fokker-Planck equation. – Transactions of the ASAE, 43(1):169–179. DOI: 10.13031/2013.2682

Seng, B, Kristanti, RA, Hadibarata, T, Hirayama, K, Katayama-Hirayama, K, Kaneko, H. 2016. Mathematical model of organic substrate degradation in solid waste windrow composting. – Bioprocess and Biosystems Engineering, 39(1):81–94. DOI: 10.1007/s00449-015-1492-6

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

Sokač, T., Šalić, A., Grgić, D. K., Runjavec, M. Š., Vidaković, M., Tušek, A. J., Horvat, Đ., Krnjak, J. J., Domanovac, M. V., Zelić, B. 2021. An enhanced composting process with bioaugmentation: Mathematical modelling and process optimization. – Waste Management & Research: The Journal for a Sustainable Circular Economy. DOI: 10.1177/0734242x211033712

Stani, A.H. 2012. Modelling of temperature in full-scale systems: a review of the biological heat generation within windrow composting. – Jurnal Teknologi Lingkungan, 13(3):291–296. DOI: 10.29122/jtl.v13i3.1399.

Stombaugh, D.P., Nokes, S.E. 1996. Development of a biologically based aerobic composting simulation model. – Transactions of ASAE, 39(1):239–250. DOI:10.13031/2013.27504

Straatsma, G., Gerrits, J.P.G., Thissen, J.T.N.M., Amsing, J.G.M., Loffen, H., van Griensven, L.J.L.D. 2000. Adjustment of the composting process for mushroom cultivation based on initial substrate composition. – Bioresource Technology, 72(1):67–74. DOI: 10.1016/S0960-8524(99)00088-7

Weppen, P. 2001. Process calorimetry on composting of municipal organic wastes. – Biomass & Bioenergy, 21:289–299. DOI: 10.1016/S0961-9534(01)00033-2.

Zhao, R.F., Gao, W., Guo, H.Q. 2017. Comprehensive review of models and methods used for heat recovery from composting process. – International Journal of Agricultural and Biological Engineering, 10(4):1–12. DOI: 10.25165/j.ijabe.20171004.2292

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THE OUTLET DESIGN OF FLAT FAN NOZZLE VARIES THE APPLICATION TIME OF DAY EFFECT ON NICOSULFURON ACTIVITY

Akbar Aliverdi[1], Abolfazl Aliverdi[2], Jason Connor Ferguson[3]

[1]Department of Agronomy and Plant Breeding, Faculty of Agriculture, Bu-Ali Sina University, Shahid Mostafa Ahmadi Roshan St., Hamedan, 6516738695, Islamic Republic of Iran
[2]Department of Horticulture, Faculty of Agriculture, Bu-Ali Sina University, Shahid Mostafa Ahmadi Roshan St., Hamedan, 6516738695, Islamic Republic of Iran
[3]Department of Plant and Soil Sciences, College of Agricultural and Life Sciences, Mississippi State University, 32 Creelman St, Mississippi State, MS 39762, United States of America

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Vastutav autor: Corresponding author: Akbar Aliverdi

E-mail: a.aliverdi@basu.ac.ir

ORCID:
0000-0002-0209-4755 (AkA)
0000-0002-7737-5420 (AbA)
0000-0003-4690-1288 (JCF)

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ABSTRACT. On two container-grown species, johnsongrass and velvetleaf, nicosulfuron was sprayed with the Anti-Drift Single, Dual, and Triplet Flat-Fan nozzles (AD/S, AD/D, AD/T nozzles, respectively) at 05:00 to 21:00, with a two-hour interval. At 5:00 to 11:00, nicosulfuron activity on both species was greatest with the AD/T followed by the AD/D and finally, the AD/S nozzle. At 15:00 to 19:00, however, nicosulfuron activity on johnsongrass was greatest with the AD/D, followed by the AD/T and finally, the AD/S nozzle, and nicosulfuron activity on velvetleaf was greatest with the AD/D followed by the AD/S and the AD/T nozzle had the lowest control. Nicosulfuron applied with the AD/T nozzle in the early morning caused the highest desiccation (70%) in both species. The best time to apply nicosulfuron was in the early morning. However, velvetleaf undergoes foliar nyctinasty depending on daylight, which made effective control achieved by only the AD/D and AD/T nozzles.

Introduction

Nicosulfuron is a postemergence herbicide that is used in corn (*Zea mays* L.) to control many monocotyledonous weeds, *e.g.* johnsongrass (*Sorghum halepense*) which is a perennial plant, and dicotyledonous weeds, *e.g.* velvetleaf (*Abutilon theophrasti*) which is an annual plant, (Dobbels, Kapusta, 1993). It belongs to the enzyme acetolactate synthase (ALS)-inhibiting herbicide group (B/2). In the chloroplast, ALS biosynthesizes some essential amino acids (isoleucine, leucine, and valine). If ALS is inactivated, cell division stops; and eventually, plant death occurs (Cobb, Reade, 2010).

The slow degradation of nicosulfuron causes carryover effects on succeeding crops, *e.g.*, cabbage, onion (Greenland, 2003), and potato (Novo, Miranda-Filho, 2006). On the other hand, it can exert the extreme selection pressure against the susceptible biotypes, causing the evolution of nicosulfuron resistance in 26 different weed species worldwide. In the meantime, nicosulfuron resistance has been reported in johnsongrass but not in velvetleaf (Heap, 2020). If nicosulfuron is used rationally, the spray droplets can be delivered the target effectively. Herbicide rational application has three essential elements: herbicide selectivity, appropriately timed application, and application accuracy (Aliverdi, Karami, 2020).

Previous study reported that nicosulfuron activity to control barnyard grass (*Echinochloa crus-galli*) depends on the application time of day (Stewart *et al*., 2009). They said that nicosulfuron was more effective when it has been applied in the early morning than other

times of day. The dependence of herbicide activity on the time of day has been termed as the application time of day effect evidencing in two other ALS herbicides included imazapic and imazethapyr (Stopps *et al*., 2013; Carter, Prostko, 2019). In general, the review of this literature revealed that the highest activity of contact herbicides is achieved when they have been used in the nighttime, especially after sunset. The greatest activity of systemic herbicides is achieved when they have been used in the daytime. Moreover, the review of this literature revealed that all herbicides mentioned above had been sprayed by a single flat-fan nozzle. In addition, there are two other designs in the market, including dual and triplet flat-fan nozzles. In previous study conducted at a specific time of day, the highest control of weed was achieved when clodinafop-propargyl has applied with AD/D nozzle as compared to AD/S nozzles (Aliverdi, Karami, 2020) but in another study, the highest control of weed was achieved when cycloxydim has applied with triplet flat fan nozzles compared to dual flat fan nozzles (Aliverdi, Karami, 2020). The triplet flat fan nozzle has recently released by the MagnoJet company in Brazil since 2014 and is newer than the single and dual flat-fan nozzles.

This experiment aims to specify the best time(s) of day for applying nicosulfuron using the AD/S, AD/D, and AD/T nozzles. Two weeds species, one broadleaf species – velvetleaf and one grass species – johnsongrass, which differs in their leaf angle at different times of day, were used in this study.

Materials and Methods

The seeds of johnsongrass and velvetleaf were collected from Hamedan and Gorgan fields, Iran, in the summer of 2018, respectively. They were stored in the laboratory until the beginning of the study conducting in the Bu-Ali Sina University, Hamadan, Iran from May to August 2019.

To break dormancy, johnsongrass seeds were immersed in concentrated sulfuric acid for 3 min (Parsa *et al*., 2013), and velvetleaf seeds were immersed for 1 hour in 60 °C water (Ravlić *et al*., 2015). Then, they were washed with cold water. Approximately 10 treated seeds of each weed species were planted at 0.5 cm soil depth in 2 L containers containing clay loam soil with 0.7% organic matter and 7.2 pH. The containers were placed in outdoor conditions. The soil surface of containers was kept continuously moist for up to a week. After the emergence of seedlings, they were thinned to maintain 4 seedlings container^{-1} and irrigated equally every two days with tap water.

For each weed species, a two-factor experiment (3 × 9) was conducted as a completely randomized design. For each treatment, there were four replications. With a one-day interval, the experiment was repeated at all stages. The 1st run was planted on 30 May 2019, sprayed on 11 July 2019, and harvested on 2 August 2019. The 2nd run was done with one-day interval after the first experimental ones. The 1st factor was the nozzle outlet design including the AD/S, AD/D, and AD/T nozzles, all types were 11002VK; and the 2nd factor was application time of day including 05:00, 07:00, 09:00, 11:00, 13:00, 15:00, 17:00, 19:00, and 21:00. Sunrise and sunset occurred at 06:10 and 20:32, respectively.

For each weed species, four unsprayed containers (untreated control) were considered for comparison purposes. In the four-leaf stage, both weed species were treated with the recommended dose of nicosulfuron, 80 g a.i. ha^{-1} (Cruz®, SC 4%, Alborz Behsam, Iran), using an a compressed-air sprayer (Solo 461 model, Germany) calibrated to deliver 210 L ha^{-1} at 300 kPa. Before applying the herbicide at different times of day, the angle of the fourth leaf of the plants inside the containers to the ground was measured, then averaged, and showed in Fig. 1. The leaf angle of 0° means it has horizontal status, the leaf angle less than 0° means it is oriented downward, the leaf angle more than 0° means it is oriented upward, and the leaf angle of 90° or –90° means it is parallel to the stem. Moreover, air properties at the application times were measured and showed in Figure 1. According to the nozzles manual (MagnoJet, 2020), the size of the droplets at 300 kPa for the AD/S and AD/D nozzles ranged from 236 to 340 µm and for the AD/T nozzle ranged 106-235 µm. In the AD/D and AD/T nozzles, the angle between the two flat fans is 40°.

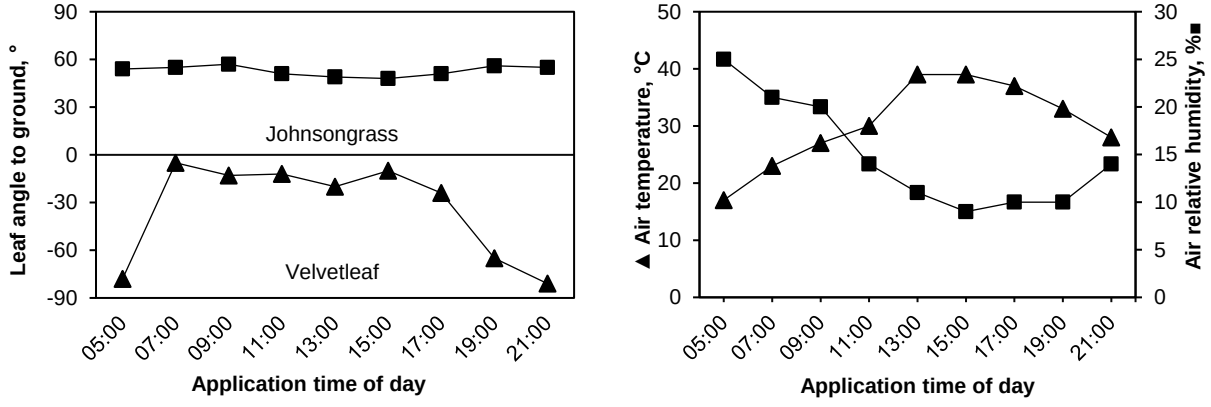

Figure 1. The fourth leaf angle of johnsongrass and velvetleaf (top), air temperature and relative humidity (down) at different times of day. Data are means of two continuous days

Twenty days after spraying, the plant biomass were removed at the soil surface. The fresh weight (FW) and dry weight (DW) of each experimental unit (container) were obtained and divided by 4 (number plant container $^{-1}$). Finally, the ratio of FW/DW was used in statistical analysis. The ratio of FW/DW has a starting range from one and up and shows the intensity of dehydration in tissues due to herbicide action. A FW/DW ratio close to one means dehydration completely (Rytwo, Tropp, 2001). The data had a normal distribution confirming the Shapiro-Wilk test more than 0.90. Then, the data were subjected to analysis of variance (ANOVA) using SAS software. No significant run-by-treatment interactions occurred. Hence, the data were pooled to give eight replications, then re-analyzed. For mean separations, Duncan's multiple range test was used at a 0.05 probability level.

Results

The ratio of FW/DW for johnsongrass and velvetleaf non-treated with nicosulfuron (control) were 7.3 and 6.8, respectively. All of the herbicide treatments reduced the ratio of FW/DW in both weed species. Hereafter, this reduction was expressed as a dehydration percentage. ANOVA showed that nozzle outlet design and application time of day significantly affected the ratio of FW/DW for johnsongrass and velvetleaf. The two-way interaction was also significant in both weed species. In johnsongrass, the lowest activity of nicosulfuron was observed when it was applied with the AD/S nozzle from 13:00 to 19:00 (49.5 to 53.6% dehydration). While, the highest activity of nicosulfuron was achieved when it was applied with the AD/T nozzle at 5:00 (73.6% dehydration) and 7:00 (72.3% dehydration) (Fig. 2). In velvetleaf, the lowest activity of nicosulfuron was observed when it was applied with the AD/S nozzle at 19:00 (43.5% dehydration) and 21:00 (42.2% dehydration). While, the highest activity of nicosulfuron was achieved when it was applied with the AD/T nozzle from 5:00 to 9:00 (69.1 to 72.1% dehydration) (Fig. 2).

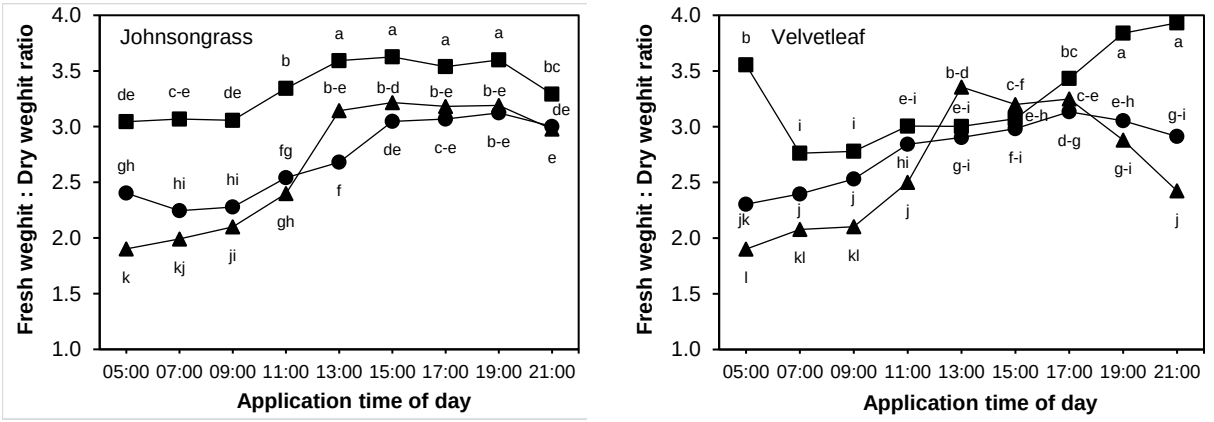

Figure 2. Fresh weight: dry weight ratio of johnsongrass (top) and velvetleaf (down) treated with nicosulfuron, which have sprayed with the anti-drift single (■), dual (●), and triplet flat-fan nozzles (▲) at different times of day. The means followed by same letter are not significantly different according to Duncan's multiple range test at the 5% probability level. Data are means of eight replicates from two runs.

At all application times of day, the use of AD/D nozzle significantly caused more dehydration in johnsongrass than the AD/S nozzle. Two non-vertical sprays created by the AD/D nozzle (one with 40° forward and another with 40° backward to the direction of nozzle trajectory) can increase the possibility of the deposition of droplets on the front and back side of monocotyledonous plants, resulting in improved activity of nicosulfuron. This finding also supports previous study (Jensen, 2012). At 5:00 and 9:00, the activity of nicosulfuron with the AD/T nozzle was higher than that with the AD/D nozzle. Conversely, at 13:00, the activity of nicosulfuron with the AD/D nozzle was higher than that with the AD/T nozzle.

Similar to the trend observed for johnsongrass, the trend of changes in the FW/DW ratio for velvetleaf over different application times of day showed that in the AD/D and AD/T nozzles, the FW/DW ratio in the early morning applications (5:00 to 9:00) are lower than in the afternoon applications (13:00 to 19:00). However, the trend of these changes in the AD/S nozzle differed from those in the AD/D and AD/T nozzles (Fig. 2) and it was correlated negatively with the trend of changes in the leaf angle of velvetleaf over different times of day (Fig. 1). When nicosulfuron was applied with the AD/S, AD/D, and AD/T nozzles at 5:00, the intensity of dehydration in tissues of velvetleaf was 47.7, 66.2, and 72.1%, respectively.

Discussion

In general, the trend of changes in the FW/DW ratio of johnsongrass over different times of day showed that in each nozzle outlet design, the FW/DW ratio in the early morning applications (5:00 to 9:00) are lower than in the afternoon applications (13:00 to 19:00). These results indicate that with each nozzle outlet design, the best time(s) to apply nicosulfuron was in the early morning. In contrast, the worst time(s) to apply nicosulfuron was in the afternoon. This result might be

related to differences in air properties at application times of day (Fig. 1). Stewart *et al*. (2009), who used nicosulfuron in Ontario, Canada to control barnyard grass with a single flat fan nozzle at different times of day, also identified in the early morning applications as the highest nicosulfuron activity. They stated that the spray droplets dry faster in the noon and afternoon applications due to high air temperatures and low relative humidity, leading to faster crystallization of the active ingredient of herbicide, resulting in decreased absorption and activity of nicosulfuron. Other studies have shown that the absorption of paraquat, fomesafen, and glufosinate (Preston *et al*., 2005; Cieslik *et al*., 2014; Ramsey *et al*., 2002) has decreased with increasing air temperature and decreasing air relative humidity. Decreased herbicide absorption is due to the faster crystallization of the active ingredient of the herbicides. However, the afternoon applications of atrazine, imazethapyr, and glyphosate (Stopps *et al*., 2013; Mohr *et al*., 2007) were the best time of day. Moreover, the noon applications of bromoxynil and 2,4-D (Stewart *et al*., 2009; Montgomery *et al*., 2017) were the best time of day.

At all times of nicosulfuron application of day, the use of AD/D nozzle significantly caused more dehydration in johnsongrass than the AD/S nozzle. The leaves of monocotyledonous weeds, such as johnsongrass, are relatively upright (perpendicular to the ground) throughout the day (Fig. 1). On the other hand, with the AD/S nozzle, the spray droplets fall perpendicularly. Therefore, the spray droplets mainly hit the leaf surface obliquely. As a result, they are more likely to bounce off from the leaf surface to the ground and be endodrifted. In a previous study, improved activity of some graminicides by changing the spray angle of a single flat fan nozzle from vertical to non-vertical has been reported (Jensen, 2012). In the current study, two non-vertical sprays created by the AD/D nozzle (one with 40° forward and another with 40° backward to the direction of nozzle trajectory) can increase the possibility of the deposition of spray droplets on the leaves of monocotyledonous weeds, resulting in improved activity of nicosulfuron. The higher performance of AD/D nozzle than AD/S nozzle (Aliverdi, Karami, 2020) has already reported.

In the early morning and morning applications, the activity of nicosulfuron with the AD/T nozzle was higher than that with the AD/D nozzle. Conversely, in the afternoon applications, the activity of nicosulfuron with the AD/D nozzle was higher than that with the AD/T nozzle. This finding might be related to differences in the spray droplet size produced by these types of nozzles. The AD/T nozzle has finer spray droplets than the AD/D nozzle (MagnoJet, 2020). The smaller the size of the spray droplets, the more their retention on the target (Ferguson *et al*., 2018). Therefore, it can be inferred from the results that in afternoon applications under the higher air temperature and the lower relative humidity conditions, the finer spray droplets produced by AD/T nozzle, although they deposit in a greater volume on the target, can evaporate faster, resulting in decreased activity of nicosulfuron in the afternoon applications. With decreasing the leaf angle of velvetleaf, the FW/DW ratio of velvetleaf increased. In other words, the more the leaf is oriented downward, the lower the leaf is dehydrated. Unlike johnsongrass, velvetleaf showed a strong leaf nyctinasty depending on daylight (Fig. 3).

Figure 3. Foliar nyctinasty in velvetleaf depending on daylight. Sunrise at 06:10

In previous studies in which herbicides have been sprayed with a single flat fan nozzle causing a perpendicular movement of spray droplets to the ground, the researchers have found that the leaf nyctinasty in weeds decreases the deposition of spray droplets on the leaf surface, resulting in decreased activity of herbicide (Sellers *et al*., 2003). For example, the leaf angle of velvetleaf at 14:00, 17:00, 18:30, 19:15, and 20:00 in the study of Mohr *et al*. (2007) was –10, –10, –30, –60 and –80° respectively. They reported that with reducing the leaf angle of velvetleaf, the activity of glyphosate decreased steadily.

It seems that the leaf nyctinasty in velvetleaf makes it irrational to apply nicosulfuron with the AD/S nozzle before sunrise, given the lowest air temperature and the highest relative humidity. However, the current study results show that nicosulfuron application before sunrise is rational if the AD/D and AD/T nozzles are used. Already, we have observed a similar result with trifloxysulfuron against velvetleaf (Aliverdi, Ahmadvand, 2021). As mentioned above, the difference between the performance of the AD/D and AD/T nozzles should be related to the difference in the size of spray droplets produced by them. However, the role of the increased spray pattern of the AD/T nozzle as compared to the AD/D nozzle should not be ignored. The AD/T nozzle creates one vertical spray and two non-vertical sprays (one with 40° forward and another with 40° backward to the direction of nozzle trajectory), while the AD/D nozzle does not create vertical spray. Aliverdi and Karami (2020) have reported that the performance of a triplet flat fan nozzle was better that of AD/D nozzle.

Conclusion

In conclusion, the best time of day for applying nicosulfuron to control johnsongrass and velvetleaf was in the early morning. However, given velvetleaf undergo leaf nyctinasty depending on daylight, the early morning applications only when it is rational that the AD/D nozzle or preferably the AD/T nozzle were used. The performance of the AD/S, AD/D, and AD/T nozzles depends on the application time of nicosulfuron of day. So, when nicosulfuron was used at 5:00 to 11:00, a performance of the AD/T > AD/D > AD/S nozzles could be observed. It seems that high air temperature and low relative humidity cause reduced activity of nicosulfuron. In those weather conditions, a method causing the spray droplets to become smaller (for example, increasing the number of flat fans in a nozzle and decreasing the nozzle flow rate) will cause the spray droplets to evaporate faster, resulting in less activity of nicosulfuron.

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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

AkA – analysis and interpretation of data and writing a manuscript;
AbA – acquisition of data;
JCF – writing, revision, and approve the final manuscript.

References

Aliverdi, A., Ahmadvand, G. 2021. The application time-of-day effect for trifloxysulfuron against velvetleaf as affected by nozzle type. – Journal of Cotton Science, 25: 45-50. URL: http://www.scopus.com/inward/record.url?eid=2-s2.0-85105498473&partnerID=MN8TOARS

Aliverdi, A., Karami, S. 2020. The effect of type and size of single, twin, and triplet flat fan nozzles on the activity of cycloxydim against wild barley (*Hordeum spontaneum* Koch.). – Journal of Plant Protection, 33: 465–474. DOI: 10.22067/JPP.V33I4.81208

Carter, O.W., Prostko, E.P. 2019. Time of day effects on peanut herbicide efficacy. – Peanut Science, 46: 174–181. DOI: 10.3146/PS18-18.1

Cieslik, L.F., Vidal, R.A., Trezzi, M.M. 2014. Fomesafen toxicity to bean plants as a function of the time of application and herbicide dose. Acta Scientiarum. – Agronomy, 36:329–334. DOI: 10.4025/actasciagron.v36i3.17630

Cobb, A.H., Reade, J.P.H. 2010. Herbicides and Plant Physiology. (2nd eds). – John Wiley and Sons, New York, USA.

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

Ferguson, J.C., Chechetto, R.G., Adkins, S.W., Hewitt, A.J., Chauhan, B.S., Kruger, G.R., O'Donnell, C.C. 2018. Effect of spray droplet size on herbicide efficacy on four winter annual grasses. – Crop Protection, 112:118–124. DOI: 10.1016/j.cropro.2018.05.020

Greenland, R.G. 2003. Injury to vegetable crops from herbicides applied in previous years. – Weed Technology, 17:73–78. DOI: 10.1614/0890-037X(2003)017[0073:ITVCFH]2.0.CO;2

Heap, I. 2020. The International Herbicide-Resistant – Weed Database. www.weedscience.org Accessed 21/2/2020.

Jensen, P.K. 2012. Increasing efficacy of graminicides with a forward angled spray. – Crop Protection, 32:17–23. DOI: 10.1016/j.cropro.2011.10.017

MagnoJet. 2020. Product Catalogue. – http://www.magnojet.com.br/produtos. Accessed 21/2/2020.

Mohr, K., Sellers, B.A., Smeda, R.J. 2007. Application time of day influences glyphosate efficacy. – Weed Technology, 21:7–13. DOI: 10.1614/WT-04-251.1

Montgomery, G.B., Treadway, J.A., Reeves, J.L., Steckel, L.E. 2017. Effect of time of day of application of 2,4-d, dicamba, glufosinate, paraquat, and saflufenacil on horseweed (*Conyza canadensis*) control. – Weed Technology, 31:550–556. DOI: 10.1017/wet.2017.34

Novo, M.C.S.S., Miranda-Filho, H.S. 2006. Effect of sulfonylurea herbicides on tuberization of two potato cultivars. – Planta Daninha, 24:115–121. DOI: 10.1590/S0100-83582006000100015

Parsa, M., Aliverdi, A., Hammami, H. 2013. Effect of the recommended and optimized doses of haloxyfop-P-methyl or imazethapyr on soybean-*Bradyrhizobium japonicum* symbiosis. – Industrial Crops and Products, 50:197–202. DOI: 10.1016/j.indcrop.2013.07.019

Preston, C., Soar, C.J., Hidayat, I., Greenfield, K.M., Powles, S.B. 2005. Differential translocation of paraquat in paraquat resistant populations of *Hordeum leporinum*. – Weed Research, 45:289–295. DOI: 10.1111/j.1365-3180.2005.00454.x

Ramsey, R.J.L., Stephenson, G.R., Hall, J.C. 2002. Effect of relative humidity on the uptake, translocation, and efficacy of glufosinate ammonium in wild oat (*Avena fatua*). – Pesticide Biochemistry and Physiology, 73:1–8. DOI: 10.1614/WS-05-051R.1

Ravlić, M., Baličević, R., Lucić, P., Mazur, P., Lazić, A. 2015. Dormancy and germination of velvetleaf (*Abutilon theophrasti* Medik.) and redroot pigweed (*Amaranthus retroflexus* L.) seeds. – Herbologia, 15: 27–39. DOI: 10.5644/Herb.15.2.03

Rytwo, G., Tropp, D. 2001. Improved efficiency of a divalent herbicide in the presence of clay, by addition of monovalent organocations. – Applied Clay Science, 8:327–33. DOI: 10.1016/s0169-1317(01)00035-7

Sellers, B.A., Smeda, R.J., Johnson, W.G. 2003. Diurnal fluctuations and leaf angle reduce glufosinate efficacy. – Weed Technology, 17:302–306. DOI: 10.1614/0890-037X(2003)017[0302:DFALAR]2.0.CO;2

Stewart, C.L., Nurse, R.E., Sikkema, P.H. 2009. Time of day impacts POST weed control in corn. – Weed Technology, 23:346–355. DOI: 10.1614/WT-08-150.1

Stopps, G.J., Nurse, R.E., Sikkema, P.H. 2013. The effect of time of day on the activity of postemergence soybean herbicides. – Weed Technology, 27:690–695. DOI: 10.1614/WT-D-13-00035.1

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EFFECT OF SOLID AND LIQUID CHELATED IRON ON GROWTH AND YIELD OF BROAD BEAN

Mohammad Salman Kareem Al-Zubaidi[1], Basem Rahem Bader[2], Mohammed Ali Abood[2], Ghassan Jaafar Hamdi[3], Hassan Rashid Jassim Al-Afraji[2]

[1]Ministry of Education, Directorate of Education, Diyala, Baqubah, Iraq
[2]Department of Soil Science and Water Resources, College of Agriculture, University of Diyala, 32001, Baqubah, Iraq
[3]Department of Horticulture and Gardening Engineering, College of Agriculture, University of Diyala, 32001, Baqubah, Iraq

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Vastutav autor: Corresponding author: Ghassan Jaafar Hamdi

E-mail: ghassanhamdi38@gmail.com

ORCID:
0000-0002-4310-0250 (BRB)
0000-0002-3664-5930 (MAA)
0000-0001-9312-8238 (GJH)

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ABSTRACT. A field experiment was carried out within the randomized complete block design in the agricultural season 2020–2021. The experiment included two factors, the first factor was solid chelated iron (S_0, S_1, and S_2 at concentrations 0, 100, and 200 ppm, respectively), which was added to the soil. The second factor was liquid chelated iron (L_0, L_1, and L_2 at concentrations 0, 2, and 4 ml L^{-1} respectively), which was spraying on the plants. The results showed that the stem diameter, number of pods, and total yield were significantly affected by adding the 100 ppm iron solid chelated treatment (18.36 mm, 25.74 pod plant^{-1}, 5.01 Mg ha^{-1} respectively). While 200 ppm treatment had the highest plant height (30.10 cm, yield (771.35 g plant^{-1}), seeds (6.18 per pod). The treatment of 4 ml L^{-1} liquid chelated iron treatment had the highest plant height (128.55 cm), biggest stem diameter (18.63 mm), highest pods per plant (25.45), yield (755.98 g plant^{-1}), total yield (4.80 Mg ha^{-1}), pod length (24.87 cm), pod weight (28.14 g) and the number of seeds per pod (7.88). The use of the interaction between solid and liquid chelated iron improves the vegetative growth and yield of broad beans.

Introduction

The broad bean *Vicia faba* L. is one of the basic winter crops, and it is one of the annual plants that belong to the legume family and constitutes an important part of the nutrition of people, especially those with limited income (Farhan, 2012). It also has many uses as it is grown as a green crop to consume its pods or to obtain its dry seeds that are used as human food or green feed crop to animals. It is important for improving the fertility of soil through its fixing of nitrogen in the soil. Therefore, it is used within agricultural rotations, and they work on the activity of Rhizobia bacteria. Further, its dry seeds contain carbohydrates 58.41% protein 21.39%, each 100 g dry weight seed 1.6 mg of iron and 90 mg calcium, 3.6 mg vitamin C 100 mg. (Chafiand *et al.*, 2009). It occupies an area of 2.577.201 hectares with a word production of 5.431.503 t (Anonymous, 2021). Foliar nutrition, which is the process of providing plants with the necessary nutrients by spraying nutrients on the vegetative system, which can absorb elements through stomata openings that are found on the upper and lower surfaces of the leaf. The foliar fertilization is one of the most important and easiest ways to deliver nutrients to the leaf stomata. It is a supplement with organic fertilizers in the soil and not a substitute for it (Rajasekar *et al*., 2017; Rachid *et al*., 2020).

Recent experiments have shown that foliar nutrition is efficient and effective compared to soil fertilizing and that it is not an alternative but rather a supplement to it, in addition to the speed of nutrients reaching the tissues of the leaf, taking into account the importance of nutrition from the soil through the roots (Bader *et al.*, 2020). Iron (Fe) deficiency chlorosis is a widespread problem for soybean grown on alkaline, calcareous soils (Hansen *et al*., 2003). Chelated compounds are derived from the word Chelate which is derived from the Greek word claw. In chemistry, 'Chelate' means the cyclic structure

resulting from the ion link to two sets or more of electron donors to form a single element molecule. Usually, ferric occupies the first rank in the sequence of elements with the ability to form chelate compounds while ferrous occupies the third rank after the zinc. Chelate compounds can be added to plant either by soil or by spraying since it is easy to absorb, transfer and decompose and does not cause damage if added in appropriate concentrations for the plant (Al-Nuaimi, 1987).

Iron is of great importance in the construction of chlorophyll and the oxidation and reduction processes within the plant tissue, including respiratory enzymes. In addition to its entry into the synthesis of cytochromes and ferredoxin, which are important in the process of carbon metabolism. It is important in the formation of plant proteins and vital processes in the plant by being active for enzymes related to the process of respiration and electron transfer. It is included in the composition of chloroplasts and many enzymes (Barker, Stratton, 2015). It provides a larger surface area for the various metabolic reactions in the plant, which increases the rate of carbonization and thus encourages the demand for mineral elements from the soil, and this leads to the production of more dry matter, as well as keeps the plant from biotic and abiotic stresses (Singh *et al*., 2017). Whereas, Faisal *et al*. (2012) observed that the spraying of chelated iron with iron concentrations 0, 150, and 300 mg Fe L^{-1} on the bean plant led to a significant increase in the average plant height, number of leaves, number of pods, pod length, the weight of 100 seeds, and yield per plant.

The research aimed to study

1. The effect of adding solid chelated iron and determining the best concentration;
2. The effect of adding liquid chelated iron and determining the best concentration.
3. The effect of the interaction between solid and liquid chelated iron and determining the best interaction between them.

Material and Methods

A field factorial experiment was carried out within the randomized complete block design in the agricultural season 2020/2021 at the Haruniya area, kilo 21 – Muqdadiyah – Diyala governorate – Iraq, (latitude 34°53'33" N, longitude 56°04'45" E, altitude 31 m) to study the effect of adding chelated iron, solid and liquid, on the growth and yield of the plant. The field designated for the experiment was prepared by ploughing it horizontally, levelling and ploughing it again vertically, then levelling and smoothing it and it was divided into three blocks, each block had 9 experimental units, 27 experimental units with dimensions of 3×2 m for each experimental unit. The distance was 1 m between one experimental unit and another and 2 m between each block. Irrigation pipes were laid with a 1.3 m distance between one pipe and another inside the experimental unit. The seedlings were planted on one side of the line, with a distance of 40 cm between one plant and another.

The study factors

The experiment included two factors, the first factor was solid chelated iron signed as S_0, S_1, and S_2, at concentrations 0, 100, and 200 ppm, respectively added to the soil. The second factor was liquid chelated iron signed as L_0, L_1, and L_2 with concentrations 0, 2, and 4 ml L^{-1}, respectively which was sequentially sprayed on the plants. Take 6.66 g of chelated iron is weighed with a sensitive scale and dissolved in 1000 ml of distilled water, then the resulting extract was placed in an ultrasonic device for half an hour at a temperature of 40 °C, then the required concentration was prepared to be added by spraying on the foliage. From the dilution equation, the concentration is prepared in a 2000 ml hand sprayer with 2 cm^3 of diffuser T_{20}, to give the concentration of 100 ppm as the first concentration, and in the same way, the second concentration was prepared and sprayed on all sides of the leaf until complete wetness and the time for the addition was in the early morning to avoid evaporation with high temperature.

The solid iron chelated prepare according to the equation:

$$C_1N_1 = C_2N_2$$
$$1000 \times N_1 = 100 \times 2000 \quad (1)$$
$$N_1 = \frac{200\,000}{1000}$$

where
C – concentration,
N – normality.

The process of planting has been done on 01/10/2019 and the harvest on 01/5/2020. Ten samples were taken randomly from the soil with a similar sample of the field to be analyzed before planting, with a depth of 0–30 cm, air-dried, ground with a wooden hammer, sifted with a sieve (2 mm). The sample was preserved in different and known places until analysis. The soil of the study field was classified as a silty loam texture (Table 1). The results were analyzed using the statistical program (SAS). The significant differences between the means were tested according to the (Duncan) polynomial test at the level of probability of 0.05 (Al-Rawi, 2000).

Studied properties

Plant height (cm) was measured from the surface of the soil to the top of the plant using a tape measure. Stem diameter (mm) was measured by (dwarf) the five stems of the plant were collected and the mean was counted. The number of seeds in a pod (seeds per pod) was calculated for: five random pods were selected, then the average was calculated. The number of pods in the plant (resonance per plant): the number of pods in each treatment was calculated, and the average was calculated. Yield per plant (g) was got by weighing all of the pods of treatment then dividing by the number of plants in treatment.

Table 1. The results of the analysis of the chemical and physical characteristics of the study soil before planting

Properties	Value	Unit
EC $_{1:1}$	1.92	dS m^{-1}
pH $_{1:1}$	7.57	
O.M	1.96	%
Nitrogen	45.18	mg kg^{-1}
Phosphorous	12.24	
Potassium	192.92	
Iron	3.47	
Bulk density	1.4	Mega g m$^{3-1}$
Soil content		
Clay	52.4	%
Silt	8.8	
Sand	38.8	
Soil texture	Silty loam	

Results

Plant height (cm)

The results in Table 2 show that adding solid chelated iron S_2 affected significantly plant height (130.10 cm), compared with control treatment S_0 (119.18 cm). The application of liquid chelated iron L_2 has produced a plant with a height of 128.55 cm, compared with other treatments. The interaction treatment of solid S_2 and liquid chelated iron L_2 was produced the highest plants (136.32 cm), compared with other treatments.

Table 2. The effect of adding solid and liquid chelated iron on plant height (cm) on growth and yield of broad bean

Factors	L_0	L_1	L_2	Average
S_0	117.21 ± 7.01 cde	119.88 ± 7.52 cd	122.51 ± 2.50 bc	119.18 ± 7.52 B
S_1	113.21 ± 3.02 e	115.58 ± 8.70 de	126.81 ± 3.01 b	118.53 ± 7.94 B
S_2	119.18 ± 7.52 cd	134.81 ± 10.51 a	136.32 ± 10.06 a	130.10 ± 11.60 A
Average	116.53 ± 5.96 C	123.42 ± 11.70 B	128.55 ± 8.16 A	

Lowercase letters refer to the significant difference between the treatments; capital letters refer to the difference in main factors; the coefficients with similar letters do not differ significantly from each other at the 0.05 probability level according to Duncan's polynomial test. S – solid chelated iron; L – liquid chelated iron

Diameter of the stem (mm)

The results of Table 3 show that there was a significant difference in stem diameter when solid chelated iron S_1 (18.36 mm) was added. The concerning of the adding of liquid chelated iron, the L_2 was revealed highest increase (18.63 mm), compared with other treatments. As for the interaction between the two factors, the treatment S_1L_2 had the highest stem diameter (19.46 mm), compared with the control treatment.

Number of pods per plant (pod plant^{-1})

The results of Table 4 show that there is a significant difference when adding solid chelated iron as treatment S_1, which resulted in 25.74 pod plant^{-1}, compared with the control treatment. As for the addition of liquid chelated iron, the L_2 treatment recorded 25.45 plant pods^{-1}, compared with the control treatment. As for the interaction between the two factors, the highest value was scored at treatment S_1L_2 as it give 27.74 pods plant^{-1}, compared with the control treatment.

Table 3. The effect of adding solid and liquid chelated iron to stem diameter (mm) on growth and yield of broad bean

Factors	L_0	L_1	L_2	Average
S_0	17.06 ± 1.41 ab	17.30 ± 4.79 ab	18.91 ± 1.03 A	17.76 ± 2.69 AB
S_1	16.50 ± 1.47 ab	19.12 ± 1.63 a	19.46 ± 3.80 a	18.36 ± 2.60 A
S_2	14.41 ± 2.67 b	16.74 ± 1.49 ab	17.51 ± 2.03 ab	16.22 ± 2.30 B
Average	15.99 ± 2.07 B	17.72 ± 2.85 AB	18.63 ± 2.38 A	

Lowercase letters refer to the significant difference between the treatments; capital letters refer to the difference in main factors; the coefficients with similar letters do not differ significantly from each other at the 0.05 probability level according to Duncan's polynomial test.S – solid chelated iron; L – liquid chelated iron

Table 4. The effect of adding solid and liquid chelated iron on the number of pods per plant (a pod of a plant) on the growth and yield of broad bean

Factors	L_0	L_1	L_2	Average
S_0	20.64 ± 3.96 cd	25.70 ± 2.62 a	26.04 ± 6.12 a	24.13 ± 4.68 A
S_1	23.76 ± 8.55 abc	25.71 ± 3.42 a	27.74 ± 1.40 a	25.74 ± 4.96 A
S_2	18.94 ± 6.61 d	20.50 ± 3.49cd	22.56 ± 3.14 bcd	20.67 ± 4.35 B
Average	21.11 ± 6.13 B	23.9 ± 3.807 A	25.45 ± 4.19 A	

Lowercase letters refer to the significant difference between the treatments; capital letters refer to the difference in main factors; the coefficients with similar letters do not differ significantly from each other at the 0.05 probability level according to Duncan's polynomial test.S – solid chelated iron; L – liquid chelated iron

Yield per plant (g)

The results of Table (5) show that there is a significant difference when adding iron solid chelated at the S_2 treatment as it recorded 771.35 g plant^{-1}.

Table 5. The effect of adding solid and liquid chelated iron to the yield of one plant (g) on the growth and yield of broad bean

Factors	L_0	L_1	L_2	Average
S_0	343.35 ± 146.82e	545.38 ± 154.58cde	717.05 ± 178.70abc	538.26 ± 213.72B
S_1	436.51 ± 95.34de	467.79 ± 90.79de	653.94 ± 14.26bcd	519.42 ± 121.43B
S_2	632.90 ± 88.47bcd	784.22 ± 349.71ab	896.9 ± 239.634a	771.35 ± 245.05A
Average	470.92 ± 161.26C	602.13 ± 242.21B	755.98 ± 185.24A	

Lowercase letters refer to the significant difference between the treatments; capital letters refer to the difference in main factors; the coefficients with similar letters do not differ significantly from each other at the 0.05 probability level according to Duncan's polynomial test. S – solid chelated iron; L – liquid chelated iron

As for the addition of liquid iron chelate. The L_2 treatment outperformed with result 755.98 g plant^{-1}. As for the interaction between the factors, it was the highest value with treatment S_2L_2 (896.94 g plant^{-1}) but the lowest value was at the treatment of S_0L_0 as it reached 343.35 g plant^{-1}.

Total yield (Mg ha^{-1})

The results in Table 6 show that the addition of iron solid chelated (S_1) significantly affected the total yield (5.01 Mg ha^{-1}), in comparison with the control treatment S0 as it gives 3.53 Mg ha^{-1}. The treatment of (L_2)

iron liquid chelated produced the most total yield 4.80 Mg ha^{-1}. The interaction of the kind of Fe chelate S_1L_2 produced the most total yield (5.45 Mg ha^{-1}), compared with other treatments. Whereas the lowest value was at the interaction S_0L_0 as it gives 2.45 Mg ha^{-1}.

Table 6. The effect of adding solid and liquid chelated iron on the total yield (Mg ha^{-1}) on the growth and yield of broad bean

Factors	L_0	L_1	L_2	Average
S_0	2.45 ± 1.05 d	3.95 ± 1.51 c	4.18 ± 1.04 bc	3.53 ± 1.33 B
S_1	4.59 ± 2.35abc	4.98 ± 1.53ab	5.45 ± 1.69A	5.01 ± 1.68 A
S_2	3.73 ± 2.00 c	3.83 ± 1.76 c	4.76 ± 1.34 abc	4.10 ± 1.59 B
Average	3.59 ± 1.87 B	4.25 ± 1.49 A	4.80 ± 1.34 A	

Lowercase letters refer to the significant difference between the treatments; capital letters refer to the difference in main factors; the coefficients with similar letters do not differ significantly from each other at the 0.05 probability level according to Duncan's polynomial test.S – solid chelated iron; L – liquid chelated iron

Pod length (cm)

The results of Table (7) show that there is no significant difference when adding solid chelated iron. As for adding liquid chelated iron, the treatment L_2 outperformed as it give 24.87 cm to the control sample treatment L_0 as it had 22.17 cm. As for the interaction between the two factors, the highest value was in the treatment S_2L_2 as it give 26.39 cm and the lowest value was at the treatment S_0L_0 as it give 21.85 cm.

Table 7. The effect of adding solid and liquid chelated iron to pod length (cm) on growth and yield of broad bean

Factors	L_0	L_1	L_2	Average
S_0	21.85 ± 1.88 b	22.81 ± 1.53 b	24.11 ± 5.68 ab	22.89 ± 3.22 A
S_1	22.78 ± 1.54 b	23.32 ± 2.25 ab	24.21 ± 3.95 ab	23.44 ± 3.20 A
S_2	21.88 ± 2.21 b	22.59 ± 2.21 b	26.39 ± 2.69 a	23.62 ± 2.94 A
Average	22.17 ± 1.70 B	22.91 ± 2.70 B	24.87 ± 3.88 A	

Lowercase letters refer to the significant difference between the treatments; capital letters refer to the difference in main factors; the coefficients with similar letters do not differ significantly from each other at the 0.05 probability level according to Duncan's polynomial test. S – solid chelated iron; L – liquid chelated iron

Pod weight (g)

The results of Table (8) show that there is no significant difference when adding solid chelated iron. As for adding liquid chelated iron, the treatment L_2 outperformed as it give 28.14 g to the control sample treatment L_0 as it amounted to 23.41 g. As for the interaction between the two factors, the highest value was in the treatment as it amounted to 29.32 g and the lowest value was at the treatment S_0L_0 as it reached 19.20 g.

The number of seeds in the pod (seeds pod^{-1})

The results of Table 9 show that there is a significant difference when adding solid chelated iron to the treatment S_2 As it gives 6.18 seeds pod^{-1} in comparison to the control treatment as it gives 5.85 seeds pod^{-1}. As for the addition of liquid chelated iron, the treatment L_2 outperformed as it reached 7.88 seeds pod^{-1} to the control sample treatment L_0 as it gives 4.68 seeds pods^{-1} as for the interaction between the two factors, the highest value was at the treatment S_2L_2 as it gives 8.25 seeds pod^{-1} while the lowest value was at the treatment S_0L_0 as it gives 3.91 seeds pods^{-1}.

Table 8. The effect of adding solid and liquid chelated iron to pod weight (g) on growth and yield of broad bean

Factors	L_0	L_1	L_2	Average
S_0	19.20 ± 8.98 b	22.67 ± 5.30 ab	25.82 ± 2.02 ab	22.50 ± 6.07 A
S_1	24.23 ± 3.27 ab	28.42 ± 5.81 a	29.32 ± 3.96 a	27.25 ± 4.59 A
S_2	27.27 ± 5.26 a	28.28 ± 4.22 a	29.26 ± 1.21 a	28.25 ± 3.54 A
Average	23.41 ± 6.52 B	26.46 ± 5.29 AB	28.14 ± 2.88 A	

Lowercase letters refer to the significant difference between the treatments; capital letters refer to the difference in main factors; the coefficients with similar letters do not differ significantly from each other at the 0.05 probability level according to Duncan's polynomial test. S – solid chelated iron; L – liquid chelated iron

Table 9. The effect of adding iron chelated steel and liquid in the number of seeds in the pod (pod seed^{-1}) on the growth and yield of broad bean

Factors	L_0	L_1	L_2	Average
S_0	3.91 ± 0.31 d	6.67 ± 0.20 b	7.65 ± 0.64 a	5.85 ± 0.39 A
S_1	5.31 ± 1.07 bc	4.36 ± 0.49 cd	7.73 ± 0.66 a	5.80 ± 0.69 A
S_2	4.82 ± 1.16 bcd	5.47 ± 0.27 bc	8.25 ± 0.34 a	6.18 ± 0.65 A
Average	4.68 ± 0.83 B	5.28 ± 0.32 B	7.88 ± 0.53 A	

Lowercase letters refer to the significant difference between the treatments; capital letters refer to the difference in main factors; the coefficients with similar letters do not differ significantly from each other at the 0.05 probability level according to Duncan's polynomial test.S – solid chelated iron; L – liquid chelated iron

Discussion

The results of the Tables (2, 3, 4, 5, 6, 7, 8, and 9) show that there are significant differences when adding chelated iron, solid and liquid, in some variables of vegetative growth of plants (plant height, leaf area, and stem diameter). The reason for these results is the role of iron. The activation of the meristematic cell division and elongation of the internodes because it is responsible for the formation of cytochrome, ferredoxin, and chlorophyll in the chloroplasts which is important for the photosynthesis process, which is reflected in the height of the plant. This result is consistent with studies by Focus (2003) and Miller *et al*. (1995).

Iron is an essential element in chlorophyll, about 29–35% of the total amount of iron is found in green leaves, and it has an important role in contributing to the building of enzymes and compounds that make up the chlorophyll molecule (Barker, Stratton, 2015). It is believed that the increase in the diameter of the stem is because iron activates several enzymes, including Peptidase, Proteinase, Aconitase and Aminolevulinate dehydrate which works to accumulate photosynthetic products and thus lead to an increase in the diameter of

the stem. This is consistent with Gheith *et al*. (1989), Al-Emadi (1991) and Al-Saadi (2021). It is clear from the results of the same tables above that there is a significant difference when adding solid and liquid chelated iron to some of the characteristics of the yield (yield of one plant, total yield, and the number of pods per plant, length, and weight of the pod). The reason is due to the role of iron in increasing the rate of photosynthesis and as a result, encouraging the demand for minerals and producing more dry matter in the plant as well as preserving the plant from various biotic and abiotic stresses. This is consistent with Singh *et al*. (2017). It is also believed that the increase in the yield of the broad bean when adding chelated iron is attributed to the role of chelated iron in activating some enzymes in the plant that have a role in the formation of basic compounds in the plant and the appropriate concentrations of nutrients used and the efficiency of plant for absorption, according to Cheith *et al*. (1989).

It is also believed that adding chelated iron leads to an increase in the qualities of the plant when spraying chelated iron. This may be attributed to its role in influencing the increase of hormones plant which are auxin and gibberellins which leads to an increase in the process of cell division and growth. Iron also has a role in building proteins in addition to its role as a catalyst in the formation of chlorophyll. It is also involved in the synthesis of cytochrome proteins important in the processes of carbon metabolism and respiration, and the formation of an important protein in the process of carbon metabolism, and this agrees with Muhammad and Yunus 1991.

It is also believed that iron is included in the synthesis of oxidation and reduction enzymes, such as cytochrome, cytochrome oxidase, and bio-oxidase, as well as its contribution to building chlorophyll in plants and then increasing the plant's activities in absorbing nutrients and increasing the processes of respiration and photosynthesis. As well as encouraging the growth of meristematic tissues and then cell division and elongation, which increases the height of the plant, this is consistent with the results of Alwan *et al*. (2004).

These results are attributed to the role of iron, which contributes to the vital activities inside the plant body, such as building chlorophyll and stimulating the activity of enzymes, especially those related to photosynthesis and respiration. The reason may be due to the role of iron in increasing the efficiency of important compounds that help in cell division and increase their growth, which was reflected in the characteristics of vegetative growth and total yield of the plant. These results were in agreement with Bozorgi *et al.* (2012) and Sure *et al*. (2012). The increase in leaf area is attributed to the physiological functions of iron in its participation in increasing the activity of respiratory and enzyme cells and photosynthesis processes, as well as its role in the formation of chlorophyll and proteins of cell walls (Abu Dahi, Al-Younis, 1988). These results are in agreement with Al-Mohammadi (2005), Al-Taher (2005) and Al-Khazraji (2011).

The reason for the increase in the yield may be due to the role of iron in increasing the process of cell division and elongation and increasing the process of carbon metabolism, and consequently, the plant height and stem diameter increased and increased The leaf area, which by increasing it, increases the carbonic representation as a result of the availability of energy needed to absorb water and nutrients, and then an increase in the length and weight of the pods, which all contribute to the yield. These results agreed with Boehme *et al*. (2005) and Sarheed (2013).

The chelated iron led to an increase in the vegetative growth characteristics and yield. The reason for this is the effect of iron in many vital processes in the plant. It is an essential element in building chlorophyll and iron-containing proteins which are important in the electron transfer reactions in the photosynthesis process that leads to an increase in the efficiency of photosynthesis, which is reflected in an increase in plant growth rates and this is consistent with Shalash *et al*. (2012) and Ahmed (2016). It is also believed that the role of iron in many of the vital activities of the plant, either through its direct participation as a component of plant materials, and this leads to an increase in the number and size of cells, and this will prompt an increase in growth rates, which was reflected on the increase in stem diameter rates and this is consistent with Abu Khumra, Abbas (2010). It is also believed that iron-works organize the function of plant hormones that encourage the growth of reproductive organs and increase the number of flower facilities and increase their fertilization, which is reflected in the increase in the number of grains, and this is consistent with Eskandri (2011).

Conclusions

1. When adding solid chelated iron, the two treatments S_2 and S_1 had the best results in most studied variables.
2. Adding liquid chelated iron to the treatment L_2 gives the best results in most studied variables.
3. As for the interaction between the two factors, the two treatments S_2L_2 and S_1L_2 had the best results in most of the studied variables.

Recommendations

1. The researcher recommends adding solid chelated iron at a concentration of (200 and 100 ppm) because it gives the best results in most of the studied variables.
2. It is recommended to add liquid chelated iron at a concentration of 4.2 ml L^{-1} because it gives the best results in most of the studied variables.
3. As for the interaction between the two factors, it is recommended to add the same concentrations determined above because they give the best results in most of the studied variables.

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 manuscript.

Author contributions

MA 25%, BB 25%, MA 25%, HJ 25% – study conception and design;
MA 50%, BB 50% – acquisition of data;
BB 25%, MA 25%, GH 50% – analysis and interpretation of data;
MA 50%, MA 25%, HJ 25% – drafting of the manuscript;
MA 25%, BB 25%, GH 50% – critical revision and approve the final manuscript.

References

Abu Dhahi, Y.M., Al Younis, M.A. 1988. Plant nutrition guide. House of books for publishing and printing. Mosul. Iraq. Pp. 410.

Abu Khumra, H.M.M. Abbas, J.A. 2010. Fertilization effect of different levels of the iron claw in the growth of the quantity and quality of essential oil plant Alcardanaa Gardenia jasminoides Ellis. – The Jordanian Journal of Agricultural Sciences, 6(4): 639–630.

Ahmed, H.M. 2016. Study of the effect of foliar fertilization with chelated iron and humic acid in two sunflower cultivars. – Ms thesis. University of Diyala, Baqubah, Iraq, 12/04/2016, 115 pp. http://en.uodiyala.edu.iq/

Al-Emadi, T.H. 1991. Micronutrients in agriculture. Ministry of Higher Education and Scientific Research. University of Baghdad, College of Agriculture, Baghdad, Republic of Iraq, 386 p.

Al-Khazraji, O.A.R.O. 2011. The effect of fertilizer levels of potash added to the soil in the growth of iron workshops and holds yellow corn (*Zea Mays* L). – Ms thesis. University of Anbar, Ramadi, Iraq, 15/02/2011, 125 pp. https://www.uoanbar.edu.iq/English/index.php

Al-Mohammadi, H.S.S. 2005. Effect of foliar feeding with zinc and iron on growth and yield of sorghum. – Ms thesis. University of Anbar, Ramadi, Iraq, 05/03/2005, 140 pp. https://www.uoanbar.edu.iq/English/index.php

Al-Nuaimi, S.N.A. 1987. Fertilizers and Soil Fertility. Ministry of Higher Education and Scientific Research, University of Mosul - College of Agriculture and Forestry, Republic of Iraq, 290 p.

Al-Rawi, K.M. Abdul Aziz, M.K.A. 2000. Design and analysis of agricultural experiments. College of Agriculture and Forestry, University of Mosul, 173 p.

Al-Saadi, S.Y.Y. 2021. Effect Two dates for planting and spraying with nano and chelated iron, growth and yield of broccoli (*Brassica Oleracesa*. L). – Ms thesis. University of Diyala, Baqubah, Iraq, 18/02/2021, 133 pp. http://en.uodiyala.edu.iq/

Al-Taher, F.M.M. 2005. The effect of foliar feeding with iron, zinc and potassium on the growth and yield of wheat *Triticum aestivum* L. – Ph.D thesis. University of Baghdad, Iraq, 12/05/2005, 140 pp. https://en.uobaghdad.edu.iq/

Alwan, O.K., Hussein, G.N. 2004. Effect of spraying with iron and zinc on some characteristics of vegetative growth and yield in tomato cultivar *Al-Wadi Lycopersicon esculentum* Mill. Tikrit University. – Journal of Agricultural Sciences, 24(2): 182–189.

Anonymous. 2020. FAOSTAT, Production/yield quantities of Broad Bean in world + (total). – Food and Agriculture Organization of the United Nations, Rome. https://www.fao.org/faostat/en/#data/QCL/visualize. Accessed 11 November 2021.

Bader, B.R., Abood, M.A., Aldulaimy, S.E., Almehmdy, S.H., Hamdi, G.H. 2020. Effect of Water Deficit and Foliar Application of Amino Acids on Growth and Yield of Eggplant Irrigated by Two Drip Systems Unter Greenhouse Conditions. – Agraarteadus, 31(2):131–138. DOI: 10.15159/jas.20.20

Barker, A.V., Stratton, M.L. 2015. Iron. Chapter 11. – In: Handbook Nutrition. Second Edition (Eds. A.V. Barker, D.J. Pilbeam). – CRC Press Taylor and of Plant Francis Group. London. New York, pp. 399–426.

Boehme, M., Schevshenko, J., Pinker, I. 2005. Iron supply of cucumbers in substrate with humate. – ISHS, 4(1):329–335.

Bozorgi, H.R., Bidarigh, S., Azarpour, E., Danesh, R.K., Moraditohaee, M. 2012. Effects of natural zeolite application under foliar spraying with humic acid on yield and yield components of cucumber (*Cucumis sativus* L.). – International Journal of Agriculture and Crop Sciences, 4–20:1485–1488.

Chafi, M.H., Bensoltane, A. 2009. (*Vicia faba* L.) A source of organic fertilizer and biological for the arid region. – World Journal Agriculture Science, 5(6):698–706.

Cheith, E.S., Abed Alhafuth, A.A., Khalil, N.A., Abdel Shaheed, A. 1989. Effect of nitrogen and some micronutrients on wheat. – Annual of Agricultural Science Moshtohor, 20(5):255–258.

Eskandari, H. 2011. The importance of iron in plant products and mechanism of its uptake by plants. – Journal of Applied Environmental and Biological Sciences, 1(10): 448–452.

Faisal, H.A., Hatef, H.J., Mohammed, S.R. 2012. The Effect of chelated Iron and thiamine on the yield of Faba bean Vicia faba. – Journal AL-Basrah University of Agricultural Sciences, 25(2):17–26.

Farhan, L.D. 2012. The effect of organic and potassium fertilizers on the growth and yield of the bean plant. – Diyala Journal of Agricultural Sciences, 4(1):16–50.

Focus, L. 2003. The importance of micro-nutrients in region and benefits of including them in fertilizers. – Agrochemicals reports, 111(1):15–22.

Gheith, E.S., Abedel-Hafith, A.A., Khalil, N.A., Abedel-Shaheed, A. 1989. Effect of nitrogen and

some micronutrients on wheat. – Assiut Journal of Agricultural Sciences, 20(5):255–268.

Hansen, N.C., Schmitt, M.A., Andersen, J.E., Strock, J.S., 2003. Iron deficiency of soybean in the upper midwest and associated soil properties. – Agronomy Journal, 95(6):1595–1601. DOI: 10.2134/agronj 2003.1595

Miller, G.W., Huang, I.J., Welkie, G.W., Pushnik, J.C. 1995. Function of iron in plants with special emphasis on chloroplasts and photosynthetic activity. In: Abadía J. (eds) Iron Nutrition in Soils and Plants. – Developments in Plant and Soil Sciences, 59:19–28. Springer, Dordrecht. DOI: 10.1007/978-94-011-0503-3_4

Muhammad, A.K., Yunus, M.A. 1991. Basics of Plant Physiology, Dar Al-Kutub for Printing and Publishing, University of Mosul, Ministry of Higher Education and Scientific Research, Republic of Iraq, 1028 p.

Rachid, A.F., Bader, B.R., Al- Alawy, H. 2020. Effect of foliar application of humic acid and nano calcium on some growth, production, and photosynthetic pigments of cauliflower (*Brassica Oleracea* Var. Botrytis) planted in calcareous soil. – Plant Archives, 20:32–37.

Rajasekar, M., Udhaya Nandhini, D., Suganthi, S. 2017. Nutrients Minerál of supplementation foliar spray review. – International Journal of Current Microbiology and Applied Sciences, 6(3):2504–2513. DOI: 10.20546/ijcmas.2017.603.283

Sarheed, B.R. 2013. Preparing natural chelating fertilizers for zinc and iron and studying the behavior of soil under greenhouse conditions and their impact on the growth and yield of cucumber. – PhD thesis. University of Anbar, Ramadi, Iraq, 05/09/2013, 135 pp. https://www.uoanbar.edu.iq/ English/index.php

Shalash, J.S., Ismail, A.A., Ghazai, A.S.K. 2012 Response of olive seedlings to foliar feeding with hemogreen and a mixture of iron and zinc. – Iraqi Journal of Agricultural Sciences, 43(1):75–58. DOI: 10.36103/ijas.v52i5.1460

Singh, M.D., Chirag, G., Prakash, P., Mohan, M.H., Prakasha, G., Vishwajith, K. 2017 Nano-F fertilizers is a new way to increase nutrients use efficiency in crop production. – International Journal of Agriculture Sciences, 9(7):3831–3833.

Sure, S., Arooic, H., Sharifzade, K., Oghadam, R.D. 2012. Response of productivity and quality of cucumber to application of the two bio-Fertilizers (humic acid and nitrogen) in fall planting. – Agricultural Journal, 7(6):401–404.

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EFFECT OF FEEDING BROILERS WITH PHYTOGENIC FEED ADDITIVES CONTAINING DIETS ON BLOOD BIOCHEMICAL AND HAEMATOLOGICAL CONSTITUENTS

Nonye Lilian Azodo[1], Peter-Damian Chukwunomso Jiwuba[1], Nchedo Thecla Mbah[2], Franscisca Chinwendu Ezeoke[3]

[1]Department of Animal Production Technology, Federal College of Agriculture, P.M.B.7008, Ishiagu, Ebonyi State, Nigeria
[2]National Root Crop Research Institute, P.M.B 7006, Igbariam Sub-station Anambra State, Nigeria
[3]Department of Animal Science, Chukwuemeka Odumegwu Ojukwu University, P.M.B. 6059, Igbariam Campus, Nigeria

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Vastutav autor: Corresponding author: Peter-Damian Chukwunomso Jiwuba

E-mail: jiwubapc@gmail.com; jiwubapc@yahoo.com

ORCID:
0000-0002-9647-3480 (P-DCJ)

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ABSTRACT. The intense pressure on the poultry sector to promote safe chicken meat and egg has sparked interest in the use of natural and consumer-accepted phytogenic feed additives. The majority of literature on the benefits of turmeric (*Curcuma longa*) and Negro pepper (*Xylopia aethiopica*) is focused on layers and there is no evidence of turmeric and Negro pepper interactive effects. Therefore, this study was conducted to evaluate the effect of turmeric and Negro pepper mixture on serum biochemical and haematological constituents of broiler chicks fed for 48 days. A total of 96 one-day-old Arbor acres chicks of mixed sexes were used for the experiment. The birds were randomly assigned to four treatment groups and replicated three times in a completely randomized design. The milled turmeric and Negro pepper were mixed in the ratio of 50:50 (50%) and used in the formulation of turmeric and Negro pepper mixture (TNPM) diets. The four experimental diets were formulated to contain 0.00, 0.50, 1.00, and 1.50% dietary levels of inclusion of TNPM at the starter phase and 0.00, 1.50, 3.00, and 4.50% inclusion levels at the finishing phase respectively. Blood samples were collected from the brachial wing vein on the 24th and 48th days of the experiment and were evaluated for serum biochemical and haematological constituents. At the starter phase, red blood cells (RBC) was significantly ($P < 0.05$) improved at a 1.50% dietary level of TNPM. Haemoglobin (Hb) was better ($P < 0.05$) in 0.50 and 1.50% inclusion levels. Mean cell haemoglobin concentration (MCHC) and White blood cells were enhanced ($P < 0.05$) among the treatment groups compared to the control. Total protein, albumin, uric acid and cholesterol concentrations were reduced significantly ($P < 0.05$) in 1.50% inclusion. Alkaline phosphatase value was significantly ($P < 0.05$) lower in birds fed 1.00% TNPM. At the finishing phase, packed cell volume was significantly ($P < 0.05$) higher in 1.50 and 3.00%. RBC was significantly ($P < 0.05$) higher in birds fed 1.50 and 4.50% TNPM. Hb and mean cell volume values were significantly ($P < 0.05$) higher in 1.50% when compared to 0.00%. MCHC was better ($P < 0.05$) among birds fed 1.50% in comparison with those fed 0.00 and 4.50%. WBC was generally improved ($P < 0.05$) among the treatment groups. Total protein and cholesterol values were higher ($P < 0.05$) in the control. Albumin was higher ($P < 0.05$) in 0.00 and 1.50%. Globulin produced a significantly ($P < 0.05$) lower value in 1.50%. Aspartate aminotransferase produced significantly ($P < 0.05$) higher value in T_2. It was concluded that up to 1.50 and 4.50% of TNPM could be included in starting and finishing broiler diets without any detrimental effect on serum biochemical and haematological constituents.

Introduction

Phytogenic products have been used for many decades as spices, herbs, in ethnoveterinary interventions, and products derived thereof, but their use in the feed industry is gaining ground in recent times. Following the European Union ban on antibiotic growth promoters in the animal feed industry in 2006 (Castanon, 2007) phytogenic plant parts have gained much interest as feed additives. Sequel to the ban in Europe, growing pressure on livestock and poultry farmers in other parts of the world to produce safe food for human consumption, alternative ingredients and methods for the promotion of animal growth and the prevention of diseases were explored, with increased attention being paid to phytogenic and herbal products as they have gained greater market acceptance as natural additives. Jin (2010) characterized phytogenic feed additives to have natural properties, multiple functions, side effect reduction, nonresistance and leaving no residues in livestock production. These may have enhanced their wide acceptability as a new alternative to age-long synthetic antibiotics and growth promoters for poultry and livestock. Among the phytogenic products commonly used in Nigeria are turmeric (*Curcuma longa*), Negro pepper (*Xylopia aethiopica*), ginger (*Zingiber officinale*), garlic (*Allium sativum*), Moringa (*Moringa oleifera*), soursop (*Annona muricata*), Pawpaw (*Carica papaya*), Never die (*Bryophyllum pinnatum*), African peach (*Nauclea latifolia*), Gmelina (*Gmelina arborea*) *etc*.

Turmeric (*Curcuma longa*), belongs to the family *Zingiberaceae* and is of Indian origin, but is highly cultivated in East and West Africa. Turmeric is known with diverse names in Nigeria such as Ukpo by Igbos, Akika by Yorubas, Kafi-nama-zaki by Hausas and Utantan by Edos. Turmeric is a perennial herbaceous plant that is planted majorly because of its tuberous rhizomes or underground stems. Turmeric serves as a major source of curcumin, turmerone, germacrone, atlantone and zingliberene. The antioxidant, anti-inflammatory, anticarcinogenic, anti-viral, anti-bacterial, anti-fungal, anti-protozoal, nematocidal and insecticidal, antivenom, anti-HIV, anti-tumour, anti-allergic and immunological activating properties of the rhizome have been reported (Ali *et al.*, 2016). Beta-carotene, ascorbic acid (vitamin C), calcium, flavonoids, fibre, iron, niacin, potassium, zinc and other nutrients, and over 300 naturally occurring components are present in turmeric.

Negro pepper (*Xylopia aethiopica*) belongs to the family *Annonaceae* and is of African origin. Negro pepper is commonly known as Uda by Igbos, as Eeru Alamo by Yoruba and as Chimba by Hausas speaking parts of Nigeria. Negro pepper is an evergreen, aromatic tree that can grow up to 15–30 m high and about 60–70 cm in diameter, which thrives in lowland rainforest and moist fringe forests in the savanna zones of Africa. Every part of *Xylopia aethiopica* such as the bark, seeds, stem, fruit and leaves are of great importance in medicine for therapeutic purposes (Ikrang, Anyanwu, 2019). *Xylopia aethiopica* is known for its high-quality wood, food spices, medicinal and pharmaceutical properties. The dried seeds of *Xylopia aethiopica* have been reported (Jirovetz *et al.*, 1997; Erhirhie, Moke, 2014) to have antioxidant, anti-inflammatory, anti-carcinogenic, insecticidal, anti-microbial, anti-malaria, anti-respiratory, natural contraceptive, pain relief, treatment of cough, cold, flu and gastric ulcer, promotes weight loss and preservative properties. It contains copper, zinc, protein, camphene, manganese, alkaloids, diter penic, limonene, folic acid, flavonoid, vitamins: A, B1, B2, C and E. The plant contains annonacin, which is an alkaloid resembling morphine in action (Alagawany *et al.*, 2015). The fruit contains volatile aromatic oil, fixed oil and rutin. However, there is a paucity of information on the effect of *Curcuma longa* and *Xylopia aethiopica* mixture on broilers. This study, therefore, aimed to determine the effect of diets with turmeric and Negro pepper mixture on the blood profile of broiler chickens. We hence assume that inclusion of 0.00 to 1.5% and 0.00 to 4.50% of *Curcuma longa* and *Xylopia aethiopica* mixture in starting and finishing broilers respectively will have a positive effect on the blood profile of broiler, due to their high phytobiotic properties.

Material and Methods

The experiment was carried out at the Poultry Unit, Federal College of Agriculture, Ishiagu, Ebonyi State, Nigeria. The College is situated at a latitude of 5.56° N and longitude of 7.31° E, with an average rainfall of 1653 mm and a prevailing temperature of 28.50 °C and relative humidity of about 80% (FCAI, Meteorological Centre Data, 2017).

Fresh turmeric (*Curcuma longa*) tubers were sourced from the National Root Crop Research Institute (NRCRI), Umudike, Ikwuano Local Government Area of Abia State, Nigeria. The turmeric tubers were washed properly and sundried to about 15% moisture, while the ripped Negro pepper (*Xylopia aethiopica*) fruits were procured from Akwete market Enugu, Enugu State, Nigeria and were also washed properly and air-dried to about 15% moisture. These materials were subsequently milled into flour differently using the harmer mill. The milled turmeric and Negro pepper were mixed in the ratio 50:50 each to have turmeric and Negro pepper mixture (TNPM). The 50:50 mixing ratio was based on the equal addition of the phytobiotics.

Four experimental diets were formulated to contain 0.00, 0.50, 1.00, and 1.50 levels of TNPM at the starter phase and 0.00, 1.50, 3.00, and 4.50 levels at the finishing phase respectively. The experimental diets were formulated according to the standards of NRC. The compositions of the experimental diets are given in Table 1 and Table 2.

Table 1. Composition of the experimental diets for starting broilers

Ingredient	Diet composition, %			
Maize	50.00			
Soya bean meal	16.00			
Groundnut cake	20.00			
Wheat offal	8.00	7.50	7.00	6.50
Negro pepper/turmeric mix	0.00	0.50	1.00	1.50
Fish meal	2.00			
Limestone	1.50			
Bone meal	1.50			
Salt	0.25			
Premix	0.25			
Methionine	0.25			
Lysine	0.25			
Total	100			

Table 2. Composition of the experimental diets for finishing broilers

Ingredient	Diet composition, %			
Maize	50.00			
Soya bean meal	16.00			
Groundnut cake	12.00			
Wheat offal	16.00	14.50	13.00	11.50
Negro pepper/turmeric mix	0.00	1.50	3.00	4.50
Fish meal	2.00			
Limestone	1.50			
Bone meal	1.50			
Salt	0.25			
Premix	0.25			
Methionine	0.25			
Lysine	0.25			
Total	100			

96 one-day-old Arbor Acres broiler chicks of mixed sexes were sourced from Chi Farms® in Ibadan, Oyo State, Nigeria. They were randomly assigned to four (4) experimental treatment groups, each replicated three times with eight (8) birds constituting a replicate. The experimental birds were managed following the permission and stipulated guidelines of the Federal College of Agriculture, Ishiagu (FCAI) Animal Ethics Committee. The birds were assigned to the four experimental diets in a Completely Randomized Experimental Design (CRD) and fed the experimental diets in two phases respectively for 24 days to have a total of 48-day feeding trials. The experimental diets were introduced from the beginning of the study (one day old). Each replicate group was housed in a poultry pen that was demarcated and covered with a wire net. Pen concrete floors were covered with wood shavings as litter material. Before the arrival of the one-day-old chicks, the brooding house was washed and disinfected and allowed to dry. The brooder house was pre-heated for 6–12 hrs to enable it to reach the normal temperature (32 ºC) required by day-old chicks. Fresh feed and water were provided *ad libitum* in the mornings on daily basis. Heat and light were provided for the first 14 days using stoves and electric bulbs. The birds were vaccinated against infectious bursal (Gumboro) disease at days 10 and 24 respectively, while the NDV – Lasota vaccine was given on days 1, 14 and 28 to protect against New Castle Disease.

Blood samples (5 ml) were drawn from one bird per replicate on the 24th (24 days old) and 48th day (48 days old) of the experiment. The birds were bled through the brachial wing vein. The samples were respectively collected in two parts for biochemical and haematological studies: 2.5 ml was collected into the labelled sterile universal bottle containing 1.0 mg ml^{-1} ethyldiamine tetraacetic acid for haematological analysis and another 2.5 ml was also collected into the anti-coagulant free bottle for biochemical analyses. The blood was allowed to clot at room temperature and serum separated by centrifuging within three hours of collection. Serum biochemistry and haematological parameters were measured using Beckman Coulter Ac-T10 Laboratory Haematology Blood Analyzer and Bayer DCA 2000+ HbA1c analyzer, respectively. Mean cells haemoglobin (MCH), mean cell volume (MCV) and mean cell haemoglobin concentrations (MCHC) were calculated.

Chemical analyses (dry matter, crude protein, crude fibre, ash, and ether extract) of experimental diets and that of the test ingredients were carried out according to the methods of AOAC (2000). The nitrogen-free extract was derived by subtracting the sum of other components (crude protein, ether extract, ash, crude fibre) from 100 on a dry matter basis. Metabolizable energy was calculated using the formula:

$$ME = (3.5 \times CP) + (8.5 \times CF) + (3.5 \times NFE) \times 10, \quad (1)$$

where
ME – metabolizable energy, kcal kg^{-1};
CP – crude protein, %;
CF – crude fat, %;
NFE – nitrogen-free extract, %.

Data obtained were analysed using analysis of variance (ANOVA) as described by SAS (2008). Significant means were separated using the Duncan Multiple New Range Test.

Results and Discussion

The chemical compositions of the experimental diets for broiler starter, turmeric and Negro pepper meals are presented in Table 3. The dry matter (DM) range of 92.15–93.08% obtained in this study for starting broilers compared well with 91.81–92.62 9% reported by Jiwuba *et al.* (2016b) for broiler starters. The crude protein (CP) range of 22.12–23.39 reported in this study is higher than 20.70–21.90%, reported by Jiwuba *et al.* (2016b).The values reported in this study nevertheless fall within the recommended values of 21–24% reported by Livestocking (2020) for broiler starters and compared well with 23% recommended by NRC (1994) for broilers within the age of 0–3 weeks. The crude fibre (CF) range of 3.32–3.47% reported in this study failed to follow a particular trend but is lower than 9.0–0.3% reported by Abu *et al.* (2015), but compared well with 3.04–3.63% reported by Jiwuba *et al.* (2017). The energy value of 2940.70–3060.35 kcal kg^{-1} reported in this study is comparable with 2959.90–3106.45 kcal kg^{-1} reported by Jiwuba *et al.* (2016a) for starter broilers and in agreement with the recommended

values of 2900–3100 kcal kg^{-1} reported by Livestocking (2020) for broiler starter.

The turmeric meal showed a high DM value of 92.56% reported in this study and compared with 91.00% reported by Ikpeama *et al.* (2014). The high DM reported for turmeric in this present study may indicate a high amount of nutrient availability to the animal since DM is an indicator of the amount of nutrients that are available to the animal in a feed sample. The CP value of 9.76% obtained in this present study is higher than 1.83 and 5.8% reported by Asagwara *et al.* (2018) and Attiaa *et al.* (2017) respectively but compared well with 9.40% reported by Ikpeama *et al.* (2014) for the same phytobiotic rhizome meal. This result may imply that turmeric can be substituted for maize in terms of crude protein and hence makes it an important feedstuff due to its relatively appreciable CP value as well as its ethnoveterinary properties. However, the high tannin content of turmeric which hinders protein digestion and utilization and the relative higher cost of turmeric rhizome may still constitute a problem. The CF value of 4.22% is higher than 1.95% but compared with 3.5 and 4.60% reported by Attiaa *et al.* (2017) and Ikpeama *et al.* (2014) respectively for turmeric meal. The percentage of fibre reported in this study make it well suited for broiler feeding since it is below 7% as recommended as ideal for broilers (Salah, 2012) and also compared favourably with 3.0–4.0% CF, depending on the age of the bird as reported by Swennen *et al.* (2010). The 6.45% ether extract (EE) reported may be attributed to a high level of curcumin, fat-soluble vitamins (A, D, E, K) and fat, hence EE, is the amount of fat and fat-soluble components in a feed. Furthermore, it includes plant pigments (chlorophyll, xanthophylls, carotene) and is fat-soluble, but it does not tell us how much of each vitamin or fatty acid is present. The result of the present study compared well with 6.85% reported by Ikpeama *et al.* (2014), but higher than 4.7% reported by Attiaa *et al.* (2017). Ash value of 6.45% observed in this study was higher than 2.85, 3.04 and 4.2% reported by Ikpeama *et al.* (2014), Asagwara *et al.* (2018) and Attiaa *et al.* (2017) respectively for Turmeric meal (TM). The differences in ash values may be attributed to varieties, soil mineral/nutrient and maturity/date of harvesting. The high ash value is an indication of a large amount of minerals. Minerals function to enhance growth, development, bone development, nerve impulse transmission, hormone synthesis, immunity and general well-being of the animals. The NFE value of 69.30% reported in this study entails the ability of TM to provide readily available energy since NFE is considered to provide an estimation of water-soluble polysaccharides in the form of sugars or starch. The value reported in this present study is lower than 71.5% reported by Attiaa *et al.* (2017) for TM. The Metabolizable energy value of 3315.35 kcal kg^{-1} reported in this study further indicated the potentials of TM in providing the required energy for broilers.

The 91.78% DM reported in this present study compared with 93.83% reported by Muhammad *et al.* (2016) for Negro pepper meal (NPM). This high DM entails high nutrient availability to the animals fed the supposed diet. The 9.99% CP reported in this study for NPM is lower than 10.59% reported by Muhammad *et al.* (2016) but higher than 8.33% reported by Ndelekwute and Enyenihi (2018). The 18.66% CF is lower than 9.23% reported by Ndelekwute and Enyenihi (2018) but higher than 3.33% reported by Muhammad *et al.* (2016) for NPM. The differences may be attributed to level of maturity before harvesting and possible variety differences. However, the CF of NPM reported in this study is above 3.0–4.0% CF reported by Swennen *et al.* (2010) but below 7% CF recommended by Salah (2012) but falls within 5 and 8% CF recommended for starter and finisher broilers respectively by Livestocking (2020). This may still indicate the relevance of NPM in broiler feeding. The 5.45% EE reported in this study reveals high level of fat and fat-soluble components of NPM. The result of this study is compared to 32.96 and 12.17% reported by Ndelekwute and Enyenihi (2018) and Muhammad *et al.* (2016) respectively for same phytogenic feed additive. The ash value (6.33%) is higher than 3.83% reported by Muhammad *et al.* (2016) but compared well with 6.05% reported by Ndelekwute and Enyenihi (2018) for same product. The high metabolizable energy of 2610.15 kcal kg^{-1} reported in this this study reveals that it can as well be used as energy source in broiler feeding.

The chemical composition of the experimental diets for broiler finishers is presented in Table 4. The nutrient values reported in this present study for broiler finisher is in agreement with the recommendations of NRC (1994) and Livestocking (2020).

Table 3. Chemical composition of the experimental diets for broiler starter, turmeric and Negro pepper mixtures and meals

Nutrient, %	Dietary levels, %					
	0.00*	0.50*	1.00*	1.50*	TM	NPM
Dry matter	92.15	93.08	92.44	92.99	92.56	91.78
Crude protein	23.39	22.39	22.25	22.12	9.76	9.99
Crude fibre	3.33	3.32	3.43	3.47	4.22	6.66
Ether extract	3.45	3.65	3.44	3.01	6.45	5.45
Ash	6.31	8.69	8.33	8.81	2.83	6.33
NFE	55.67	55.03	54.99	54.59	69.30	53.35
ME, kcal kg^{-1}	3060.35	3019.95	2995.80	2940.70	3315.35	2610.15

* Turmeric and Negro pepper mixture 50:50 ratio; TRM – turmeric rhizome meal; NPM – Negro pepper meal; NFE – nitrogen-free extract; ME – metabolizable energy

Table 4. Chemical composition of experimental diets for broiler finisher

Nutrient, %	Dietary levels, %			
	0.00*	1.50*	3.00*	4.50*
Dry matter	93.49	92.96	93.24	92.21
Crude protein	20.39	20.21	20.38	20.27
Crude fibre	3.76	3.82	4.03	3.32
Ether extract	4.02	3.65	3.44	4.01
Ash	4.31	6.34	6.77	7.34
NFE	61.01	58.94	58.62	57.27
ME, kcal kg^{-1}	3190.70	3080.50	3057.40	3054.75

* Turmeric and Negro pepper mixture 50:50 ratio; NFE – nitrogen-free extract; ME – metabolizable energy

The effect of turmeric and Negro pepper mixture containing diets on haematological indices of broiler starter is presented in Table 5. Packed cell volume (PCV), Mean cell volume (MCV) and Mean cell haemoglobin (MCH) showed no significant (P >0.05) difference across the groups. Red blood cell (RBC), haemoglobin, mean cell haemoglobin concentration (MCHC) and white blood cells (WBC) differed significantly (P <0.5). The haemoglobin of the broiler starter ranged from 11.13–12.88 g dl^{-1} for 1.00 and 0.50, respectively. The haemoglobin values of the starter birds fed TNPM in their diets were within the normal physiological range of 7.5–13.1 g dl^{-1} for broilers (Mitruka, Rawnsley, 1977), an indication that the diets supported high oxygen-carrying capacity of blood in the birds. The result of the present study is in agreement with 8.65–11.80 g dl^{-1} for broiler starters fed turmeric (*Curcuma longa*) powder and cayenne pepper (*Capsicum frutescens*) reported by Adegoke *et al.* (2018) and 10.24–11.31 g dl^{-1} for broiler chickens fed diets containing ginger and black pepper reported by Aikpitanyi and Egweh (2020). The RBC range of 2.27–3.81×10^{12} L^{-1} reported in this study for broiler starter birds fell within the values of 1.5–3.9×10^{12} L^{-1} reported for apparently healthy broilers by Mitruka and Rawnsley (1977). This may indicate that the utilization of the experimental diets ensured effective transport of haemoglobin through the red blood cells of the broilers. This further gave a clear indication of adequate oxygen transportation within the tissues of the birds for oxidation of digested feeds. The significant (P <0.05) effect obtained in this study for starter broilers fed turmeric and Negro pepper mixture agreed with the results of Adegoke *et al.* (2018) and Aikpitanyi and Egweh (2020) for broiler starter birds fed turmeric (*Curcuma longa*) powder and cayenne pepper (*Capsicum frutescens*) and broiler chickens fed diets containing ginger and black pepper respectively. The mean cell haemoglobin concentration (MCHC) values of 26.38–33.04% reported in this study were within the normal range of 25.3–32.5% reported by Mitruka and Rawnsley (1977). The normal physiological range for the MCHC reported in this study gave a clear indication that the birds were not anaemic. The range of values (9.72–12.74×10^{9} L) reported in this present study for WBC are within 9.7–31.0×10^{9} L^{-1} reported normal physiological range for apparently healthy birds by Mitruka and Rawnsley (1977). This indicated that there were no microbial infections or presence of foreign bodies or parasites in the circulatory system of the experimental birds which further indicates that the feeding of turmeric and Negro pepper mixture in the diets of broilers do not affect the immune system negatively. This corroborates the finding of Adegoke *et al.* (2018) and Aikpitanyi and Egweh (2020) for broiler starter birds fed turmeric (*Curcuma longa*) powder and cayenne pepper (*Capsicum frutescens*) and broiler chickens fed diets containing ginger and black pepper respectively. Jiwuba *et al.* (2017) noted that the white blood cell function is to fight infections, defend the body through phagocytosis against invasion by foreign organisms and produce or transport antibodies in the immune response. The normal physiological values of WBC obtained in this study may suggest a well-developed immune system of the broilers at the starter phase. The highest WBC values recorded for birds fed 1.00 and 1.50% turmeric and Negro pepper mixture groups possibly suggests that Negro pepper and turmeric at this level facilitated immunity of the birds. Earlier studies on the antimicrobial activity of *X. aethiopica* have been reported. Mono- and sesqui-terpene hydrocarbons from *X. aethiopica* have been shown to have antimicrobial properties against a wide range of Gram-positive and Gram-negative bacteria, and *Candida albicans* (Tatsadjieu *et al.*, 2003; Asekun, Adeniyi, 2004). Turmeric, however, has been reported to promote brain health, courtesy of its potent antioxidant and anti-inflammatory properties (Adegoke *et al.*, 2018). Curcumin has been reported to (Subash *et al.*, 2011) affect signalling molecules and has been demonstrated to influence about 700 genes. Akram *et al.* (2010) described curcumin exertion on anti-inflammatory activity by inhibiting several different molecules that play an important role in inflammation.

Table 5. Effect of turmeric and Negro pepper mixture containing diets on haematological indices of broiler starter

Parameters	Dietary levels, %				SEM
	0.00*	0.50*	1.00*	1.50*	
Packed cell volume, %	35.67	38.10	37.28	38.78	2.61
Red blood cell, $\times10^{12}$ L^{-1}	2.66^{b}	2.27^{c}	2.32^{bc}	3.81^{a}	0.28
Haemoglobin, g dl^{-1}	11.17^{b}	12.88^{a}	11.13^{b}	12.30^{a}	0.79
Mean cell volume, f	104.61	106.40	104.70	105.16	13.55
Mean cell haemoglobin, pg	28.61	28.29	29.55	30.17	2.41
Mean cell haemoglobin concentration, %	26.38^{b}	33.04^{a}	32.58^{a}	32.58^{a}	4.65
White blood cells, $\times10^{9}$ L^{-1}	9.72^{c}	11.11^{b}	12.07^{a}	12.74^{a}	1.20

$^{a–c}$ means on the same row with different subscript are significantly different (P <0.05); * turmeric and Negro pepper mixture 50:50 ratio

The effect of turmeric and Negro pepper mixture containing-diets on serum biochemistry of broiler starter is presented in Table 6. Total protein, albumin, uric acid, cholesterol and alkaline phosphatase (ALP) showed significant differences across the treatments. 1.50% showed significantly (P <0.05) lower total protein value. The lower total protein in 1.50% may indicate poor absorption of dietary protein. The values are perhaps in agreement with 2.38–5.22 g dl^{-1} recorded by Meluzzi *et al.* (1992) for apparently healthy broilers. Albumin was significantly improved (P <0.05) at 0.00 and 1.50% A range of 1.18 to 2.69 g dl^{-1} recorded in this present study

is in agreement with 1.17 to 2.74 g dl^{-1} reported by Meluzzi *et al.* (1992) for apparently healthy broilers. The importance of albumin in blood clotting and transporting of insoluble substances in the blood was enumerated by Fischbach and Dunning (2009).

Table 6. Effect of turmeric and Negro pepper mixture containing diets on serum chemistry of broiler starter chickens

Parameters	Dietary levels, %				SEM
	0.00*	0.50*	1.00*	1.50*	
Total protein, g dl^{-1}	4.53^{a}	4.17^{ab}	3.66^{b}	3.05^{c}	0.21
Albumin, g dl^{-1}	2.69^{a}	2.56^{ab}	2.11^{b}	1.18^{c}	0.37
Globulin, g dl^{-1}	1.84	1.61	1.55	1.87	0.45
Urea, mg dl^{-1}	9.52^{a}	6.83^{ab}	4.76^{b}	2.31^{c}	2.74
Creatinine, mmol L^{-1}	48.98	49.07	47.65	48.87	1.15
Cholesterol, mg dl^{-1}	153.3^{a}	144.3^{ab}	124.5^{b}	117.36^{c}	3.84
AST, U L^{-1}	123.09	120.94	121.85	122.54	3.63
ALT, U L^{-1}	26.84	28.37	28.04	29.51	0.98
ALP, U L^{-1}	48.18^{ab}	49.72^{a}	47.29^{c}	47.65^{b}	1.14

$^{a–c}$ means on the same row with different subscript are significantly different ($P < 0.05$); AST – aspartate aminotransferase; ALP – alkaline phosphatase; ALT – alanine aminotransferase; * turmeric and Negro pepper mixture 50:50 ratio

No significant difference ($P > 0.05$) was observed for globulin but the highest value was recorded for 1.50% (1.87 g dl^{-1}). This implies that the immunity of the broilers was not compromised and the values were numerically improved at 1.50%. From this study, broilers fed a 0.00% diet had better total protein and albumin than the other dietary groups at the chick phase, this is in agreement with the findings of Adegoke *et al.* (2018) but disagrees with the findings of Aikpitanyi and Egweh (2020). The serum uric acid concentration differed significantly ($P < 0.05$) and fell within the physiological value of 1.9–12.5 mg dl^{-1} reported by Clinical Diagnostic Division (1990). Serum uric acid is the main end-product of protein metabolism in poultry and Eggum (1970) associated high blood urea concentration with poor protein quality in the animal. The significant lower uric acid value reported for the treatment groups (0.50, 1.00 and 1.50%) may suggest better utilization of protein and amino acid digestibility. The cholesterol values were significantly different ($P < 0.05$), and decreased linearly with incremental levels of TNPM in the diets. The findings of this study reveal that the TNPM caused a significant reduction in the levels of serum cholesterol, which is in agreement with the reports of Aikpitanyi and Egweh (2020). The significant reduction in serum cholesterol concentration of broilers fed TNPM diets may suggest a general decline in lipid mobilization. In addition, the progressive lower cholesterol values reported in this study with incremental levels of TNPM indicated the ability of the test ingredients in reducing heart-related diseases associated with high cholesterol in the blood. The activities of the liver enzymes; aspartate aminotransferase (AST), alkaline phosphatase (ALP), and alanine aminotransferase (ALT) in the blood are bio-indicators of liver function and damage (Yildirim *et al.*, 2011). Lumeij (2008) attributed an increase in the concentration of liver enzymes to liver or muscle damage, resulting from the body's response to stress. The non-significant effect reported in this study for AST and ALT and the significantly ($P < 0.05$) lower concentration of ALP for 1.00 and 1.50% may indicate better liver function among the birds.

The effect of turmeric and Negro pepper mixture containing diets on haematological indices of finishing broilers is presented in Table 7. Birds fed 1.50 and 3.00% had higher ($P < 0.05$) packed cell volume values in comparison with those fed 0.00 and 4.5% turmeric and Negro pepper mixture. The packed cell volume concentration (31.86 to 38.00%) obtained in this study however was within the normal physiological range of 25–41% reported by Mitruka and Rawnsley (1977). The result of this present study is similar to the findings of Shivappa-Nayaka *et al.* (2013) who reported that the inclusion of turmeric and combination with neem and vitamin E in the diet of broilers had a significant effect on PCV values. PCV is the quickest and reliable indirect way of evaluating values of red blood cells in a circulating medium and is often used as a modest screening test for anaemia. Birds fed 0.00 and 3.00% turmeric and Negro pepper mixture recorded similar ($P > 0.05$) RBC concentration values while birds fed 1.50 and 4.5% were ($P > 0.05$) similar, but higher ($P < 0.05$) than those fed 0.00 and 3.00% turmeric and Negro pepper mixture. The significant effect recorded in this study for RBC for finisher broilers fed phytogenic mixture agreed with the findings of Adegoke *et al.* (2018). The RBC values (3.00–3.96×10^{6} $mm^{3\,-1}$) obtained in this study were slightly higher than the normal physiological range of 1.5–3.9 reported by Mitruka and Rawnsley (1977). Haemoglobin was highest ($P < 0.05$) in birds fed 1.50% when compared with the control diet. The Hb values (11.88–13.02 g dl^{-1}) obtained in this study however were within the normal physiological range of 7.5–13.1 g dl^{-1} reported by Mitruka and Rawnsley (1977). The result of this present study is similar to the findings of Shivappa-Nayaka *et al.* (2013) who reported that the inclusion of turmeric and combination with neem and vitamin E in the diet of broilers had a significant effect on Hb values. The increase in the PCV, Hb and RBC of broiler finisher fed turmeric and Negro pepper mixture indicates an improvement in the health status. This can be attributed to the antioxidant capacities of turmeric and Negro pepper. Red blood cell is formed in the long bones of the body, and sufficient production is dependent on the amount of iron absorbed from food digested. Furthermore, Reece (2009) disclosed the key constituent of erythrocytes as haemoglobin, as it forms about one-third red blood cell content, which, according to Sugiharto *et al.* (2011) generated increased haemoglobin concentration by possibly signalling production of haemoglobin. 1.5% had the highest value for these parameters (PCV, RBC and Hb) which may be in consonance with the adaptation of chickens to antioxidants fed, as well as proper absorption of iron from feed at the finisher phase may explain high values for circulating red blood cells among the treatment group mentioned above. The mean corpuscular haemoglobin (27.40–32.69 pg) and mean corpuscular haemoglobin

concentration (28.60–31.78%) values reported in the finisher phase of the present study were within the physiological range of 25.3–33.4 pg and 25.3–32.5% respectively for broiler birds. The within normal physiological range for the MCH and MCHC reported in this study gave a clear indication that the birds were not anaemic, hence, the diets were nourishing and supported erythropoiesis among the experimental birds. The WBC aids to protect the body from pathogens; turmeric and Negro pepper build up immunity (Ali *et al.*, 2016). The turmeric and Negro pepper mixture containing diets increased the WBC of the birds in the current study. This is similar to an earlier report that supplementation of a mixture of phytogenic materials increases WBC concentration in broilers (Adegoke *et al.*, 2018; Aikpitanyi, Egweh, 2020).

Table 7. Effect of turmeric and Negro pepper mixture containing diets on haematological indices of finishing broilers

Parameters	Dietary levels				SEM
	0.00*	1.50*	3.00*	4.50*	
Packed cell volume, %	31.86^{b}	38.00^{a}	37.87^{a}	32.59^{b}	1.54
Red blood cell, $\times10^{6}$ mm$^{3\ -1}$	3.00^{b}	3.96^{a}	3.20^{b}	3.75^{a}	0.15
Haemoglobin, g dl^{-1}	11.88^{b}	13.02^{a}	12.06^{ab}	12.30^{ab}	0.53
Mean cell volume, f	109.16	107.52	104.01	104.21	2.28
Mean cell haemoglobin, pg	27.40^{c}	32.69^{a}	30.64^{b}	31.10^{ab}	0.76
Mean cell haemoglobin concentration, %	28.60^{b}	31.78^{a}	29.48^{ab}	30.65^{b}	0.54
White blood cells, $\times10^{9}$ L^{-1}	10.59^{c}	14.41^{b}	16.47^{ab}	18.35^{a}	1.13

$^{a–c}$ means on the same row with different subscript are significantly different (P <0.05); * turmeric and Negro pepper mixture 50:50 ratio

The effect of turmeric and Negro pepper mixture containing diets on serum chemistry of finishing broiler is presented in Table 8. The total serum protein, albumin, globulin, cholesterol and aspartate transaminase (AST) were significantly (P <0.05) influenced by the experimental diets. It was found that the 0.00% group had a significant (P <0.05) increase in total protein in comparison to the other groups. Total serum protein is made up of albumin and globulin. The within normal physiological range of 3.0–4.9 mg dl^{-1} reported by Clinical Diagnostic Division (1990) for apparently healthy birds is an indication that the turmeric and Negro pepper mixture supported good protein digestibility, as high protein in blood is an indicator of protein adequacy. According to Melillo (2013), serum albumin aids in the movement of molecules and the maintenance of blood pressure. A high albumin concentration usually indicates dehydration, whereas a low concentration indicates poor liver function owing to malnutrition or infection. The results of this investigation, which ranged from 2.03 to 2.62 g dl^{-1}, were similar to those published by Meluzzi *et al.* (1992) for apparently healthy broilers, which ranged from 1.17 to 2.74 g dl^{-1}. The fact that albumin concentrations are within normal physiological ranges suggests that the liver and other extrahepatic organs involved in protein synthesis are in good condition. Serum albumin and globulin depend on the availability of dietary protein. Globulin values of 1.40 to 1.81 mg dl^{-1} fell within the reference range of 0.5 to 1.8 mg dl^{-1} reported by Thrall (2007) for *Gallus gallus* species. Since the liver is the site of serum protein production, this could indicate a stronger immune system and better hepatic function. The cholesterol of finishing broilers fed turmeric and Negro pepper mixture containing diets showed a significant decrease with increasing levels of the phytogenic feed additives. However, the cholesterol was within the reported range of 52.00–148.00 mg dl^{-1} by Mitruka and Rawnsley, (1977). This suggests that turmeric and Negro pepper in the treatment diets may promote liver and vascular function by increasing cholesterol transfer to the liver. Ademola *et al.* (2009) found that having an ideal cholesterol level is beneficial to the welfare of animals. The liver enzymes are vital in determining the liver's healthy functioning (Jiwuba *et al.*, 2017). The damaged or diseased liver may cause a rise in the levels of these enzymes. The decreasing AST concentration with increasing levels of inclusion indicates that the liver of birds fed phytogenic feed additives were functioning efficiently. The AST levels obtained in this experiment, however, are within the normal range of 70–220 U L^{-1} reported by Meluzzi *et al.* (1992).

Table 8. Effect of turmeric and Negro pepper mixture containing diets on the serum biochemistry of finishing broiler chickens

Parameters	Dietary levels				SEM
	0.00	1.50	3.00	4.50	
Total protein, mg dl^{-1}	4.49^{a}	4.02^{b}	3.90^{b}	3.87^{b}	0.89
Albumin, mg dl^{-1}	2.61^{a}	2.62^{a}	2.03^{b}	2.06^{b}	0.66
Globulin, mg dl^{-1}	1.88^{a}	1.40^{b}	1.87^{a}	1.81^{a}	0.40
Uric acid, mmol L^{-1}	20.47	20.61	20.39	20.10	0.13
Creatinine, mmol L^{-1}	49.81	50.39	49.19	51.11	0.01
Cholesterol, mg dl^{-1}	124.92^{a}	93.53^{b}	88.56^{bc}	85.18^{c}	6.01
AST, U L^{-1}	48.77^{b}	51.37^{a}	47.55^{bc}	46.59^{c}	0.70
ALT, U L^{-1}	61.40	62.94	61.45	66.46	1.10
ALP, U L^{-1}	78.58	77.25	78.39	77.88	1.03

$^{a–c}$ means on the same row with different subscript are significantly different (P <0.05); Aspartate aminotransferase (AST); Alkaline phosphatase (ALP); Alanine aminotransferase (ALT)

Conclusion

Blood can be used to determine the response of chickens to hazardous substances as well as organ function. It is well known that birds with a healthy (normal) blood composition are more likely to perform well. The results showed that inclusion of turmeric and Negro pepper up to 1.5 and 4.5% levels at starting and finishing phases respectively produced no deleterious effect on haematology and serum constituents of the broilers. In conclusion, the research shows that all dietary additives can have a favourable impact on blood profile at demonstrated levels of inclusion.

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Conflict of interest
The authors have declared that no competing interest exists.

Author contributions
NLA – wrote the first draft of the manuscript, reviewed the experimental design, managed the analyses of the study and performed the statistical analysis
PCJ – guidance and monitoring of experiment, designed the study, wrote the protocol, critical revision on the initial draft and approval of the final manuscript
NTM and FCE – sourced the turmeric and Negro pepper, performed the chemical analyses and carried out literature search.
All authors read and approved the final manuscript.

References

Abu, O.A., Olaleru, I.F., Oke, T.D., Adepegba, V.A., Usman, B. 2015. Performance of broiler chicken fed diets containing cassava peel and leaf meals as replacements for maize and soya bean meal. – International Journal of Science and Technology, 4(4):176–183.

Adegoke, AV., Abimbola, M.A., Sanwo, K.A., Egbeyale, L.T., Abiona, J.A., Oso, A.O., Iposu, S.O. 2018. Performance and blood biochemistry profile of broiler chickens fed dietary turmeric (*Curcuma longa*) powder and cayenne pepper (*Capsicum frutescens*) powders as antioxidants. – Veterinary and Animal Science, 6:95–102. DOI: 10.1016/j.vas.2018.07.005

Ademola, S.G., Farinu, G.O., Babatunde, G.M. 2009. Serum lipid, growth and haematological parameters of broilers fed garlic, ginger and their mixtures. – World Journal of Agricultural Science, 5:99–104.

Aikpitanyi, K.U., Egweh, N.O. 2020. Haematological and biochemical profile of broiler chickens fed diets containing ginger and black pepper additives. – Nigerian Journal of Animal Science, 22(2):114–125.

Akram, M., Shahab-Uddin, A.A., Usmanghani, K., Hannan, A., Mohiuddin, E., Asif, M. 2010. Curcuma longa and curcumin: a review article. – Romanian Journal of Biology-Plant Biology, 55(2):65–70.

Alagawany, M.M., Farag, M.R., Dhama, K. 2015. Nutritional and biological effects of turmeric (*Curcuma longa*) supplementation on performance, serum biochemical parameters and oxidative status of broiler chicks exposed to endosulfan in the diets. – Asian Journal of Animal and Veterinary Advances, 10(2):86–96. DOI: 10.3923/ajava.2015.86.96

Ali, A., Bordoh, P.K., Singh, A., Siddiqui, Y., Droby, S. 2016. Post-harvest development of anthracnose in pepper (*Capsicum* spp.): Etiology and management strategies. – Crop Protection, 90:132–141. DOI: 10.1016/j.cropro.2016.07.026

Ali, M.Z., Islam, M.M., Zaman, S. 2020. Effects of turmeric powder on *Clostridium perfringens* load in broiler chickens. – SAARC Journal of Agriculture, 18(1):209–218. DOI: 10.3329/sja.v18i1.48394

AOAC. 2000. Association of Official Analytical Chemists: Official Methods of Analysis. (6th ed.). – Washington DC, USA, 167 p.

Asagwara, J.O., Emeribe, E.O., Enoch, L.N. 2018. Minerals determination of turmeric (*Curcuma longa* Linn) leaves and rhizomes. – Direct Research Journal of Biology and Biotechnology, 4(4):46–50. DOI: 10.26765/DRJBB.2018.7198

Asekun, O.T., Adeniyi, B.A. 2004. Antimicrobial and cytotoxic activities of the fruit essential oil of *Xylopia aethiopica* from Nigeria. – Fitoterapia, 75(3–4):368–370. DOI: 10.1016/j.fitote.2003.12.020

Attiaa, Y.A., Al-Harthia, A.M., Hassanb, S.S. 2017. Turmeric (*Curcuma longa* Linn.) as a phytogenic growth promoter alternative for antibiotic and comparable to mannan oligosaccharides for broiler chicks. – Revista Mexicana de Ciencias Pecuarias, 8(1):11–21. DOI: 10.22319/rmcp.v8i1.4309

Castanon, J.I.R. 2007. History of the use of antibiotic as growth promoters in European poultry feeds. – Poultry Science, 86(11):2466–2471. DOI: 10.3382/ps.2007-00249

Clinical Diagnostic Division. 1990. Veterinary Reference Guide, Eastman Kodak Company, Rochester, New York, 243 p.

Eggum, B.O. 1970. Blood urea measurement as a technique for assessing protein quality. – British Journal of Nutrition, 24(4):983–988. DOI: 10.1079/BJN19700101

Erhirhie, E.O., Moke, G.E. 2014. *Xylopia Aethiopica*: A review of its ethnomedicinal, chemical and pharmacological properties. – American Journal of PharmTech Research, 4(6):21–37.

FCAI, Meteorological Centre Data, 2017. Guide to meteorological data. – Federal College of Agric. Ishiagu, Ebonyi state. Unpublished.

Fischbach, F.T., Dunning, M.B. 2009. A manual of laboratory and diagnostic tests. – Philadelphia: Lippincott Williams & Wilkins, 64 p.

Ikpeama, A., Onwuka, G. I., Nwankwo, C. 2014. Nutritional composition of Tumeric (*Curcuma longa*) and its antimicrobial properties. – International Journal of Scientific and Engineering Research, 5(10):1085–1089.

Ikrang, E.G., Anyanwu, C.S. 2019. Some physical properties (*Xylopia aethiopica*). – International Journal of Trend in Scientific Research and Development, 3(6):525–529.

Ilusanya, O.A.F., Odunbaku, O.A., Adesetan, T.O., Amosun, O.T. 2012. Antimicrobial activity of fruit extracts of *Xylopia aethiopica* and its combination with antibiotics against clinical bacterial pathogens. – Journal of Biology, Agriculture and Healthcare, 2(9): 170–177.

Jin, L. 2010. Phytogenic feed additives: nutritional functions and mechanism of action in monogastric animals. – Chinese Journal of Animal Nutrition, 22(5):1154–1164.

Jirovetz, L., Buchbauer, G., Ngassoum, M. 1997. Investigation of the essential oils from the dried fruits of *Xylopia aethiopica* (West African "Peppertree") and *Xylopia parviflora* from Cameroun. – Ernährung/Nutrition, 21: 324–325.

Jiwuba, P.C., Ezenwaka, L.C. Eluagu, C.J., Njoku, C. 2016a. Growth and haematological characteristics of broiler starter birds fed processed taro cocoyam (*Colocasia esculenta*) corn meal. – Journal of Applied Life Sciences International, 8(3):1–6. DOI: 10.9734/JALSI/2016/27949

Jiwuba, P.C., Kadurumba, O.E., Nwoko, A.C., Dauda, E. 2016b. Nutritional evaluation of graded levels of pigeon pea (*Cajanus cajan*) seed meal on growth performance and blood chemistry of broiler starter birds. – Case Studies Journal, 5(9):188–192. DOI 10.5281/zenodo.3533525

Jiwuba, P.C., Ogbuewu, I.P., Dauda, E., Azubuike, C.C. 2017. Blood profile and gut microbial load of broilers fed Siam weed (*Chromolaena odorata*) leaf meal in their diets. – Agricultura, 14(1–2):7–13.

Livestocking 2020. Nutrient requirements of broilers. Retrieved 9th October, 2020 at https://www.livestocking.net/nutritional-requirements-broiler

Lumeij, J.T. 2008. Avian clinical biochemistry. In Clinical Biochemistry of Domestic Animals. 6th ed. (Eds. J.J. Kaneko, J.W. Harvey, M.L. Bruss). – Academic Press, Burlington, MA, pp. 839–872.

Melillo, A. 2013. Applications of serum protein electrophoresis in exotic pet medicine. – Veterinary Clinics of North America Exotic Animal Practice, 16(1):211–225. DOI: 10.1016/j.cvex.2012.11.002

Meluzzi, A., Primiceri, G., Giordani, R.A., Fabris, G. 1992. Determination of blood constituents reference values in broilers. – Poultry Science, 71(2):337–345. DOI: 10.3382/ps.0710337

Mitruka, B.M., Rawnsley, H.M. 1977. Chemical, biochemical and haematological references values in normal experimental animal. – Mason Publishing, USA Inc. N.V., pp. 88–142.

Muhammad, N., Musa, I., Maigandi, S.A., Buhari, S., Aljamee, K.M. 2016. Intake and digestibility of Uda Sheep with graded levels of *Xylopia aethiopica* (Ethiopian pepper). – American Journal of Experimental Agriculture, 12(6):1–10. DOI: 10.9734/AJEA/2016/26581

Ndelekwute, E.K., Enyenihi, G.E. 2018. Negro pepper (*Xylopia ethiopica*) in feed is antibacterial and can improve broiler chickens productivity. – British Journal of Poultry Sciences, 7(1):10–15. DOI: 10.5829/idosi.bjps.2018.10.15

NRC. 1994. Nutrient requirements of poultry (9th ed). – National Academy Press. Washington DC, USA, 34 p.

Reece, O.W. 2009. Functional anatomy and physiology of domestic animals (4th ed.). – Wiley-Blackwell, pp. 168–173.

Salah, H.E. 2012. Fibre plays a supporting role in poultry nutrition. – Retrieved 8th January, 2021 at https://www.poultryworld.net/Breeders/Nutrition/2012/2/Fibre-plays-a-supporting-role-in-poultry-nutrition-WP009965W

SAS 2008. Statistical Analysis System User's Guide, Version 13 for Windows. – Statistical Analysis Institute, Inc., SAS Camp Drive Cary, North Carolina U.S.A.

Shivappa-Nayaka, H.B., Umakantha, B., Wilfred-Ruban, S., Murthy, H.N.N., Narayanaswamy, H.D. 2013. Performance and hematological parameters of broilers fed neem, turmeric, vitamin e and their combinations. – Emirates Journal of Food and Agriculture, 25(6):483–488. DOI: 10.9755/ejfa.v25i6.15514

Subash, C., Sahdeo, G., Ji, P., Kim, H., Patchva, S., Webb, J. 2011. Multi-targeting by curcumin as revealed by molecular interaction studies. – Natural Product Reports, 28(12):1937–1955. DOI: 10.1039/c1np00051a

Sugiharto, S., Isroli, E., Widiastuti, N.S. 2011. Effect of turmeric extract on blood parameters, feed efficiency and abdominal fat content in broilers. – Journal of the Indonesian Tropical Animal Agriculture, 36(1):21–26. DOI: 10.14710/jitaa.36.1.21-26

Swennen, Q., Everaert, N., Debonne, M., Verbaeys, I., Careghi, C., Tona, K., Janssens, G.P.J., Decuypere, E., Bruggeman, V., Buyse, J. 2010. Effect of macronutrient ratio of the pre-starter diet on broiler performance and intermediary metabolism. – Journal of Animal Physiology and Animal Nutrition, 94:375–384. DOI: 10.1111/j.1439-0396.2009.00918.x

Tatsadjieu, L.N., Essia-Ngang, J.J., Ngassoum, M.B., Etoa, F.X. 2003. Antibacterial and antifungal activity of *Xylopia aethiopica*, *Monodora myristica*, *Zanthoxylum xanthoxyloides* and *Zanthoxylum leprieurii* from Cameroon. – Fitoterapia. 74:469–472. DOI: 10.1016/s0367-326x(03)00067-4

Thrall, M.A. 2007. Hematologia e bioquímica clínica veterinária. – Philadelphia, Lippincott, Williams &Wilkins, São Paulo: Roca, 582 p. (In Portugese)

Venugopal, P.M., Adluri, R.S. 2007. Antioxidant and anti-inflammatory properties of curcumin. – Advances in Experimental Medicine and Biology, 595:105–125. DOI: 10.1007/978-0-387-46401-5_3

Yildirim, E.I., Yalchinkaya, M., Kanbur, M. Ç., Oruc, E. 2011. Effects of yeast lucomannan on performance, some biochemical parameters and pathological changes in experimental aflatoxicosis in broiler chickens. – Révue de Médicine Vétérinaire, 162:413–420.

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CASE STUDY: DYNAMICS OF SUNFLOWER SEED MOVEMENT IN THE VIBRATING TRAY OF THE INFRARED DRYER AND ITS INFLUENCE ON THE DRYING PROCESS

Valentyna Bandura[1], Leonid Yaroshenko[2], Larisa Fialkovska[3], Dmytro Kondratyuk[2], Vladyslav Palamarchuk[3], Yurij Paladiichuk[2]

[1]National University of Life and Environmental Sciences of Ukraine, 19 Henerala Rodimtseva St, 03041 Kyiv, Ukraine
[2]Vinnytsia National Agrarian University, 3 Sonyachna St, 21008 Vinnytsia, Ukraine
[3]Vinnytsia Institute of Trade and Economics of Kyiv National University of Trade and Economics, 87 Soborna St, 21050 Vinnytsia, Ukraine

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Vastutav autor: / Corresponding author: Valentyna Bandura

E-mail: bandura_3@ukr.net

ORCID:
0000-0001-8074-3020 (VB)
0000-0002-0261-006X (LY)
0000-0002-4353-0963 (LF)
0000-0003-1827-1717 (DK)
0000-0002-7478-9521 (VP)
0000-0003-4257-9383 (YP)

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ABSTRACT. Analysis of researches on the study of the material particle movement on the vibrating surface of the container machine intended for seed drying in the infrared field is carried out. Comparison of traditional devices for dehydration of raw materials with energy supply of infrared irradiation is performed. It is shown that current tendencies of the development of heat and mass transfer equipment are connected with the use of electromagnetic generators of infrared energy. The purpose of the work is to study the process of movement of sunflower seeds on a vibrating tray dryer. To achieve this goal, a dynamic scheme of the vibrating tray has been proposed and theoretical and experimental studies of the process of grain movement have been carried out. It has been established that when the speed of drive electric motors increases from 950 to 970 rotations per minute, the speed of vibro-transportation increases as well, but when reaching a certain value of speed, under a further increase in speed, the speed of vibro-transportation decreases. Experimental studies have allowed to specify the design parameters of vibrating trays and select rational parameters of the technological process of drying, namely the oscillation frequency of the vibrating tray, which is f = 100 s^{-1}.

Introduction

Analysis of recent research and publications

Zare *et al.* (2014) studied the kinetics of paddy drying using a hot air-infrared dryer. They used three levels of inlet air temperature (30, 40 and 50 °C), three levels of air velocities (0.01, 0.015 and 0.020 m s^{-1}) and three levels of infrared radiation intensity (2000, 4000 and 6000 W m^{2-1}). They reported that the application of low-intensity infrared radiation with lower values of inlet air temperature and moderate values of inlet air velocity can effectively improve the final quality of paddy in terms of bending stress and percentage of cracked kernels.

Nindo *et al.* (1995) stated that although infrared heating is a rapid drying method, it is suitable for surface heating applications. When the increase in the grain bed depth is desired, the layer close to the infrared source dries more quickly compared to the deeper layers. One of the methods for faster and uniform drying of grains is the use of vibration.

Finzer *et al.* (2003) studied the drying of coffee berries in a hot air vibration dryer. They reported that vibration can improve product quality. In addition, the combination of hot air vibration reduces the time of drying.

In their article, Das *et al.* (2009) reported that both heating and drying of high moisture paddy using

vibrating platform coupled with infrared heating source dryer give uniform and quick-drying by exposing every grain uniformly to the IR source. A laboratory apparatus capable of modulating both frequency and amplitude of vibration has been developed to study vibration aided drying characteristics of high moisture paddy. The effective moisture diffusivity of the grain during drying under this model has been evaluated. The drying characteristics of high moisture paddy have been studied under different vibrating conditions for five levels of radiation intensity (1509, 2520, 3510, 4520 and 5514 Wm^{2-1}) and four levels of grain bed depths (single kernel thickness of 3, 6, 12 and 25 mm). The optimum frequency and amplitude of the vibrations are in the range of 20–22 Hz and 8–9 mm for all the three-grain bed depths of paddy (25, 12 and 6 mm) for obtaining nearly complete and uniform mixing (mixing index ffi 1.0).

Some of the authors as Tripathy, Kumar (2008); Coradi *et al.* (2016) focused on the mathematical modelling of various drying processes and process identification. Using a proper model, it is possible to predict the final moisture content in a product, and therefore models are often used as tools to estimate the optimal heating or cooling time to optimize product quality.

Drying behaviour of corn and modes of drying bed (fixed and vibratory) were investigated on grain moisture variation during the drying process by Nourmohamadi-Moghadami *et al.* (2017). Corn kernels were dehydrated from the initial moisture content of 24.5 ± 0.5% (w.b) to the final moisture content of 14 ± 0.2%. The thin layer drying characteristics were experimentally investigated and appropriate mathematical drying models were correlated with temperature and radiation intensity. Among models fitted to experimental data, the Page model was found to be the best model for describing the drying behaviour of corn in thin layer drying form. The effective moisture diffusivity ranged from 0.6170×10^{-8} m^2 s^{-1} for the vibratory bed mode.

Bulgakov *et al*. (2018) proposed technologies of targeted energy supply for intensification of heat-and-mass transfer when drying rapeseed and other food raw materials. Bandura *et al.* (2019) describe the technological features of drying sunflower seeds using infrared energy supply and substantiates the prospects of vibration monolayer drying sunflower seeds. Specific energy costs in the process of infrared drying of the product are determined. An infrared dryer design has been developed, which ensures uniform drying of sunflower seeds by the principle of vibration fluidization. Vibrators installed on both sides of the machine provide the necessary vibration parameters of the working body of the vibrating dryer. Even when the product is fed to the working body of the vibrating dryer, a uniform, completely distributed flow of raw materials is created through vibration. This saves space and increases the efficiency and quality of drying.

Formulation of the problem

Traditionally, convective drying technologies are widely used in the food and processing industry and implemented in dryers of various designs, including mine, band, drum-type ones, in which heat is transferred to raw materials utilizing a drying agent, through the outer shell of the product to inner layers. Analysis of the most widespread technologies of convective drying reveals that drying equipment does not meet modern requirements by the energy consumption, ecological regulations, and safety of grain goods. Reduction of energy costs for drying oilseeds as the most energy-intensive process in its production is considered to be the most important task in the development of new drying technologies and designs of dryers as well as the improvement of existing ones. Any modernization of the dryer can be considered quite effective if the reduction of specific energy costs is achieved under compulsory maintenance of the product quality.

Traditional approaches to drying technologies have faced several insurmountable contradictions. On the one hand, to intensify the processes of heat-and-mass transfer, it is necessary to increase the speed (*i.e.* consumption) of the drying agent. On the other hand, the higher the coolant consumption is, the more heat energy is lost with the emissions of the installation. The way out for resolving this contradiction is surely based on changes in the principles of energy supply to grain. The proposed idea, which is defended in this paper, is based on two provisions. Firstly, it is necessary to remove from the air the task of the coolant and leave only the task of the diffusion medium, which provides an effective "reception" of moisture from the product. Secondly, it is necessary to organize the process of grain rotation to dry it evenly. This process can provide a combination of infrared energy supply and the use of vibration. However, if the drying processes in the infrared field have been sufficiently researched, the vibration processes, namely the dynamic process of grain movement, have been studied much less.

The purpose of the work is to study the movement of sunflower seeds on the vibrating tray dryer and rational parameters of the technological process of drying.

Material and Methods

In the vibrating dryer, the technological processing of grain is carried out in the course of its movement on the working body of the machine. In this regard, the decisive influence on the efficiency of the process of technological processing of the product is made by the observance of necessary modes (speed) of vibratory movement and heat transfer to the processed product. When determining effective modes of transport and technological machines, it is of great interest to establish the dependence of the transportation speed, energy consumption of the process, the degree of speed transfer to the processed product, its mixing intensity, the combination of vibration boiling conditions, *etc*. on the parameters of oscillation modes(shape of the

trajectory, frequencies, amplitudes, phase shift angle between harmonic components of double-component oscillations, the vibration angle and the angle of the working body). The study of the influence of characteristics of the environment, degree of filling of the working body and operating conditions on the listed parameters of the process of vibration transport and technological processing is equally important.

The developed vibrating dryer and the schematic diagram of the machine are shown in Figures 1 and 5, respectively.

The machine consists of a closed housing *1*, on the platforms *2* of which using elastic elements *3* thermal *4* and grate *5* trays are installed. The working path of thermal tray *4* is made of heat-resistant sheet steel. The working path of the grate tray is formed by longitudinal vertical strips *7* welded to the brackets *8*, so that there is a longitudinal gap δ = 1.5–2.0 mm between them. In the middle of each tray, vibratory drives containing two centrifugal vibrators installed on the sides of the tray are mounted.

Figure 1. Photo of the experimental vibrating tray infrared dryer

Each centrifugal vibro-exciter comprises a shaft with unbalanced loads *9*, which is connected through elastic coupling *10* with the asynchronous drive electric motor *11*. Moreover, in each vibratory drive, electric motors *11* are connected in such a way that when connected to the network, their rotors rotate towards each other. Shafts with unbalanced loads *9* are mounted on bearings parallel to each other at an angle β to the planes of the working paths of the trays. Above the surfaces of thermal trays *4*, there are fixed heat generators *12* (IR emitters). At the top and sides, thermal tray *4* is closed by thermal insulation *13*. Above the beginning of the thermal tray 4, the feeding throat 14 is fixed, and at the end of the impeller *15*, at the beginning of the grate tray *5* there is fan discharge pipe *16*, and above the receiving hopper *6*, there are outlet pipes *17* with adjusting gates *18*. At the end of the grate tray *5*, there is a receiving hopper *6*.

The machine works this way, when the drive electric motors *11* are switched on, their rotors start to rotate towards each other in each vibratory drive, which leads to dynamic synchronization of their rotation, as a result of which translational oscillations of trays *4* and *5* at an angle β to the planes of their working paths are generated. Bulk products are fed through the feeding throat *14* on the tray surface, where under the action of oscillations they are distributed in a monolayer. Under the action of oscillations of the trays between their surface and the particles of bulk products, there arises an asymmetry of friction forces, which leads to the directional movement of particles of bulk products (vibro-transportation) along the surface of the trays. The points on the surface of the trays oscillate relative to some centre without directional movement as a whole for a period of one oscillation. By changing static moments of the unbalanced loads *9* relative to the axis of rotation, the mode of vibro-transportation is established with the continuous tossing of particles of bulk products during their movement along with the trays. The continuous tossing of product particles leads to their chaotic rotation when moving along the thermal trays *4*, above which are heat generators *12* can be found and this contributes to their uniform irradiation on all sides with infrared rays, which leads to intensive, rapid and uniform heating of bulk granules.

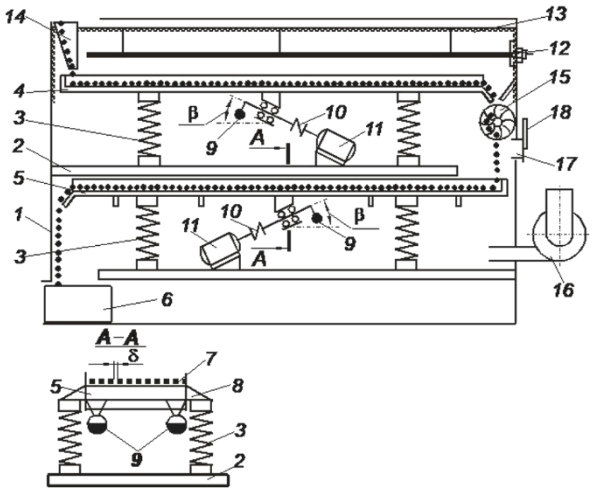

Figure 2. Scheme of laboratory vibrating dryer:
1 – housing; 2 – platform; 3 – elastic elements; 4 – thermal tray; 5 – grate tray; 6 – receiving hopper; 7 – longitudinal vertical strips; 8 – bracket; 9 – unbalanced load; 10 – elastic coupling; 11– electric motor; 12 – heat generators; 13 – thermal insulation; 14 – feeding throat; 15 – impeller; 16 – fan; 17 – outlet pipes; 18 – adjusting gate

Having passed the thermal tray, the heated bulk products are fed through the drum impeller *15* to the grate tray *5*, where it is blown by atmospheric air from the fan *16*. At the same time, continuous chaotic tossing and turning of product particles also improve the uniformity of their blowing with the air, which leads to an imbalance in the moisture content in product particles, when the water vapour pressure in them becomes greater than the partial vapour pressure of water in the air, as a result of which moisture begins to evaporate intensively (Bandura *et al.*, 2019). Having passed the grate tray *5*, the processed products are fed into the receiving hopper *19*. The drum impeller *15* prevents access of cold air flow from fan *16* into the

high-temperature chamber above the thermal tray *4* and at the same time allows the product to flow from the thermal tray *4* to the grate tray*5*. The intensity of airflows is regulated by gate *18*. The speed of vibro-transportation of bulk products, and therefore its time on the surface of the trays is regulated by changing the static moments of unbalanced loads *9* relative to their axis of rotation, or angle *β*. Since the infrared radiation of the heat generator *12* allows to create a very intense heat flow, which promotes rapid heating of product particles, and the process of moisture evaporation from them requires a longer time, the speed of vibro-transportation on the grate *5* is set higher and it is made with wider working paths.

Results and Discussion

An experimental-industrial sample of a vibration machine (Bandura *et al.*, 2019) for drying sunflower seeds allows a wide range of drying temperature control (from 20 to 180 °C), air velocity varies within 0.5–2.5 mm s^{-1}, oscillation amplitude of the working body of the vibration dryer, *i.e.* vibrating tray (0.5–6.0 mm).

The dynamic scheme of the vibration tray is shown in Figure 3. The working body (tray) is considered to be a rigid solid body, which is mounted on a fixed base through sufficiently soft elastic elements with rigidity *k* and resistance coefficient *b*. Two unbalanced vibrators are mounted on the tray, symmetrically to the vertical axis, at the distance *l* from each other. The axes of rotation of vibrators are in the plane that passes through the centre of the mass of the vibrating tray. Vibrators are equipped with drive electric motors that rotate towards each other. The generalized coordinates of the system are as follows: *x*, *y* and *φ*, which correspond to the horizontal, vertical and angular movement of the tray. Chubyk, Yaroshenko (2011) in their work showed the differential equation of motion of the vibrating tray under uniform rotation of vibrators will be as follows:

$$M\frac{d^2s}{dt}+b\frac{ds}{dt}+k\cdot s=F_0\cdot\sin(\omega\cdot t), \qquad (1)$$

where *M* – the reduced mass of the vibrating tray;
s – movement of the vibrating tray;

$b=-\frac{f}{s}$; (*f* – friction forces, air resistance);

k – rigidity of the elastic system of the vibrating tray;
F_0 – cyclic coercive force.

The cyclic centrifugal coercive force that occurs during the rotation of imbalances, the location of which on the drive shaft is shown in Figure 4, will be equal to:

$$F=m_{unb}\cdot e\cdot\omega^2, \qquad (2)$$

where *m* – the mass of the unbalanced load of vibrators;
e – eccentricity of an unbalanced load of vibrators;
ω – angular velocity of the drive shaft rotation.

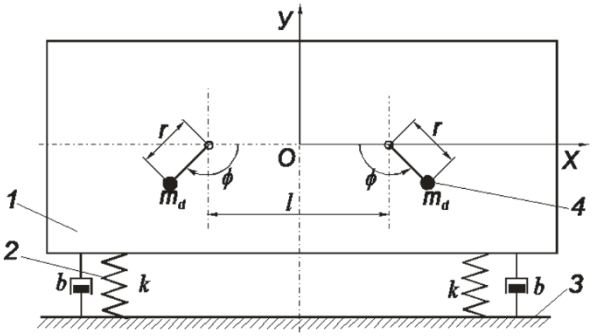

Figure 3. Calculation scheme of the unbalanced vibro-exciter of oscillationsof the vibration tray:1 – working body; 2 – spring; 3 – support frame; 4 – unbalanced load

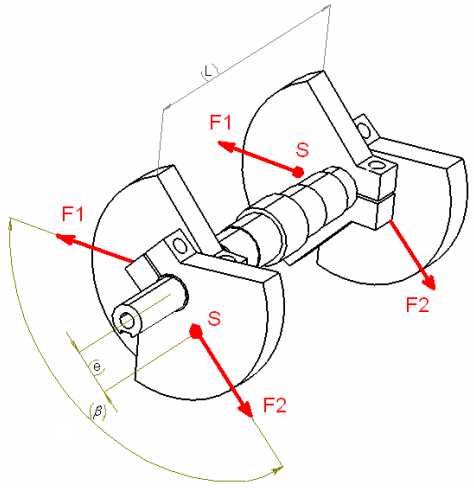

Figure 4. The layout of imbalances on the drive shaft

Analyzing the initial Equation (1), it can be concluded that if the circular frequency *ω* of the external coercive forceF_0 is small compared to the natural frequency $\omega_0$of the vibrating tray, then in the left part of the Equation (1), according to Timoshenko *et al.* (1985), a substantial role is played only by the member $k\cdot s\approx F_0\cdot\sin(\omega\cdot t)$. Therefore, under $\omega<\omega_0$the external force is mainly spent on overcoming the elastic forces in the mechanical system, and the amplitude of the displacement ($s_0=\frac{F_0}{k}$) coincides with the phase with the external force.

If the frequency *ω* of the external coercive forceF_0 is large compared to the natural oscillation frequencyω_0 of the vibrating tray, then in the left part of Equation (1), according to Timoshenko *et al.* (1985), an important role is played only by the term ($M\frac{d^2s}{dt^2}$), therefore, $M\frac{d^2s}{dt^2}\approx F_0\cdot\sin(\omega\cdot t)$,*i.e.* under $\omega>\omega_0$ the external force is mainly spent to give acceleration to the vibrating tray. The amplitude of the acceleration $A_\infty=\frac{F_0}{m}$ coincides by the phase with the external force, and the displacement has the opposite phase. In the field of resonance, when $\omega\approx\omega_0$ members ($M\frac{d^2s}{dt^2}$), and $(k\cdot s)$ are approximately the same by their meaning but opposite to the sign. Since the oscillations of the vibrating tray occur according to the law $s=S\cdot\sin(\omega\cdot t)$, then:

$$M\frac{d^2s}{dt^2} = -M\cdot\omega^2\cdot S\cdot\sin(\omega\cdot t),$$
$$k\cdot s = k\cdot S\cdot\sin(\omega\cdot t) \quad . \tag{3}$$

Hence, $\frac{k}{M} = \omega_0^2$; $\omega\approx\omega_0$, therefore: $-(M\frac{d^2s}{dt^2}) \approx ks$.

Both of these terms compensate each other in Equation (1) and as a consequence:

$$b\frac{ds}{dt} \approx F_0\cdot\sin(\omega\cdot t). \tag{4}$$

Based on Equation (4) and considering the research conducted by Timoshenko *et al.* (1985), it can be concluded that in the field of resonance ($\omega\approx\omega_0$) the elastic system itself, overcoming external forces, gives necessary acceleration to the mass *m*; the role of the external force is reduced to overcoming the forces of friction, and the amplitude of the velocity ($V_{max} = \frac{F_0}{b}$) coincides by its phase with the external force. Moreover, the external force F_0performs the most useful work because the direction of the vibrating tray constantly coincides with the direction of external coercive force. And vice versa, when ω is substantially different fromω_0, the direction of movement of the vibrating tray coincides with coercive force during some part of the period, and during the second part of the period, it is opposite to it. Therefore, from the energy point of view, the phenomenon of resonance is caused by the fact that when the frequencies$\omega\approx\omega_0$coincide, the most favourable conditions are provided for the entry of energy into the system from an external source.

According to Timoshenko *et al.* (1985) and Povidailo (2004), the solution of a differential Equation (1) can be expressed as the following:

$$S(t) = S\cdot\sin(\omega\cdot t-\varepsilon), \tag{5}$$

where $$S = \frac{F}{\sqrt{(-M\cdot\omega^2+k^2)+(b\cdot\omega)^2}} = \frac{F}{M\cdot\sqrt{(\omega_0^2-\omega^2)^2+4\cdot\alpha^2\cdot\omega^2}} = \frac{q}{\omega_0^2}\cdot\frac{1}{\sqrt{\left(1-\frac{\omega^2}{\omega_0^2}\right)^2+\gamma^2\cdot\frac{\omega^2}{\omega_0^2}}},$$

where $q = \frac{F}{M}, \omega_0^2 = \frac{k}{M}$,

$$\varepsilon = \arctan\left(\frac{b\cdot\omega}{-M\cdot\omega^2+k}\right) = \arctan\left(\frac{2\cdot\omega\cdot\alpha}{\omega_0^2-\omega^2}\right) = \arctan\left(\frac{\gamma\cdot\frac{\omega}{\omega_0}}{1-\frac{\omega}{\omega_0}}\right)$$

The concept of dynamic coefficient of the gain coefficient is introduced for resonant machines designed by Timoshenko *et al.* (1985); Povidailo (2004). This coefficient characterizes the dynamic properties of resonant machines throughout the amplitude-frequency response and can be expressed as follows:

$$\mu = \frac{1}{\sqrt{\left(1-\frac{\omega^2}{\omega_0^2}\right)^2+\gamma^2\cdot\frac{\omega^2}{\omega_0^2}}} = \frac{1}{\sqrt{(1-z^2)^2+\gamma^2\cdot z^2}}, \tag{6}$$

where $z = \frac{\omega}{\omega_0}$ – the adjustment coefficient (Povidailo, 2004).

Vibrating trays are devices for the continuous supply of bulk (grain) material. The vibrating tray is usually inclined at an angle α to the horizon (Fig. 5) and receives a reciprocating movement with small amplitude and significant frequency in the direction at an angle β to the working surface of the tray.

If the translational movement of the tray is slow and the reverse one is fast, then the particle of bulk material lying on the tray will move only translationally. Since the movement of the particle occurs under the action of friction, which cannot be greater than Gf, then the maximum acceleration of the particle W_{cr} (so-called critical) will determine the nature of the particle movement. If the acceleration of the tray is greater than the critical one, then the particle will slip on the tray in the direction that is opposite to the movement of the tray.

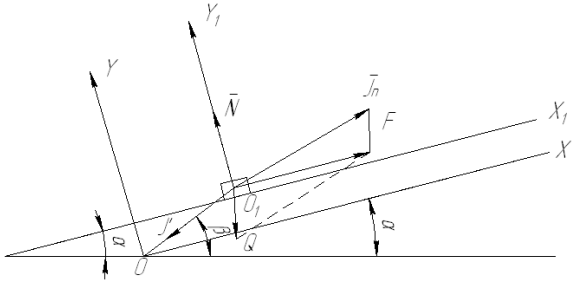

Figure 5. Scheme of action of forces on a particle of bulk material, which is placed on a vibrating tray

If the forward movement of the particle requires an oscillating motion (Povidailo, 2004), with different accelerations in the forward and reverse directions, then in the case of the forward movement of the tray, the acceleration will be lessW_{cr}, *i.e.*$W_{tr}^{f} < W_{cr}$and the particle will move together with the tray without slipping, in the case of the tray movement back under $W_{tr}^{b} > W_{cr}$, the particle will slide forward on the tray. Critical acceleration, the excess of which will create a sliding particle relative to the tray "back – down", is equal to:

$$W_{cr}^{H} = g(f\cos\alpha - \sin\alpha), \quad (7)$$

According to Povidailo (2004), the critical acceleration, the excess of which will create sliding of the particle relative to the tray "forward – up", is equal to:

$$W_{cr}^{b} = g(f\,cos\,\alpha - \sin\alpha), \quad (8)$$

where g – acceleration of gravity;
f – coefficient of friction of the particle on the tray.

When the tray moves up, the force of inertia of the particle will act opposite to the direction of movement and press the particle to the tray, increasing the friction force under the action of which the particle moves. When the tray moves down, the force of inertia will reduce the pressure of the particle on the tray and thereby reduce the friction force, creating conditions for forwarding sliding of the particle on the tray. Depending on the tray acceleration and angles βandα, there may be different modes of particle movement, both detachable, when the material particle – part of each cycle – flies without touching the tray surface, and continuous, when the particle is constantly in contact with the tray surface.

In our opinion, detachable modes are the most effective modes of operation of the vibrating tray, which enable to obtain high speeds of movement under high efficiency and maintenance of high stability of the particle movement. The main conditions that determine the particle movement are the angles of the tray and direction of vibration, speed and acceleration of the tray, as well as the coefficient of sliding friction $f$between the particle and the tray.

To describe the oscillatory movement of the vibrating tray, it is possible to accept two coordinate systems, *i.e.* axes of coordinates: the first one is XOY – motionless (on a bed of the bunker), connected with a motionless bed, the second one is $X_1O_1Y_1$ – relative, and connected with a mobile tray (Fig. 5). When considering the movement of the particle of bulk material on a tray inclined at an angle $\alpha$to the horizon, which performs harmonic oscillations at an angle β (under $\beta > \alpha$), the equation of the tray movement in the coordinate system XOY is as follows:

$$\ddot{x}_{tr} = \frac{A_{tr}}{2}\omega^2\cos\varphi, \quad (9)$$

$$\dot{x}_{tr} = \frac{A_{tr}}{2}\omega\sin\varphi, \quad (10)$$

$$\ddot{y}_{tr} = \frac{A_{tr}}{2}\omega^2\cos\varphi, \quad (11)$$

$$\dot{y}_{tr} = \frac{A_{n}}{2}\omega\sin\varphi, \quad (12)$$

where A_{tr} – amplitude of tray oscillations in the direction in parallel to its working surface;
A_n – amplitude of oscillations in the direction perpendicular to the working surface of the tray;
ω– angular frequency of the tray oscillations;
$\varphi = \omega t$ –phase angle of oscillations;
t – time.

Differential equation of motion of the particle of bulk material and the initial period relative to the tray in the coordinate system $X_1O_1Y_1$connected with the tray is as follows:

$$m\ddot{x}' = -mg\sin\alpha - m\frac{A_{tr}}{2}\omega^2\cos\varphi + F, \quad (13)$$

$$m\ddot{y}' = -mg\cos\alpha - m\frac{A_{tr}}{2}\omega^2\cos\varphi + N \quad , \quad (14)$$

Where m – the mass of bulk material;
g – acceleration of gravity;
N – normal reaction;
F– force of friction.

The process of movement of the particle of bulk material in the modes with its separation from the tray in the general case can be considered in five stages. At the first stage (acceleration stage), the particle of bulk material is in the plane of the tray (ÿ' = 0). The equation of the particle movement at the first stage is as follows:

$$\ddot{x}_a' = g(f\cos\alpha - \sin\alpha) + \left(\frac{A_n}{2}f - \frac{A_{tr}}{2}\right)\omega^2\cos\varphi. \quad (15)$$

While the equation of absolute motion (*i.e.* relative to a fixed coordinate system) will be as follows:

$$\ddot{x}_a = g(f\cos\alpha - \sin\alpha) + \frac{A_n}{2}fU^{-2}\cos\varphi, \quad (16)$$

$$\dot{x}_a = \frac{g}{W}(f\cos\alpha - \sin\alpha) + \frac{A_n}{2}fW\sin\varphi + C, \quad (17)$$

where ($\varphi = 0$, $C = 0$)

According to Bandura *et al.* (2019), since the tray performs harmonic oscillations, the particle slides relative to the tray and moves with the acceleration determined by the formula (16). The speed of the particle increases along the curve expressed by Equation (17) until the speeds of the particle and the tray are equalized. At this point there comes the second stage, which is called the stage of the first braking. The particle begins to move with deceleration on the tray, which slows down, but faster than it.

The equation of the particle movement at the stage of braking is as follows:

$$\ddot{x}_{b_1} = -g(f\cos\alpha + \sin\alpha) - \frac{A_n}{2}f^2\,cos\,\varphi, \quad (18)$$

$$\dot{x}_{b_1} = -\frac{g}{\omega}(f\cos\alpha - \sin\alpha)\varphi - \frac{A_n}{2}f\omega\,sin\,\varphi, \quad (19)$$

In the second quarter of the period of movement, acceleration of the tray will be negative and the force of inertia of the particle (Fig. 5) will be directed upwards, and at the moment when the normal reaction *N* becomes zero, the particle will separate from the tray.

The phase angle at which the separation of the particle from the tray begins is equal to:

$$\varphi_0 = \arccos\left(-\frac{2\,g\cos\alpha}{A_n\omega^2}\right). \quad (20)$$

The mode of the particle movement, during its separation and its falling on the tray, depends on the magnitude of the amplitude of the normal acceleration of the tray $\frac{A_n\omega^2}{2}$, which is convenient to be set by a generalized dimensionless parameter:

$$\xi = \frac{A_n\omega^2}{2\,g\cos\alpha}, \quad (21)$$

$$\varphi = \arccos\left(-\frac{1}{\xi}\right). \quad (22)$$

From the moment the particle is separated from the tray, the third stage of the movement, *i.e*. a microflow of the particle in the air with the speed of separation, begins. Absolute acceleration of the particle along *X* axis, if the air resistance is neglected, will be as follows:

$$\ddot{x}_f = g\sin\alpha, \quad (23)$$

$$\dot{x}_f = -g\frac{\varphi}{\omega}\sin\alpha. \quad (24)$$

After the microflow, the duration of which depends on the mode of the tray operation, which is determined by the value of parameter ξ, the particle falls on the tray and the fourth stage of its movement, *i.e*. the stage of the second braking, begins. The phase angle of contact of the particle with the tray can be determined by the following formula:

$$\varphi_b = \varphi_0 + \sqrt{\xi^2-1}+\sqrt{\xi^2+2\xi\cos\varphi\varepsilon+1}. \quad (25)$$

Under efficient modes of the vibrating tray operation, the speed of the particle at the time of meeting with the tray (provided that the impact of the particle on the tray is not elastic) will be greater than the speed of the latter, so during the fourth stage, the particle will move with negative acceleration, as determined by the equations 23 and 24, until the velocities of the particle and tray equalize.

Then there begins a cycle, in which the particle will slip on the tray and its speed will increase, when the speeds of the particle and the tray get equalized, there will begin three other stages, movement of the next period. As a result of the first oscillation, the particle acquires a certain speed, the second oscillation leads to the particle acceleration to a slightly higher speed. During the next few oscillations, the increase in the speed of the particle will continue until the mode of steady motion begins.

The latter will begin when the increase in the speed of the particle during acceleration will be equal to the sum of the speed drops during decelerations. The speed of the particle in the steady mode of operation will vary and range from υ_{max} to υ_{min}. Under certain conditions, in addition to four stages of movement considered, there begins the fifth joint movement of the particle and the tray without slipping. This stage can occur either at the end of acceleration or at its beginning if at these moments tray acceleration will be less than critical. The occurrence of this condition can be recorded in general terms, considering the sum of projections of all forces on X_1 axis (Fig. 5).

$$m\frac{A_{tr}}{2}\omega^2\cos\varphi \le \pm F - mg\sin\alpha \quad (26)$$

In Equation 26 the sign "plus" is put for the segment of the particle acceleration, and the sign "minus" is put at the stopping segment.

If the tray is given oscillating motion with accelerations equal in absolute value in both directions, the action of the particle lying on it on the tray will not be the same when the tray moves in one direction or another, namely, when lifting the tray, the particle pressure on the tray will be higher when lowering it – smaller. So, the pressure of the particle on the tray when moving it up will be equal to:

$$Q_1 = m(q_n + J_n), \quad (27)$$

where *m*– the mass of the particle;

q_n – component of acceleration of free fall that is normal to the tray surface;

J_n – component of acceleration of the force of inertia that is normal to the tray surface.

Thus, when moving down, the pressure of the particle on the tray will be as follows:

$$Q_2 = m(q_n - J_n). \quad (28)$$

When the tray is moving up, the force of inertia is as follows:

$$P_1 = m(J_t - q_t), \quad (29)$$

where q_t– component of acceleration of the free fall that is horizontal to the tray surface;

J_n –component of acceleration of the force of inertia that is horizontal to the tray surface.

The force of inertia when the tray is moving down:

$$P_1 = m(J_t - q_t). \quad (30)$$

Since the interaction between the tray and the particle lying on it is determined by the force of friction that is equal to:

$$F = fQ, \quad (31)$$

where f – coefficient of friction

Then acceleration of the tray is transmitted to the particle until the force of inertia of the particle does not exceed the force of friction, and if $f_m(q_n + J_n) \geq m(J_t - q_t)$, the particle moves up together with the tray. Under the reverse movement of the tray, when $f_m(q_n - J_n) \leq m(J_t - q_t)$, the particle detaches from it and moves in the direction of the direct course of the tray on the parabola until a new collision with it.

Vibratory movement of grains during the working process of their drying is performed as a result of the total effect of a large number of oscillations that follow one another. A very slight movement of grain occurs during one oscillation, however, since there are 1000–3000 oscillations per minute, this process is very effective.

For the mode of operation of a monolayer dryer, when vibro-transportation of grain is carried out on a vibrating tray with continuous tossing (Bandura*et al.*, 2019), the average speed of vibro-transportation (Ganiev, Ukrainskij, 1975), can be determined by the following dependence:

$$v = A\omega\left(\cos\beta - \frac{1+R}{1-R}\cdot\frac{2-\lambda}{\lambda}\cdot sin\,\beta\cdot tg\alpha\right), \quad (32)$$

where A – amplitude of oscillations of the tray surface, m;

ω – tray oscillation frequency, s;

β – angle between the direction of oscillation and the tray surface plane, $\beta = 0\ldots30°$;

α – angle of inclination of the tray surface to the horizon, $\alpha = 0–20°$;

λ – coefficient of instantaneous friction of grain on the tray surface when hitting, $\lambda = 0.5–0.7$;

R– recovery coefficient when the grain hits the tray surface, $R = 0.2–0.4$.

Since the dryer trays are placed horizontally, $\alpha = 0^\circ$.

Then the required amplitude of oscillations of the tray will be equal to:

$$A = \frac{v}{\omega\left(\cos\beta - \frac{1+R}{1-R}\cdot\frac{2-\lambda}{\lambda}\cdot\sin\beta\cdot tg\alpha\right)}. \quad (33)$$

In the developed experimental-industrial sample of the vibrating machine for drying sunflower seeds, it is constructively accepted: β = 30°, α = 0–20°, and ω = 99, s, we receive:

$$A = \frac{0{,}0232}{99\left(\cos 30° - \frac{1+0{,}3}{1-0{,}3}\cdot\frac{2-0{,}6}{0{,}6}\cdot\sin 30°\cdot tg0°\right)} = 1{,}6\cdot10^{-3}, \text{ m} \quad (32)$$

Based on the generalization of these studies, it is possible to determine the main characteristics of the process of transport and technological processing of various food products depending on the mode of operation of the vibrating machine and the properties of the moving mass. The main dependences of the speed of vibro-transportation on the speed of the drive electric motors have been investigated (Table 1).

Table 1. Dependence of the speed of grain vibro-transportationon the speed of drive electric motors

n, min	900	910	930	940	950	960	970	980	990
v_1, m s^{-1}		0.0188	0.0191	0.0195	0.0202	0.0200	0.0193	0.0187	0.0183
v_2, ms^{-1}	0.0114	0.0115	0.0120	0.0127	0.0134	0.0140	0.0141	0.0132	0.0124

According to the graph of dependence of the speed of grain vibro-transportation on the speed of drive electric motors (Fig. 6), the speed of vibro-transportation increases under the growth of the engine speed. When reaching a certain value of speed, under a further increase in the engine speed of drive electric motors, the speed of grain vibro-transportation decreases. This nature of curves can be explained by the fact that at first there takes place continuous vibro-transportation of grain and therefore the speed increases under the increase in the engine speed. And at a certain value of the frequency of rotation, the particles of bulk products (grains) begin to break away from the tray and the speed of their movement along the tray begins to decrease. However, this improves the rotation of seeds during vibro-transportation, which contributes to their uniform heating at all sides.

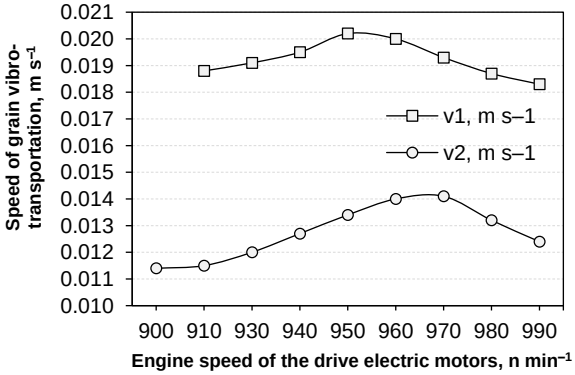

Figure 6. Dependence of the speed of grain vibro-transportation on the engine speed of the drive electric motors: 1 – speed of vibro-transportion under eccentricity of imbalances e = 0.025 m; 2 – speed of vibro-transportion under eccentricity of imbalances e = 0,015 m.

The frequency of oscillations also has a significant effect on the drying process in a vibrating tray dryer of continuous action. Several experimental studies have been conducted taking into account the following considerations:

- ensure the maximum intensity of the drying process;
- create a monolayer of the product that moves evenly and intensively, which will enable to avoid overheating of the product and achieve its uniform drying;
- application of vibration should make it possible to rotate the seeds during vibro-transportation for uniform irradiation at all sides.

Statistical analysis

The influence of oscillation frequency of the vibration tray of the dryer on the drying kinetics of sunflower seeds was studied by the influence of dispersion analysis. The Cochren's test was used to check the homogeneity of the dispersions at each level of tray oscillations. The hypothesis of homogeneity of variances was accepted in the case when the tabular value of Cochren's criterion was greater than the calculated one. The variance differences were assessed by Fisher's test at a 5% significance level. If the tabular value of Fisher's criterion exceeded the calculated one, it meant that the influence of the level of the tray oscillation frequency on the drying kinetics of sunflower seeds exceeded the level of error of the experimental data.

The results of studies on the influence of oscillation frequency of the vibrating tray on the kinetics of the process of drying sunflower seeds, which has an initial moisture content of W = 20.7, 23 and 25%, are presented in Figures 7, 8, 9.

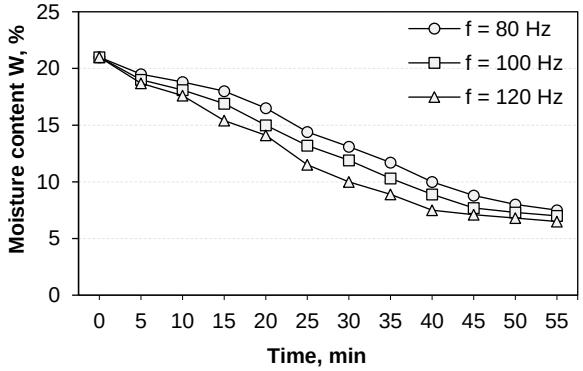

Figure 7. Influence of oscillation frequency of the vibrating tray on the kinetics of the sunflower seed drying process under initial moisture content of W = 20.7%.

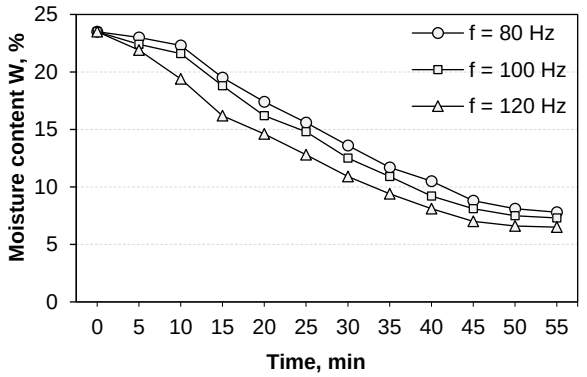

Figure 8. Influence of oscillation frequency of the vibrating tray on the kinetics of the sunflower seed drying process under initial moisture content of W =23%.

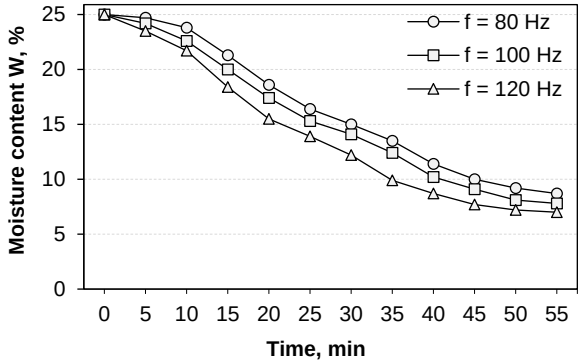

Figure 9. Influence of oscillation frequency of the vibrating tray on the kinetics of the sunflower seed drying process under initial moisture content of W = 25%.

Analysis of the presented curves has shown an almost uniform increase in the drying intensity under all considered oscillation frequencies of 80; 100; 120 oscillations per second. The increase in the frequency above f = 100 oscillation per second results in the decrease of the speed of vibro-transportation. Such speed is sufficient for the seed separation from the tray surface, which facilitates its rotation and uniform irradiation at all sides. Therefore, the rational value of vibration can be taken as f = 100 oscillations per second.

Conclusions

According to the results of experimental studies, it can be concluded that the highest speed of vibro-transportation of oilseeds is achieved under the speed of rotation of the drive electric motors within 950–970 rotations per minute. In addition, under the specified speed of rotation, there begins vibro-transportation of seeds with the separation from the tray surface, which facilitates rotation of seeds and their uniform irradiation at all sides. The conducted experimental research has allowed us to specify the design parameters of the vibrating tray of the dryer and choose rational parameters of the technological process of drying, namely the oscillation frequency of the vibrating tray, which is f = 100 oscillations per second.

Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions

VP, LF –critical analysis of the literature;
VB, LY – writing of the manuscript;
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References

Bandura, V., Mazur, V., Yaroshenko, L., Rubanenko, O. 2019. Research on Sunflower Seeds Drying Process in a Monolayer Tray Vibration Dryer Based on Infrared Radiation. –INMATEH – Agricultural Engineering, 57(1):233–242.

Bulgakov, V., Bandura, V., Arak, M., Olt, J. 2018. Intensification of rapeseed drying process through the use of infrared emitters. – Agronomy Research, 16(2):349–356. DOI: 10.15159/AR.18.054.

Coradi, P.C., Fernandes, C.H.P., Helmich, J.C. 2016. Adjustment of mathematical models and quality of soybean grains in the drying with high temperatures. – Revista Brasileira de Engenharia Agricola e Ambiental, 20(4):385–392. DOI: 10.1590/1807-1929/agriambi.v20n4p385-392

Chubyk, R.V., Yaroshenko, L.V. 2011. Kerovani vibratsiini tekhnolohichni mashyny: monohrafiia [Controlled vibrating technological machines: monograph]. – Vinnytsia: VNAU, p. 355. ISBN978-966-2462-35-7.

Das, I., Das, S.K., Bal, S. 2009. Drying kinetics of high moisture paddy undergoing vibration-assisted infrared (IR) drying. – Journal of Food Engineering, 95(1): 166–171. DOI: 10.1016/j.jfoodeng.2009.04.028

Finzer, J.R.D., Limaverde, J.R., Freitas, A.O., Limaverde Junior, J.R., Sfredo, M.A. 2003. Drying of coffee berries in a vibrated tray dryer operated with solids recycle and single-stage. – Journal of Food Process Engineering, 26(2):207–222. DOI: 10.1111/j.1745-4530.2003.tb00597.x

Ganiev, R.F., Ukrainskij, L.E. 1975. Dinamika chastic privozdejstvii vibracij [Particle dynamics under the influence of vibrations]. – Kyiv: Naukova dumka, 168 p.

Nindo, C.I., Kudo, Y., Bekki, E. 1995. Test model for studying sun drying of rough rice using far-infrared radiation. – Drying Technology, 13(1–2):225–238.

Nourmohamadi-Moghadami, A., Rahmanian-Koushkaki, H., Zare, D., Karimi, G. 2017. Experimental and theoretical investigation of hot air-infrared thin layer drying of corn in a fixed and vibratory bed dryer. – Engineering in Agriculture, Environment and Food, 10(3):191–197. DOI: 10.1016/j.eaef.2017.01.004

Povidailo, V.O. 2004. Vibratsiini protsesy ta obladnannia: monohrafiia [Vibration processes and equipment: monograph]. – Lviv: Publishing House «Lviv Polytechnic National University», 248 p.

Timoshenko, S.P., Young, D.Zh., Weaver, U. 1985. Kolebaniya v inzhenernom dele [Fluctuations in engineering]. – Moscow: Mashinostroenie, p. 472.

Tripathy, P.P., Kumar, S. 2008. Neural network approach for food temperature prediction during solar drying. – International Journal of Thermal Sciences, 48(7):1452–1459. DOI: 10.1016/j.ijthermalsci.2008.11.014

Zare, D., Naderi, H., Ranjbaran, M. 2014. Energy and quality attributes of combined hot air infrared drying of paddy. – Drying Technology, 33(5):570–582. DOI: 10.1080/07373937.2014.962143

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STORABILITY OF SWEET POTATO GENOTYPES UNDER ORDINARY AMBIENT STORAGE CONDITIONS

Prakash Bhattarai[1], Kalyani Mishra Tripathi[2], Durga Mani Gautam[2], Arjun Kumar Shrestha[2]

[1]Nepal Agricultural Research Council, National Potato Research Programme, Khumaltar15, Lalitpur Metropolitan City, 44700, Nepal
[2]Agriculture and Forestry University, Rampur, Chitwan, Bharatpur 15, Bharatpur Metropolitan City, 44209, Nepal

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Vastutav autor: Corresponding author: Prakash Bhattarai

E-mail:
prkash235@yahoo.com (PB)
kmishra@afu.edu.np (KMT)
durgagautam2013@gmail.com (DMG)
akshrestha@afu.edu.np (AKS)

ORCID:
0000-0002-7016-9472 (PB)
0000-0002-4434-9306 (KMT)
0000-0002-0730-5427 (DMG)
0000-0002-9253-2033 (AKS)

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ABSTRACT. The study was carried out to evaluate the storage performance of sweet potatoes in different conditions under ordinary ambient temperature (10.11–17.49 °C) at Khumaltar, Lalitpur (1350 masl) district of Nepal from December, 20 to March, 13 during the years 2018/19 and 2019/20. The experiment was laid out in Factorial Completely Randomized Design with three replications. Tuberous roots of three sweet potato genotypes ('CIP 440015', 'CIP 440267', and 'Local White') harvested at 4-month maturity were stored inside an ordinary room in dry sand, sawdust, thin jute sack, natural mud pot, and open crates (control). Data were taken on the 2nd, 4th, 6th, 8th, 10th, and 12th weeks of storage. The pooled results showed a significant effect of storage conditions on physiological loss in weight and rotting (%) of sweet potato genotypes. With the progression of the storage period, physiological weight loss (PLW) and rotting (%) were significantly increased in all treatments. At the 12th week of storage, the highest PLW was recorded in the tubers stored in open crates (70.2%) followed by natural mud pot (65.2%) whereas the lowest PLW was observed in tubers stored inside the dry sand (50.2%). Genotype 'CIP 440015' showed good storability with minimum PLW. No weevil infestation and sprouting were observed during the experimental period. The lowest percentage of tuber rotting was recorded in the genotype 'CIP 440015' (55.3%) and inside dry sand (48.7%) at the 12th week of storage while it was the highest up to 85.9% in 'CIP 440267'. The highest rotting 76.7%) was recorded in thin jute bags which is statistically at par with natural mud pot (76.5%). The interaction effect of storage conditions and genotypes was found not significant. The results showed an increment in dry matter and reducing sugar content while the reduction in ß-carotene and starch content of tubers after 3 months of storage inside dry sand. There was positive and strong correlation of storage duration with dry matter (r = 0.750) and reducing sugar (r = 0.658) whereas, negative correlation with starch (r = –0.918) and ß-carotene (r = –0.352) content of sweet potato genotypes. The study concluded that sweet potato tuber can be kept for 8 to 10 weeks in dry sand with minimum postharvest loss in ordinary room condition and the genotype 'CIP 440015' has good storability among the tested genotypes in similar conditions.

Introduction

Sweet potato, *Ipomoea batatas* (L.) Lam., is one of the important tuber crops grown in the tropics. It belongs to the family *Convolvulaceae* (Tortoe, 2010). After wheat, rice, maize, potato, barley, and cassava, it is the world's seventh most important food crop (FAO, 2016). It is a tropical perennial crop but cultivated as an annual; grown in more than 100 countries. China alone produced 80 to 85% of sweet potato production in the world while the remaining countries in Asia have the next highest production and then, followed by Africa and Latin America (CIP, 2009). Sweet potato consumption is thought to be declining as income increases, a

trend that is often attributed to urbanization, partly because it is seen as a "poor man's food," but mainly due to a lack of post-harvest processing and storage (FAOSTAT, 2008; CIP, 2009).

In Nepal, most of the middle hill districts and terai are the main sweet potato growing areas (Lohani, 1981) and are mainly grown in the kitchen garden in small areas (Gautam, 1991). It is one of the neglected and underexploited food crops of Nepal but has religious and cultural values in some festivals. Sweet potato is a good source of vitamin-A, carbohydrates, dietary fibre, potassium, and iron. Vitamin A deficiency is common in developing countries, including Nepal, and has severe consequences for young children (Low *et al*., 2007). The orange and red-fleshed sweet potato are additionally enriched with beta-carotene, the precursor of Vitamin A. As a result of their high nutritional value, productivity, and low input requirements, sweet potatoes have become a valuable food in developing countries. Sweet potatoes are transformed into functional ingredients, foods, and industrial products using a variety of processing technologies. Orange and purple-fleshed sweet potatoes can be used to produce natural beta carotene and anthocyanin pigments used in beverages and other food products, as well as starch and sugar.

In Nepal, post-harvest losses of vegetables are 15–30% (Gautam, Bhattarai, 2012). Sweet potato post-harvest losses vary from 15–65% due to fresh weight loss during one to four months of storage (Coursey, 1984; Rashid, 1987; Kone, 1991; Ray, Balagopalan, 1997). Nepal still lacks reliable statistics on areas, production, and post-harvest losses of sweet potato tubers. But, high perishability and poor storage of sweet potato roots in ambient conditions remain a major constraint to the farmers. No systematic work on storage methods and losses has been done so far. Sweet potato utilization is mainly confined to the production sites because of the poor keeping quality of the tubers. Being perishable and poorly handled in developing countries; sweet potato roots may suffer higher post-harvest losses. About 45–54% of roots and tubers in Sub-Saharan Africa are spoiled after harvest (Gustavsson *et al*., 2011; FAO, 2003).

Sweet potato roots have a thin, delicate skin that is high in moisture (60–70%) and free sugar (4–15%) (Woolfe, 1992). They also have a high respiratory rate right after harvest, which causes the texture to soften as a result of the heat output and made sweet potato a perishable product. Once removed from the plant, sweet potatoes cannot be stored for long periods (Wagner *et al*., 1983; Mtunda *et al*., 2001; Rees *et al*., 2001). Sweet potato roots have a shelf life that varies from a few days to a few weeks depending on the varieties, harvest maturity, and storage conditions **(**Lewis, Morris, 1956; Wagner *et al*., 1983; Doku, 1989; Kurup, Balagopalan, 1991; Acedo *et al*., 1996; Cabanilla, 1996; Mtunda *et al*., 2001). Sweet potato storage is not practised in many parts of the world, including Nepal, due to its limited shelf life (Bourke, 1982; Doku, 1989; Jusuf *et al*., 1997; Rees *et al*., 2001; Rees *et al*., 1998). Larger roots are often removed from individual plants, allowing smaller roots to grow and be harvested as required (Karuri, Ojijo, 1994).

In Nepal, the possible causes of post-harvest losses are mechanical damage during harvest, rough handling, and weevil, and other pest infestation, sprouting, and weight loss. A lack of an adequate, experimentally validated, and tested storage system is one of the most common causes of spoilage after harvest. During the long-term storage of sweet potato tubers, biochemical and physiological processes occur, resulting in qualitative and quantitative changes (Grace *et al.*, 2014; Abidin *et al*., 2016).

In Nepal, sweet potato is stored by leaving the root in the mounds even when matured, which ties the soils down to the crop and leads to fibrous roots and high weevil infestation. A few farmers stored in lined pits and on the floors of dark airy rooms where losses are very high. The roots are usually stored in clamps, in bamboo baskets (*Thunse, Dali*), and jute sacks in the shaded corner of the house. Some farmers store sweet potatoes in heaps on the earthen floor where sprouting and rooting is high particularly at a higher temperature.

Long-term storage of sweet potato gives rise to a major challenge to its food security in global marketing (Rees *et al*., 2001; van Oirschot *et al*., 2003). In the tropics, sweet potatoes can sprout in two to three weeks if stored at room temperature (Rees *et al.*, 2003). In ordinary conditions, sweet potato roots cannot be kept for more than one month (Gautam *et al*., 1993a). The cool chain is commonly used to store roots in advanced countries, with optimum storage conditions of 13.5 °C and relative humidity of 90–95%. This has been reported to extend the shelf-life up to a year (Picha, 1986). Sweet potatoes are stored in cold storage, ventilated storage, and tunnels in developed countries. Cold storage facilities, however, are not always accessible in developing countries like Nepal due to economic and technical constraints. Poor farmers cannot afford such sophisticated technology. Sweet potato farmers in developing countries lack adequate storage technology, which discourages large-scale investment in the crop and restricts its food security prospects. This has sparked a hunt for viable storage alternatives that small farmers in these areas can follow.

Sweet potato is largely eaten by poor village people and its storage in the sophisticated method involves high cost and at the same time, it is hardly affordable by the village people (Gautam *et al*., 1993b). The present research looked at the storage performance of sweet potatoes in different conditions. Improved storage methods can improve sweet potato tuber supply throughout the year at current production levels as well as add value to the crop, increasing returns to farmers and potentially improving their quality of living (Dukuh *et al*., 2015). The present study is important because it aims at determining genotypes that have greater storability. This study was carried out to evaluate the storage performance of sweet potato genotypes in different storage conditions at ambient temperature.

Materials and Methods

Storage experiment was conducted during the consecutive years 2018/19 and 2019/20 in mid-hill at National Potato Research Programme (NPRP), Khumaltar, Lalitpur (located at 27° 40' N, 85° 20' E, 1350 m asl) Nepal. The experiment was laid out using Factorial Completely Randomized Design with three replications in ambient room temperature. The experiment consisted of a total of fifteen treatment combinations of five different storage conditions *i.e.*, inside dry sand (S_1), inside sawdust (S_2), thin jute sack (S_3), natural mud pot (diameter 32 cm and length 43 cm) (S_4), and open plastic crates as control (S5) and three sweet potato genotypes ('CIP 440015', 'CIP 440267' and 'Local White') (Fig. 1). The general information of used genotypes is presented in Table 1. The selected two elite orange-fleshed sweet potatoes (OFSP) genotypes and a 'Local White' (Table 1) grown in respective sites were used for experimentation. Tuberous roots were harvested 4 months after planting. Roots more than 20-gram weight free from wounds, diseases were selected and cured by spreading in the floor for two days at ordinary room temperature with enough ventilation.

Table 1. Sweet potato genotypes were used as the treatments for the experiment

Genotypes (G)	Variety	Origin	Source and date
G1.'CIP 440015'	W-220	USA	CIP, Peru, Lima (2010)
G2.'CIP 440267'	Hung Loc 4	Vietnam	CIP, Peru, Lima (2010)
G3. 'Local White'	–	Lamjung, Nepal	Farmer, Nepal (2014)
Planting date	August 18, 2018, and August 19, 2019		
Harvesting date	December 18, 2018 and December 19, 2019		

Source: NPRP, 2018

Each treatment had 30 tuberous roots from each genotype and was kept in different storage conditions accordingly. In S1 and S2 treatments, sweet potatoes were placed in perforated plastic crates and covered by dry sand and sawdust leaving 2 cm from the top. The initial moisture content (%) of sweet potato roots were 75.27, 73.65, and 75.46 in the genotypes 'CIP 440015', 'CIP 440267', and 'Local White' respectively. The study was conducted from December to March (90 days) in both years.

The temperature and relative humidity of the storage room was recorded with the help of a digital Thermo-Hygrometer daily at 6.00 AM and 5.00 PM. Physiological weight loss (%) was recorded on the 2nd, 4th, 6th, 8th, 10th and 12th weeks of storage. Observations were also made on sprouting, rotting, and insect attack. Weight loss was determined by the difference between initial weight and final weight. The number of rotten roots was taken and recorded. The total per cent rotting was determined as the number of rotten roots divided by the total roots count and expressed as a percentage. Similarly, roots were examined for the presence of sweet potato weevil. The number of roots damaged was divided by the total number of roots count and expressed as a percentage to obtain per cent weevil damage.

Dry matter, starch, reducing sugar, and beta carotene content was analyzed by the AOAC method (AOAC, 2005). Dry matter content (%) was determined by chopping and mixing of tubers into small pieces and drying of 100 g sample in a hot air oven at 80 °C for the first six hours and then at 65 °C till constant weight was obtained (Kumar *et al.*, 2006).

Reducing sugar (%) was determined by the dinitrosalicyclic colourimetric method (Miller, 1959). Light absorbance was recorded in a spectrophotometer (Agilent Technologies, Cary 60 UV-VIS, USA) at 510 nm. To calculate the milligrams reducing sugars per 100 g fresh weight, a standard curve was plotted with different concentrations of glucose (100–600 µg glucose mL^{-1} water on the x-axis and absorbent reading on the y-axis. The absorbent reading of samples was recorded and calibrated based on a standard curve and presented as milligram reducing sugars per 100 gram fresh weight of sweet potato. The ß-carotene content of the sweet potato tuber samples was determined by the solvent partition method as described in Ranganna (2007). The starch content of sweet potato was determined by the Lane and Enyone method described by Ranganna (2007). The data were analyzed with GenStat version 18 software for windows (VSN International, 2016). Means were separated by Duncan's Multiple Range Test at a 5% level of significance. The correlation was calculated for different parameters. The Karl Pearson Correlation coefficient was introduced to measure the association which follows a parametric test.

Figure 1. Different storage conditions and sweet potato genotypes. A – inside dry sand; B – inside sawdust; C – thin jute sack; D – natural mud pot; E – open crates; F – 'CIP 440015'; G – 'CIP 440267' and H – 'Local White'

Results and Discussion

Storage environment

During the storage periods of 2018/19 and 2019/20, the average temperature ranged from 10.86 °C to 17.06 °C and 10.11 °C to 17.49 °C, respectively. In the same way, relative humidity ranged from 52.57 to 70.29%, which was consistently low (Table 2). The average temperature of the storage environment was increased slightly later in the storage period, which might be associated with temperature rises in the outer environment. The coefficient of variation clearly showed that the variability of temperature and humidity at the storage room (Table 2). According to Kushman and Deonier (1975), the best storage conditions are 15 °C and 85–90% relative humidity. Improving the storage environment can be able to extend the storage life (Samarasinghe, 1991; Ray, Balagopalan, 1997; Rees *et al*., 1998).

Table 2. Weekly average temperature (Temp) and relative humidity (RH) of the experimental site

Week	December 2018 to March 2019				December 2019 to March 2020			
	Temp, °C		RH, %		Temp, °C		RH, %	
	6:00 AM	5:00 PM	6:00 AM	5:00 PM	6:00 AM	5:00 PM	6:00 AM	5:00 PM
1	12.49	13.97	65.14	63.14	11.06	12.0	62.0	60.13
2	11.04	12.40	59.00	56.14	11.03	12.02	68.14	65.14
3	10.86	12.21	59.86	57.00	11.07	12.61	70.29	70.14
4	11.30	12.66	62.71	61.86	11.57	13.04	59.43	66.43
5	11.86	13.16	64.71	62.43	10.11	12.07	52.86	61.00
6	11.79	12.93	67.00	64.29	11.23	12.89	63.57	63.43
7	12.06	13.79	63.57	61.29	11.06	13.19	59.86	58.29
8	12.89	13.56	68.43	65.71	13.07	14.97	66.57	67.29
9	13.31	14.86	69.29	67.00	14.56	16.30	68.29	67.71
10	14.49	16.03	61.14	58.71	14.10	15.79	66.43	66.71
11	13.36	14.79	60.71	60.29	14.73	16.91	65.29	59.71
12	14.89	17.06	60.00	54.71	15.59	17.49	61.57	58.57
Mean	12.52	13.95	63.46	61.04	12.43	14.10	63.69	63.71
SD	1.29	1.49	3.48	3.83	1.86	2.05	4.86	4.05
CV, %	10.37	10.69	5.49	6.27	14.97	14.54	7.63	6.36

Physiological loss in weight

The combined results revealed a significant impact of storage conditions on physiological loss in weight (PLW) of sweet potato genotypes. Cumulative PLW was significantly increased in all the treatments with the progression of the storage period (Table 3). At the end of the storage period (12th week), the highest PLW was recorded in the tubers stored in open crates (70.2%) followed by natural mud pot (65.2%) whereas the lowest PLW was observed in tubers stored inside the dry sand (50.2%). Reduction in the cumulative weight loss was observed in the tubers stored in dry sand, sawdust, and thin jute sack with significant variations. Regarding genotype, 'CIP 440015' showed good storability with minimum PLW (55.4%) as compared to other genotypes. The data showed that the maximum weight loss (70.0%) was observed in genotype 'CIP 440267'. Data reveals that the interaction effect of storage conditions and genotype was non-significant on PLW of sweet potato (Table 4). Sweet potato weight loss is aided by respiration (Kushman, Pope, 1972; Winarno, 1982; Picha, 1986). Respiration rate has an inverse relationship with storage life. Picha (1986) also stated that respiration rates were the highest on harvest day, decreased during curing, and continued to decrease at a slower rate during the first few months of storage. Sweet potatoes stored in sand lost less weight than those held at room temperature. Similar results were reported by Smamarasinghe (1991); Karuri, Ojijo (1994); Ray *et al*. (1994) and Hoa (1997). Sand storage altered the atmosphere by limiting oxygen supply and maintaining a low temperature, as well as serving as a barrier to sweet potato weevil entry (Ray, Balagopalan, 1997). Barabara *et al*. (2020) reported that the genetic features of the cultivars had significant influences on the number of losses during storage.

Table 3. Effect of storage conditions and genotype on the weight loss and sprouting of sweet potato stored at ambient room temperature during the storage period (December–March) of 2018/19–2019/20

Treatments	Cumulative PLW (%)						Sprouting (%)
	Weeks after storage						
	2nd	4th	6th	8th	10th	12th	2nd–12th
A. Storage conditions (S)							
S1 (Inside dry sand)	3.59^{c}	10.52^{c}	18.2^{b}	27.4^{b}	40.2^{b}	50.2^{b}	0.0
S2 (Inside saw dust)	9.22^{b}	20.73^{ab}	30.8^{a}	39.6^{a}	51.8^{a}	62.9^{a}	0.0
S3 (Thin jute sack)	9.12^{b}	19.05^{ab}	29.5^{a}	40.2^{a}	53.7^{a}	63.4^{a}	0.0
S4 (Natural mud pot)	7.94^{b}	16.98^{b}	27.6^{a}	40.0^{a}	53.5^{a}	65.2^{a}	0.0
S5 (Open crates, control)	13.40^{a}	22.33^{a}	31.7^{a}	45.0^{a}	59.9^{a}	70.2^{a}	0.0
P-value	<0.001	<0.001	<0.001	0.002	0.008	0.017	–
LSD (0.05)	2.462	3.594	6.70	8.57	10.53	11.59	–
B. Genotypes (G)							
G1 ('CIP 440015')	7.73	14.61^{b}	22.3^{b}	30.4^{c}	43.7^{b}	55.4^{b}	0.0
G2 ('CIP 440267')	9.33	20.75^{a}	34.0^{a}	47.4^{a}	60.3^{a}	70.0^{a}	0.0
G3 ('Local White')	8.90	18.40^{a}	26.4^{b}	37.5^{b}	51.4^{b}	61.7^{ab}	0.0
P-value	0.232	<0.001	<0.001	<0.001	<0.001	0.007	–
LSD (0.05)	1.907	2.784	5.19	6.64	8.16	8.98	–
CV, %	42.9	30.2	36.6	33.6	30.6	28.0	–
S	***	***	***	**	**	*	–
G	NS	***	***	***	***	**	–

NS – not significant, * – significant at P < 0.05, ** – significant at P < 0.01, *** – significant at P < 0.001
The same lowercase letters in the column are not significantly different by DMRT at a 0.05 level of significance

Table 4. Interaction effect of storage conditions and genotype on the PLW and sprouting of sweet potato stored at ambient room temperature during the storage period (December–March) of 2018/19–2019/20

Treatments	Weight loss, %						Sprouting, %
	Weeks after storage						
	2nd	4th	6th	8th	10th	12th	2nd–12th
S1G1	2.56	6.40	15.58	23.50	34.00	43.63	0.0
S1G2	4.03	14.71	24.09	36.00	48.89	58.47	0.0
S1G3	4.18	10.46	14.94	22.62	37.57	48.53	0.0
S2G1	8.82	17.41	24.03	31.98	45.47	54.75	0.0
S2G2	10.94	23.95	40.13	50.43	63.90	75.21	0.0
S2G3	7.90	20.85	28.10	36.39	46.05	58.77	0.0
S3G1	7.28	15.78	22.19	30.10	45.59	55.78	0.0
S3G2	8.64	20.37	35.66	47.79	60.91	71.40	0.0
S3G3	11.42	20.98	30.79	42.71	54.58	62.93	0.0
S4G1	8.02	13.86	22.64	32.00	43.05	58.80	0.0
S4G2	8.57	19.40	32.39	46.80	61.30	70.50	0.0
S4G3	7.24	17.69	27.73	41.18	56.16	66.39	0.0
S5G1	11.96	19.62	27.15	34.30	50.63	64.21	0.0
S5G2	14.46	25.33	37.63	56.19	66.39	74.30	0.0
S5G3	13.75	22.03	30.26	44.40	62.60	72.10	0.0
P-value	0.697	0.986	0.965	0.938	0.977	0.995	–
S × G	NS	NS	NS	NS	NS	NS	–
LSD (0.05)	4.265	6.224	11.61	14.85	18.24	20.08	–
CV, %	42.9	30.2	36.6	33.6	30.6	28.0	–

Storage conditions: S1 – inside dry sand, S2 – inside saw dust, S3 – thin jute sack, S4 – natural mud pot, S5 – open crates, control. Genotypes: G1 – 'CIP 440015', G2 – 'CIP 440267', G3 – 'Local White'. NS – not significant

Sprouting

Sprouting is one of the reasons for the post-harvest deterioration of sweet potatoes (Ravi, Aked, 1996). No sprouting was observed on the stored tuber during the experimental period. No sprouting could be due to prevailing lower temperatures (13±3 °C) during the storage period at ambient room conditions (Table 2). Sprouting can be inhibited by storing roots at a lower temperature (14 °C), according to Ray and Ravi (2005). After harvest, sweet potato roots sprout if environmental conditions are favourable (Afek, Kays, 2004). Sprouting is favoured by high temperature coupled with humidity during storage (Bourke, 1982; Jana, 1982; Winarno, 1982). In the present experiment, the temperature of the storage room was low and not favourable for sprouting.

Rotting and insect attack

The rotting of the tubers was very much affected by different storage conditions (Table 5). Tuber rotting caused the most storage waste during the 12th week of storage. The pooled data showed that the rotting of sweet potato genotypes was significantly differed by different storage conditions at the 8th, 10th, and 12th weeks of storage. The rotting (%) was found significant among the genotypes. The lowest percentage of rotting was recorded in the genotype 'CIP 440015' (55.3%) and inside dry sand (48.7%) at the 12th week of storage while it was the highest up to 85.9% in 'CIP 440267' genotype. The highest rooting (76.7%) was noticed in thin jute sack which was statistically at par with natural mud pot (76.5%). The interaction effect of storage conditions and genotypes on rotting was found insignificant (Table 6).

Table 5. Effect of storage conditions and genotype on the rotting, weevil infestation and dry matter content of sweet potato stored at ambient room temperature during the storage period (December–March) of 2018/19–2019/20

Treatments	Weeks after storage					
	6th	8th	10th	12th	6th–12th	8th
	rotting, %				insect attack, %	dry matter, %
	A. Storage conditions (S)					
S1 (Inside dry sand)	13.0^{b}	25.4^{c}	35.9^{b}	48.7^{b}	0.0	31.30
S2 (Inside saw dust)	19.3^{ab}	32.6^{bc}	51.3^{a}	69.0^{a}	0.0	33.69
S3 (Thin jute sack)	17.6^{ab}	40.9^{ab}	58.7^{a}	76.7^{a}	0.0	34.12
S4 (Natural mud pot)	24.4^{a}	48.1^{a}	61.3^{a}	76.5^{a}	0.0	35.13
S5 (Open crates, control)	18.7^{ab}	38.2^{abc}	54.0^{a}	71.0^{a}	0.0	34.44
P value	0.222	0.008	0.006	<0.001	–	0.659
LSD (0.05)	–	12.5	14.0	12.0	–	–
	B. Genotypes (G)					
G1 ('CIP 440015')	6.2^{c}	21.1^{b}	33.6^{c}	55.3^{b}	0.0	32.14^{b}
G2 ('CIP 440267')	33.7^{a}	59.4^{a}	77.8^{a}	85.9^{a}	0.0	38.44^{a}
G3 ('Local White')	15.9^{b}	30.7^{b}	45.3^{b}	63.9^{b}	0.0	30.63^{b}
P-value	<0.001	<0.001	<0.001	<0.001	–	0.001
LSD (0.05)	7.4	9.7	10.8	9.3	–	4.1
CV, %	77.5	50.9	40.5	26.4	–	16.6
S	NS	**	**	***		NS
G	***	***	***	***		**

NS – not significant, * – significant at P < 0.05, ** – significant at P < 0.01, *** – significant at P < 0.001
The same lowercase letters in the column are not significantly different by DMRT at a 0.05 level of significance

Minimum tuber rotting in the sand and sawdust could be due to the stability of uniform temperature. Fluctuating ambient temperature during day and night might have accelerated the rotting of tubers kept exposed to the open environment. The temperature record showed the range from 10.11 to 17.49 °C ambient temperature (Table 2). Chilling injury at low temperatures can cause tuber decay, and sweet potato roots are particularly susceptible to chilling injury at temperatures of 12.5 °C (55 °F) or lower because they are native to the tropics. Symptoms of chilling injury include fungal decay, internal pulp browning, and root shriveling. Sweet potato roots should not be stored at a temperature below 12 °C as they are susceptible to chilling injury. Ray and Ravi (2005) reported that optimal storage temperatures in sweet potatoes range from 13 to 15 °C with 85 to 95% RH. Reese*t al*. (2001) and Mtunda *et al.* (2001) observed that postharvest physiological deterioration

(PPD) in sweet potatoes was caused by postharvest injury, increased respiration, rooting, and microbial damage, which accounted for 41 to 93% of root damage.

Table 6. Interaction effect of storage conditions and genotype on the rotting and weevil infestation of sweet potato stored at ambient room temperature during the storage period (December–March) of 2018/19–2019/20)

Treatments	Weeks after storage					
	6th	8th	10th	12th	6th–12th	8th
	rotting, %				insect attack, %	dry matter, %
S1G1	3.9	13.9	23.3	30.0	0.0	30.41
S1G2	25.6	43.3	55.0	77.2	0.0	35.08
S1G3	9.4	18.9	29.4	38.9	0.0	28.41
S2G1	7.8	17.2	30.6	57.2	0.0	29.74
S2G2	38.9	62.8	85.6	88.1	0.0	41.44
S2G3	11.1	17.8	37.8	61.7	0.0	29.88
S3G1	7.2	21.1	32.8	62.8	0.0	33.37
S3G2	30.0	67.2	93.3	95.6	0.0	34.84
S3G3	15.6	34.4	50.0	71.7	0.0	34.17
S4G1	8.9	30.0	42.2	64.5	0.0	33.31
S4G2	41.1	70.0	85.6	86.4	0.0	40.79
S4G3	23.3	44.4	56.1	78.7	0.0	31.29
S5G1	3.3	23.1	39.2	62.2	0.0	33.87
S5G2	32.8	53.4	69.8	82.2	0.0	40.06
S5G3	20.0	38.1	53.2	68.7	0.0	29.39
P-value	0.893	0.740	0.581	0.574	–	0.769
S × G	NS	NS	NS	NS	–	NS
LSD (0.05)	–	–	–	–	–	–
CV, %	77.5	50.9	40.5	26.4	–	16.6

Storage conditions: S1 – inside dry sand, S2 – inside saw dust, S3 – thin jute sack, S4 – natural mud pot, S5 – open crates, control. Genotypes: G1 – 'CIP 440015', G2 – 'CIP 440267', G3 – 'Local White'. NS – Not significant

No weevil infestation was noticed in all the treatments during the experimental period (Table 5). Prevailing low temperatures during the study period could be unfavourable for weevil infestation. The infestation has a strong relationship with location, altitude, and planting season. Several studies have concluded that higher temperatures may increase the growth rate of the insect's population as well as the risk and severity of the outbreaks (Ladányi, Hufnagel, 2006; Gomi *et al*., 2007). Ladányi and Hufnagel (2006) also reported that the increase in temperature, the higher the rate of the population of insect growth. At a lower elevation of fewer than 2000 m above sea level damage, the crop tends to be more (Okonya, Kroschel, 2013; Lutulele, 2001). In the drier period, the higher the temperature, the higher the frequency, which may be the possible influence on sweet potato weevils (Okonya, Kroschel, 2013). As shown by previous findings, the conditions in this experiment were not conducive to weevil infestation.

Biochemical changes

Dry matter (DM) content of tuber was not influenced significantly by storage conditions after eight weeks of storage whereas, the highest DM (35.13%) content was in a natural mud pot and lowest in dry sand (31.13%) (Table 5). Interaction effect of storage conditions and genotypes was not significant on dry matter content, while genotypes significantly differed with the highest (38.44%) in 'CIP 440267' and the lowest 30.63% in 'Local White'. The value of this characteristics may be influenced by the genetic features of genotypes and similar results were reported by Barabara *et al*. (2020) in sweet potatoes.

Selected chemical constituents were analyzed twice in this study, once at the time of harvest and again after three months of storage, to determine their level of change after three months of storage from the best storage method (inside dry sand) found (Tables 7, 8). The results showed an increase in dry matter and reducing sugar content, as well as a decrease in beta carotene and total starch content after 3 months of storage inside dry sand. Table 8 shows the correlation matrix for the simple correlation coefficient for the association between parameter values of the variable. There was a positive and strong correlation of storage duration with dry matter (r = 0.750) and reducing sugar (r = 0.658) whereas, a negative correlation with starch (r = –0.918) and ß-carotene (r = –0.352) content of sweet potato genotypes (Figs. 2–5). It is well known that physiological and biochemical changes in tubers after storage cause this, but it is also influenced by endogenous factors.

Table 7. Dry matter, starch, reducing sugar and Beta-carotene content after 3 months (12 weeks) storage of sweet potato genotypes inside dry sand during 2018/19

Quality parameters	Storage Duration					
	0 month (at harvest)			3 months (after storage)		
	genotypes			genotypes		
	'CIP 440015'	'CIP 440267'	'Local White'	'CIP 440015'	'CIP 440267'	'Local White'
Dry matter, %	24.73	26.35	24.54	25.96	29.12	27.92
Starch content FWB, %	22.73	25.51	24.19	15.12	19.53	16.48
Reducing sugar FWB, %	4.21	3.16	4.66	9.79	4.72	5.89
ß-carotene content DWB, mg 100 g^{-1}	124.71	161.48	6.64	56.87	106.16	5.87

FWB – fresh weight basis, DWB – dry weight basis

Table 8. Correlation matrix for the association between dry matter, starch, reducing sugar and Beta-carotene content of sweet potato genotypes

Quality parameters	Dry matter, %	Starch content FWB, %	Reducing sugar FWB, %
Starch content FWB, %	–0.453		
Reducing sugar FWB, %	0.021	–0.845*	
Beta-carotene content DWB mg 100 g^{-1}	0.047	0.467	–0.451

* – significant at P < 0.05; FWB – fresh weight basis, DWB – dry weight basis

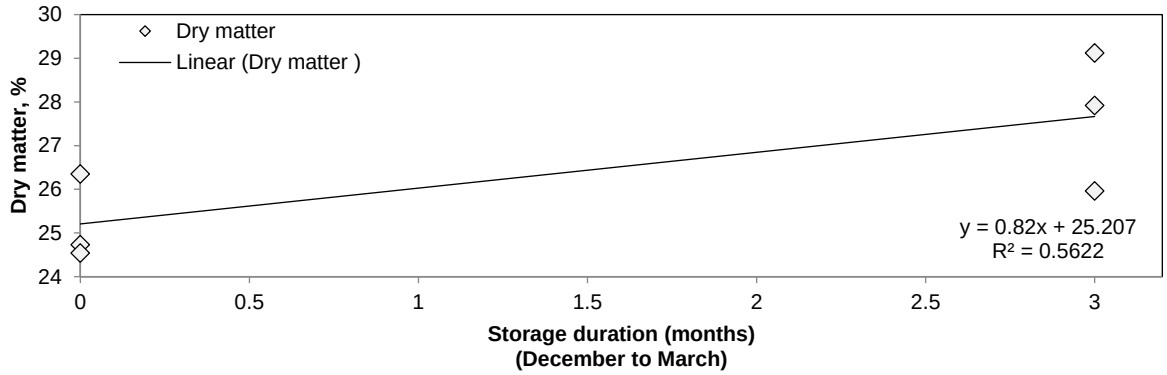

Figure 2. Correlation between storage duration and dry matter in G1 ('CIP 440015'), G2 ('CIP 440267') and G3 ('Local White')

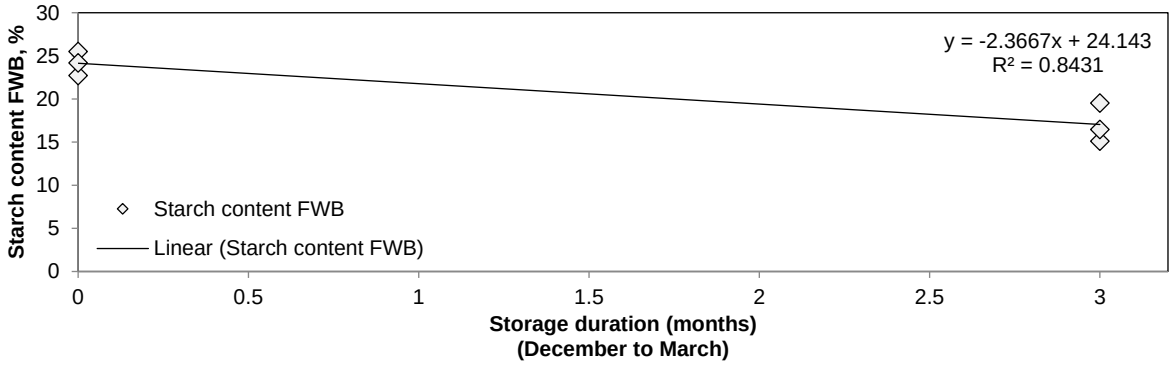

Figure 3. Correlation between storage duration and starch content in G1 ('CIP 440015'), G2 ('CIP 440267') and G3 ('Local White') (FWB – fresh weight basis)

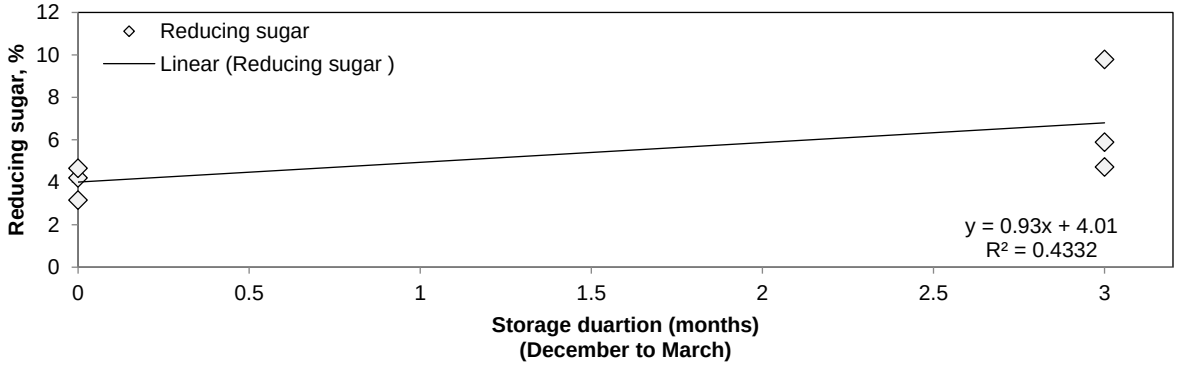

Figure 4. Correlation between storage duration and reducing sugar content in G1 ('CIP 440015'), G2 ('CIP 440267') and G3 ('Local White')

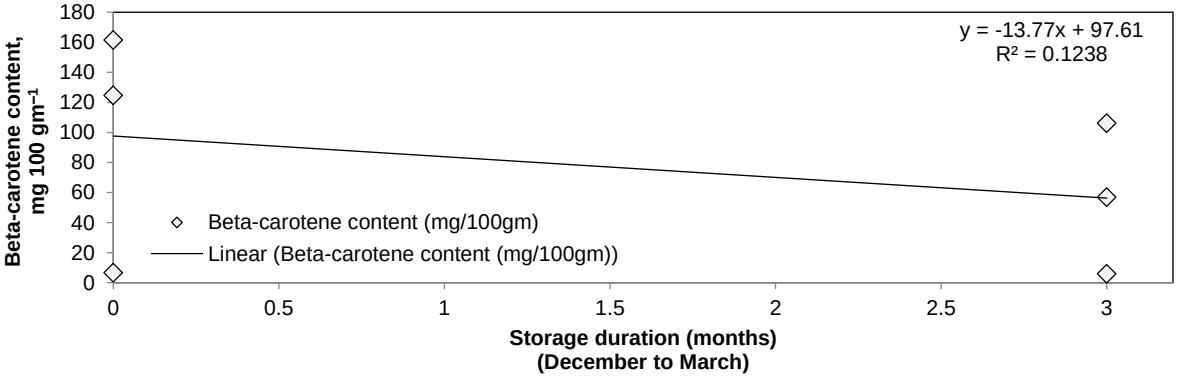

Figure 5. Correlation between storage duration and beta carotene content in G1 ('CIP 440015'), G2 ('CIP 440267') and G3 ('Local White')

The chemical composition of tubers analyzed after storage was affected by all experimental factors. According to Shuzbusha *et al.* (2010) and Grace *et al.* (2014), the higher the storage temperature, the more intense the transpiration, which results in higher tuber dry matter content. The physiological processes (transpiration and respiration) and the progress of temperature and humidity in storage are the indicators to monitor dry matter content changes during storage (Dandago, Gungula, 2011).

After 6 months of storage at 5 °C and 15 °C, there was a change in the content of starch, which is the main carbohydrate in sweet potato tubers (Barabara *et al*., 2020). Its composition is closely related to dry matter content, according to several authors (Njiti *et al.*, 2014; Kitahara *et al*., 2017; Krochmal-Marczak *et al*., 2018; Niu *et al*., 2019). The starch content of sweet potato tubers decreases over time during storage (Dandago, Gungula, 2011). Zhang *et al.* (2002) also observed a decrease in starch content during tuber storage, but it varied depending on genotype. According to Nabubuya *et al*. (2012), enzyme activity, especially amylase activity, causes starch content to decrease in sweet potato tubers during storage. Their activity increases in sweet potato tubers during storage, and they play a key role in reducing starch content during storage. To better understand the production of cold-induced sweetening (CIS), Yamdeu *et al.* (2015) analyzed carbohydrate metabolic changes in potato tubers stored at 15 °C and 4 °C for 150 days. They discovered that low-temperature storage had a negligible effect on the tubers' starch or maltose content, but did cause a significant increase in reducing sugars and total soluble sugars. Namutebi *et al.* (2004) reported that ß-carotene is generally decreased with the storage period for sweet potatoes.

Conclusion

The findings showed a significant effect of storage conditions on physiological loss in weight and rotting (%) of sweet potato genotypes. Despite the significant weight loss, the healthy tubers appeared to be edible and in good condition for up to 8–10 weeks. The comparative study showed sweet potatoes can be kept in better condition in dry sand and sawdust with minimum post-harvest losses. Genotype 'CIP 440015' had good storability at ambient conditions. In terms of quality, the results showed an increase in dry matter and reducing sugar content while decrease in beta carotene and total starch content after 3 months of storage. The findings of the experiment could be worth beneficial for the poor farmers of underdeveloped and developing countries like Nepal to prolong the shelf-life of sweet potatoes at ambient conditions.

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Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions

PB – the lead investigator and also responsible for data collection from the field, literature search, and write-up.
KMT, DMG, and AKS – responsible for guidance and monitoring research activities.
All the authors read and approved the final manuscript.

References

Abidin, P.E., Kazembe, J., Atuna, R.A., Amagloh, F.K., Asare, K., Dery, E.K., Carey, E.E. 2016. Sand storage, extending the shelf-life of fresh sweet potato roots for home consumption and market sales. – Journal of Food Science and Engineering, 6:227–236. DOI: 10.17265/2159-5828/2016.04.005

Acedo, A.L. Jr., Data, E.S., Quevedo, M.A. 1996. Genotypic variations in quality and shelf life of fresh roots of Philippines sweet potato grown in two planting seasons. – Journal of the Science of Food and Agriculture, 72(2):209. DOI: 10.1002/(SICI) 1097-0010(199610)72:2<209:AID-JSFA640>3.0. CO;2-N

Afek, U., Kays, S. 2004. Postharvest physiology and storage of widely used root and tuber crops. – Horticultural Reviews, 30:253–316. DOI: 10.1002/ 9780470650837.ch7

AOAC, 2005. Official Method of Analysis (18th Ed). W. Horwitz, G.W. Latimer (Eds.). – USA: AOAC International.

Barabara, K.M., Barabara, S., Barabara, K., Honorata, D., Elvyra, J. 2020. The effects of temperature on the quality and storage stability of sweet potato (*Ipomoea batatas* L.) grown in central Europe. – Agronomy, 10:1665. DOI: 10.3390/agronomy10111665

Bourke, R.M. 1982. Sweet potato in Papua New Guinea. – 45. International: Review. Sweet Potato. Villareal, L., Griggs, T.D. (Eds.). – Proceedings of 1st International Symposium. Asian Vegetable Research Developmental Centre (AVRDC), Shanhua, Tainan, Taiwan, pp. 45–57.

Cabanilla, L.S. 1996. Sweet Potato in the Philippines: Production, Processing and Future Prospects. – International Potato Center (CIP), Lima, Peru, 100 p.

CIP, 2009. Sweet potato. – http://www.cipotato.org/ sweet potato/ Accessed on 06/10/12.

Coursey, D.G. 1984. Potential utilization of major root crops, with special emphasis on human, animal and industrial uses. – In Tropical root crops: Production and utilization in Africa. – Proceedings of the 2nd Triennial Symposium International Society for Tropical Root Crops. E.R. Terry, E.V. Doku, O.B.

Arene, N.B. Mahungu (Eds.). Africa Branch, Ibadan, Nigeria, pp. 25–36.

Dandago, M.A., Gungula, D.T. 2011. Effects of various storage methods on the quality and nutritional composition of sweet potato (*Ipomoea balatas* L.) in Yola Nigeria. – International Food Research Journal, 18:271–278.

Doku, E.V. 1989. Root crops in Ethiopia. – In Root crops and low input agriculture: Helping to meet food self-sufficiency goals in Eastern and Southern Africa. – Proceedings of the 3rd Eastern and Sothern Africa regional Workshop on root and tuber crops, Mzunza, Malawi, 7–11 Dec. 1987. M.N. Alvares, S.K. Hahn (Eds.). International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, pp. 101–106.

Dukuh, I.G., Okyere, J., Braimah, M.M. 2015. Developing technology to improve the shelf life of sweet potato tubers. – International Journal of Pure and Applied Bioscience, 3(4):65–71.

FAO, 2003. Food loss, and waste facts. – http://www.fao.org/save-food/resources/infographic/en Accessed on 29/12/2016.

FAO, 2016. Crop production Data. – http://www.fao.org/faostat/en/#data/QC Accessed on 29/12/2016.

FAOSTAT, 2008. Production and area harvested statistics for sweet potato for 2007. – http://www.faostat.fao.org/site/567/default.aspx?PageID=567#ancor Accessed on 29/12/2016.

Gautam, D., Sharfuddin, A.F.M., Hussain, M., Siddique, M.A. 1993b. Underground storage method in sweet potato. – Bangladesh Horticulture, 21(2):33–42.

Gautam, D.M., Bhattarai, D.R. 2012. Postharvest horticulture. – Bhawani Printers. Chabahil, Kathmandu, Nepal.

Gautam, D.M. 1991. Production, post-harvest handling, and utilization of sweet potato in Nepal. – In Sweetpotato in South Asia: Postharvest handling, storage, processing, and uses. Dayal, T.R., Scott, G., Kurup, G.T., Balalagopalan, C. (Eds.). – Proceedings of a workshop held at CTCRI, Skeerariyam, Trivandrum, India, 9-13 September 1991, pp. 23–28.

Gautam, D.M., Sharfuddin, A.F.M., Siddique, M.A., Hussain, M. 1993a. Storage of sweet potatoes by various methods at ambient temperature. – Bangladesh Horticulture, 21(2):17–24.

Gomi, T., Nagasak, M., Fukuda, T., Hagihara, H. 2007. Shifting of the life cycle and life-history traits of the fall webworm in relation to climate change. – Entomologia Experimentalis et Applicata, 125(2): 179–184. DOI: 10.1111/j.1570-7458.2007.00616.x

Grace, M.H., Yousef, G.G., Gustafson, S.J., Truong, V.D., Yencho, G.C., Lila, M.A. 2014. Phytochemical changes in phenolics, anthocyanins, ascorbic acid, and carotenoids associated with sweet potato storage and impacts on bioactive properties. – Food Chemistry, 145:717–724. DOI: 10.1016/j.foodchem.2013.08.107

Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., Meybeck, A. 2011. Global food losses and food waste: Extent, causes, and prevention. – FAO, Rome, Italy, 29 p.

Hoa, V.D. 1997. Sweet potato production and research in Vietnam. – Proceedings of the International Workshop on Sweet Potato Production System Toward the 21st Century, Dec. 9–10. Miyazaki, Japan, p. 109.

Jana, R.K. 1982. Status of sweet potato cultivation in East Africa and its future. – Proceedings of 1st International Sweet Potato Symposium (Eds. R.L. Villareal, T.D. Griggs). Asian Vegetable Research Development Center (AVRDC), Shanhua, Tainan, Taiwan, p. 63.

Jusuf, M., Widodo, Y., Antarlina, S.S. 1997. Problems and subject of sweet potato production and utilization in Indonesia, – Proceedings of International Workshop on Sweet Potato Production System toward the 21st Century. Miyakonjo, Miyazaki, Japan, p. 83.

Karuri, E.G., Ojijo, N.K.O. 1994. Storage studies on sweet potato roots: Experience with KSP20 cultivar. – International Symposium Post-Harvest Treatment of Horticulture Crops. – Acta Horticulturae, 368:441–478. DOI: 10.17660/ActaHortic.1994.368.54

Kitahara, K., Nakamura, Y., Otani, M., Hamada, T., Nakayachi, O., Takahata, Y. 2017. Carbohydrate components in sweet potato storage roots: Their diversities and genetic improvement. – Breeding Science, 1:62–72. DOI: 10.1270/jsbbs.16135

Kone, S. 1991. Traditional methods for prolonged storage of sweet potatoes in Mali. – German Appropriate Technology Exchange (GATE), Eschborn, German, 2:14.

Krochmal-Marczak, B., Sawicka, B., Tobiasz-Salach, R. 2018. Impact of cultivations technology on the yield of sweet potato (*Ipomoea batatas* (L.) tubers. – Emirates Journal of Food and Agriculture, 30(11): 978–983. DOI: 10.9755/ejfa.2018.v30.i11.1863

Kumar, D., Singh, B.P., Paul Khurana, S.M. 2006. Processing quality of potato hybrid Ht/92-621 during storage at intermediate temperature along with sprout suppressant treatment. – Potato Journal, 33(1–2):90–93.

Kurup, G.T., Balagopalan, C. 1991. Sweet potato production, post-harvest handling and utilization in India. – In Sweetpotato in South Asia: Postharvest handling, storage, processing, and uses. Dayal, T.R., Scott, G., Kurup, G.T., Balalagopalan, C. (Eds.). – Proceedings of a workshop held at CTCRI, Skeerariyam, Trivandrum, India, 9-13 September 1991, pp. 33–39.

Kushman, L.J., Deonier, M.T. 1975. Effects of Storage temperature on Porto Rico and Goldrush sweet potatoes. – U.S. Department of Agriculture, Meridian, MS, USA.

Kushman, L.J., Pope, D.T. 1972. Causes of pithiness in sweetpotatoes. – N. Carolina Agric. Exp. Stn. Tech. Bull., 207.

Ladányi, M., Hufnagel, L. 2006. The effect of climate change on the population of Sycamore lace bug (*Corythuca ciliata*, Say, *Tingidae Heteroptera*) based on a simulation model with phenological response. –

Applied Ecology and Environmental Research, 4:85–112. DOI: 10.15666/aeer/0402_085112

Lewis, D.A., Morris, L.L. 1956. Effects of chilling storage on respiration and deterioration of several sweet potato varieties. – Proceeding of the American Society for Horticultural Sciences, 68:421–428.

Lohani, S.N. 1981. Sharkharkanda. – In: Nepal Ko Krishi Bali. Pub. D. Lohani, Kathmandu, pp. 366–370.

Low, J.W., Arimond, M., Osman, N., Cunguara, B., Zano, F., Tschirley, D. 2007. A food-based approach introducing orange-fleshed sweet potatoes increased vitamin A intake and serum retinol concentrations in young children in rural Mozambique. – Journal of Nutrition, 137:1320–1327. DOI: 10.1093/jn/137.5.1320

Lutulele, R.P. 2001. Sweet potato variety developments in the PNG highlands: Implications for future research and extension focus. – Proceedings of the Papua New Guinea Food Nutrition, pp. 683–688.

Miller, G.L. 1959. Use of dinitrosalicyclic acid reagent for determination of reducing sugar. – Analytical Chemistry, 31:426–428. DOI: 10.1021/ac60147a030

Mtunda, K., Chilosa, D., Rwiza, E., Kilima M., Kiozya, H., Munisi, R.,Kapinga, R., Rees, D. 2001. Damage reduced shelf life of sweet potato during marketing. – Fifth Trennial Congress of the African potato Association, 28 May–2 June, 2000, Kampla, Uganda. African Crop Science Journal, 9(1):301–308. DOI: 10.4314/acsj.v9i1.27652

Nabubuya, A., Namutebi, A., Byaruhanga, Y.B., Narvhus, J., Stenstrøm, Y., Wicklund, T. 2012. Amylolytic activity in selected sweet potato (*Ipomoea batatas* Lam.) varieties during development and in storage. – Food Nutrition Science, 3(5):660–668. DOI: 10.4236/fns.2012.35090

Namutebi, A., Natabirwa, H., Lemaga, B., Kapinga, R., Matovu, M., Tumwegamire, S., Nsumba, J., Ocom, J. 2004. Long-term storage of sweet potato by small scale farmers through improved post-harvest technologies. – Uganda Journal of Agriculture Science, 9(1):914–922.

Niu, S., Li, X.-Q., Tang, R., Zhang, G., Li, X., Cui, B., Mikitzel, L., Haroon, M. 2019. Starch granule sizes and degradation in sweet potatoes during storage. – Postharvest Bioogy and Technology, 150:137–147. DOI: 10.1016/j.postharvbio.2019.01.004

Njiti, V., Xia, C.Q., Zhang, Y., Meng, A., Nanjundaswamy, A., Madlock, D. 2014. Inheritance of amylase activity and dry matter in the sweet potato storage root. – Proceedings of the ASA, CSSA and SSSA International Annual Meeting, Long Beach, CA, USA, 2–5 November, 2014.

NPRP, 2018. Annual Report of the fiscal year 2016/2017. – National Potato Research Programme, Khumaltar, Lalitpur, Nepal.

Okonya, J.S., Kroschel, J. 2013. Incidence, abundance and damage by the sweet potato butterfly (*Acraea acerata* Hew.) and the African sweet potato weevils (Cylasspp.) across an altitude gradient in Kabale district, Uganda. – International Journal of Agriculture Science, 3(11):814–824.

Picha, D.H. 1986. Weight loss in sweet potatoes during curing and storage: contribution of transpiration and respiration. – Journal of the American Society for Horticultural Science, 111:889–892.

Ranganna, S. 2007. Handbook of Analysis and Quality control for fruits and vegetable products (2nd Ed.). – Tata McGraw-Hill Publishing Company Ltd. New Delhi, India, 1112 p.

Rashid, M.M. 1987. Indigenous technologies and recent advances in sweet potato production, processing, utilization, and marketing in Bangaladesh. – Paper presented at an International Sweet Potato Symposium, 20–26th May. VISCA, Baybay, Leyte, Phillippines.

Ravi, V., Aked, J. 1996. Review on tropical root and tuber crops. II. Physiological disorders in freshly stored roots and tubers. – Critical Reviews in Food Science and Nutrition, 36:711–731.

Ray, R.C., Balagopalan, C. 1997. Post-Harvest Spoilage of Sweet Potato. – Technical Bulletin Series 23 Central Tuber Crops Research Institute (CTCRI), Trivandrum, India.

Ray, R.C., Ravi, V. 2005. Post-harvest spoilage of sweet potato in tropics and control measures. – Critical Reviews in Food Science and Nutrition, 45(7–8):623–644. DOI: 10.1080/10408390500455516

Ray, R.C., Chowdhury, S.R., Balagopalan, C. 1994. Minimizing weight loss and microbial rotting of sweet potato (Ipomoea batatas) in storage under tropical ambient conditions. – Advances in Horticultural Science, 8(3):159–163.

Rees, D., Kapinga, R., Mtunda, K., Chilosa, D., Kiozya, H., Rwiza, E., Kilma, M., Munisi, R. 2001. Effect of damage on market value and shelf life of sweet potato in urban markets of Tanzania. – Tropical Science, 41(3):142–150.

Rees, D., Kapinga, R., Rwiza, E. 1998. The potential for extending the shelf-life of sweet potato in East Africa through cultivar selection, in Tropical Root crops: staples for Sustainable Food security into the next Millennium. – Proceedings of the 11th International Society of Tropical Root Crops Symposium, St. Augustine, Trinidad, 20–28 Oct, 1997. – Tropical Agriculture, 75:208.

Rees, D., van Oirschot, Q.E.A, Amour, R., Rwiza, E., Kapinga, R., Carey, T. 2003. Cultivar variation in keeping quality of sweet potatoes. – Postharvest Biology and Technology, 28(2):313–325. DOI: 10.1016/S0925-5214(02)00180-1

Samarasinghe, S.H.M.C. 1991. Production postharvest handling, and utilization of sweet potato in Sri Lanka. – In Sweetpotato in South Asia: Postharvest handling, storage, processing, and uses. Dayal, T.R., Scott, G., Kurup, G.T., Balalagopalan, C. (Eds.). – Proceedings of a workshop held at CTCRI, Skeerariyam, Trivandrum, India, 9-13 September 1991, pp. 29–32.

Shuzbusha, D., Tusiime, G. Edema, R., Gibson, P., Mwanga, R.O.M. 2010. Diallel analysis of root dry

matter content in sweet potato. – Proceedings of the 2nd RUFORUM Biennial Meeting, Entebbe, Uganda, 20–24 September, 2010. p. 1013–1017.

Tortoe, C., Obodai, M., Amoa-Awua, W. 2010. Microbial deterioration of white variety sweet potato (*Ipomoea batatas*) under different storage structures. – International Journal of Plant Biology, 1:10–15. DOI: 10.4081/pb.2010.e10

van Oirschot, Q.E.A., Rees, D., Aked, J. 2003. Sensory characteristics of five sweet potato cultivars and their changes during storage under tropical conditions. – Food Quality and Preference, 14:673–680. DOI: 10.1016/S0950-3293(02)00209-4

VSN International. 2016. GenStat for Windows 18th Edition. – VSN International, Hemel Hempstead, UK.

Wagner, A.B., Burns, E.E., Paterson, D.R. 1983. The effect of storage systems on sweet potato quality [Ipomoea batatas]. – Horticulture Science, 18:336–338.

Winarno, F.G. 1982. Sweet potato processing and by-product utilization in the tropics. – Sweet potato: Proceedings of the First International Symposium Shanhua (Taiwan). L. Villareal, T.D. Griggs (Eds.). Asian Vegetable Research Developmental Centre (AVRDC), Shanhua, Tainan, Taiwan, pp. 373–384.

Woolfe, J.A. 1992. Sweet potato an untapped food resource. – Cambridge University Press, Cambridge, UK, 660 p.

Yamdeu, J.H.G., Gupta, P.H., Patel, N.J., Shah, A.K., Talati, J.G. 2015. Effect of storage temperature on carbohydrate metabolism and development of cold-induced sweetening in Indian potato (*Solanum Tuberosum* L.) varieties. – Journal of Food Biochemistry, 40:71–83. DOI: 10.1111/ jfbc.12190

Zhang, Z., Wheatley, C.C., Corke, H. 2002. Biochemical changes during storage of sweet potato roots differing in dry matter content. – Postharvest Biology and Technology, 24(3):317–325. DOI: 10.1016/S0925-5214(01)00149-1

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THE EFFECT OF A LATERAL AIRFLOW CREATED ON NOZZLE TIP ON THE SPRAY DROPLETS DEPOSITION

Volodymyr Bulgakov[1], Jüri Olt[2], Simone Pascuzzi[3], Jaroslav Gadzalo[4], Semjons Ivanovs[5], Valerii Adamchuk[6], Volodymyr Panasyuk[6], Yevhen Ihnatiev[7]

[1]National University of Life and Environmental Sciences of Ukraine, 15 Heroyiv Oborony St, UA 03041 Kyiv, Ukraine
[2]Estonian University of Life Sciences, Institute of Technology, 56 Kreutzwaldi St, 51006 Tartu, Estonia
[3]University of Bari Aldo Moro, Via Amendola, 165/A, IT 70125 Bari, Italy
[4]National Academy of Agrarian Sciences of Ukraine, 9 Mykhailo Omelyanovych-Pavlenko St, UA 01010, Kyiv, Ukraine
[5]Latvia University of Life Sciences and Technologies, 2 Liela St, LV-3001 Jelgava, Latvia
[6]National Scientific Centre, Institute for Agricultural Engineering and Electrification, 11 Vokzalna St, Glevakcha 1, Vasylkiv District, UA 08631 Kyiv Region, Ukraine
[7]Dmytro Motornyi Tavria State Agrotechnological University, 18[B] Khmelnytsky Av, UA 72310 Melitopol, Zaporozhye Region, Ukraine

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Vastutav autor: Corresponding author: Jüri Olt

E-mail: jyri.olt@emu.ee

ORCID:
0000-0003-3445-3721 (VB)
0000-0003-4302-3176 (JO)
0000-0002-6699-3485 (SP)
0000-0002-5028-2048 (JG)
0000-0002-9072-1340 (SI)
0000-0003-0358-7946 (VA)
0000-0003-4138-914X (VP)
0000-0003-0315-1595 (YI)

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ABSTRACT. Improved application efficacy of a plant protection products by using a pneumatic device to change the dispersion of spray droplets is depended on the intensity of crosswind. The laboratory investigations of the spraying process of plants by means of the nozzles of a pneumatic system determined the quality indicators of pressure in the injection process of 0.4 MPa – the droplet coating density of 19–46 pcs cm^{2-1} for the weighted mean droplet diameters (WMD) in the other experimental variants was within 304–543 μm. These indicators were compared with those for the standard, anti-drift and air injection nozzle types in which the droplet coating density was 23–59 pcs cm^{2-1} and the weighted mean droplet diameters (WMD) were in the range of 350 to 485 μm. An analytical dependence was obtained of the influence of the lateral airflow and air pressure in the pneumatic system upon the amount of the deposited spray liquid.

Introduction

To increase the yield in agricultural crops, it is important to controlling pests (weeds, pests and diseases) (Directive 2009; Arvidsson *et al*., 2011; Hanafi *et al*., 2016; Ivanovs *et al*., 2018; Pascuzzi *et al*., 2020). Unless appropriate means of protection are taken in due time, the crop losses (based on FAO), can reach up to 30% of the potential crop, and the grown products lose their quality and cannot be used for the purpose they are intended (IYPN, 2020).

Intensification of agricultural production and widespread introduction of mechanized technologies for growing field crops require use application of the plant protection means. Such increase poses an acute problem how to reduce their impact upon the ecology of the environment and contamination of the food products with the residual amount of pesticides. The

process of applying pesticides is accompanied by losses, in particular, the drift of droplets of the working fluid by the wind outside the processing zone. Particularly urgent is the problem of the drift of the preparation during its application under unfavorable weather conditions, caused by windy weather, as a result of which the efficiency of plant protection with the preparations decreases, and the load on the ecology of the environment increases (Fritz, 2006; Wang *et al*., 2015; Fornasiero *et al*., 2017). One of such technical solutions is applying a sprayer equipped with a pneumatic device to force the droplet to move downward, leading a better deposition of the working fluid of which corresponds to the spraying of standard, anti-drift and air injection nozzles, which makes it essentially universal (Felsot *et al*., 2011; Yuan *et al*., 2013).

Based on the literature (Jasinskas *et al*., 2015; Aliverdi, Zarei, 2020; Biocca *et al*., 2021), there have been determined the main trends in the development of technical means of plant protection, aimed at improving the assimilation of chemical preparations by the plant. To solve this problem, the European manufacturers use devices with air supply to the nozzle. The TeeJet has developed the AirJet nozzle (Fig. 1) and the AirMatic controller for the implementation of pneumatic spraying (Kravchuk *et al*., 2004; TeeJet Technologies, 2014).

The advantage of pneumatic spraying is that the droplet size is adjusted during operation. Even with the same droplet size, in contrast to the conventional atomizers, we can get a lesser drift at windy conditions. The principle of operation of this nozzle is that air and the working fluid are fed into the mixing chamber, where emulsion is formed, which reaches the plant through a deflector sprayer. To study the pneumatic spraying process, a prototype of a pneumatic nozzle is shown in Figure 2. A pneumatic system of a sprayer with AirJet nozzles is shown in Figure 3.

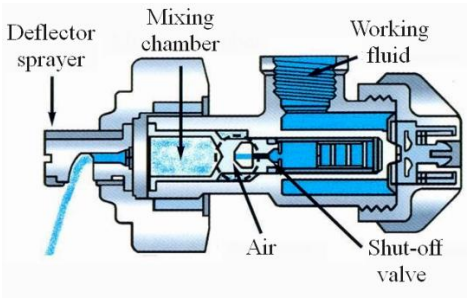


Figure 1. Hydropneumatic deflector AirJet nozzle (TeeJet Technologies)

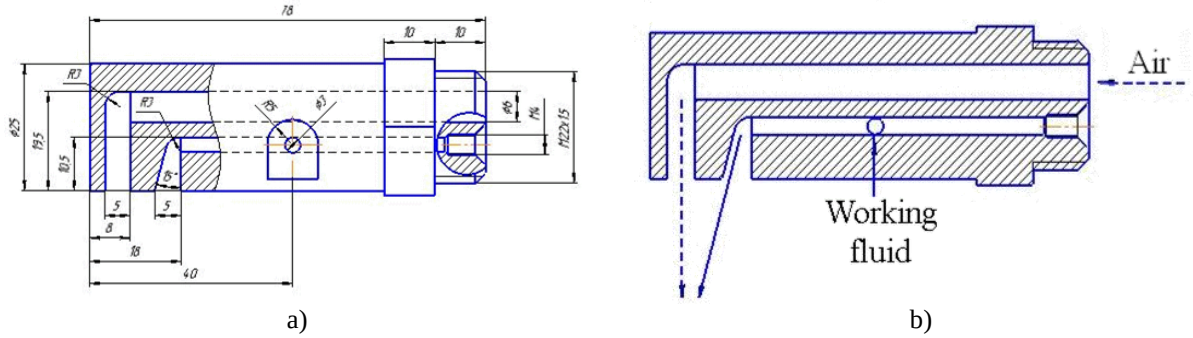


Figure 2. A scheme (a) and cross-section (b) of the pneumatic hydraulic nozzle

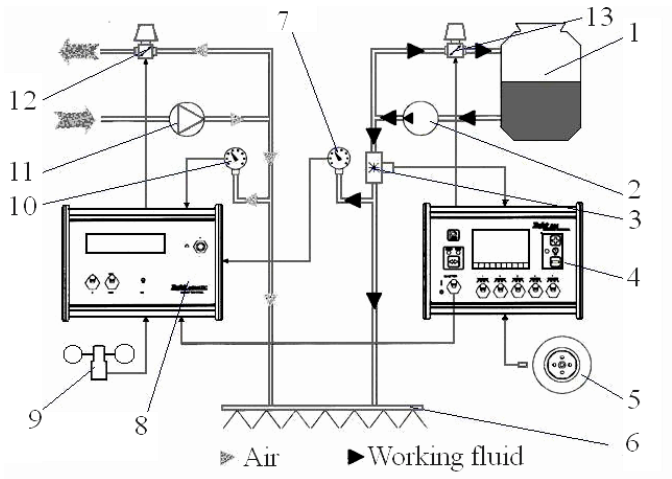


Figure 3. The pneumatic system of a sprayer with the Airjet nozzles (TeeJet Technologies): 1 – a tank for the working fluid; 2 – a membrane-piston pump; 3 – a flow meter; 4 – a liquid flow control console; 5 – a touch sensor of the wheel movement; 6 – a manifold with the pneumatic sprayers; 7 – a pressure sensor; 8 – an airflow control panel; 9 – a wind speed sensor; 10 – a pressure sensor 2.5 – bar; 11 – an oil-free compressor; 12 – a control valve (for air); 13 – a control valve (for the liquid)

In this pneumatic system, the airflow pressure is always adjusted to the variable fluid pressure in the system. The fluid pressure, in its turn, is adjusts to the change in the wind speed in the processed area of the field. These two systems work as a whole. The main task that these systems perform is to maintain the required constant dispersion of the droplet spraying, depending on the cultivated crop, the speed of the lateral airflow at the present time at a stable rate of application of the working fluid per hectare. This system operates in four modes of operation depending on the air pressure in the pneumatic system. The pressure of the liquid and air are interconnected through the graphical dependences of the droplet size on the three modes of the wind speed programmed in the system.

The purpose of the work was to study the possibilities how to increase the efficacy of the use of the plant protection means, by using a pneumatic device to change the spraying dispersion of the droplets, depending on the intensity of the lateral wind.

Materials and Methods

The laboratory investigations were carried out on an experimental setup, a general view of which is shown in Figure 4.

a) b)

Figure 4. A general view of the experimental setup and the spraying process: a) pumping device and adjuster; b) customized laboratory equipment.

The experimental setup was a pneumatic fluid sprayer, installed directly into the manifold. A voltage piston-diaphragm pump, using hoses, from a 100 L tank, supplied the working fluid. Air was supplied from a cylinder by air, compressed up to 5.5 MPa, through a reducer located directly on the cylinder. A valve adjusted the air pressure, and the pressure of the working fluid and pressure gauges adjusted air.

The liquid supply and spraying system contained a liquid tank with a filter, a membrane pump 8000-543-138 SHURflo with a high-pressure filter (up to 0.68 MPa) from the HYPRO Company, which was connected to a laboratory DC source of the LIPS-35 device with a voltage of 12 V (Fig. 4). The prototype of the pneumatic sprayer, installed directly into the manifold, the sleeves, and the adjusting valve with a pressure gauge were fixed directly on the manifold holder. The working pressure of the fluid in the manifold was regulated by means of a valve and monitored by a pressure gauge. The studies were performed at the height of installation of the sprayer, 60 cm above the corrugated surface.

The device for creating a lateral airflow is driven by a centrifugal fan. The airflow rate was adjusted by changing the amount of the air entering the fan due to blocking its inlet.

The setup for collecting liquid contains was a corrugated surface, installed with a slope for water drainage, with a depression pitch of 48 mm. The liquid, settled from the sprayer, was collected into containers, installed under these depressions.

The objective of the experimental study was to optimize the processes of deposition of the sprayed liquid on the corrugated surface. The variable factors were the lateral airflow velocity and the air pressure in the pneumatic system.

During the deposition process of the liquid, sprayed onto the corrugated surface, the following indicators were determined: the liquid flow rate through the sprayer, the speed of the lateral airflow created by the centrifugal fan, the air pressure in the pneumatic system, and the mass of the liquid collected in the container. The liquid flow rate through the sprayers at a constant pressure of 0.4 MPa was determined in accordance with Standard ISO 22866:2005 for one minute with an accuracy of 0.1 g by weighing these containers on an electronic balance CERTUS BALANCE. The value of the working pressure was set according to the EN 837-1 standard using a WIKAI manometer, installed in the manifold with a sprayer, the measurement range being 0–2.5 MPa, the measurement accuracy of the manometer – 0.01 MPa.

The speed of the airflow, created by the centrifugal fan at the location of the prototype sprayer, was determined using a SKYWATCH ATMOS digital anemometer with a measurement range from 2 to 42 m s^{-1}; the anemometer measurement accuracy was ± 3%. The pressure in the compressed air supply system was measured using pressure gauges, installed on the reducer.

Influence of various factors upon the value of drift and deposition of the sprayed liquid was assessed by the method of planning a two-factor experiment.

Before conducting the research, the corrugated surface was moistened with water and kept in a wet state during the research. The investigations were performed at a constant pressure of the liquid of 0.4 MPa and the air pressure from 0 to 0.3 MPa, and the sprayer height above the corrugated surface of 60 cm. In addition, the sprayer was located above the thirteenth depression of the corrugated surface, counting from the manifold holder with the pneumatic sprayer. The sprayer was installed so that the spraying pattern was perpendicular to the direction of the depressions of the corrugated surface.

Investigation of the drift of the drops was carried out at the lateral airflow rates: 0; 3.0 and 6.0 m s^{-1}. The collection time of the liquid, sprayed on the corrugated surface, was 1 min. After the end of each spraying cycle, we waited up to 5 minutes for all the liquid to drain into the container, and then measured these containers with the liquid in it on the measuring glass.

Processing of the research results made on a personal computer using the methods of mathematical statistics. Data processing was used to determine the distribution of liquid by weight along the entire length of the corrugated surface of the laboratory setup. As the optimization criterion there was taken the mass of the liquid collected in the container under the corrugated surface, within the actual area of action of the pneumatic sprayer from 0 to 158.4 cm.

Setting of the dispersion parameters of spraying took place due to the control of the drops, trapped on the distribution pattern, depending on the intensity of the lateral wind, artificially created by an axial fan. The purpose of the laboratory investigations was also to establish the value of the drift of the drops from the actual zone of spraying of the liquid by the pneumatic sprayer at different speeds of the lateral wind and variable parameters of the air pressure in the pneumatic liquid spraying system. The amount of liquid that settled along the operating width of the sprayer at different distances from it was determined in accordance with Standard ISO 22866:2005 and Standard of Ukraine 74.3-37-266:2005.

During the study of the performance indicators of the pneumatic sprayer there was a comparison made of the spraying dispersion of droplets of the prototype sample with the dispersion of the injection IDK-120-04, anti-drift AD-120-04 and standard ST-110-04 nozzles. Comparison of these research results was performed at a working fluid pressure of 0.4 MPa, an air pressure in the pneumatic system of 0.1; 0.2; 0.3 MPa, but without the action of the artificially created lateral airflow.

Results

Processing of the results of the conducted laboratory investigations in order to determine the efficiency of application of the pneumatic sprayers for spraying a liquid revealed an improvement in the quality of the spraying process and savings of the plant protection means.

Diagrams of the droplet distribution by the prototype pneumatic sprayer are shown in Figures 6 and 7 at a fluid pressure in the system of 0.4 MPa.

By microscopic analysis of the cards there was established the value of the density of the droplet deposition on the treated surface and their weighted mean diameter (WMD) and mass-median-diameter (MMD), which at a pressure in the injection communication of 0.4 MPa are, respectively: 19–46 pcs $cm^{2\,-1}$ and 304–543 μm for a pneumatic sprayer; 23–59 pcs $cm^{2\,-1}$ and 350–485 μm for standard, anti-drift and injection nozzles. As evident from Table 1, the spray by one «universal» pneumatic sprayer corresponds to the total spray of three different types of sprayers, and it is this circumstance that makes it universal.

These investigations confirmed the possibility to influence the dispersion of the droplet spraying by changing the air pressure in the pneumatic system depending on the change in the intensity of the lateral airflow.

The results of microscopic processing of the distribution pattern are listed in Table 1.

Impact of factors upon the amount of the collected sprayed liquid

Factors, their code designation and levels during the two-factor experiment in order to establish the impact of factors (the lateral airflow velocity and air pressure in the pneumatic system) are shown in Table 2.

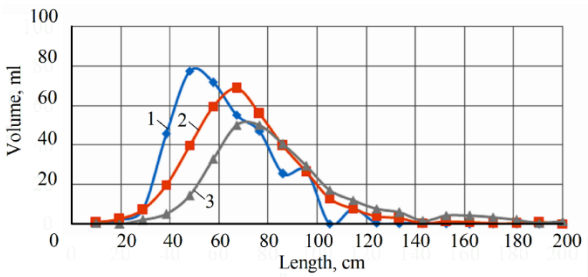


Figure 6. Distribution of the sprayed liquid over the corrugated surface at a speed of the lateral airflow of 0–6 m s^{-1} and air pressure in the pneumatic system to 0.15 MPa: 1 – V = 0 m s^{-1}; 2 – V = 3 m s^{-1}; 3 – V = 6 m s^{-1}

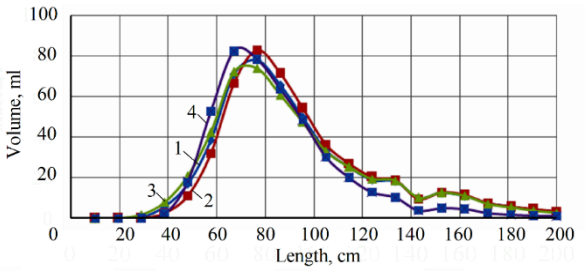


Figure 7. Distribution of the liquid over the corrugated surface depending on the air pressure in the pneumatic system 0–0.15 MPa at speed of a lateral air stream of 6 m s^{-1}: 1 – P_p = 0 MPa; 2 – P_p = 0.05 MPa; 3 – P_p = 0.10 MPa; 3 – P_p = 0.15 Mpa

Table 1. Microscopic processing of the distribution pattern at a fluid pressure of 0.4 Mpa

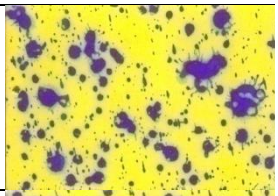
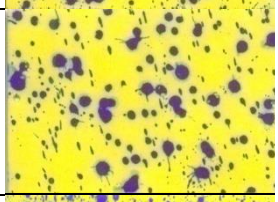
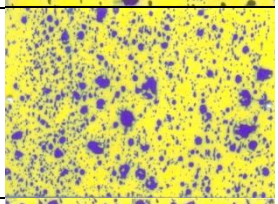
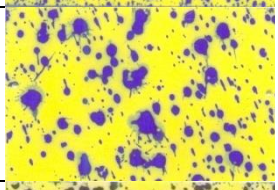
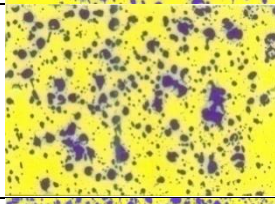
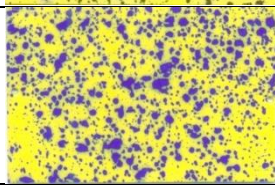
Number of drops, pcs cm^{2-1}	WMD, µm	Air pressure, MPa	Nozzles	MMD, µm	Polydispersity coefficient, µm	Distribution pattern
19	543	0.1	Pneumatic	1 125	3.73	
29	393	0.2		515	3.36	
46	304	0.3		495	4.50	
23	485	0	IDK-120-04 	860	2.24	
43	410	0	AD-120-04 	574	3.67	
59	350	0	ST-110-04 	488	4.19	

Table 2. Levels of the laboratory research factors of a prototype model of the pneumatic setup

Name of the factor	Designation	Variation levels of factors			Variation interval
		upper (1)	Zero (0)	Lower (-1)	
The airflow velocity V, m s^{-1}	X_1	6	3	0	3
The working air pressure in system P_p, MPa	X_2	0.2	0.1	0	0.1

Table 3. The results of the implementation the matrix of a two-factor experiment of the prototype model of the pneumatic setup

No.	V, m s^{-1}	P_p, MPa	Collected liquid (Q), kg
1	0	0.00	1.041
2	0	0.15	1.001
3	0	0.20	0.880
4	3	0.00	1.018
5	3	0.10	0.971
6	3	0.15	0.865
7	6	0.00	0.974
8	6	0.05	0.974
9	6	0.10	0.960

But the mass of the liquid, sprayed by the prototype model of the pneumatic sprayer, that has settled within the actual coverage of the corrugated surface by the sprayer flow, which in this case is already 295 cm, is shown in Table 3.

All the investigations were carried out at a constant fluid pressure in the pneumatic system of 0.4 MPa, the height of the sprayer above the corrugated surface of 0.6 m, the collection time of one minute at a relative atmospheric humidity of 57% and an air temperature of 22 °C.

Analysis of the data in Table 3 showed that the amount of the liquid sprayed by the prototype model of the pneumatic sprayer at the air pressure of up to 0.1 MPa has little effect upon the dispersion of the droplet spraying since a small amount of liquid is carried away by a lateral airflow, and this indicates that in the fraction of small droplets there is a fairly small

number of them. But at an air pressure of more than 0.12 MPa, it is observed that the airflow begins to affect more the dispersion of the droplets.

According to the conducted studies of the deposition process of the droplets, sprayed under the impact of the lateral airflow and the air pressure in the pneumatic system of the prototype of the pneumatic sprayer above the corrugated surface, the obtained analytical dependence is:

$$Q = -4.39P_p^2 - 0.13V + 1.06, \quad (1)$$

where Q – the amount of liquid that has passed through the sprayer, l min^{-1};

P_p – the air pressure in the pneumatic system, MPa;

V – velocity of the lateral airflow, m s^{-1}.

This equation is adequate for the probability $\rho = 0.9$. The obtained analytical dependence makes it possible to determine the amount of the deposited sprayed liquid at the corresponding values of the variable factors.

Conclusions

1. Trends in the development of the technical means of chemical plant protection have been determined: application of pneumatic sprayers that are capable to change the spraying dispersion of the droplets depending on the intensity of the lateral airflow, which allows the operator to work in a wider range of the wind speeds (up to 9 m s^{-1}) and the movement of the aggregate (up to 25 km h^{-1}). To improve the quality of the spraying, devices with the air supply into the nozzles are used to regulate the spraying dispersion depending on the intensity of the lateral wind while maintaining a pre-set rate of application of the working fluid per hectare.
2. As a result of investigations, there was revealed a possibility to influence the air pressure upon the spraying dispersion of the droplets. It has been experimentally established that with an increase in the air pressure in the pneumatic system, starting from 0.12 MPa, a decrease in the diameter of the sprayed drops is observed, and after an increase in the air pressure of more than 0.25 MPa, spraying takes place that is equivalent to a standard fine-dispersed slot sprayer.

Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions

VB, JO, VA – study conception and design;
VB, JO – drafting of the manuscript;
VB, VA, JO, SP – analysis and interpretation of data;
JG, SI, SP, YI – 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

Aliverdi, A., Zarei, M. 2020. Forward angled spray: A method for improving the efficacy of herbicides. – Journal of Plant Protection Research, 60(3):275–283. DOI: 10.24425/jppr.2020.133952.

Arvidsson, T., Bergström, L., Kreuger, J. 2011. Spray drift as influenced by meteorological and technical factors. – Pest Management Science, 67(5):586–598. DOI: 10.1002/ps.2114

Biocca, M., Cutini, M., Romano, E., Pallottino, F., Gallo, P. 2021. Evaluation of drift-reducing nozzles for pesticide application in hazelnut (Corylus avellana L.). – AgriEngineering, 3:230–239. DOI: 10.3390/agriengineering3020015.

Directive 2009/128/EC of the European parliament and the council of 21 October 2009 establishing a framework for community action to achieve the sustainable use of pesticides. 2009 – Official Journal of the European Union, 309, pp. 71–86.

Felsot, A.S., Unsworth, J.B., Linders, J.B.H.J., Roberts, G. 2011. Agrochemical spray drift; assessment and mitigation. – A review. – Journal of Environmental Science and Health, Part B. Pesticides, Food Contaminants, and Agricultural Wastes, 46:1–23. DOI: 10.1080/03601234.2010.515161

Fornasiero, D., Mori, N., Tirello, P., Pozzebon, Duco, C., Tescari, E., Bradascio, R., Otto, S. 2017. Effect of spray drift reduction techniques on pests and predatory mites in orchards and vineyards. – Crop Protection, 98:283–292. DOI: 10.1016/j.cropro.2017.04.010.

Fritz, B.K. 2006. Meteorological effects on deposition and drift of aerallyapplied sprays. – Transactions of the ASABE, 49:1295–1301.

Hanafi, A., Hind, M., Ghani, S. 2016. Effect of spray application techniques on spray deposits and residues of bifenthrin in peas under field conditions. – Journal of Pesticide Science, 41(2):49–54. DOI: 10.1584/jpestics.D15-071.

ISO 22866:2005. Equipment for Crop Production – Methods for Field Measurements of Spray Drift. International Organization for Standardization: Geneva, Switzerland, pp. 1–17.

Ivanovs, S., Panasyuk, V., Bulgakov, V., Dukulis, I. 2018. Impact of forced airflow upon introducing pesticides under conditions of lateral wind. – Research in Agricultural Engineering, 64(4):176–180. DOI: 10.17221/100/2017-RAE.

IYPN (International Year of Plant Health). 2020. Protecting plants, protecting life. Food and Agriculture Organization of United Nations. International Plant Protection Convention. 7 p.

Jasinskas, A., Steponavicius, D., Šniauka, P., Zinkevicius, R. 2015. Weed control by Chemical and Mechanical Means. 1712. – In: Weed Biology and Control (Ed. Vytautas Pilipavicius). – IntechOpen. DOI: 10.5772/58738.

Kravchuk, V., Gritsishina, M., Blacksmith, S. 2004. Modern trends in the design of agricultural machinery. – Kyiv: Agrarian Science, 396 p.

Pascuzzi, S., Bulgakov, V., Santoro, F., Anifantis, A.-S., Ivanovs, S., Holovach, I. 2020. A study on the drift of spray droplets dipped in airflows with different directions. – Sustainability, 12(11):4644. DOI: 10.3390/su12114644.

Standard of Ukraine 74.3-37-266:2005. Testing of agricultural equipment. Tractor and self-propelled sprayers. Program and test methods.

TeeJet Technologies. 2014. Catalog 51A-M. 164 p. www.teejet.com

Wang, X., He, X., Song, J., Herbst, A. 2015. Effect of adjuvant types and concentration on spray drift potential of different nozzles. – Nongye Gongcheng Xuebao/Transactions of Chinese Society of Agricultural Engineer, 31(49):49–55. DOI: 10.11975/j.issn. 1002-6819.2015.22.007.

Yuan, J., Liu, X., Zhang, X., Zuo, W., Wang, X., Chen, L. 2013. Modeling and compensation for characteristic of droplet drift on air-assisted boom spraying accounting for wind speeds. – Nongye Gongcheng Xuebao/Transactions of Chinese Society of Agricultural Engineer, 29(14):45–52. DOI: 10.3969/j.issn. 1002-6819.2013.14.006.

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ECONOMIC EFFICIENCY OF *Camelina sativa* GROWING WITH NUTRITION OPTIMIZATION UNDER CONDITIONS OF PRECARPATHIANS OF UKRAINE

Yaroslava Hryhoriv[1], Andrii Butenko[2], Valentyna Nechyporenko[2], Margarita Lyshenko[2], Tetiana Ustik[2], Vladyslav Zubko[2], Nataliia Makarenko[2], Valentyna Mushtai[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

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Vastutav autor: Corresponding author: Andrii Butenko

E-mail: andb201727@ukr.net

ORCID:
0000-0002-5892-9483 (YH)
0000-0001-9639-9826 (AB)
0000-0001-8257-2720 (VN)
0000-0002-6321-5178 (ML)
0000-0001-9967-0669 (TU)
0000-0002-2426-2772 (VZ)
0000-0001-7354-5122 (NM)
0000-0001-9042-0241 (VM)

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ABSTRACT. The results of research conducted during 2015–2018 in a field experiment on sod-podzolic soils while studying the effect of different fertilizers on productivity of *Camelina sativa* and oil-bearing crops and, accordingly, economic efficiency and competitiveness of this crop growing have been presented. The dependence of elements of productivity and yielding capacity on the application of mineral fertilizers has been revealed. It has been found that the application of mineral fertilizers had a significant impact on the productivity of *Camelina sativa* seeds and the cost index and profitability of *Camelina sativa* seeds, accordingly. Depending on the studied elements in growing technology of little-known in Ukraine crop of *Camelina sativa*, the main indices of economic efficiency were determined. It has been found that with optimization of plant nutrition, regardless of the increase in cultivation costs, conditionally net profit and profitability level increased. This was facilitated by foliar fertilization with modern restrictive preparations or complex micro fertilizers in critical periods of crop vegetation. Depending on the variant of the experiment, the average conditionally net profit during growing years ranged from 471.78 to 688.48 € ha^{-1} (1 UAH = 0.032 €), and profitability level ranged from 178.8 to 222.0%.

Introduction

World experience shows that the way to overcome the crisis in the economy and agricultural sector, in general, lies primarily in the production, both for domestic and foreign markets, of competitive products which meet purchasing competence of consumers and at the same time is beneficial for producers. This can be achieved as a result of a complex approach to the production, practice and sale of crop products, and wide mastering of the latest scientific and technical research. At the same time, there is a need for more and more purposeful introduction into the production of crops with high yield potential which were tested by world and domestic practice and which, for one or another reasons, have not become properly widespread. *Camelina sativa* belongs to such crops in our country (Hryhoriv, 2012; Cheţan *et al.*, 2021; Demydas *et al.*, 2021).

Currently, the sown area under oil-bearing crops in the world covers over 150 million hectares, and oil production is about 185 million tons. Recently, world consumption of oils and vegetable fats grew by 4% annually, and annual increase of oil production over the past decade is about 3.5 million tons. Crops of this family are grown in almost all countries of the world,

but each of them has its leading oil crop. Today in Austria, Great Britain, Denmark, Germany, Russia, the USA, Finland and France work on selection and agrotechnical of red rice as an oil plant are actively conducted. In Ukraine, such main crops are sunflower and rapeseed, which are included in crop rotation structure of natural and climatic zones of the Steppe, Central and Eastern Forest-Steppe, and occupies over 70% of all cultivated oil-bearing crops in Ukraine (Havryliuk, 2008; Poliakov, 2011; Namayunova *et al.*, 2018; Madhav *et al.*, 2020; Yakupoglu *et al.*, 2021).

Reduction of sown area for rapeseed to a scientifically sound level replacing it by other, not less valuable oil-bearing crops, will improve sown area, increase oil assortment for various purposes (Hryhoriv *et al.*, 2020).

Solution of production problem for oil-bearing crops less widespread than rapeseed, such as mustard, and little widespread – *Camelina*, is closely connected with improvement of agrotechnologies setting parameters of basic agronomic measures for their growing, taking into account biological characteristics of varieties and specific properties of crops for obtaining high productivity. Therefore, the transition from extensive to adaptive-intensive methods with the successful combination of elements of intensification, resource-saving and biologization of crop production depending on climate, relief and soil conditions – is a progressive way in modern crop production (Demydas *et al.*, 2011; Moskva, 2016; Long *et al.*, 2018; Cerbari *et al.*, 2021).

Camelina sativa Grantz is a promising oil crop of the *Brassicaceae* family. Interest in *Camelina* is stipulated by the fact that it successfully combines the high potential of seed yield (2.0 t ha^{-1} in Canada, 2.1–2.2 t ha^{-1} in Ireland in 2011–2013) (Hryhoriv *et al.*, 2020). And unique properties and composition of *Camelina* oils: healthy composition of fatty acids, high content of vitamins, high resistance to oxidation (Prianyshnykov, 1963; Volokh *et al.*, 2005; Hryhoriv *et al.*, 2020; Hryhoriv *et al.*, 2021). Despite all advantages of the crop, today in Ukraine, *Camelina* is grown only in large areas in the zones of Forest-Steppe and Polissya, although there are all conditions for expanding sown areas throughout the country (Hospodarenko, Rassadina 2015; Namayunova *et al.*, 2018).

The research was aimed to study the economic efficiency of *Camelina sativa* growing under conditions of Precarpathians of Ukraine.

Materials and Methods

Field research was conducted in technological crop rotation at the Department of Growing Technology, Seed Production and Biochemistry of Cruciferous Crops at Precarpathian State Agricultural Research Station of the National Academy of Agrarian Sciences of Ukraine on sod podzolic soil during 2015–2018 GPS binding: latitude $58^0$56'55', longitude – $34^0$41'45".

The soil of the experimental plot was the sod, deep podzolic gleyed soil. By mechanical composition, they were coarse-dusty heavy-gleyed with a strong humus horizon up to 75 cm and are characterized by the following indices: acidity, pH – 5.3, humus content 2.75%, soil provision with main nutrition elements: nitrogen – 82, phosphorus – 46.0 and potassium – 119.0 mg kg^{-1}.

A predecessor is winter wheat. The sowing was conducted according to the experimental scheme. A variety of Girsky of the selection of institute AIP was used for sowing. Taking into consideration the insensitivity of *Camelina sativa* to the application of potassium fertilizers (Poliakov, 2011; Hryhoriv, 2020; Kvitko *et al.*, 2021; Cerdà *et al.*, 2020), the effect of only nitrogen and phosphorus fertilizers was studied. In the experiment, mineral fertilizers in the form of ammonium nitrate and granular superphosphate were applied with main tillage according to the following scheme:

- Control – without fertilizers;
- Background – ($P_{45}K_{45}$);
- Background – ($N_{30}P_{45}K_{45}$);
- Background – ($N_{30}P_{45}K_{45}$) + N_{60};
- Background – ($N_{30}P_{45}K_{45}$) + Vympel (500 g ha^{-1}) + Oracul multicomplex (1 l ha^{-1}) + Oracul colamine boron (1 l ha^{-1}) + Oracul sulphur active (2 l ha^{-1}).

The experiment was based on four repetitions; the area of the accounting plot was 20 m^2. The variant without fertilizers was used as control (absolute control), which is based on the natural soil fertility. Fertilization of *Camelina sativa* grass crops was carried out with nitrogen fertilizers, micro fertilizers and growth stimulators according to corresponding variants of the experimental scheme in the rosette phase.

In the experiment, was sown *Camelina sativa* variety Girsky of selection of Ivano-Frankivsk Institute AIP NAAS entered on the State Register of varieties suitable and adapted to the soil and climatic conditions in Ukraine. Potential seed yield is about 2.0 t ha^{-1}, green mass – 40.5 t ha^{-1} (Abramyk *et al.*, 2003). Growing technology of *Camelina sativa* in the experimental plots was generally accepted for soil and climatic conditions of Precarpathians, except the factors, studied (Syvyryn, Reshetnykov, 1988; Semenova *et al.*, 2005; Lü *et al.*, 2019; Landré *et al.*, 2020; Bulyhin *et al.*, 2021; Lys *et al.*, 2021).

The economic efficiency of spring ryegrass cultivation was calculated according to modern generally accepted methods, namely determined by technological maps. When determining production costs of the work, we included amount of wages, cost of soil tillage, herbicides, seeds, depreciation, maintenance and inspection, cost of fuel and lubricants, fertilizers, and cost of storing seeds. Calculations of economic efficiency of *Camelina sativa* growing are given in prices of 2020.

Evaluation of growing technologies for competitiveness was carried out according to the method of Garkavy, Petrychenko, Spirin (Garkavy *et al.*, 2003).

Weather and climatic conditions of the region are one of determining factors in the formation of productivity

and quality of agricultural crop yields. It can be a decisive criterion for the expediency of growing crops and their implementation in a particular region, so much attention is paid to the analysis of weather conditions during the research period, which aimed to determine the economic efficiency of growing *Camelina sativa* depending on varietal characteristics and farming techniques under conditions of Precarpathians of Ukraine. Natural and climatic conditions which have developed in the Ivano-Frankivsk region contribute to the development of agriculture and forestry, growing of main crops. Analysis of hydrothermal conditions, which developed during the vegetation period of *Camelina sativa* during the years of research, was conducted according to Ivano-Frankivsk regional meteorological station. In the years of research, weather conditions differed significantly from the average long-term data both in terms of temperature and precipitation during the *Camelina sativa* growing season (Fig. 1).

Results and Discussion

The main task of agricultural production in the process of growing *Camelina sativa* at the present stage is increasing its profitability with an increase of agricultural production with minimal energy and resources. The above mentioned is relevant especially in modern business conditions, when technology elements that are being developed and proposed for implementation in the production, first of all, have to reduce energy costs for growing crops, reduce costs for production unit and as a result – increase profits. In addition, modern technologies of growing crops must be competitive. It should be noted that the competitiveness of crop products depends on many different factors, including elements of growing technology. At the same time, the shortage of resource potential and pricing policy for main elements and tools, that are an integral part of the development of agronomic cultivation measures, requires certain revision of technological approaches to crop production. The cost of mineral fertilizers has increased significantly during recent years and organic fertilizers are almost not used because of the significant reduction in livestock breeding. This has led to further deterioration of soil quality, their content depletion concerning movable, available for plants nutrients. According to Gamayunova's research, it is established that nutrition optimization, depending on the use of biological products for seed treatment and sowing on the background of moderate fertilizer gives a relatively net profit of 534.74 to 2370.58 € ha^{-1}, which indicates the feasibility of growing spring rye in the south of Ukraine. Under such conditions, optimization of crop nutrition on measures of resource-saving becomes actual (Hryhoriv 2012; Peyraud *et al.,* 2016; Namayunova *et al.,* 2018; Tanchyk *et al.,* 2021).

It was found that studied doses of mineral fertilizers significantly affected economic efficiency indices of *Camelina sativa* growing (Table 1).

Calculations of economic efficiency of mineral fertilizers applied for *Camelina sativa* growing showed that the highest conditionally net profit – 688.38 € ha^{-1} on average for the years of research 2015–2018 was obtained on the variant with applying mineral fertilizers at a dose of $N_{30}P_{45}K_{45}$ in main fertilization and N_{60} in replenishment. Production cost in this variant was 998.40 €, total costs – 310.02 €, and the cost of 1 ton of seeds was 158.98 €, profitability level was 222%. Whereas according to the research of Mariusz *et al.* (2018) in Poland, the average income from ryegrass seeds is € 876.3 ha at a seed cost of 455.5 €.

We note that in the control (without fertilizers) was received conditionally net profit in the amount of 315.20 € ha^{-1}, at the cost of 1 ton of seeds – 183.65 €, general expenses – 176.32 € and profitability level – 178.8%.

Analyzing the structure of costs, it should be noted that with increasing fertilizer doses the share of costs for fertilizers also increased, while the share of costs for fuel, pesticides, and seeds decreased.

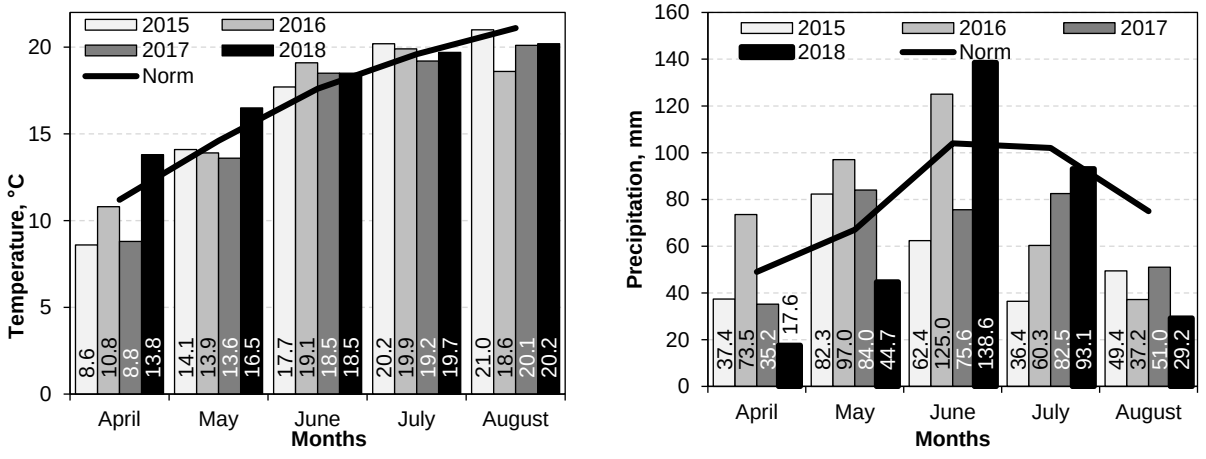

Figure 1. Air temperature and amount of precipitation during the growing season of *Camelina sativa* 2015–2018, ºC

Table 1. Economic efficiency of *Camelina sativa* growing technologies (average for 2015–2018)

Variant of fertilization	Yielding capacity, t ha^{-1}	Cost of the harvest, € ha^{-1}	Production costs, € ha^{-1}	Cost price of 1 t, €	Net profit, € ha^{-1}	Profitability level, %
Without fertilizers (control)	0.96	491.51	176.32	183.65	315.20	178.8
$N_0P_{45}K_{45}$	1.39	711.68	239.90	172.61	471.78	196.7
$N_{30}P_{45}K_{45}$	1.61	824.32	273.44	169.82	550.88	201.5
$N_{30}P_{45}K_{45}+N_{60}$	1.95	998.40	310.02	158.98	688.38	222.0
$N_{30}P_{45}K_{45}$+microfertilizers	1.86	952.32	290.78	156.32	661.54	227.5
$\bar{X} \pm S_{\bar{x}}$	1.55±0.08					
LSD_{05}	0.17					

1 UAH = 0.032 €

Table 2. Economic efficiency of technologies for growing spring oil-bearing crops (Hryhoriv *et al.,* 2014)

Crop	Yielding capacity, t ha^{-1}	Cost of the harvest, € ha^{-1}	Production costs, € ha^{-1}	Cost price of 1 t, €	Net profit, € ha^{-1}	Profitability level, %
Spring *Brassica napus*	2.23	927.68	473.92	212.51	453.76	95.7
Sinapis juncea	1.69	730.08	443.36	262.33	286.72	64.7
Sinapis alba	1.89	816.48	443.36	234.56	373.12	84.2
Camelina sativa	1.95	998.40	310.01	158.97	688.38	222.0
Linum usitatissimum	2.11	979.04	354.78	168.12	624.26	176.0

1 UAH = 0.032 €

Therefore, it is not for nothing that recently, in various EU projects (eg ITAKA, ICON, COSMOS), red rice has been reopened as a multi-purpose crop as a source of oil and protein (Righini *et al.,* 2016), using low costs and cost, and competitive agronomic management (Tonin *et al.,* 2018). Due to the great interest in this species in Europe and the driving force of this interest, the authors consider it necessary to gather all European knowledge about the cultivation of ryegrass to provide guidelines for the future sustainable development of this culture (Righini *et al.,* 2016).

It should be noted that the *Camelina sativa* alternative, first, is that no pests and diseases have been detected in this crop, unlike in other *Brassicaceae* plants. Therefore, *Camelina sativa* does not require the use of insecticides and fungicides during growing, which in practice will result in significant cost savings for chemical means of protection for *Camelina sativa* crops in comparison with other oil-bearing crops (Table 2).

Rapeseed, in contrast to *Camelina sativa*, is strongly damaged by pests: *Phyllotreta, (Meligethes aeneus* F.*), Ceuthorrhynchus, Aphidoidea, Dasineura brassicae* Winn. Therefore, rapeseed growing requires chemical protection with the application of effective insecticides from germination to budding, the cost of which by the prices of 2020 is 110.78 € ha^{-1}, which is 23% of all growing costs. In addition to all *Camelina sativa* advantages, the technology of its seed growing is environmentally friendly.

Researchers have also found that in milder Mediterranean environments, such as Spain (Martinez *et al.,* 2020) and Italy (Bacenetti *et al.,* 2017), red spring is well adapted to growing with the autumn cycle on marginal soils. Mauri *et al.* (2019) reported that spring red, sown in autumn in semi-arid conditions in central Spain, reached an average yield of 1 Mg DM ha^{-1} in a 2-year study. This value can be considered a reliable yield threshold for profitable cultivation on marginal or semi-marginal soils (Zanetti *et al.,* 2021)

It was found that the lowest production costs (310.01 and 354.78 €) were for growing *Camelina sativa* and *Linum usitatissimum*. Insecticides were additionally used three times in *Sinapis juncea* and *Sinapis alba* crops, so the costs increased to 443.36 €. The highest production costs were for growing *Spring Brassica napus* (473.92 €) because of two additional uses of fungicides and insecticides.

It should be noted that in the general growth of all oil-bearing crops was highly profitable. This is explained by relatively high yielding capacity in the experiments and high prices for the seeds of oil-bearing crops. Net profit from 1 ha was lower while growing species of *Sinapis* (286.72–373.12 €). *Camelina sativa* and *Linum usitatissimum* provided twice more profit – 688.38 and 61.06 €, respectively. The level of profitability is very high for *Camelina sativa* (222%) and *Linum usitatissimum* (176%). Other crops range from 64 to 95%.

It should be noted that red rice has an advantage as an alternative raw material for the production of biodiesel due to its low cost compared to commercial oils. Recently, jet fuel based on rye oil has been developed and test flights of various passenger aircraft, as well as fighters, have been successfully conducted (Moser, 2010). These facts indicate the suitability of rye oil for biofuel production. In addition, due to its unique nutritional properties, ryegrass flour has been recognized as a valuable animal feed (Pilgeram *et al.,* 2007). Thus, it has a high economic potential. Such a high economic value of rye meal has great potential in ensuring the economic efficiency of rye biodiesel.

As it is known, that the most promising growing technologies are considered to be the ones with energy costs reducing and energy efficiency coefficient increasing. It should be noted that the competitiveness of crop products depends on many different factors including elements of growing technology.

The basic technology for growing *Camelina sativa* was the variant of the experiment, where no mineral fertilizers were applied. Obtained results in determining coefficients of energy, integral evaluation and complex coefficient of competitiveness showed that they change depending on the doses of mineral fertilizers (Table 3).

Table 3. Competitiveness of *Camelina sativa* growing technologies

Variant of fertilization	Coefficient of energy evaluation, K_{Et}[1]	Coefficient integral evaluation, J[2]	Complex coefficient of competitiveness $K_к$[3]
Without fertilizers (control)	2.04	0.80	0.87
$N_0P_{45}K_{45}$	1.45	0.78	0.93
$N_{30}P_{45}K_{45}$	0.83	0.71	0.96
$N_{30}P_{45}K_{45}+N_{60}$	0.72	0.69	1.32
$N_{30}P_{45}K_{45}$ +micro-fertilizers	0.75	0.61	1.27

[1] $K_{Et} = \frac{Eu}{Et} = \frac{(\alpha oUo + \alpha dUd)}{Et}$, where *αo*, *αd* – respectively, the energy equivalent main and additional products, MJ kg^{-1}; Wow, Wood – respectively the harvest of the main and additional products, kg ha^{-1}; *Et* – total energy consumption technologies, MJ ha^{-1}.

[2] $J = \frac{Qn}{Qb}$, where *Qn*, *Qb* – the monetary expression of products produced per year per 1 hectare of area per 1 € of reduced costs, by the new and basic technology options.

[3] $K_к = \frac{Qq}{Qe}$, where *Qq* – quality parameters, *Qe* – economic parameters.

It was revealed that the application of the studied doses of mineral fertilizers leads to a decrease in the energy evaluation coefficient of *Camelina sativa* growing technology. Thus, when applying mineral fertilizers at a dose of $N_{30}P_{45}K_{45}$ in combination with foliar nitrogen fertilization at a dose of 60 kg ha^{-1}, the energy evaluation coefficient was 0.83. Whereas the variants without mineral fertilizers were noted the highest coefficient of energy assessment – 2.04.

The highest coefficient of integral evaluation of growing technologies was observed in the variants without mineral fertilizers, and which was respectively 0.80.

The maximum complex coefficients of competitiveness were observed in *Camelina sativa* – 1.32, and 1.27 was noted when growing *Camelina sativa* in the variants with mineral fertilizers at a dose of $N_{30}P_{45}K_{45}$ in combination with foliar nitrogen fertilization at a dose of 60 kg ha^{-1} and in the variant with stimulants of growth and micro fertilizers. In the variants where mineral fertilizers were not used, the minimum complex coefficients of competitiveness were noted, which were 0.87, respectively.

Conclusions

Under conditions of Precarpathians on sod-podzolic soils, the highest seed yield among spring oil-bearing crops was provided by spring rape (*Brassica napus* L.) – 2.23 t ha^{-1}. Slightly lower yields were provided by *Camelina* and *Linum usitatissimum* – respectively 1.95–2.11 t ha^{-1}. Other crops provided a much lower seed yield. The yielding capacity of *Camelina sativa* seeds under influence of mineral fertilizers increased from 0.96 t ha^{-1} in the variant without fertilizers to 1.95 t ha^{-1} in the variant with the application of $N_{30}P_{45}K_{45}+ N_{60}$, *i.e.* increased by 0.99 t ha^{-1} or 106.8%.

With intensive technology of growing *Camelina sativa*, variety Girsky, it is expedient to increase the dose of mineral fertilizers to $N_{30}P_{45}K_{45} + N_{60}$, in this case, the net profit increases to 688.38 € from 1 hectare. The best indices of economic efficiency were obtained for growing *Camelina* and *Linum usitatissimum*: their profit was 688.38 and 624.26 € ha^{-1}, respectively, and the level of profitability was 222 and 176%.

So, when applying nitrogen fertilizers in a dose of 90 kg ha^{-1} on the background of phosphorus and potassium fertilizers ($P_{45}K_{45}$) there was a decrease in competitiveness coefficient ($K_к$), energy efficiency coefficient (K_{Et}) and increase of integral evaluation coefficient (J) compared to the basic technology.

For the production of competitive products, increasing the yield and profitability of *Camelina sativa* cultivation in the conditions of Prykarpattia Ukraine on sod podzolic soil, it is recommended to obtain a yield of 2.23 t ha^{-1} to apply complete mineral fertilizer at a dose of $N_{30}P_{45}K_{45}$ with nitrogen fertilizers at a dose of N_{60} in the phase of socket formation. The results obtained in this study provide valuable information on the costs and cost-effectiveness of rice biomass production. However, further research is needed to verify the results of the study and further improve production technology, reduce costs, and increase the efficiency of seed collection (reduce losses during harvesting). This should in the future help increase the economic efficiency of rice production.

Conflict of interest

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

Author contributions

YH – study conception and design, drafting of the manuscript;
AB – analysis and interpretation of data and is the corresponding author;
ML – an author of the idea, guided the research;
TU, VZ, – acquisition of data, drafting of the manuscript;
NM – performed the literature data analysis and discussion of the results;
VM – critical revision and approval of the final manuscript.
All authors read and approved the final manuscript.

References

Abramyk, M.I., Mazra, V.O., Kunychak, H.I., Kozak, T.I. 2003. Catalog of varieties of Carpathian breeding. [Kataloh sortiv karpat·s′koyi selektsiyi]. – Ivano-Frankivsk, 58 p. (In Ukrainian)

Bacenetti, J., Restuccia, A., Schillaci, G., Failla, S. 2017. Biodiesel production from unconventional oilseed crops (*Linum usitatissimum* L. and *Camelina sativa* L.) in Mediterranean conditions: environmental sustainability assessment. – Renew Energy, 112:444–456. DOI: 10.1016/j.renene.2017.05.044

Bulyhin, S.Yu., Vitvitskiy, S.V., Butenko, A.O., Tonkha, O.L., Antonuk, D.O., Bykova, O. 2021. Regulation of technological load on soils. – AMA, Agricultural Mechanization in Asia, Africa and Latin America, 51(03):1813–1822.

Cerbari, V., Leah, T. 2021. Preventative restoration of ordinary chernozem before implementing zero tillage. In: Regenerative Agriculture (Eds. D. Dent, B. Boincean). – Springer, Cham. DOI: 10.1007/978-3-030-72224-1_15

Cerdà, A., Rodrigo-Comino, J., Yakupoğlu, T., Dindaroğlu, T., Terol, E., Mora-Navarro, G., Arabameri, A., Radziemska, M., Novara, A., Kavian, A., Vaverková, M.D., Abd–Elmabod, S.K., Hammad, H.M., Daliakopoulos, I.N. 2020. Tillage versus no-tillage. soil properties and hydrology in an organic persimmon farm in Eastern Iberian peninsula. – Water, 12(6):539. DOI: 10.3390/w12061539

Cheţan, F., Cheţan, C., Bogdan, I., Pop, A.I., Moraru, P.I., Rusu, T. 2021. The effects of management (tillage, fertilization, plant density) on soybean yield and quality in a three-year experiment under Transylvanian plain climate conditions. – Land, 10(2):200. DOI: 10.3390/land10020200

Demydas, H.I., Galushko, I.V., Butenko, A.O., Karbivska, U.M., Asanishvili, N.M. 2021. Fodder productivity of different meadow clover varieties depending on the elements of growing technology. – AMA, Agricultural Mechanization in Asia, Africa and Latin America, 51(03):1801–1811.

Demydas, H.I., Kvitko, H.P., Hetman, N.Ya. 2011. *Camelina sativa* – oilseed alternative to spring rapeseed for biodiesel production [*Camelina sativa* – al′ternatyva oliynomu nasinnyu ripaku dlya vyrobnytstva biodyzelyu]. – Collection of Scientific Works VNAU. Vinnytsia, 8(48):3–8. (In Ukrainian)

Garkavy, A.D., Petrichenko, V.F., Spirin, A.V. 2003. Competitiveness of technologies and machines. [Konkurentospromozhnist′ tekhnolohiy i mashyn]. – Textbook. Vinnytsia: VSAU. Tiras, 68 p. (In Ukrainian)

Hamayunova, V.V., Moskva, I.S., Averchev, O.V. 2018. Economic efficiency of *Camelina glabrata* cultivation for optimization of plant nutrition under conditions of Southern Steppe of Ukraine. [Ekonomichna efektyvnist′ vyroshchuvannya Camelina glabrata dlya optymizatsiyi zhyvlennya roslyn v umovakh Pivdennoho Stepu Ukrayiny]. – Tavriia scientific bulletin, 104:27–34. (In Ukrainian)

Havryliuk, M.M. 2008. Oil crops in Ukraine. [Oliyni kul′tury v Ukrayini]. – Kyiv: Osnova, 420 p. (In Ukrainian)

Hospodarenko, H.M., Rassadina, I.Yu. 2015. Quality of *Camelina sativa* seeds depending on fertilizer. [Yakist′ nasinnya *Camelina sativa* zalezhno vid dobryv]. – Submontane and montane crop growing and husbandry, 58:55–60. (In Ukrainian)

Hryhoriv, Ya.Ya. 2012. Economic efficiency of *Camelina sativa* cultivation under conditions of Pre-carpathians. [Ekonomichna efektyvnist′ vyroshchuvannya *Camelina sativa* v umovakh Peredkarpattya]. – Bulletin of Poltava State Sgrarian Scademy: Sagronomy, 1:198–201. (In Ukrainian)

Hryhoriv, Ya.Ya., Butenko, S.O., Masyk, I.M., Onychko, V.I., Onychko, T.O., Pshychenko, O.I., Komar, V.I., Berezniak, O.P. 2020. Influence of mineral fertilization level on productivity of *Camelina sativa* in the conditions of Prycarpattia. – Ukrainian Journal of Ecology, 10(2):28–32.

Hryhoriv, Ya.Ya., Butenko, A.O., Moisiienko, V.V., Panchyshyn, V.Z., Stotska, S.V., Shuvar, I.A., Kriuchko, L.V., Zakharchenko, E.A., Novikova, A.V. 2021. Photosynthetic activity of *Camelina sativa* plants depending on technological measures of growing under conditions of Precarpathians of Ukraine. – Modern Phytomorphology, 15:17–21.

Hryhoriv, Ya.Ya., Stelmakh, O.M., Kyforuk, I.M., 2014. *Camelina sativa* is a new word on the market of cruciferous oilseeds in Ukraine [Ry`zhik yarovoj – novoe slovo na ry`nke maslichny`kh krestoczvetny`kh kul`tur Ukrainy`]. – Youth and Science. International Agrarian Scientific Journal, Ural State University, 4:18–21. (In Russian)

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, 32(1):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 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.

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

Lys, N.M., Tkachuk, N.L., Butenko, A.O., Onychko, V.I., Rozhko, V.M., Karpenko, O.Yu., Chernega, T.O., Masyk, I.M., Berdin, S.I. 2021. Five-year cycle efficiency of willow and poplar growing under conditions of Pre-carpathians. – AMA, Agricultural Mechanization in Asia, Africa and Latin America, 51(01):821–830.

Stolarski, J.M., Kwiatkowski, J., Tworkowski, J., Szczukowski, S. 2018. Energy and economic efficiency of camelina and crambe biomass production on a large-scale farm in north-eastern Poland. – Energy, 150:770–780. DOI: 10.1016/j. energy.2018.03.021

Martinez, S., Alvarez, S., Capuano, A., del Mar Delgado, M. 2020. Environmental performance of animal feed production from *Camelina sativa* (L.) Crantz: influence of crop management practices under Mediterranean conditions. – Agricultural Systems, 177:102717. DOI: 10.1016/j.agsy.2019.102717

Mauri, P.V., Mostaza, D., Plaza, A., Ruiz-Fernandez, J., Prieto, J., Capuano, A. 2019. Variability of camelina production in the center of Spain in two

years of cultivation, a new profitable and alternative crop. – In Proceeding of 27th European Biomass Conference and Exhibition, 2, 7–30 May 2019, 196–200. DOI: 10.5071/27thEUBCE2019-1BV.8.16

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

Moskva, I.S. 2016. Status and prospects of *Camelina sativa* growing in the Southern Steppe of Ukraine. – Bulletin of agrarian science of Prychornomor'ia. [Stan ta perspektyvy vyroshchuvannya Camelina sativa u Pivdennomu Stepu Ukrayiny]. Visnyk ahrarnoyi nauky Prychornomor″ya], 1:99–109. (In Ukrainian)

Moser, B.R. 2010. Camelina (*Camelina sativa* L.) oil as a biofuels feedstock: Golden opportunity or false hope. – Lipid Technology, 22(12):270–273.

Peyraud, J., Peeters, A. 2016. The role of grassland based production system in the protein security, The multiple roles of grassland in the European bioeconomy. – Proceedings of the 26th General Meeting of the European Grassland Federation. Trondheim, Norway, 29–43 p.

Pilgeram, A.L., Sands, D.C., Boss, D., Dale, N., Wichman, D., Lamb, P., Lu, C., Barrows, R., Kirkpatrick, M., Thompson, B., Johnson, D.L. 2007. *Camelina sativa*, a Montana omega-3 and fuel crop. In Issues in new crops and new uses (Eds. J. Janick, A. Whipkey). – USA: ASHS Press, pp. 129–131.

Poliakov, O.I. 2011. Agrotechnical and bioclimatic peculiarities of formation of productivity and quality of seeds of sunflower, soybean, flax, sesame, Camelina sativa, milk weed in the Southern Steppe of Ukraine. [Ahrotekhnichni ta bioklimatychni osoblyvosti formuvannya vrozhaynosti ta yakosti nasinnya sonyashnyku, soyi, l′onu, kunzhutu, kameliny satyvnoyi, molochnoho bur″yanu v Pivdennomu Stepu Ukrayiny]. – Author's abstract of dis. of d. a. s. Dnipropetrovsk, 38 p. (In Ukrainian)

Prianyshnykov, D.N. 1963. Camelina. Selected Works. [Kamelina. Vybrani tvory]. – T.II. Moskva, p.418. (In Russian)

Righini, D., Zanetti, F., Monti, A. 2016. The bio-based economy can serve as the springboard for camelina and crambe to quit the limbo. – OCL, 23(5):D504. DOI: 10.1051/ocl/2016021

Semenova, E.F., Buiankyn, V.Y., Tarasov, A.S. 2005. Oilseed Camelina sativa: biology, technology, efficiency. [Oliyne maslo Camelina sativa: biolohiya, tekhnolohiya, efektyvnist′]. – Novocherkask: Sintez, 87, 19 p. (In Ukrainian)

Syvyryn, A.H., Reshetnykov, V.N. 1988. Crop of saffron milk intensive technology. [Tekhnolohiya intensyvnoho posivu shafranovoho moloka]. – Technical crops'. Moskva: Kolos, 19 p. (In Russian)

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.21.08

Tonin, P., Gosselet, N., Halle, E., Henrion, M. 2018. Ideal oil and protein crops – what are users ideotypes, from the farmer to the consumer. – OCL, 25(6). D605. DOI: 10.1051/ocl/2018060

Volokh, V.H., Dubrovetskyi, S.V., Kyiak, H.S., Onyshchuk, D.M. 2005. Crop production: Textbook. [Roslynnytstvo] (Ed. V.H. Vlokha). – K. Highschool, 382 p. (In Ukrainian)

Yakupoglu, T., Gundogan, R., Dindaroglu, T., Kusvuran, K., Gokmen, V., Rodrigo-Comino, J. Gyasi-Agyei, Y., Cerdà, A. 2021. Tillage impacts on initial soil erosion in wheat and sainfoin fields under simulated extreme rainfall treatments. – Sustainability, 13(2)789. DOI: 10.3390/ su13020789

Zanetti, F., Alberghini, B., Jeromela, A.-M., Grahovac, N., Rajković, D., Kiprovski, B., Monti, A. 2021. Camelina, an ancient oilseed crop actively contributing to the rural renaissance in Europe. A review. – Agronomy for Sustainable Development. 41:2. DOI: 10.1007/s13593-020-00663-y

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THE FORECASTING OF POLYPHENOLIC SUBSTANCES IN SWEET CHERRY FRUITS UNDER THE IMPACT OF WEATHER FACTORS

Iryna Ivanova[1], Marina Serdyuk[1], Vira Malkina[1], Tetiana Tymoshchuk[2], Anna Kotelnytska[2], Vira Moisiienko[2]

[1]Dmytro Motornyi Tavria State Agrotechnological University, 18B Khmelnytsky Ave, UA72312 Melitopol, Zaporizhzhia region, Ukraine

[2]Polissia National University, 7 Staryi Blvd, UA10008 Zhytomyr, Ukraine

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Vastutav autor: / Corresponding author: Tetiana Tymoshchuk

E-mail: tat-niktim@ukr.net

ORCID:
0000-0003-2711-2021 (II)
0000-0002-6504-4093 (MS)
0000-0002-2076-2093 (VM)
0000-0001-8980-7334 (TT)
0000-0001-7419-6374 (AK)
0000-0001-8880-9864 (VM)

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ABSTRACT. It has been proved that during the period of research the weather factors had dominating effects on the formation of phenolic substances fund for the fruits of early and late groups of cultivars. The cultivar features affected the accumulation of the phenolic substances in the fruits of a group of cultivars of a medium-term ripening. It has been established that the fruits of 'Kazka' cultivar (203.17 mg 100 g^{-1}) were selected from among the cultivars of an early-term ripening according to the average phenol substances content. The fruits of 'Rubinova Rannia' (175.27 mg 100 g^{-1}) are characterized by the optimal variation indices as well as by the average content of polyphenolic substances. From the technological point of view, the most perspective from among the cultivars of medium- and late-terms of ripening was: 'Uliublenytsia Turovtseva' (226.85 mg 100 g^{-1}), 'Udivitelna' (288.55 mg 100 g^{-1}). The results of experimental analysis for the fruits of early- and late-terms of ripening as well as their dispersion analysis allow us to forecast the content of the phenolic substances by the average indices but not separately for every pomological cultivar. Based on designed regression models, the analysis of the degree of impact of each weather factor on the rate of the phenolic substance has been made. The humidity index (the average monthly amount of rainfalls in May) had maximal effects on the accumulation of phenolic substances fund for the cherry fruits of three terms of ripening. The humidity indices of the last months of fruits formation (May and June) had the greatest effects on the accumulation of phenolic substances for a test group of plants of all terms of ripening.

Introduction

Increasing interest in biologically active compounds of stone fruits necessitates the selection of not only crops but also cultivars with a higher content of endogenous antioxidants. Natural phenolic compounds, including anthocyanidins, are considered the most important natural antioxidants (Xu *et al.*, 2017). Their composition and concentration affect the organoleptic characteristics of fruits and determine the antioxidant activity (Fu *et al.*, 2011; Nowak *et al.*, 2018). From among the most important kinds of fruit plants with corymbose inflorescences, which belong to sub-genus *Cerasus*, *Prunus avium* L. is of special importance. Cherry fruits are one of the most popular fruits of a moderate climate, they are much valued by the consumers and studied by scientists due to high taste qualities, attractive fruit appearance, valuable biochemical composition (Lovato *et al.*, 1994; Kask, Jalakas, 2004; Bastos *et al.*, 2015; Pissarda *et al.*, 2016). Sweet fruits have cellulose, vitamins, the compounds of the polyphenolic group, vitamin C, that provide good taste qualities and resistant characteristics (He *et al.*, 2007). The anti-tumour action of the extractions of fruits *P. avium*, which was caused by available phenolic compounds, has been established (Li *et al.*, 2016; Xu *et al.*, 2017).

The researchers pay much attention to studying the phenolic compounds of the fruits, which affect the fruits colour and the taste qualities like bitterness and astringency. Polyphenolic substances can be found in plants in the form of glycosylated derivatives, though a conjugation with non-organic acid is also known. These molecules take part in the protection against ultraviolet radiation or aggression from plants pathogens. As

follows from the results of the research carried out on animal and man simulations, the phenols are bioaccessible and have a protective action against oxidative stress and against the damage caused by free radicals (Prior, 2003; Szajdek, Borowska, 2008; Lobo *et al.*, 2010; Alkadi, 2020). Phenolic compounds present secondary metabolites of plants, which are characterized by the availability of at least one aromatic ring with one or few affiliated hydroxyl groups. The phenols vary from simple low-molecular compounds with one aromatic ring to tannins, which contain a great number of hydroxyl groups (-OH). They can be classified according to the amount and to the location of carbon atoms (de la Rosa *et al.,* 2019). Some researchers have established that phenolic substances reduce vitamin C oxidation, and the vitamin, in its turn, has a stabilizing action on bioflavonoids (Díaz-Mula *et al.*, 2010; Smeriglio *et al.*, 2017).

According to the data, the sugars can serve as a material for the synthesis of phenolic substances in sweet cherry fruits. The total sugar content, as a substrate for the phenols formation, is in the range of 10.55–14.59% (Ivanova *et al.*, 2021b). The fruit ripening stage in sweet cherries, like in other red fruits, is connected with the change of primarily green colour for a red one due to the accumulation of polyphenolic compounds, anthocyanidins. Biologically active phenolic compounds are concentrated in the skin and have beneficial effects on the sensor and organoleptic characteristics of fruits, such as flavour (Jakobek *et al.,* 2009). The accumulation of substances that colour the sweet cherry fruits red (with different shades) during the last period of ripening are due to an increase in the content of anthocyanins. They are the main phenolic substances in the fruits of dark-coloured cultivars (Karaaslan *et al.*, 2016). As it has been stated in the research, the sweet cherry cultivars show high changeability of phenolic compounds rates. According to the data of some researchers, it has been found that the total amount of sweet fruits anthocyanidins is from 30 ('Black Gold' cultivar) to 79 ('Cristalina' cultivar) mg of the cyanidin-3-glycosidic equivalent of (CGE) 100 g^{-1}, when a total amount of cherry anthocyanidins is from 45 ('Balaton' cultivar) to 109 ('Sumadinka' cultivar) mg CGE mg 100 g^{-1} (Serrano *et al.*, 2009; Ferretti *et al.*, 2010).

The research has proved that the fruits of 13 sweet cherry cultivars had the total phenols content from 44.3 to 87.9 mg in the equivalent of gallic acid g^{-1} 100 FW and the antioxidant activity ranged from 8.0 to 17.2 mg the equivalent of the antioxidant capability of the ascorbic acid, mg 100 g^{-1} FW. The authors suppose that the correlation of the antioxidant activity of the total amount of phenols and anthocyanidins depended on the cultivar (Usenik *et al.,* 2008). However, it has to be noted that the cultural genetic factors and the weather conditions affect the formation of macroelements, micronutrients and phytonutrients in the fruits (Bureau *et al.*, 2009; Iglesias *et al.*, 2012). The temperature, lightning intensity and fruit ripening (Pissarda et al., 2016) can affect the content and the stability of phytochemical substances, as well as sweet cherry and cherry nutritional value.

There are some investigations, which show that the temperature fluctuations during the day (in a daytime or at night) affect the phenol total content (Pissarda *et al.*, 2016). When sweet cherry fruits grow under high temperatures (25–30 °C) it increases the amount of anthocyanidins as well as phenol (Ferretti *et al.*, 2010). The research conducted by Lakatos *et al.* (2010; 2014) showed that the content of biochemical indices depended on climatic characteristics (average maximal and minimal temperatures, humidity) during the period of blooming up to the period of stone fruits ripening. The weather factors, such as the sum of the effective temperatures and the amount of precipitation 10–15 days before harvesting, had a significant impact on the fruits quality indices (Revell, 2009; Lakatos *et al.,* 2014). The nature and the phenol compounds distribution vary depending on plant fibre. Thus, the rate of content of polyphenolic substances in sweet cherry fruits, their accumulation and further storage depend on many factors.

Based on literature references it can be stated that there is a strong correlation between the content of polyphenolic substances and the weather conditions of the region where the fruits are growing (de Souza *et al.*, 2014; Skrovankova *et al.,* 2015). In the regions similar to the Southern Steppe sub-zone of Ukraine it is expedient to determine the degree of impact of stress weather factors on the formation of polyphenolic substances fund in sweet cherry fruits. In literature sources, the question of the formation of the polyphenolic substances fund of a given region and similar ones (according to weather conditions) under the condition of global climate changes has not been covered. In literature sources, the problem of the formation of phenolic substances fund in a tested region and similar ones according to the weather factors and to the global climate changes is inadequately treated. The amount and the content of polyphenols in sweet cherry fruits differ depending on genotype impact, ripeness, climatic conditions, term of fruits ripening (Vuletić *et al.*, 2017). The data as to seasonal as well as to the geographic differences in the accumulation of polyphenols content in sweet cherry fruits are not available. That is why singling out of particular weather factors which have a maximal impact on the accumulation of phenolic substances in different (as to the term of ripening) sweet cherry cultivars is a topical matter.

Material and Methods

The goal of the research was to develop a mathematical model, which will help to improve the prediction of phenolic substances content in sweet cherry fruits under different weather conditions. The designed mathematical model can be used under the conditions of the regions with hydrometrical indices, which are similar to the Southern part of Ukraine. The program of the research prognosticates choosing of the cultivars of sweet cherry fruits of an early, medium- and late-terms

of ripening with a maximal index of polyphenolic substances for the further storing of fruits with high-quality parameters and with biological value.

To realize the goal it is necessary to do the following tasks:

- to analyses the weather conditions during the period of fruits formation; to determine the content of the phenolic substances in sweet cherry fruits during the period of economic maturity of the cultivars of each term of ripening;
- to select the best ones according to test characteristic;
- to establish the correlation between the processes of phenolic substances accumulation and stress weather conditions;
- to develop the mathematical models of dependence of phenolic substances content on weather factors or varietal features;
- to analyse the designed model to determine the degree of impact of each factor on the accumulation of phenolic substances found in sweet cherry fruits of three terms of ripening.

By making a two-factor dispersion analysis the expediency of predicting the content of the phenolic substances in sweet cherry fruits by average indices for a definite group of cultivars will be justified and factors (factor A – climatic conditions of a year or factor B – cultivar features) which have maximal effects on phenolic substances accumulation in sweet cherry fruits will be revealed.

The research was conducted from 2008 to 2019 on horticulture farms of a Southern Steppe sub-zone of Ukraine. Sweet cherry fruits were chosen at a research commercial farm unit of a horticulture station named after M.F. Sydorenko (town of Melitopol) and at farm enterprises of Melitopol district (46° 49'N, 35° 22'E). Daily meteorological data of Melitopol meteorological station of Zaporizhia oblast (Ukraine) was used. The climate of the region is continental with a high-temperature regime and insufficient humidity. The relief of the territory is flat with eastern and north-eastern winds. The average annual air velocity is 3.7 m s^{-1}. The average annual air temperature in a test zone is 9.1–9.9 °C. In the warmest months of summer, the temperature is from 20.5 °C to 23.1 °C. The sum of active temperatures above 10 °C in the period from April to October is equal to 3316 °C. The average amount of precipitation during a year is 475 mm. The average annual relative air humidity in the region is within 73%. The readings of a hydrometrical index are in the range of 0.22–0.77 (Serdyuk *et al.*, 2020a; Ivanova *et al.*, 2021a,b). During the years of the research, the soil preparation in all areas satisfied the agrotechnological demands. Moisture accumulation in soil occurs mostly in autumn, partly in winter and in early spring. Black southern loamy soil was the soil on the test areas where the crop was grown. Loess was a soil-forming rock. This type of soil, by its particle-size distribution, has a great content of physical sand. The sweet cherry fruits of 33 cultivars were chosen for the research. They were divided into 3 groups according to the term of ripening (Table 1).

Table 1. The list of cultivars taken for studying

1st cultivar group (early-term of ripening)	2nd cultivar group (medium-term of ripening)	3rd cultivar group (late-term of ripening)
'Merchant', 'Swit Erliz', 'Rubinova Early', 'Bigaro Burlat', 'Kazka', 'Zabuta', 'Valeriy Chkalov'	'Oktavia', 'Vynka', 'Temp', 'Kordia', 'Pervistok', 'Talisman', 'Uliublenytsia Turovtseva', 'Melitopolska Chorna', 'Dilema', 'Orion', 'Dachnytsia', 'Chervneva Early', 'Prostir'	'Regina', 'Karina', 'Mirazh', 'Mirazh', 'Zodiak', 'Udivitelna', 'Kolhoznytsia', 'Ciurpryz', 'Temporion', 'Prazdnichna', 'Anons', 'Meotyd'

For each pomological cultivar, the samples of 100 fruits from six trees in a fruiting stage were taken for determining the content of the phenolic substances. The trees typical for a definite pomological cultivar of the same age, with average fruiting intensity were taken for the research. Three-fold frequency. The trees of 2001 were planted on the scheme 5×3, the spacings were under autumn fallow. The fruits were weighed and counted when picking (Serdyuk *et al.*, 2020b).

The sweet cherry fruits of each pomological cultivar were picked when the pulp was firm enough, but the flavour and the colour were typical for a given pomological cultivar. The fruits were picked from the trees from 4 different sides of the crown. The fruits of each pomological cultivar were harvested with a fruit stalk and of the first commercial quality. The harvest date of picking fruits was determined according to the following quality indices of fresh sweet cherry fruits which are common to each pomological cultivar: fruit appearance (fruit analysis by their shape and colour which must be typical for a given pomological cultivar, availability of fruit stalk, the degree of mechanical damages of fruit skin, the degree of fruit vermin damage, fungus disease affection) fruits size by the largest transverse diameter. When estimating the polyphenolic substances, the fruits in a state of a consumer ripeness were characterized by their appearance and flavour typical for a consumer sort of a corresponding term of ripening.

Polyphenols content was estimated by Folin-Denis' reagent. The method encompasses conducting polyphenols complexation reaction by Folin-Denis' reagent, as well as the formation of stained substances with further optical density determination. As standard, rutin was used to estimate polyphenols content in sweet cherry fruits. The optical density of the received test solutions and the solution of the standard rutin sample was estimated with a spectrophotometer under a wavelength of 670 nm in a cuvette and 10 mm distance between active areas.

The mass portion of polyphenols was estimated by Equation (1).

$$X = \frac{C \times V \times A \times 100}{M \times V_1}, \quad (1)$$

where C is the rutin mass concentration, which is determined by calibration graph (mg cm^{-3}), and V is the extract volume (cm^3), and V_1 is the extract volume for analysis (cm^3), and M (g) is the mass of a product assay sample (sweet cherry fruits), and 100 is the coefficient of polyphenols content determination per 100 g of product, and A is the coefficient of a rate of reconstitution of the extract of a sample (Ivanova *et al.*, 2019, Serdyuk *et al.*, 2020b).

The design of the models of dependence of phenolic substances in sweet cherry fruits of three terms of ripening depending on weather factors was as follows (Ivanova *et al.*, 2021a,b):

1. The determination of phenolic substances content by Folin-Denis' reagent.
2. The development of the informational data system of the indices of weather-climatic factors in the research years: average minimal air temperatures, average air temperatures, average maximal air temperatures, amount of precipitation, average relative air humidity, minimal relative air humidity, and absolute minimal relative air humidity.
3. The hydrothermal coefficient, the temperature difference during definite periods, the sums of active temperatures, the sums of effective temperatures were determined based on mentioned above indices.
4. The selection of weather-climatic factors, which showed the indices of correlation coefficients, are meaningful according to Student's test under the significance level of 0.05. The factors, which are logically substantiated from the point of view of their impact on the test characteristic (the accumulation of phenolic substances in sweet cherry fruits) but did not show a high correlation with it, were selected as well. For this purpose, we run a check on a statistical hypothesis about the significance of the calculated correlation coefficients between the factors and the index of polyphenolic substance content in sweet cherry fruits. We run a check on a statistical hypothesis by Student's test.
5. We build the regression model of dependence of the index of polyphenolic substances content in sweet cherry fruits from the selected factors in item 4.
6. Based on a designed regression model we determine the degree of impact of each factor.

The first stage of correlation analysis is the estimation of matching correlation coefficients and further checking their significance. It helps to find the most significant weather factors. The analysis of correlation coefficients presents the basis and makes it possible to select the factors, which strongly correlate with a test characteristic. However, it is necessary to use more accurate methods for comparing the degree of impact of the factors among themselves and their ranking in terms of the degree of impact. Such analysis is often made based on regression model coefficients. As a rule, a method of the least squares is used to design a regression model. One more reason, which entails some restrictions on using the algorithm of regression analysis, is a multicollinearity effect. But it is necessary to satisfy the conditions of the Gaus-Markov theorem for the calculated coefficients to be effective and unbiased evaluations of the parameters of a generalized regression model (Gujarati, 2004).

If the factors, which have some impact, correlate among themselves, the multicollinearity effect is manifested. It is a violation of the Gaus-Markov theorem. In this case, the evaluations of the coefficients of the model designed by the least-squares method are not biased. According to this model, the results of the analysis of the degree of impact of each factor separately is not reliable.

One of the recommended methods for designing the regression model under the condition of multicollinearity is the LASSO method (Least absolute shrinkage and selection operator) (Kutner *et al.*, 2004; James *et al.*, 2013; Hastie *et al.*, 2020).

An algorithm for the analysis of the impact of correlating factors on the final index based on a regression model designed by the LASSO method was suggested in the research (Ivanova *et al.*, 2021a,b):

Thus, it is suggested to research by the algorithm:

1. Based on experimental data x_{ij}, ($i = 1 \dots n$ – the weather factor number, $j = 1 \dots m$ – the number of a research year) we design a regression model by the LASSO method in Equation (2).

$$\hat{Y} = a_0 + \sum_{j=1}^{n} a_j \cdot X_{j,} \quad (2)$$

where X_j is the factor, and a_j is the model parameters, and $\hat{Y}$ is the test characteristic.

2. Calculate the values of the coefficient of a corresponding regression model in standardized factors by Equation (3).

$$\tilde{a}_i = a_i \frac{\bar{S}_{X_i}}{\bar{S}_Y}, \quad (3)$$

where b_i is the calculated coefficients of a regression model, and; $\bar{S}_{X_i}$ is the average quadratic deviation of factors X_i; $\bar{S}_Y$ – average quadratic deviation of a test characteristic Y.

3. Analyze the designed regression to estimate the degree of impact of each of the climatic factors on the content of a polyphenolic substance. To estimate the degree of impact of weather factors in a total impact of all factors, we estimate delta-coefficients Δ_j, by the formula:

$$\Delta_i = \left| \frac{\tilde{a}_i \cdot r_{YX_i}}{R^2} \right| \quad (4)$$

where $\tilde{a}_i$ is the parameter of a regression model in standardized factors $\tilde{X}_i$, and r_{YX_i} is the matching coefficients of correlation, and R^2 is the determination coefficient.

The means of modern computer technologies DataMining – software environment Rstudio were used to perform statistical analysis.

Results and Discussion

The results received during 12 years give a possibility to state that the average content of phenolic substances in a test plant fruits of all terms of ripening equalled 205.86 mg 100 g^{-1} in rutin equivalent. Similar studies with 13 cultivars of sweet cherry fruits of different terms of ripening were conducted by the researchers from Slovenia (Usenik *et al.*, 2008). According to their data, the total phenols content varied from 44.3 to 87.9 mg gallic acid equivalents 100 g^{-1} FW. The research conducted by Serrano *et al.* (2005) proved that the maximal accumulation of phenolic substances was registered at the 8th stage of sweet fruits ripening.

The average phenolic substances content in sweet cherry fruits of the cultivars of an early-term of ripening was on the level of 177.53 mg 100 g^{-1} (Table 2). It was 13.8% lower as compared to an average cultivar coefficient. Minimal phenolic substances content from among the given group of cultivars has been determined in the fruits of the 'Bigaro Burlat' cultivar (116.01 mg 100 g^{-1}) of 2017. It was lower than the average cultivar index by 27.8%. Maximal phenolic substances content on the level of 274.12 mg 100 g^{-1} was determined in the fruits of the 'Zabuta' cultivar of 2016. Herewith, the excess over the average cultivar index was 48.3%. As follows from the results of 12-year research, from among the cultivars of an early-term ripening 'Kazka' cultivar was characterized by the highest phenolic substances content, and Sweet Earliz was characterized by the lowest content of phenolic substances (Table 2). Among the tested sweet cherry cultivars grown in Alicante (Spain), the highest total phenols content (54,02 mg GAE 100 g^{-1} FW) was registered in the cultivar of an early-term ripening – Brooks (Legua *et al.* 2017).

The phenolic substances content in sweet cherry fruits of the cultivars of a medium-term ripening was lower than the average cultivar index by 3.7%. Thus, from among the analyzed cultivars, the sweet cherry fruits of a cultivar group of a late-term of ripening were characterized by the maximal phenolic substances content. The average phenolic substances content in their fruits exceeded the average cultivar index by 17.5%.

The accumulation of phenolic substances in the fruits of two cultivars of early and medium-terms of ripening was analyzed by Ponce *et al.* (2021). The tested cultivars 'Lapins' and 'Glenred' showed different dynamics of phenolic substances accumulation during the period of fruit ripening. This suggests that the accumulation of phenolic substances depends on cultivar features.

The fruits of 'Dachnitsia' and 'Temp' cultivars which were picked in 2015 and 2017 are characterized by a minimal phenolic substances content among the cultivars of a medium-term of ripening. The amount of phenolic substances was lower than the average cultivar index by 18.8 and 37.6% respectively. The maximal amount of polyphenolic substances was determined in the fruits of 2010 in 'Uliublenytsia Turovtseva' and 'Melitopolska Chorna' cultivars. Herewith, the excess over the average cultivar index was in the range of 30.6–28.6% respectively. From among the cultivars of a medium-term ripening maximal average content of phenolic substances was determined in the fruits of 'Prostir', 'Uliublenytsia Turovtseva' and 'Melitopolska Chorna' cultivars.

The dependence of phenolic substances accumulation in stone fruits, cherry and sweet cherry in particular, on them of cultivar features, was established by the studies conducted by other researchers in Romania (Popescu *et al.*, 2014), Croatia (Vuletic *et al.*, 2017) and Poland (Bieniek *et al.*, 2011; Sokół-Łętowska *et al.*, 2020).

The fruits of 'Prazdnichna', 'Temporion', 'Anons', which were picked in 2008, were characterized by the minimal amount of polyphenolic substances among the cultivars of a late-term ripening. The amount of P-active substances was lower than the average cultivar y index by 27.3–38.8%. The maximal amount of polyphenolic substances was determined in the fruits of 'Zodiak' and 'Udivitelna' cultivars of 2014. Herewith, the excess over the average cultivar index was 13.8 and 10.6 respectively. The maximal average polyphenolic substances contained in the fruits of the cultivars of a late-term ripening was determined in the fruits of 'Udivitelna' and 'Regina' cultivars.

Similar studies as to the content of the phenolic substances in the fruits of cherry cultivars (21 cultivars) were conducted under conditions of Poland. The analysis of the research results testifies to the fact that stone fruits of mid- and late-terms of ripening contain more flavonols and anthocyanins than early ripening cultivars. The tested mid-ripening and late-ripening cherry cultivars had a higher antioxidant capacity as compared with early ripening cultivars (Sokół-Łętowska *et al.*, 2020).

The results of the research (Table 2) testify to a significant and average variation of polyphenolic substances content by the years of research in a group of cultivars of an early-term of ripening. The fruits of the 'Zabuta' cultivar (with the variation coefficients of 23.1%) were exposed to the greatest impact of abiotic factors on the content of the polyphenolic substances among the fruits of a given group. The cultivars 'Merchant' 'Bigaro Burlat' are the most resistant according to the test characteristic. Corresponding variation coefficients are in the range of 14.2–14.7 %. The

variation of given cultivars under the weather factors impact in terms of polyphenolic substances content is considered to be average, and the fruits have a minimum average index of phenolic substances content during the years of research.

The variation of phenolic substances content by the years of the research in the sweet cherry fruits of the cultivar groups of medium and late-terms of ripening was average in a range of Vp = 11.1–19.9%. 'Mirazh' and 'Surprise' cultivars of late-term ripening are an exception (Vp = 20.7–26.2% respectively). Among the group of cultivars of a medium-term of ripening the most stable content of phenolic substances was in the fruits of 'Pervistok' cultivar (Vp = 11.8%), 'Uliublenitsia Turovtseva' (Vp = 12.6%), and the most changeable content was in 'Vynka' cultivar (Vp = 19.9%). The least variability in a group of cultivars of a late-term ripening was determined in 'Udivitelna' and 'Zodiak' cultivars (Vp = 11.1–11.2%).

Thus, within the cultivars of an early-term of ripening 'Kazka' cultivar was selected by the average content of phenolic substances; 'Rubilnova Rannia' and 'Bigaro Burlat' cultivars were selected by the variation of polyphenolic substances formation under the weather factors impact and the average content of polyphenolic substances. Under conditions of an analyzed region, the most perspective from the technological point of view in a group of cultivars of medium- and late-terms of ripening were the fruits of 'Uliublenytsia Turovtseva' cultivar (of a medium-term of ripening) and 'Udivitelna' cultivar (of a late-term of ripening). These cultivars had a high content of phenolic substances and minimal variation within the test groups by the years of research.

Table 2. Phenolic substances content in sweet cherry fruits of the cultivars of three terms of ripening in rutin equivalent, mg 100 g^{-1} (2008–2019), $\bar{x} \pm s$, n = 5

Pomological cultivar	Average phenolic substances content, mg 100 g^{-1}	Minimal phenolic substances content, mg 100 g^{-1}	Maximal phenolic substances content, mg 100 g^{-1}	Variation by the years, Vp, %
An early-term of ripening				
'Rubinova Rannia'	175.27 ± 26.40	131.27	215.03	15.0
'Valeriy Chkalov'	194.07 ± 38.22	145.94	251.28	19.6
'Sweet Erliz'	155.63 ± 24.16	126.09	189.75	15.5
'Merchant'	157.24 ± 22.42	130.32	199.58	14.2
'Kazka'	203.17 ± 38.78	149.71	272.04	19.0
'Bigaro Burlat'	160.78 ± 23.74	116.01	197.90	14.7
'Zabuta'	196.54 ± 45.43	151.15	274.12	23.1
Average value	177.53 ± 36.53	135.78	228.52	17.3
LSD_{05}	28.82	–	–	–
A medium-term of ripening				
'Vynka'	172.51 ± 34.35	126.69	219.15	19.9
'Pervystok'	171.05 ± 20.25	139.05	210.18	11.8
'Temp'	173.74 ± 32.00	108.42	229.09	18.4
'Uliublenytsia Turovtseva'	226.85 ± 28.59	179.89	296.34	12.6
'Talisman'	216.60 ± 31.56	177.23	280.02	14.5
'Dilema'	185.79 ± 26.64	141.51	222.89	14.3
'Melitopolska Chorna'	227.08 ± 30.38	200.07	292.08	13.3
'Kordia'	239.47 ± 38.93	170.14	289.85	16.2
'Oktavia'	203.33 ± 31.83	167.43	261.37	15.6
'Orion'	210.54 ± 28.10	161.95	251.17	13.3
'Chervneva Rannia'	179.57 ± 51.62	130.17	287.67	13.5
'Dachnytsia'	128.70 ± 24.09	104.41	170.79	18.7
'Prostir'	240.24 ± 41.21	166.83	279.27	17.1
Average value	198.11 ± 44.95	151.80	253.06	13.7
LSD_{05}	27.42	–	–	–
A late-term of ripening				
'Krupnoplidna'	245.79 ± 39.36	160.09	289.05	16.0
'Karina'	252.17 ± 35.42	170.09	291.19	14.0
'Regina'	273.11 ± 36.82	198.03	305.52	13.4
'Mirazh'	209.73 ± 43.48	111.23	268.65	20.7
'Udivitelna'	288.55 ± 32.16	204.41	319.23	11.1
'Zodiak'	272.95 ± 30.75	207.71	310.65	11.2
'Surpryz'	238.34 ± 62.44	175.65	311.01	26.2
'Kolhoznytsia'	238.84 ± 39.18	175.73	291.34	16.4
'Kosmichna'	246.87 ± 28.89	196.80	290.45	11.7
'Prazdnichna'	225.34 ± 40.80	137.69	283.08	18.1
'Anons'	195.04 ± 31.21	141.71	241.05	16.0
'Temporion'	202.06 ± 32.93	141.01	246.16	16.2
'Meotyda'	256.49 ± 34.55	201.81	299.01	13.4
Average value	241.94 ± 45.89	170.89	288.75	15.7
LSD_{05}	37.09	–	–	–

Table 3. The results of two-factor dispersion analysis under the formation of phenolic substances found in sweet cherry fruits

Source of variation	Sum of squares	Degree of freedom	Dispersion	F_{fact}	$F_{table095}$	Impact, %
Sweet cherry cultivars group of an early period of ripening						
Factor A (year)	224 355.2	11	20 395.9	65.0	1.8	53.3
Factor B (cultivar)	81 372.8	6	13 562.1	43.2	2.2	19.3
Interaction AB	46 654.7	66	706.8	2.2	1.4	11.0
Sweet cherry cultivar group of a medium period of ripening						
Factor A (year)	33 6751.6	11	30 613.7	107.8	1.8	31.1
Factor B (cultivar)	467 108.8	12	38 925.7	137.1	1.8	43.2
Interaction AB	136 210.0	132	1031.8	3.6	1.3	12.6
Sweet cherry cultivars group of a late period of ripening						
Factor A (year)	502 235.1	11	45 657.7	87.9	1.8	42.5
Factor B (cultivar)	345 148.2	12	28 762.3	55.4	1.8	29.2
Interaction AB	132 038.2	132	1000.2	1.9	13.0	11.1

A dominating impact of weather factors on the accumulation of phenolic substances fund for a group of cultivars of early- and late-terms of ripening was confirmed by the results of a dispersion analysis (Table 3). The degree of impact of factor A for the cultivars of a group of an early-term of ripening was equal to 53.3%, for a group of cultivars of a late-term it was equal to 42.5%. The impact of cultivar features (factor B) was less weighty. The degree of impact of this factor was equal to 19.3 and 29.2% respectively for the analyzed groups.

The results of our research were proved by the data received by the researchers of Groatia (Vuletic *et al.*, 2017). They established that the impact of weather factors during the years of research on the accumulation of anthocyanins and polyphenolic substances in sweet cherry fruits was dominating. The dependence of fruits quality indices on the years of research was proved by A. Bieniek (Bieniek *et al.*, 2011). For a group of cultivars of a medium-term ripening, cultivar features had greater effects on the accumulation of substances P-vitamin activity. The degree of impact of factor B for the cultivars of the medium-term ripening was equal to 43.2%. The impact of factor A was on the level of 31.1%. A dominating impact of cultivar features on the accumulation of phenolic substances and anthocyanins in sweet cherry fruits of 13 cultivars of different terms of ripening was proved by the scientists of Slovenia (Usenik *et al.*, 2008).

Thus, the received results confirm the expediency of determining the amount of phenolic substances in sweet cherry fruits by the average values for a definite group of cultivars of early- and late-terms of ripening, but not separately for each pomological cultivar. As for the cultivars of a medium-term ripening, it is expedient to analyze both the average values for the whole group of these cultivars, and for each cultivar separately, which will be done in further research.

Further, the analysis of the correlation relationship availability between the indicator of phenolic substances found in the fruits of an early-term of ripening (Y_1), medium-term (Y_2), late (Y_3) term of ripening and a complex of weather conditions (factors X_i) was made. The calculated matching coefficients $r_{Y_1X_i}$, $r_{Y_2X_i}$, helped to choose the most important weather factors. The significance of these coefficients is checked by the statistical hypothesis $H_0: \rho = 0$ (where ρ – the correlation coefficient of general totality) under an alternative hypothesis $H_1: \rho \neq 0$ when the significance level $\alpha = 0{,}05$. Student's criteria helped to check the statistical hypothesis As it was determined in our case, the significant correlation coefficients (under the level of significance equal to 0.05 and the number of the degrees of freedom $k = 10$) were within the interval of [-1; -0.55] and [0.55; 1].

As a result, based on the data taken from Table 4, 13 weather factors indices (X_i), which is a definite vegetation period that can significantly influence the accumulation of the phenolic substances in sweet cherry fruits of an early (Y_1), medium (Y_2), and late (Y_3) term of ripening, were selected.

These indices are: air humidity indices (mm; %; per day), the average monthly amount of precipitation in May (X_1), the number of days with precipitation more than 1 mm in May (X_6), and in June (X_7), the average relative humidity in May (X_2) and in June (X_3), the amount of rainfalls in blooming period (X_{10}) and during the whole vegetation period (X_{11}), the average minimal relative humidity in May, mm (X_4) and in June (X_5). The thermal air indices (°C): the average air temperature in the period of fruits picking (X_{12}); absolute maximal temperature in the period of fruits picking (X_{13}); the difference between average maximal and minimal temperatures in May (X_8) and June (X_9).

The parameters of the regression models designed by the LASSO method are given in Table 5, view 1. Table 5 shows the dependence of polyphenolic substances index for early $\hat{Y}_1$ medium $\hat{Y}_2$ and late $\hat{Y}_3$ cultivar on weather factors X_i.The model's coefficients are shown in Table 5.

Table 4. Table of the coefficients of matching correlation between weather factors (X_i,) and the content of the phenolic substances in sweet cherry fruits of an early (r_{YX_i}), medium ($r_{y_2x_i}$), and late ($r_{y_3x_i}$) terms of ripening

Relative factors term (X_i)	Factors	Matching coefficients of correlation ($r_{Y_jX_i}$) for the cultivars groups		
		early	medium	late
X_1	Average monthly amount of precipitation in May, mm	0.9623	0.7693	0.926621
X_2	Average monthly relative air humidity in May, %	0.7322	0.4084**	*
X_3	Average monthly relative air humidity in June, %	*	*	0.325988**
X_4	Average minimal relative air humidity in May, %	0.7678	0.4372	*
X_5	Average minimal relative air humidity in June, %	*	*	0.347651**
X_6	Total amount of days with precipitation more than 1 mm in May, per day	0.8246	0.5631	*
X_7	Total amount of days with precipitation more than 1 mm in June, per day	*	*	0.620387
X_8	Difference between average maximal and minimal temperatures in May, °C	–0.5997	*	*
X_9	Difference between average maximal and minimal temperatures in June, °C	*	*	–0.15941
X_{10}	Amount of precipitation in blooming period, mm	0.6124	0.4589**	*
X_{11}	Amount of precipitation during a vegetation period, mm	*	0.4696**	0.54163
X_{12}	Average air temperature in a period of fruits picking, °C	*	0.5386	0.356956**
X_{13}	Absolute maximal temperature in a period of fruits picking, °C	*	0.7693	0.508837

*insignificant matching coefficients of correlation $\left|r_{Y_jX_i}\right| \leq 0.55,\ i = 1-25, j = 1-3$ (according to checking a hypothesis on the significance of the correlation, coefficients by Student's criteria under significance level of 0.05).
**factors whose impact is hard to study from the point of view of the expediency and logic of the experiment, paying no attention to the insignificance of the coefficients of correlation.

Table 5. The coefficients of a regression model

	a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7
$\hat{Y}_1$	82.8707	0.6144	0.1438		0.0717		2.6540	0.5944
$\hat{Y}_2$	69.7499	0.4063	–0.6469		–0.35405		2.1382	
$\hat{Y}_3$	154.0456	0.6671		–0.3377		0.2387		1.9068
	a_8	a_9	a_{10}	a_{11}	a_{12}	a_{13}		
$\hat{Y}_1$	1.9414		0.0333					
$\hat{Y}_2$			0.0058	0.0653	0.0672	5.8783		
$\hat{Y}_3$		0.55716		0.0063	2.2567	–0.0819		

The formula of a regression model for the sweet cherry fruits of an early-term of ripening:

$$\hat{Y}_1 = 82{,}8707 + 0{,}6144X_1 + 0{,}1438X_2 + 0{,}0717X_4 + 2{,}6540X_6 + 0{,}5944X_7 + 1.9414X_8 + 0{,}0333X_{10} \quad (5)$$

The formula of a regression model for the sweet cherry fruits of a mid-term of ripening:

$$\hat{Y}_2 = 69.7499 + 0{,}4063X_1 - 0{,}6469X_2 - 0{,}35405X_4 + 2{,}1382X_6 + 0{,}0058X_{10} + 0{,}0653X_{11} + 0{,}0672X_{12} + 5.8783X_{13} \quad (6)$$

The formula of a regression model for the sweet cherry fruits of a late-term of ripening:

$$\hat{Y}_3 = 154.0456 + 0{,}6671X_1 - 0{,}3377X_3 + 0{,}2387X_5 + 1.9068X_7 + 0{,}55716X_9 + 0{,}0063X_{11} + 2.2567X_{12} - 0.0819X_{13} \quad (7)$$

Thus, according to Table 6, within the group of cultivars, a group of weather factors with average and strong linear correlation dependence with an analyzed index (phenolic substances), has been determined. The number of factors for early cultivars amounted to – 6, for medium cultivars – 7 and late cultivars – 7.

For the cultivars of an early, medium and late-terms of ripening Δ_i varies from 0.26 to 68.63% (Table 6). For further analysis of the results of the research all the factors, depending on the values of the coefficient Δ_i (i = 1–13), were divided into the ranks. According to Table 6, the humidity index (the average monthly amount of precipitation in May (X_1)) had maximal effects on the accumulation of phenolic substances for the fruits of sweet cherries of three terms of ripening. It was first in a rank according to the indices of the degree of factors impact on the accumulation of polyphenolic substances fund $\Delta_{X1}$and is from 43.21% to 68.63%.

The weather temperature indices, as well as humidity indices, had a significant impact on the accumulation of polyphenolic substances in sweet cherry fruits. Second in rank for the varieties of an early-term of ripening goes the index (X_6) – the number of days in May with the amount of precipitation more than 1mm; for the cultivars of medium and late-terms of ripening second in a rank is an index (X_{12}) – the average air temperature in a period of fruits picking. The values of the degree of impact of factors Δ_{X6} and Δ_{X12}were from 17.53% to

22.79%. Some noticeable impact on the test characteristic accumulation in sweet cherry fruits of three terms of ripening on the third rank level had the weather factors like: the number of days in May with the amount of precipitation more than 1 mm (X_6); the number of days in June with the amount of precipitation more than 1 mm (X_7); and the difference between average maximal and minimal temperatures in May (X_8). For the cultivars of an early-term of ripening the degree of impact Δ_{X8} = 3.60%, for the cultivars of medium and late-terms of ripening Δ_{X6} and Δ_{X7} equalled 14.47% and 11.46% respectively.

The cultivars of an early-term ripening maximal impact on the accumulation of phenolic substances had the factors of ranks 1, 2 and 3. The range of Δ_i index for them is 3.60–68.63%. The rest humidity indices: the amount of precipitation in blooming period (X_{10}), the average monthly relative humidity (X_2) and the average minimal relative humidity (X_4) in May had insignificant impact on the formation of phenolic substances found in sweet cherry fruits of an early, term of ripening. The value of the total impact of factors X_{10}, X_2 and X_4 was equal to 5.67%.

For the cultivars of a medium-term ripening maximal impact on the accumulation of phenolic substances had the factors of ranks 1–3. The range of Δ_i = 14.47–43.21%. The rest of weather humidity indices are to a high degree common for early and for medium cultivars of sweet cherry fruits, namely – the amount of precipitation during the vegetation period (X_{11}), average monthly relative humidity (X_2), and average minimal relative humidity (X_4) in May. They had a lower impact on the formation of phenolic substances in sweet cherry fruits. The values of the total impact of factors for a group of cultivars of a medium-term ripening of the 4th–6th ranks (X_{11}, X_2, X_4) was equal to 19.14%. The amount of precipitation in the blooming period (index X_{10}) is rank 7 with Δ_i = 0.39%.

For the cultivars of a late-term ripening maximal impact on the accumulation of phenolic substances had the factors of ranks 1–3. The range of Δ_i = 11.46–66.23%. The rest of the weather factors had a less significant impact on the accumulation of phenolic substances in sweet cherry fruits of a late-term ripening. The value of the total impact of factors X_3, X_5, X_{11}, X_7 on the accumulation of the polyphenolic substances in sweet cherry fruits of a late-term of ripening of 4th–7th ranks was equal to 4.54%. The impact of a surplus rainfall on the anthocyanins and polyphenolic substances synthesis in sweet cherry fruits harvest of two regions was proved by the research conducted by Vuletic (2017). The accumulation of phenolic substances in sweet cherry fruits depended on the humidity indices in the last month of fruit ripening. It was May for early-ripening cultivars and June for mid-ripening cultivars.

Table 6. The indices of the degree of impact of factors (Δ_i, %) on polyphenolic substances accumulation as well as on their rank

Factors (X_i)	Relative factors term (X_i)	The coefficients of the degree of factors impact (Δ_i, %) and the indices of factors rank for the cultivars of early, medium and late-terms of ripening					
		early		medium		late	
		rank	Δ_i, %	rank	Δ_i, %	rank	Δ_i, %
X_1	Average monthly amount of precipitation in May, mm	1	68.63	1	43.21	1	66.23
X_2	Average monthly relative air humidity in May, %	5	2.14	5	6.39		
X_3	Average monthly relative air humidity in June, %					4	1.90
X_4	Average minimal relative air humidity in May, %	6	1.05	6	3.53		
X_5	Average minimal relative air humidity in June, %					5	1.51
X_6	Total amount of days with precipitation more than 1 mm in May, per day	2	22.10	3	14.47		
X_7	Total amount of days with precipitation more than 1 mm in June, per day					3	11.46
X_8	Difference between average maximal and minimal temperatures in May, °C	3	3.60				
X_9	Difference between average maximal and minimal temperatures in June, °C					7	0.28
X_{10}	Amount of precipitation in the blooming period, mm	4	2.48	7	0.39		
X_{11}	Amount of precipitation during a vegetation period, mm			4	9.22	6	0.82
X_{12}	Average air temperature in a period of fruits picking, °C			2	22.79	2	17.53
X_{13}	Absolute maximal temperature in a period of fruits picking, °C					8	0.26

Conclusion

The fruits of 'Kazka' cultivar were selected by the amount of phenolic substances (203.17 mg 100 g^{-1}) among the cultivars of an early-term of ripening. The cultivars 'Merchant', 'Bigaro Burlat' were selected by the minimal variation index (Vp = 14.2–14.7%). The fruits of 'Rubinova Early' cultivar had the optimal variation indices and the average content of polyphenolic substances (175.27 mg 100 g^{-1}; Vp = 15.0). By the amount of phenolic substances and by their variation, the cultivars of medium and late-terms of ripening – 'Uliublenytsia Turovtseva' (226.85 mg 100 g^{-1} under Vp = 12.6 %), 'Udivitelna' (288.55 mg 100 g^{-1} under Vp = 11.1 %) were the best as to their qualitative technological indices. The weather conditions during the period of research (the impact of factor A 53.3% and 42.5% respectively) had a dominating impact on the formation of phenolic substances fund for all groups of cultivar of an early and late-terms of ripening. The impact of cultivar features was less significant and equalled 19.3% and 29.2% respectively. For the cultivars of a medium-term ripening, the accumulation of phenolic substances was under the impact of cultivar features (factor B) with the degrees of impact of factors A, B for the cultivars (31.1% and 43.2% respectively).

The correlation analysis of the impact of weather factors on the content of the phenolic substance in the sweet cherry fruits of early, medium and late-terms of ripening has been made. The average and strong correlation dependence between 13 weather factors (X_i, $i = 1 - 13$ and the phenolic substances content for the cultivars of sweet cherry fruits of early, medium and late-terms of ripening ($\left|r_{Y_j X_i}\right| \geq 0.55$, $i = 1 - 13, j = 1 - 3$) has been determined. The model of dependence of the accumulation of phenolic substances fund on the impact of weather factors for the groups of cultivar of early, medium and late-terms of ripening was designed based on a principal components method and the method of the least-squares.

The analysis of the degree of impact of each weather factor on the phenolic substances index was made based on designed regression models. The humidity index (average monthly amount of precipitation in May) had a maximal impact on the accumulation of phenolic substances fund for the cultivars of sweet cherry fruits of three terms of ripening. It belonged to rank 1 by the indices of the degree of factors impact on the accumulation of phenolic substances fund Δ_{X1} (from 43.21% to 68.63%). During the period of sweet cherry fruits ripening the greatest impact on the formation of phenolic substances content in fruits had the humidity indices in May (for early ripening and mid-ripening cultivars) and in May (for late-ripening cultivars).

Conflict of interest

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

Author contributions

MS – study conception and design, drafting of the manuscript;
II, MS – author of the idea, guided the research;
II, VM, TT – analysis and interpretation of data and is the corresponding author;
II, VM – acquisition of data, drafting of the manuscript;
VM, AK – performed the literature data analysis and discussion of the results;
TT, AK – critical revision and approval of the final manuscript.
All authors read and approved the final manuscript.

References

Alkadi, H.A. 2020. Review on free radicals and antioxidants. – Infectious Disorders – Drug Targets, 20(1):16–26. DOI: 10.2174/1871526518666180628124323

Bastos, C.A.A., Barros, L., Dueñas, M., Calhelha, R. C., Queiroz, M.J.R.P., Santos-Buelga, C., Ferreira, I.C.F.R. 2015. Chemical characterisation and bioactive properties of *Prunus avium* L.: the widely studied fruits and the unexplored stems. – Food Chemistry, 173:1045–1053. DOI: 10.1016/j.foodchem.2014.10.145

Bieniek, A., Kawecki, Z., Kopytowski, J., Zielenkiewicz, J. 2011. Yielding and fruit quality of Lithuanian sweet cherry cultivars grown under the climatic and soil conditions of Warmia. – Folia Horticulturae, 23(2):101–106. DOI: 10.2478/v10245-011-0015-4

Bureau, S., Renard, C.M.G.C., Reich, M., Ginies, C., Audergon, J.-M. 2009. Change in anthocyanin concentrations in red apricot fruits during ripening. – LWT-Food Science and Technology, 42(1):372–377. DOI: 10.1016/j.lwt.2008.03.010

de la Rosa, L.A., Moreno-Escamilla, J.O., Rodrigo-García, J., Alvarez-Parrilla, E. 2019. Phenolic compounds. In Postharvest physiology and biochemistry of fruits and vegetables (1st ed.) (Eds. E.M. Yahia, A. Carrillo-Lopez). – United Kingdom Duxford: Woodhead, pp. 253–271. DOI: 10.1016/B978-0-12-813278-4.00012-9

de Souza, V.R., Pereira, P.A., da Silva, T.L., de Oliveira Lima, L.C., Pio, R., Queiroz, F. 2014. Determination of the bioactive compounds, antioxidant activity and chemical composition of Brazilian blackberry, red raspberry, strawberry, blueberry and sweet cherry fruits. – Food Chemistry, 156:362–368. DOI: 10.1016/j.foodchem.2014.01.125

Díaz-Mula, H., Castillo, S., Martínez-Romero, D., Valero, D., Zapata, P.J. 2010. Sensory, nutritive and functional properties of sweet cherry as affected by cultivar and ripening stage. – Food Science and Technology International, 15(6):535–543. DOI: 10.1177/1082013209351868

Ferretti, G., Bacchetti, T., Belleggia, A., Neri, D. 2010. Cherry antioxidants: from farm to table. – Molecules, 15(10):6993–7005. DOI: 10.3390/molecules15106993

Fu, L., Xu, B.T., Xu, X.R., Gan, R.Y., Zhang, Y., Xia, E.Q., Li, H.B. 2011. Antioxidant capacities and total phenolic contents of 62 fruits. – Food Chemistry, 129: 345–350. DOI: 10.1016/j.foodchem.2011.04.079

Gujarati, D.N. 2004. Basic Econometrics. (4th ed). – New York: The McGraw-Hill Companies, 1027 p.

Hastie, T., Tibshirani, R., Wainwright, M. 2020. Statistical learning with Sparsity. The lasso and generalization. – Chapman and Hall/CRC, 367 p.

He, F.J., Nowson, C.A., Lucas, M., MacGregor, G.A. 2007. Increased consumption of fruit and vegetables is related to a reduced risk of coronary heart disease: meta-analysis of cohort studies. – Journal of Human Hypertension, 21:717–728. DOI: 10.1038/sj.jhh.1002212

Iglesias, I., Echeverría, G., Lopez, M.L. 2012. Fruit color development, anthocyanin content, standard quality, volatile compound emissions and consumer acceptability of several 'Fuji' apple strains. – Scientia Horticulturae, 137:138–147. DOI: 10.1016/j.scienta.2012.01.029

Ivanova, I., Kryvonos, I., Shleina, L., Taranenko, G., Gerasko, T. 2019. Multicriteria optimization of quality indicators of sweet cherry fruits of Ukrainian selection during freezing and storage. Modern development paths of agricultural production (Ed. V.

Nadykto). – Springer, Cham. p. 707–717. DOI: 10.1007/978-3-030-14918-5_69

Ivanova, I., Serdiuk, M., Malkina, V., Bandura, I., Kovalenko, I., Tymoshchuk, T., Tonkha, O., Tsyz, O., Mushtruk, M., Omelian, A. 2021a. The study of soluble solids content accumulation dynamics under the influence of weather factors in the fruits of cherries. – Potravinarstvo Slovak Journal of Food Sciences, 15:350–359. DOI: 10.5219/1554

Ivanova, I., Serdyuk, M., Malkina, V., Priss, T., Herasko, T., Tymoshchuk, T. 2021b. Investigation into sugars accumulation in sweet cherry fruits under abiotic factors effects. – Agronomy Research, 19(2):444–457. DOI: 10.15159/ar.21.004

Jakobek, L., Šeruga, M., Voća, S. 2009. Flavonol and phenolic acid composition of sweet cherries (cv. Lapins) produced on six different vegetative rootstocks. – Scientia Horticulturae, 123(1):23–28. DOI: 10.1016/j.scienta.2009.07.012

James, G., Witten, D., Hastie, T., Tibshhirani, R. 2013. An Introduction to Statistical Learning with Application in R. – New York: Springer, 426 p.

Karaaslan, M., Yılmaz, F.M., Karaaslan, A., Vardin, H. 2016. Synthesis and accumulation of anthocyanins in sour cherries during ripening in accordance with antioxidant capacity development and chaconne synthase expression. – European Food Research Technolology, 242(2):189–198. DOI: 10. 1007/s00217- 015-2530-y

Kask, K., Jalakas, M. 2004. Winter damages of sweet cherry trees at the Rõhu Experimental Station 1998–2003. – Agraarteadus, 15(2):96–101.

Kutner, M.H., Nachtsheim, C.J., Neter J. 2004. Applied learning regression. (4th ed.). – New York: McGraw-Hill Education, 701 p.

Lakatos, L., Dussi, M.C., Szabo, Z. 2014. The influence of meteorological variables on sour cherry quality parameters. – Acta Horticulturae, 1020:287–292. DOI: 10.17660/ActaHortic.2014.1020.41.

Lakatos, L., Szab, T., Sun, Z., Soltész, M. 2010. The role of meteorological variables of blossoming and ripening within the tendency of qualitative indexes of sour cherry. – International Journal of Horticultural Science, 16(1):7–10. DOI: 10.31421/IJHS/16/1/854

Legua, P., Domenech, A., Martínez, J.J., Sánchez-Rodríguez, L., Hernández, F., Carbonell-Barrachina, A.A., Melgarejo, P. 2017. Bioactive and volatile compounds in sweet cherry. – Journal of Food and Nutrition Research, 5(11):844–851. DOI: 10.12691/jfnr-5-11-8

Li, Y., Zhang, J.J., Xu, D.P., Zhou, T., Zhou, Y., Li, S., Li, H.B. 2016. Bioactivities and health benefits of wild fruits. – International Journal of Molecular Sciences, 17(8):1258. DOI: 10.3390/ijms17081258

Lobo, V., Patil, A., Phatak, A., Chandra, N. 2010. Free radicals, antioxidants and functional foods: Impact on human health. – Pharmacognosy Reviews, 4:118–126. DOI: 10.4103/0973-7847.70902

Lovato, P.E., Hammat, N., Gianinazzi-Pearson, V., Gianinazzi, S. 1994. Mycorrhization of micropropagated mature wild cherry (*Prunus avium* L.) and common ash (*Fraxinus excelsior* L.). – Agricultural and Food Science, 3(3):297–302. DOI: 10.23986/afsci.72708

Nowak, D., Gośliński, M., Wojtowicz, E., Przygoński, K. 2018. Antioxidant properties and phenolic compounds of vitamin C-rich juices. – Journal of Food Science, 83(8):2237–2246. DOI: 10.1111/1750-3841.14284

Pissarda, A., Lateura, M., Baetenb, V., Mageinc, H., Duponta, P., Tabartd, J., Pincemaile J., Keversd, C. 2016. Determination of total phenolic compound content and antioxidant activity in cherry species and cultivars. – Journal of Berry Research, 6:81–91. DOI: 10.3233/JBR-150109

Ponce, C., Kuhn, N., Arellano, M., Time, A., Multari, S., Martens, S., Carrera, E., Sagredo, B., Donoso, J.M., Meisel, L.A. 2021. Differential phenolic compounds and hormone accumulation patterns between early- and mid-maturing sweet cherry (*Prunus avium* L.) cultivars during fruit development and ripening. – Journal Agricultural Food Chemistry, 69(31):8850–8860. DOI: 10.1021/acs.jafc.1c01140

Popescu, S., Velciov, A.B., Riviș, A., Costescu, C., Petolescu, C. 2014. Antioxidant activity and phenolic content of sweet cherries (*Prunus avium* L.) from West and South-West of Romania. – Bulletin UASVM Food Science and Technology, 71(2):215–216. DOI: 10.15835/buasvmcn-fst:10762

Prior, R.L. 2003. Fruits and vegetables in the prevention of cellular oxidative damage. – American Journal of Clinical Nutrition, 78(3):570–578. DOI: 10.1093/ajcn/78.3.570S

Revell, J. 2009. Sensory profile & consumer acceptability of sweet cherries. – MRes thesis, University of Nottingham. 2009. P. 130.

Serdyuk, M.Ye., Ivanova, I.Ye., Malkina, V.M., Kryvonos, I.A., Tymoshchuk, T.M., Yevstafiieva, K.S. 2020a. The formation of dry soluble substances in sweet cherry fruits under the influence of abiotic factors. – Scientific Horizons, 3(88):127–135. (In Ukrainian).

Serdyuk, M.E., Priss, O.P., Haprindashvili, N.A., Ivanova, I.Ye. 2020b. Research methods of fruit, vegetable and berry products. (Ch. 1). – Melitopol: Liuks, 370 p. (In Ukraine).

Serrano, M., Guillén, F., Martínez-Romero, D., Castillo, S., Valero, D. 2005. Chemical constituents and antioxidant activity of sweet cherry at different ripening stages. – Journal Agricultural Food Chemistry, 53(7):2741–2745. DOI: 10.1021/jf0479160

Serrano, M., Díaz-Mula, H. M., Zapata, P.J., Castillo, S., Guillén, F., Martínez-Romero, D., Valverde, J.M., Valero, D. 2009. Maturity stage at harvest determines the fruit quality and antioxidant potential after storage of sweet cherry cultivars. – Journal of Agricultural and Food Chemistry, 57(8):3240–3246. DOI: 10.1021/jf803949k

Skrovankova, S., Sumczynski, D., Mlcek, J., Jurikova, T., Sochor, J. 2015. Bioactive compounds and antioxidant activity in different types of berries. – International Journal of Molecular Sciences, 16:24673–24706. DOI: 10.3390/ijms161024673

Smeriglio, A., Barreca, D., Bellocco, E., Trombetta, D. 2017. Proanthocyanidins and hydrolysable tannins: occurrence, dietary intake and pharmacological effects. – British Journal of Pharmacology, 174(11):244–1262. DOI: 10.1111/bph.13630

Sokół-Łętowska, A., Kucharska, A.Z., Hodun, G., Gołba, M. 2020. Chemical composition of 21 cultivars of sour cherry (*Prunus cerasus*) fruit cultivated in Poland. – Molecules, 25(19):4587. DOI: 10.3390/molecules25194587

Szajdek, A., Borowska, E.J. 2008. Bioactive compounds and health-promoting properties of berry fruits: a review. – Plant Foods and Human Nutrition, 63:147–156. DOI: 10.1007/s11130-008-0097-5

Usenik, V., Fabčič, J., Stampar, F. 2008. Sugars, organic acids, phenolic composition and antioxidant activity of sweet cherry (Prunus avium L.). – Food Chemistry, 107(1):185–192. DOI: 10.1016/j. foodchem.2007.08.004

Vuletić, M.V., Dugalić, K., Mihaljević, I., Tomaš, V., Vuković, D., Zdunić, Z., Puškar, B., Jurković, Z. 2017. Season, location and cultivar influence on bioactive compounds of sour cherry fruits. – Plant, Soil Environment, 63:389–395. DOI: 10.17221/ 472/2017-PSE

Xu, D.-P., Li, Y., Meng, X., Zhou, T., Zhou, Y., Zheng, J., Zhang, J.-J., Li, H.-B. 2017. Natural antioxidants in foods and medicinal plants: Extraction, assessment and resources. – International Journal of Molecular Sciences, 18(1):96. DOI: 10.3390/ijms18010096

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EFFECT OF SEED PRE-TREATMENT WITH PLANT GROWTH COMPOUND REGULATORS ON SEEDLING GROWTH UNDER DROUGHT STRESS

Peipei Jia[1,2], Andrii Melnyk[2], Zhiyong Zhang[1], Sergey Butenko[2], Volodymyr Kolosok[2]

[1]School of Life Science and Technology, Henan Institute of Science and Technology, 90 Hualan St, 453003, Xinxiang, People's Republic of China
[2]Department of Agronomy and Agricultural Technology, Sumy National Agrarian University, 160 Herasima Kondratieva St, 40021, Sumy, Ukraine

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Vastutav autor: Corresponding author: Andrii Melnyk

E-mail: melnyk_ua@yahoo.com

ORCID:
0000-0003-0454-6695 (PJ)
0000-0001-7318-6262 (AM)
0000-0003-1742-1306 (ZZ)
0000-0002-9925-3029 (SB)
0000-0001-5550-6058 (VK)

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ABSTRACT. The experiment aimed to evaluate the effect of different compound regulators on the germination rate, seedling morphology of two mustard (*Brassica juncea* L.) cultivars ('Felicia' and 'Prima') under simulated drought stress with PEG-6000. The eight commercial growth compound regulators (ALBIT, VERMISTIMD, ANTISTRESS, AGRINOS, REGOPLAN, BIOFOGE, STIMULATE, and FAST START) were pretreated seeds at recommended doses. The application of growth regulators promoted the growth of seedlings under drought stress but had no obvious effect on the germination rate of the two varieties. The root fresh weight, total root length, leaf area, stem length, and stem volume in 'Felicia' significantly increased with ANTISTRESS treatment by 24.28, 3.30, 24.70, 19.40, and 30.90%. In addition, the number of lateral roots reached the maximum with AGRINOS and REGOPLAN treatment compared with plants without regulators under drought conditions, which were 135.55 and 121.20%, respectively. For 'Prima', the application of FAST START had a remarkable effect on root fresh weight, total root length, lateral root number and primary root length, root surface area, leaf area, and stem volume by 17.62, 18.12, 211.20, 53.75, 28.57, 15.90, and 32.30%, respectively.

Introduction

As the climate changes, drought is the most important natural factor, which influences plant growth and production. Drought stress caused changes in plant morphology, physiology, and gene expression (Hamidi, Safarnejad, 2010; Khan *et al.*, 2019). Available literature suggested that polyethylene glycol (PEG) can be used to simulate drought conditions and study the effects of drought stress on plants (Bressan *et al.*, 1981; Berg, Zeng, 2006). PEG is an inert long-chain polymer with high molecular weight, which has little effect on cells. Moreover, PEG osmotic stress method has the advantages of being simple, easy to control, good repeatability, and short test cycle.

Plant growth regulator (PGR) shows prominent effects on plant metabolism, resistance, growth, and productivity (Rademacher, 2015; Cao *et al.*, 2017). In current agricultural practice, the commercial growth regulators mainly include (1) Organic components, such as amino acids, humic acid, seaweed extract, organic carbon, acetic acid, sugar alkyd, chitin, chitosan, *etc*. (2) Biological components, such as nitrogen-fixation bacteria, plant growth promoting rhizobacteria, and remediation of contaminated soil microorganisms. (3) Inorganic components, such as iron, boron, calcium, magnesium, silicon, titanium, and other nutrients, and phosphate. (4) Other components, such as plant endogenous hormones. The sugarcane has

shown root improvement (from 60 to 118% in length, and 33 to 233% in surface area) by inoculation with plant growth-promoting bacteria (PGPB) combined with humic substances (Aguiar *et al.*, 2016). A study of cotton showed that the applied plant growth regulators (PGRs) had significant positive effects on the cottonseed yield, plant height, average number of open bolls, and so on (Osman *et al.*, 2010).

Brown mustard is an important cash crop, which has a long history of cultivation as an important oil crop all over the world. Meanwhile, It can also be used as a medicine, which has been proved to have a key role in cancer prevention and bactericidal, and it has attracted more and more attention (Delaquis, Mazza, 1995; Trachootham *et al.*, 2006). Most of the previous studies focused on the effects of a single endogenous hormone or nutrient on plants under drought stress (Gill, Tuteja, 2010; Yavas, Unay, 2016; Arnao, Hernández-Ruiz, 2019). However, there are few studies on the effects of compound growth regulators on the morphology of mustard. The objective of the study was to evaluate the effectiveness of PGRs on the root and shoot morphology of mustard during the seedling stage under simulated drought conditions, which would provide a theoretical basis for the practice of compound growth regulators in mustard and simplify cultivation and management.

Materials and Methods

Plant materials and treatments

Mustard cultivars 'Felicia' and 'Prima' were used in the experiment and were provided by the Department of Agronomy and Agricultural Technology of Sumy National Agrarian University, Sumy, Ukraine. The following the commercial growth regulators were used: ALBIT, VERMISTIMD, ANTISTRESS, AGRINOS, REGOPLAN, BIOFOGE, STIMULATE, and FAST START. PGRs were applied for the pre-treatment of seeds at the recommended dose (Table 1). The same size, healthy seeds were selected and coated with eight kinds of PGRs to cultivate in germination bags. Each treatment contained six germinate bags which were considered six replicates.

Each bag was added with 110 ml distilled water or 10% PEG-6000 (Sigma Chemicals Co., USA) solutions to simulate drought stress. All experiments were conducted in the growth chamber (day/night temperature at 28/20 °C) with the provision of 14 h light (350 μmol $(m^2 \cdot s)^{-1}$) as well as 10 h dark. The germination rate was counted after 2 days of culture, and the growth parameters of root and shoot of 15 seedlings were calculated after 6 days of treatment. The fresh weight of five plants was weighed for one repetition and divided into three replicates.

Statistical analysis

Statistical analysis was performed using one-way analysis of variance (ANOVA) followed by SPSS 22 (IBM, Armonk, NY, USA) with Duncan's multiple range tests ($P < 0.05$). All the collected data were shown as the mean values ± SD (standard deviations). The difference between control and PGR treated groups was denoted by the lowercase letters.

Table 1. Pre-treatment of mustard seeds with different plant growth regulators

Treatment	Producer PGRs, country	PEG 6000, %	Growth regulator concentration, ml t^{-1}
CK1		0	0
CK2		10	0
T1 (ALBIT)	LLC "Research and Production Firm, Albit", Russia	10	30
T2 (VERMISTIM D)	PE "Bioconversion", Ukraine	10	6–8
T3 (ANTISTRESS)	BP "Humintech GmbH", Germany	10	0.68
T4 (AGRINOS)	Agrinos LLC, USA	10	0.15
T5 (REGOPLAN)	Agrobiotech LLC, Ukraine	10	0.25
T6 (BIOFOGE)	Stoller LLC, USA	10	1.5–2.5
T7 (STIMULATE)	Stoller LLC, USA	10	0.5–1.5
T8 (FAST START)	Stoller LLC, USA	10	2.0–2.5

CK1 – distilled water; CK2 – 10% PEG-6000; T1 – 10% PEG-6000 + ALBIT; T2 – 10% PEG-6000 + VERMISTIMD; T3 – 10% PEG-6000 + ANTISTRESS; T4 – 10% PEG-6000 + AGRINOS; T5 – 10% PEG-6000 + REGOPLAN; T6 – 10% PEG-6000 + BIOFOGE; T7 – 10% PEG-6000 + STIMULATE; T8 – 10% PEG-6000 + FAST START.

Results

The effects of PGRs on germination rate under drought stress. As shown in Figure 1, the germination rate of the two cultivars changed under different treatments. In 'Felicia', the germination rate under T1 reached the minimum value (81%) compared to the CK1 (89%), CK2 (87%), and other treatments. The germination rate reached the maximum with T7 and T8, both by 90%, and was higher than normal growing conditions (89%) (Fig. 1A). For 'Prima', the germination rate of T1 (89%), T2 (88%), and T3 (87%) was slightly higher than that of CK1 (83%) and CK2 (85%) (Fig. 1B). Besides, there was a difference between the two cultivars in terms of germination rate. The germination rate of 'Felicia' was higher (89%) than that of 'Prima' (83%) under normal conditions. Although the sensitivity of 'Prima' and 'Felicia' to PGRs was different, the difference was not significant.

The effects of PGRs on fresh weight of mustard under drought stress. The results indicated that drought stress reduced the root fresh weight of 'Felicia' and 'Prima' by 22.22 and 17.93% compared with the CK1 (Fig. 2). The root fresh weight in 'Felicia' increased after the application of T3 and T5 by 24.28 and 17.85%. However, the application of T1 and T2 significantly reduced the root fresh weight of 'Felicia' by 36.43 and 20%, and the root fresh weight of T4 was not different compared with CK2. For the root fresh weight of 'Prima', the application of T5 and T8 was 23.96 and 17.62% higher than CK2. In addition, there was no significant difference between all treatments regarding the shoot fresh weight of 'Felicia' and 'Prima'. Compared with the CK1, the effect of drought stress on root fresh weight

was greater than shoot, indicating that root was very sensitive to drought stress.

The effect of PGRs on root growth of mustard under simulated drought stress. An extensive root system is advantageous to support plant growth during the early crop growth stage and absorb more water from the rhizosphere. Mustard is a straight root system, and its total root length consists of lateral roots and primary root (Fig. 3).

The root system architecture (RSA) was determined by multiple environmental factors. In 'Felicia' and 'Prima', drought stress (CK2) reduced TRL (total root length) by 12 and 15% compared to normal conditions (CK1) (Table 2), although there was no significant difference. For other root parameters, the effects of drought on the two cultivars showed opposite results. Drought significantly reduced lateral root number and primary root length in 'Prima' but not in 'Felicia'. Drought significantly reduced average root diameter and total root volume in 'Felicia', but these indexes were not affected in 'Prima'. The responses of the two cultivars to PGRs were different under drought conditions. In 'Felicia', the application of T3 and T4 significantly increased the total root length by 3.3 and 8.2%, while other treatments were lower than CK2. In addition, the number of lateral roots reached the maximum under T4 and T5 treatment compared with that of CK2, which were 135.55 and 121.20%, respectively. For 'Prima', the PGRs increased the root length and the surface area under drought stress, except for T4 and T7. For lateral root number and primary root length, all regulators showed positive effects, and T8 treatment had the most prominent effect. Notably, the application of T8 had a remarkable effect on the root growth by increasing the root length (18.12%), surface area (28.57%), average diameter (6.06%), root volume (37.76%), lateral root number (211.20%) and primary root length (53.75%).

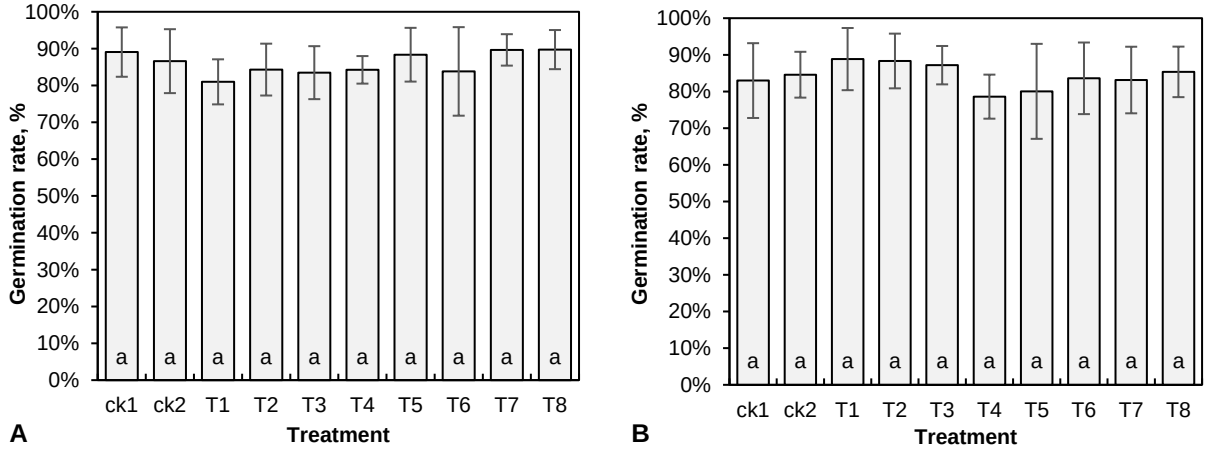

Figure 1. Seed germination rate of mustard under different treatments. A – 'Felicia', B – 'Prima'. CK1 – distilled water; CK2 – 10% PEG-6000; T1 – 10% PEG-6000 + ALBIT; T2 – 10% PEG-6000 + VERMISTIMD; T3 – 10% PEG-6000 + ANTISTRESS; T4 – 10% PEG-6000 + AGRINOS; T5 – 10% PEG-6000 + REGOPLAN; T6 – 10% PEG-6000 + BIOFOGE; T7 – 10% PEG-6000 + STIMULATE; T8 – 10% PEG-6000 + FAST START (similar lowercase letters denote non-significantly different according to Duncan's multiple range test, P >0.05)

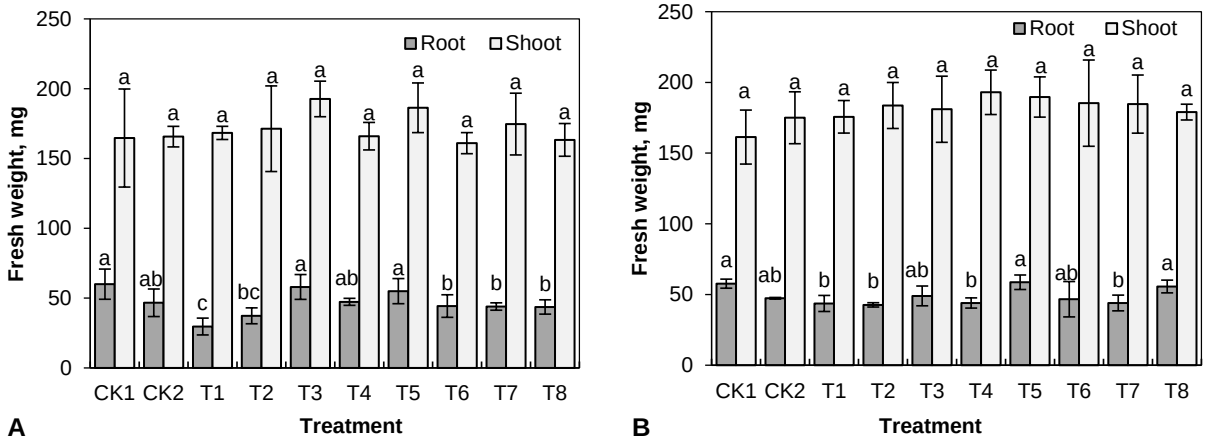

Figure 2. Fresh weight of mustard under different treatments. A – 'Felicia', B – 'Prima'. CK1 – distilled water; CK2 – 10% PEG-6000; T1 – 10% PEG-6000 + ALBIT; T2 – 10% PEG-6000 + VERMISTIMD; T3 – 10% PEG-6000 + ANTISTRESS; T4 – 10% PEG-6000 + AGRINOS; T5 – 10% PEG-6000 + REGOPLAN; T6 – 10% PEG-6000 + BIOFOGE; T7 – 10% PEG-6000 + STIMULATE; T8 – 10% PEG-6000 + FAST START (similar lowercase letters denote non-significantly different according to Duncan's multiple range test, P >0.05)

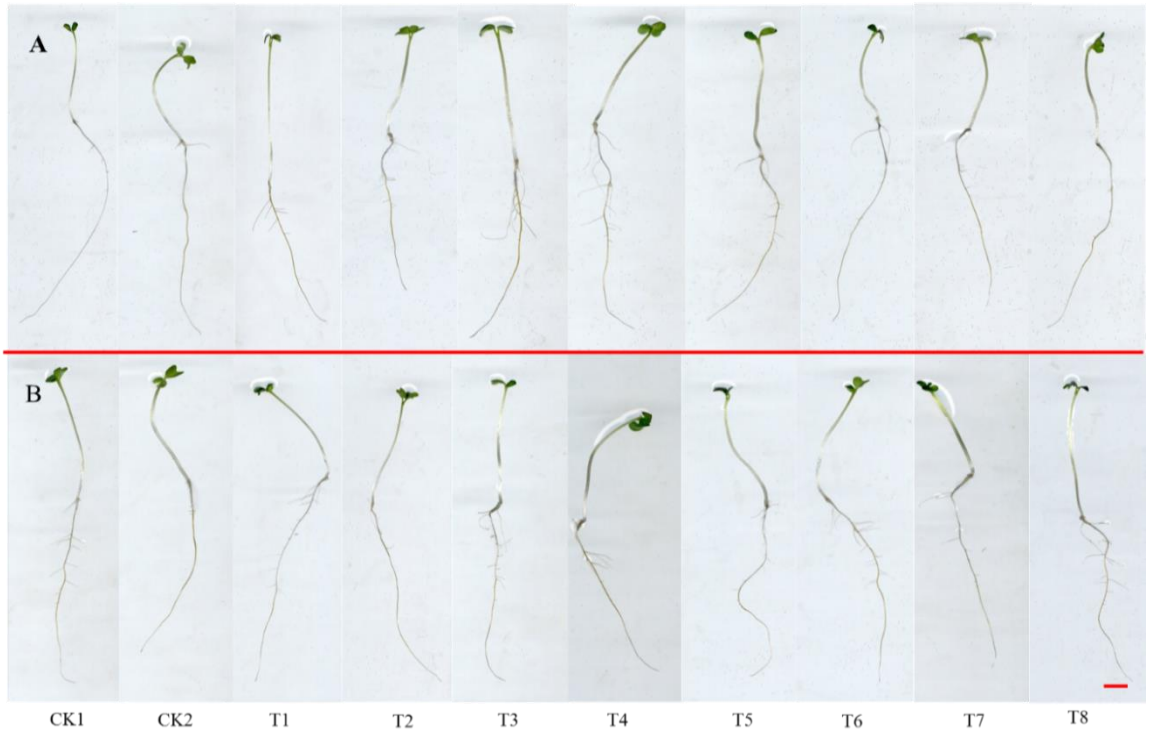

Figure 3. The appearance of the root system under the use of growth regulators. A – 'Felicia', B – 'Prima'

Table 2. Root growth parameters in different experimental setups

Cultivars	Treatments	Total root length, cm	Total root surface area, cm^2	Average root diameter, mm	Total root volume, cm^3	Number of first-order lateral roots	Length of primary root, cm
'Felicia'	CK1	9.18 ± 1.37^{ab}	1.07 ± 0.07^{a}	0.38 ± 0.04^{a}	10.00 ± 1.00^{a}	3.33 ± 0.58^{e}	8.81 ± 0.17^{a}
	CK2	9.01 ± 2.82^{abc}	0.96 ± 0.25^{ab}	0.34 ± 0.03^{bc}	8.20 ± 2.04^{b}	4.67 ± 0.58^{de}	8.42 ± 0.50^{ab}
	T1	7.19 ± 1.35^{c}	0.78 ± 0.14^{c}	0.35 ± 0.03^{bc}	6.67 ± 1.45^{c}	5.33 ± 0.58^{cd}	6.48 ± 0.20^{e}
	T2	7.87 ± 2.34^{abc}	0.84 ± 0.23^{bc}	0.34 ± 0.03^{bc}	7.20 ± 2.27^{bc}	6.33 ± 1.15^{bcd}	7.34 ± 0.36^{cd}
	T3	9.31 ± 2.51^{ab}	0.96 ± 0.22^{ab}	0.33 ± 0.04^{bc}	8.00 ± 2.00^{bc}	7.75 ± 0.96^{b}	7.12 ± 0.54^{cde}
	T4	9.75 ± 2.81^{a}	0.98 ± 0.18^{ab}	0.33 ± 0.04^{c}	7.87 ± 1.13^{bc}	11.00 ± 1.73^{a}	6.94 ± 0.21^{cde}
	T5	8.09 ± 2.30^{abc}	0.90 ± 0.20^{bc}	0.36 ± 0.04^{ab}	7.93 ± 1.71^{bc}	10.33 ± 1.15^{a}	5.68 ± 0.38^{f}
	T6	7.99 ± 2.79^{abc}	0.87 ± 0.24^{bc}	0.35 ± 0.03^{abc}	7.60 ± 1.88^{bc}	5.33 ± 0.58^{cd}	7.72 ± 0.36^{bc}
	T7	7.49 ± 1.61^{bc}	0.88 ± 0.16^{bc}	0.38 ± 0.04^{a}	8.27 ± 1.83^{b}	5.67 ± 0.58^{cd}	7.04 ± 0.65^{cde}
	T8	8.41 ± 2.06^{abc}	0.88 ± 0.16^{bc}	0.34 ± 0.03^{bc}	7.47 ± 0.99^{bc}	6.75 ± 0.96^{bc}	6.61 ± 0.64^{de}
'Prima'	CK1	10.48 ± 2.26^{a}	1.04 ± 0.23^{ab}	0.32 ± 0.03^{ab}	8.33 ± 2.44^{b}	6.00 ± 1.00^{f}	9.47 ± 1.29^{a}
	CK2	8.94 ± 1.89^{ab}	0.91 ± 0.16^{bc}	0.33 ± 0.04^{ab}	7.60 ± 1.80^{b}	3.75 ± 0.96^{h}	5.73 ± 0.23^{c}
	T1	9.13 ± 1.94^{ab}	0.97 ± 0.15^{bc}	0.34 ± 0.05^{ab}	8.33 ± 1.80^{b}	8.75 ± 0.96^{cd}	7.96 ± 0.27^{b}
	T2	9.10 ± 1.57^{ab}	0.91 ± 0.15^{bc}	0.32 ± 0.04^{ab}	7.33 ± 1.72^{b}	7.50 ± 0.55^{de}	6.19 ± 0.39^{c}
	T3	9.91 ± 3.12^{ab}	0.96 ± 0.24^{bc}	0.32 ± 0.04^{b}	7.60 ± 1.59^{b}	10.33 ± 0.58^{ab}	6.36 ± 0.47^{c}
	T4	8.47 ± 2.65^{b}	0.83 ± 0.23^{c}	0.32 ± 0.05^{b}	6.73 ± 2.22^{b}	10.67 ± 0.58^{ab}	5.58 ± 0.50^{c}
	T5	9.11 ± 1.74^{ab}	0.95 ± 0.15^{bc}	0.34 ± 0.05^{ab}	8.07 ± 2.09^{b}	7.80 ± 1.10^{de}	7.53 ± 0.08^{b}
	T6	9.18 ± 3.05^{ab}	0.94 ± 0.24^{bc}	0.33 ± 0.04^{ab}	7.80 ± 1.74^{b}	7.00 ± 1.00^{ef}	7.46 ± 0.27^{b}
	T7	8.39 ± 1.95^{b}	0.85 ± 0.15^{c}	0.33 ± 0.04^{ab}	6.93 ± 1.33^{b}	9.33 ± 0.58^{bc}	6.37 ± 0.47^{c}
	T8	10.56 ± 1.92^{a}	1.17 ± 0.19^{a}	0.35 ± 0.03^{a}	10.47 ± 2.17^{a}	11.67 ± 1.53^{a}	8.81 ± 0.51^{a}

Means ± SD, followed by different lowercase letters are significantly different according to Duncan's multiple range test, $P<0.05$, $n=3$

The effects of PGRs on the shoot growth of mustard under drought stress. For 'Felicia', the PGRs promoted the growth of the shoot under the drought condition, except for the T6 treatment group (Table 3). Leaf area, stem length, and stem volume after the application of T3 increased significantly compared with CK2 by 24.7, 19.4, and 30.9%, respectively. For the shoot growth of 'Prima', the application of T8 significantly increased the leaf area and stem volume by 15.9 and 32.3%, while there was no significant difference between other regulators and CK2.

Discussion

Drought stress is one of the most common abiotic stresses in agricultural production, and with climate change, drought stress becomes more frequent and severe in the world. The application of plant growth regulators is considered an effective strategy to improve plant stress resistance in agricultural production (Ma *et al.*, 2006; Sharma *et al.*, 2016). This study used PEG 6000 to simulate drought stress in mustard seedlings, and different types of PGRs were applied to evaluate the changes in germination rate and growth indicators of root and shoot.

Table 3. Shoot growth parameters in different experimental setups

Cultivars	Treatments	Leaf area, cm^2	Stem length, cm	Stem diameter, mm	Stem volume, mm^3
'Felicia'	CK1	0.94 ± 0.18^{bc}	3.62 ± 0.67^{bc}	0.82 ± 0.05^{a}	19.40 ± 4.32^{ab}
	CK2	0.89 ± 0.15^{c}	3.56 ± 0.67^{c}	0.80 ± 0.07^{a}	17.73 ± 3.13^{b}
	T1	1.03 ± 0.15^{abc}	4.02 ± 0.47^{abc}	0.81 ± 0.08^{a}	21.07 ± 4.62^{ab}
	T2	1.03 ± 0.20^{abc}	4.21 ± 0.92^{ab}	0.79 ± 0.07^{a}	20.33 ± 4.47^{ab}
	T3	1.11 ± 0.17^{a}	4.25 ± 0.68^{a}	0.83 ± 0.06^{a}	23.20 ± 4.02^{a}
	T4	0.97 ± 0.14^{abc}	3.96 ± 0.58^{abc}	0.78 ± 0.04^{a}	19.07 ± 2.94^{b}
	T5	1.06 ± 0.18^{ab}	4.22 ± 0.81^{ab}	0.80 ± 0.07^{a}	21.07 ± 3.86^{ab}
	T6	0.88 ± 0.13^{c}	3.54 ± 0.53^{c}	0.80 ± 0.08^{a}	17.67 ± 3.54^{b}
	T7	1.05 ± 0.24^{ab}	4.14 ± 0.98^{abc}	0.81 ± 0.06^{a}	21.27 ± 5.20^{ab}
	T8	0.98 ± 0.27^{abc}	3.78 ± 0.80^{abc}	0.82 ± 0.09^{a}	20.40 ± 8.45^{ab}
'Prima'	CK1	1.00 ± 0.13^{b}	4.03 ± 0.48^{ab}	0.79 ± 0.05^{a}	19.93 ± 3.28^{b}
	CK2	1.07 ± 0.14^{ab}	4.23 ± 0.47^{ab}	0.81 ± 0.08^{a}	22.07 ± 4.67^{ab}
	T1	1.05 ± 0.19^{ab}	4.06 ± 0.57^{ab}	0.82 ± 0.08^{a}	21.93 ± 5.92^{ab}
	T2	1.04 ± 0.19^{ab}	4.16 ± 0.74^{ab}	0.80 ± 0.08^{a}	20.93 ± 4.70^{b}
	T3	1.03 ± 0.14^{b}	4.15 ± 0.61^{ab}	0.79 ± 0.06^{a}	20.33 ± 3.35^{b}
	T4	1.01 ± 0.33^{b}	3.91 ± 1.15^{b}	0.80 ± 0.12^{a}	21.00 ± 7.37^{b}
	T5	1.15 ± 0.16^{ab}	4.64 ± 0.80^{a}	0.79 ± 0.05^{a}	22.93 ± 3.10^{ab}
	T6	1.13 ± 0.13^{ab}	4.55 ± 0.61^{a}	0.79 ± 0.07^{a}	22.27 ± 3.45^{ab}
	T7	1.14 ± 0.32^{ab}	4.53 ± 1.00^{a}	0.80 ± 0.10^{a}	23.20 ± 9.55^{ab}
	T8	1.24 ± 0.49^{a}	4.51 ± 0.64^{ab}	0.86 ± 0.23^{a}	29.20 ± 24.13^{a}

Means ± SD, followed by different lowercase letters are significantly different according to Duncan's multiple range test, $P < 0.05$

Seed germination is the first stage for plants to endure environmental stress. Growth regulators are used in the pre-sowing seed treatment and play an important role in regulating germination and vigour (Basra *et al.*, 1989). Previous reports suggested that seed germination and seedling vigour depend on the priming method and the concentration used (Kumari *et al.*, 2017). In this study, it has been determined that compound regulator has little effect on the germination rate of 'Felicia' and 'Prima'. This is different from previous reports that growth regulators promote germination rate of wheat (ZeQiong *et al.*, 2019) and rapeseed (Khan *et al.*, 2019). We hypothesized that it may be due to differences in PGRs. On the other hand, mustard is considered a well-adapted crop, and its germination may be related to the genotype and the ability to transform nutrients in the endosperm. To some extent, germination rate is not a good indicator to screen the effects of the regulator on mustard under drought conditions.

Roots are the first organ to sense and respond to environmental factors. In response to stress, root system changes include not only the elongation of primary roots but also the occurrence and elongation of lateral roots (Ötvös *et al.*, 2021). In the present results, although drought did not significantly reduce the total root length of the two cultivars, it did significantly reduce the lateral root number and lateral root number of 'Prima' (Table 2). Furthermore, cultivar 'Felicia' presented no significant response to 10% PEG stress regarding lateral root formation and primary root elongation, but its root diameter and total root volume were significantly reduced by the mimicked drought stress, indicating root thickening was retarded. The results suggest that 'Prima' is more sensitive to drought than 'Felicia'. The PGRs significantly promoted the root growth of cultivated 'Prima' under drought conditions. Not like for 'Prima', T1–T8 treatments did not improve those root parameters for 'Felicia'. These results suggested that PGRs had a positive role against drought on drought sensitive cultivar; on the contrary, for drought non-sensitive cultivar, the PGRs exhibited relatively poor effects against drought. These results indicated the response of mustard to PGRs under simulated drought in the climate chamber, and the evaluation of regulators in field experiments under natural conditions needs to be further verified.

Conclusions

Drought reduced root fresh weight in both cultivars but had no effect on shoot fresh weight and germination rate. There were differences in the inhibition degree of root growth between 'Felicia' and 'Prima' under drought stress. Drought significantly reduced average root diameter and total root volume in 'Felicia', as well as the lateral root number and primary root length of 'Prima'. According to the morphological parameters of roots, 'Prima' was more sensitive to drought than 'Felicia'. The PGRs mitigated the effects of drought on seedlings to some extent, but there were differences between the two cultivars. For drought-sensitive 'Prima', PGRs had a positive role against drought; on the contrary, for drought non-sensitive 'Felicia' the PGRs exhibited relatively poor effects against drought.

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Conflict of interest
The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions

PJ – performed the data analysis and discussion of the results, drafted the manuscript;
AM – studied the conception and interpretation of data, and is the corresponding author;
ZZ – the author of the idea, critical revision, and approval of the final manuscript;
SB, VK –collected data from the field, made literature search and acquisition of data.
All authors read and approved the final manuscript.

References

Aguiar, N.O, Medici, L.O, Olivares, F.L, Dobbss, L.B, Torres-Netto, A, Silva, S.F, Canellas, L.P. 2016. Metabolic profile and antioxidant responses during drought stress recovery in sugarcane treated with humic acids and endophytic diazotrophic bacteria. – Annals of Applied Biology, 168(2):203–213. DOI: 10.1111/aab.12256

Arnao, M.B., Hernández-Ruiz, J. 2019. Melatonin: a new plant hormone and/or a plant master regulator? – Trends in Plant Science, 24(1):38–48. DOI: 10.1016/j.tplants.2018.10.010

Basra, A.S, Dhillon, R., Malik, C.P. 1989. Influence of seed pre-treatments with plant growth regulators on metabolic alterations of germinating maize embryos under stressing temperature regimes. – Annals of Botany, 64(1):37–41. DOI: 10.1007/BF02911565.

Berg van den, L., Zeng, Y.J. 2006. Response of South African indigenous grass species to drought stress induced by polyethylene glycol (PEG) 6000. – South African Journal of Botany, 72(2):284–286. DOI: 10.1016/j.sajb.2005.07.006.

Bressan, R.A., Hasegawa, P.M., Handa, A.K. 1981. Resistance of cultured higher plant cells to polyethylene glycol-induced water stress. – Plant Science Letters, 21(1):23–30.

Cao, F.B., Shan, S.L., Gao, W., Li, Z.B., Zou, Y.B., Zhang, H.D. 2017. Effects of xinqing attapulgite microbial compound fertilizer and conditioning agent on growth and cadmium content in rice. – Tillage and Cultivation, 4:4–6.

Delaquis, P.J., Mazza, G. 1995. Antimicrobial properties of isothiocyanates in food preservation. – Food Technology, 49(11):73–84.

Gill, S.S., Tuteja, N. 2010. Polyamines and abiotic stress tolerance in plants. – Plant Signaling & Behavior, 5(1):26–33. DOI: 10.4161/psb.5.1.10291

Hamidi, H., Safarnejad, A. 2010. Effect of drought stress on alfalfa cultivars (*Medicago sativa* L.) in germination stage. – American-Eurasian Journal of Agricultural & Environmental Sciences, 8(6):705–709.

Khan, M.N., Zhang, J., Luo, T., Liu, J., Rizwan, M., Fahad, S., Hu, L.. 2019. Seed priming with melatonin coping drought stress in rapeseed by regulating reactive oxygen species detoxification: Antioxidant defense system, osmotic adjustment, stomatal traits and chloroplast ultrastructure perseveration. – Industrial Crops and Products, 140:111597. DOI: 10.1016/j.indcrop.2019.111597

Kumari, N., Rai, P.K., Bara, B.M., Singh, I. 2017. Effect of halo priming and hormonal priming on seed germination and seedling vigour in maize (*Zea mays* L) seeds. – Journal of Pharmacognosy and Phytochemistry, 6(4):27–30.

Ma, Q.Q., Wang, W., Li, Y.H., Li, D.Q., Zou, Q. 2006. Alleviation of photoinhibition in drought-stressed wheat (*Triticum aestivum*) by foliar-applied glycinebetaine. – Journal of Plant Physiology, 163(2), 165-175. DOI: 10.1016/j.jplph.2005.04.023

Osman, C., Demirel, U., D, Karakus, M. 2010. Effects of several plant growth regulators on the yield and fiber quality of cotton (*Gossypium hirsutum* L.). – Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 38(3):104–110. DOI: 10.15835/nbha3834588

Rademacher, W. 2015. Plant growth regulators: backgrounds and uses in plant production. – Journal of plant growth regulation, 34(4):845–872. DOI: 10.1007/s00344-015-9541-6

Sharma, A., Kumar, V., Singh, R., Thukral, A.K., Bhardwaj, R. 2016. Effect of seed pre-soaking with 24-epibrassinolide on growth and photosynthetic parameters of *Brassica juncea* L. in imidacloprid soil. – Ecotoxicology and Environmental Safety, 133:195–201. DOI: 10.1016/j.ecoenv.2016.07.008

Trachootham, D., Zhou, Y., Zhang, H., Demizu, Y., Chen, Z., Pelicano, H., Liu, J.S. 2006. Selective killing of oncogenically transformed cells through a ROS-mediated mechanism by β-phenylethyl isothiocyanate. – Cancer Cell, 10(3):241–252.

Ötvos, K., Marconi, M., Vega, A., O'Brien J., Johnson, A., Abualia, R., Antonielli, L., Montesinos J.C., Zhang, Y., Tan S., Cuesta, C., Artner, C., Bouguyon, E., Gojon, A., Friml, J., Gutiérrez, R.A., Wabnik, K., Benková, E. 2021. Modulation of plant root growth by nitrogen source defined regulation of polar auxin transport. – The EMBO Journal. DOI: 10.15252/embj.2020106862

Yavas, I, Ünay, A. 2016. Effects of zinc and salicylic acid on wheat under drought stress. – Journal of Animal and Plant Sciences, 26(4):1012–1101.

ZeQiong, W., Jun C., GuoLiang, H., Yong, L. 2019. Effects of plant growth regulators on germination of black wheat seeds under salt-stress. – Fujian Journal of Agricultural Sciences, 34(3):358–363.

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LÜHIARTIKKEL: MULDKATTE TALITLEMISE PEDOÖKOLOOGILISED SEADUSPÄRASUSED

SHORT COMMUNICATION: PEDOECOLOGICAL REGULARITIES OF SOIL COVER FUNCTIONING

Raimo Kõlli

Eesti Maaülikool, põllumajandus- ja keskkonnainstituut, mullateaduse õppetool, Fr. R. Kreutzwaldi 5, 51006 Tartu

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Vastutav autor: Raimo Kõlli
Corresponding author:

E-mail: raimo.kolli@emu.ee

ORCID: 0000-0002-7725-3757

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ABSTRACT. The contradictory statements and opinions, which need by the mind of author additional explanation or disentangle are in the work followings: stages in the forming soil covers' humus status; additional carbon sequestration into the soil; discord between consumption and accumulation of soil organic matter; the influence of land use, land-use change and soil tillage on soil humus status; permanent and dynamic properties of soil; the role of agriculture in carbon turnover; degradation of soil fertility; the influence of different components of soil organic matter on soil functioning; pedoecological approach of peat soils; biodiversity and species richness of soils; weediness of agroecosystems; ethical statements concerning land use.

Sissejuhatus

Mistahes mullaliik talitleb tema omadustest tulenevate ökoloogiliste seaduspärasuste järgi. Kahjuks vajavad paljud otseselt või kaudselt muldasid puudutavad publitseeritud seisukohad täpsustavaid selgitusi. Nii näiteks ei saa pidada õigustatuks seletada lokaalse muldkattega seotud nähtusi globaalsetele näidetele tuginedes, millised ei pruugi olla adekvaatsed lokaalsetele tingimustele. Spekulatiivsed on ka taolised käsitlused, millistes ei võeta arvesse lokaalseid ökoloogilisi tingimusi ja muldkatte omadusi. Esineb ökosüsteemide käsitlusi, kus muldkatte rolli on täielikult ignoreeritud, teisalt aga selliseid, milliste puhul ei arvestata mullaliikide omaduste erinevusi. Käesolevas töös arutellu võetud mõtted ja käsitlused, kui ka meie poolt toetatavad alternatiivsed seisukohad pärinevad rohkearvulistest kirjanduslikest allikatest ehk legaalsest mullateaduse varasalvest (Lal, 2016; FAO, 2021). Kuigi iga arvustatava teesi kohta oleks võimalik arvukalt lisada nn. digiajastust pärinevaid viiteid, on autoril praktiliselt võimatu sedastada nende teeside algallikaid, mis võivad pärineda hoopiski digiajastu eelsest perioodist. Järgnevalt teeside või võtmesõnade kaupa antud autori poolehoiu pälvinud seisukohad pärinevad samuti valdavas enamuses teaduslikest allikatest. Vaid mõnel juhul ei õnnestunud autoril leida vastavasisulist toetavat publikatsiooni.

Muldkatte huumusseisundi kujunemise etapid

Huumuse sisaldus (antuna kontsentratsiooni või varuna) näitab kõnekalt mulla taimekasvatuslikku potentsiaali ja keskkonna hea seisundi tagamise võimet. Stabiilse huumuse lisandumisega muldkattesse paranevad saagi kujunemiseks vajalikud režiimid ja luuakse muldkeskkond elustiku tegevuseks. Samas on saagi kujunemisel ikkagi kõige olulisim mõjur mulla orgaanilise aine (MOA) voog läbi muldkatte. MOA vooga seotud pedo-ökoloogiliste protsesside käigus varustatakse mullaelustikku eksisteerimiseks vajaliku energia-

ga, vabastatakse varise koosseisus olevaid toiteelemente ning kujuneb sümbioos mikroorganismide ja kultuurtaimede juurte vahel. Huumusseisundile hinnangu andmisel on probleem selles, et ei hinnata vääriliselt MOA voo neid (eelnevalt mainitud) eluliselt tähtsaid protsesse, mille käigus toimuvad biokeemilised reaktsioonid, tegutsevad organismid ja moodustub saak. Kuigi olulist rolli mulla talitlemises ja saagi moodustamises omab ka mulda akumuleerunud stabiilne huumus ja sellega seotud režiimide toimimine, peaks senisest rohkemal määral hindama MOA voo elusorganismide talitlemisega seotud bioloogilist külge võrreldes füüsikalisega, milleks on vee- ja õhurežiimide kulgemiseks soodsa (poorse) muldkeskkonna loomine sh stabiilse huumuse osavõtul organismide tegevuseks sobiva eluruumi loomine ja mulla neeldamisvõime suurendamine. MOA voo bioloogilised ja füüsikalised protsessid erinevad mullaliikide ja maakasutusviiside lõikes.

Süsiniku täiendav akumulatsioon muldkattesse sõltub mullaliigile omasest tasemest

Süsinikuneutraalsuspoliitikaga seoses on üheks lootuseks atmosfääri süsinikdioksiidi võimalikult rohke ladustamine maakasutusvõtete abil stabiilse huumuse kujul muldkattesse. Täiendav süsiniku akumulatsioon mulda sõltub aga muude tegurite kõrval ka mullaliigipõhisest olemasolevast MOA tasemest. Sõltuvalt mullaliigile omasest huumusvarust ja kvaliteedist tuleks iga uue süsinikukoguse akumuleerimiseks mulda rakendada mullaliigiti erinevaid tehnoloogilisi võtteid. Mullaliigile(-erimile) omasest optimaalsest madalama MOA sisalduse, eriti aga kriitilise piiri lähedase madala sisalduse korral, tuleks rakendada MOA sisaldust suurendavaid võtteid: doteerimine orgaaniliste väetisetega, mitmeaastaste heintaimede kasvatamine, liialt sügava künni vältimine jms. Optimaalsest madalama MOA sisalduse korral on täiendava süsinikukoguse lisamine igati võimalik ja vähekulukas. Samas on optimaalsest kõrgema MOA sisalduse korral täiendav deponeerimine raskendatud seoses huumuse akumulatsioonivõime ülempiiri (küllastumise) lähedusega. Ka on sellisel juhul varude kasvatamine kulukam ja eksisteerib risk juurde antava orgaanilise aine kiireks mineraliseerumiseks. MOA optimaalse sisalduse korral tuleks hea tava kohaselt taastada igal aastal kulutatud MOA kogused võimalikult täies mahus.

Kas suurem saak või rohkem stabiilset süsinikku mulda?

Agronoomilise tulemuslikkuse seisukohalt on määrava tähtsusega vegetatsiooniperioodi jooksul toimuvad protsessid haritava maa muldkattes ja nende mõjul moodustunud saagil. Ainete voog saab alguse päikeseenergia abil ja mulla toel moodustunud primaarsest orgaanilisest ainest ehk fütomassist. Teatud osa sellest suundub muldkattesse läbimaks erinevaid põhimõtteliselt ühes suunas kulgevaid etappe alates fütomassi varisest, selle arvel moodustunud mullaelustiku (sh mikroorganismide) biomassi varisest, labiilse huumusega seotud talitlemisest kuni stabiilse huumuse moodustumiseni. Kõigil nendel etappidel kulutatakse teatud hulk energiat heterotroofseks hingamiseks ehk toimub süsinikdioksiidi emissioon.

Keskkonna- ja kliimapoliitika aspektist on põhinäitajaks pikaks ajaks mulda talletatud süsiniku kogus, mis on samas väga oluline ka agronoomilisest aspektist. Muldkatte süsinikuvaru ja selle käibe näitajaid kasutatakse ka erinevate mullakooslustega ja geograafilise päritoluga muldkatete võrdlemisel ning kaasaegse kliimapoliitika tulemuslikkuse hindamisel. Läbi muldkatte toimuva ainevoo käsitlemisel tuleks eraldi tähelepanu pöörata nii protsesside kulgemisele (seire, kaasaaitamine, võimalusel reguleerimine) kui ka tulemitele (saak, mulda deponeeritud täiendav süsinikuvaru). Kliimapoliitika tõstab esile süsiniku deponeerimise, unustades üsna sageli saagikuse. Agronoomia seisukohalt on määravam bioloogiliselt tegus (labiilne) huumus, mis kulutatakse muldkatte talitlemisprotsessidele (energia ja ainete voog, lagunemine ja muundumine, mullaelustiku talitlemine ning fütomassi produtseerimine). See tähendab prioriteedi andmist protsesside kulgemisele. Protsessidest järele jäänud MOA osa ei ole üldsegi mitte väärtusetu jääde, kuna selle rolliks on muldkatte hea struktuursuse ja parema neelamismahutavuse tagamine. Dilemmaks on kas saada suurem saak või talletada rohkem stabiilset süsinikku mulda. Mõlema hüve üheaegne saavutamine on keeruline. Mõistlik oleks püüda saavutada tasakaal kahe nimetatud eesmärgi vahel.

Maakasutuse muutuse mõju mulla huumusseisundile

MOA voos on suured erinevused looduslike ja haritavate muldade vahel. Kui esimesel juhul on süsinikuringed aasta-aastalt suhteliselt ühetaolised, siis agroökosüsteemide süsinikuringed ja vood on inimese vajadusest sõltuvalt muutlikud. Aineringed on erinevad mitte üksnes maakasutusviiside vaid ka mullaliikide lõikes. Kritiseerimist vääriv on üksnes süsinikupoliitikast johtuv soovitus haritavate maade asendamise kohta rohumaade ja metsadega. See soovitus ei arvesta kahjuks üsna sageli muldade kasutussobivust, ega seda, et mullaliikide kooslused on kõlvikute lõikes suuresti erinevad. Ignoreerides nende kolme kõlviku muldade taksonoomilise koosseisu erinevusi, võrreldakse ekslikult võrreldamatuid nähtusi.

Eestis on metsamaaks enamjaolt jäetud põlluks ja rohumaadeks vähesobivad või piirkonna madalama viljakusega mullad, kusjuures enamasti on nendeks alaliselt liigniisked mineraalmullad ja valdav osa turvasmuldadest. Parasniiskete mineraalmuldade huumusseisund erineb mitte ainult turvas- ja turvastunud muldadest, vaid ka niisketest ja kuivendatud gleimuldadest. Kui haritavateks muldadeks on valitud enamasti parasniisked või ka kuivendatud niisked mullad, siis suurem enamus rohumaid asub ikkagi suuresti erineva huumusseisundiga niisketel ja märgadel muldadel. Siit

järeldub, et rohumaamuldade suurem huumusevaru ei tulene mitte suuremast varise hulgast, vaid hoopiski ringe stagneerumisest liigniiskuse mõjul. Seega tuleks erinevate kõlvikute muldade huumusseisundi hindamist ja võrdlust teha ikkagi mullaliikide kaupa, millisel juhul (meie uurimustele toetudes) usutavaid maakasutusest tingitud erinevusi MOA pindtihedustes (t ha^{-1}) ei esine (Kõlli jt, 2010).

Mulla püsi- ja dünaamilised omadused ning mullavälised tegurid

Mulla ainelisest koostisest tulenevad püsiomadused (mineraalse osa lõimis, keemiline potentsiaal, huumushoiuvõime) fikseeritakse praktika jaoks piisava detailsusega mullaerimi määramisega. Muldade talitlemise dünaamiline aspekt on kooskõlas mullas elavate organismide ja mullal kasvava taimkattega. Muldkatte talitlemist mõjutavad tublisti ka mullavälised keskkonnatingimused (soojusressurss, sademed, veeolud, pinnamood) ja maakasutuse viisid. Mullaliigi MOA majanduse (kogum MOA bilansi, talitlemise, seisundi jms seotud nähtustest) hinnang tuleks anda seostatult regiooni mullatekke- ja meteoroloogiliste tingimustega. Muldkatte talitlemise mõistmiseks ja otstarbeka kasutuse huvides on vaja teada nii mulla püsi- ja dünaamilisi omadusi, kui ka muldkatteväliseid mõjusid mullaliikide (-erimite) tasemel. Manipuleerimisele alluvad vaid mulla dünaamilised omadused ja välistest teguritest maakasutuse viisid. MOA otstarbeka majandamise rusikareegel kajastub adekvaatselt selle võrdlusest töömehe päevatööga. Olgu mees kõhn (muld optimaalsest madalama huumusvaruga) või kogukas (optimaalsest kõrgema huumusevaruga) on kõige tähtsam ikkagi see, et ta on korralikult toidetud (mulda on tagastatud kulutatud varud).

Põllumajanduse roll süsinikuringes

On kurb tõdeda, et süsinikneutraalse keskkonnapoliitikaalastel aruteludel nähakse üsna sageli põllumajanduslikus tegevuses üksnes süsiniku suurenenud emissiooni põhjustajat. Ühekülgse ehk pooliku käsitluse asemel oleks õigem vaagida tasakaalu kahe vastandliku suuna, süsiniku ökosüsteemi sidumise ja selle emissiooni vahel. Süsinikuringest osalise väljavõtu tulemiks on ühelt poolt saak, teiselt poolt aga täiendava süsinikukoguse mulda deponeerimine. Õigetel (agro)ökoloogilistel alustel kavandatud külvikordade süsiniku sisend- ja väljundvood on paljuaastate keskmisena tasakaalus, nii saagi kui huumuse deponeerimise osas. Seega ei ole valdavatel juhtudel õige nimetada põllumajanduslikku tegevust bioloogilisest aspektist süsiniku emissiooni suurendavaks teguriks.

Teatavasti kulgeb ökosüsteemi seaduspärane areng produktsiooni maksimeerimise suunas. Piduriks või vastutöötavaks teguriks sellele on klimaatiliste ja mullastiku tingimuste sobimatus ning mitteadekvaatne majandamine. Juhul kui toetatakse (subsideeritakse) lokaalsetele tingimustele aldis tootmist, vähendatakse või välditakse kadusid ja soodustatakse võimalikult suurema hulga fütomassi produtseerimist, tagatakse nii suurem saagikus, kui luuakse ka eeldused muldkatte süsinikuvarude suurendamiseks.

Maaharimisvõtete mõju mulla huumusseisundile

Harimissügavuse vähendamine minimaalse harimisega toob kaasa MOA sisalduse kasvu pealmises 0–10 cm mullakihis, kuna maapealse varise sissetulek kontsentreerub vaid sellesse kihti. Huumushorisondi alumine osa saab uue ainena vaid siin paiknevate juurte jäänused, mille tõttu siit tehtud kulud jäävad kompenseerimata. Samal ajal laguneb MOA intensiivsemalt pealismulla õhukeses haritud kihis tänu paremale õhustusele võrreldes künnipõhise maaharimisega. Vaatamata huumuse kontsentratsiooni diferentseerumisele künnikihis ei suurene enamjaolt usaldusväärselt huumuskatte MOA koguvarud. Seega ei ole pädev väide, et minimaalne mullaharimine suurendab mulla huumuse varu.

Mullaviljakuse degradeerumine

Laialdaselt on levinud arvamus, et muldade viljakus väheneb jätkuvalt nende huumusesisalduse vähenemise tõttu. See arvamus võib Eestis olla tõene vaid mõningate põllumullaliikide puhul nende ebaõige (agroökoloogilisi põhimõtteid ignoreeriva) kasutuse tingimustes, kuid on täiesti kaheldav metsa- ja rohumaamuldades. Nõustuda ei saa ka sellega, et metsamuldade huumusehoiuvõime on põllumuldadest suurem. Mõlemad seisukohad vajaksid täpsustavaid selgitusi. Õigustatud on vaid sama liiki parasniiskete ja niiskete metsa- ja põllumuldade huumushorisontide võrdlus, milliste huumusprofiilis A horisont on olemas. Tegelikult on viljakad ja selgesti väljakujunenud huumushorisondiga mullad võetud suures enamuses põllumajanduslikule kasutusele. Kui taolised viljakad mullaliigid moodustavad põllumaast *ca* $^{2}/_{3}$, siis metsamaast vaid $^{1}/_{5}$. Meie uurimuste järgi on ühenimeliste mullaliikide huumusvarud praktiliselt võrdsed nii metsa- kui põllumaana kasutamisel (Kõlli jt, 2010). Üldreeglina ei ole huumuse kontsentratsioon sobivaks metsamulla huumusseisundi näitajaks. Kuigi metsamuldade A horisondi huumuse kontsentratsioon on tavaliselt kõrgem põllumullast, on nad samal ajal aga õhukesemad ja väiksema lasuvustihedusega. Metsamuldade huumusseisundit ei iseloomusta kuigi hästi ka huumuse varu. Hoopiski suurem tähtsus on siin pidevalt mulla pinnale ja mulda variseval värskel orgaanilisel ainel (varisel) ja selle muundumisel tekkinud eelhuumusel. Vaid varise (kui mulla energiaallika) toimel käivituvate laguahelate mõjul tagatakse mulla ökoloogiliselt otstarbekas ja kestlik talitlemine koos taimse massi produtseerimisega. Mida otstarbekamalt MOA-t kasutatakse, seda suurem on produktiivsus.

MOA koostisosade talitluste erisused

Mullaliikide eristamiseks MOA rolli järgi ei piisa üksnes MOA kontsentratsiooni ja varu määramisest. Detailseim lähend huumusseisundile eeldab MOA

käsitlemist koostiskomponentide kaupa ja nende talitluste tundmist. Aegade jooksul on kasutatud väga mitmesuguse detailsuse ja põhimõttega MOA jaotusi. Näiteks huumuse fraktsioneerimine keemiliste reaktiivide abil ning jaotamine humifikatsiooni ja lagunemisastmete järgi. Praegu peetakse kõige informatiivsemaks MOA jaotamist tema oleku, mullaelustikuga seonduvate talitluste ja mullas paiknemise ning lagunemisele vastupidavuse järgi. Eraldi käsitlust leiab lagunemisele kergesti alluv taimne varis, mis muundub nõrgalt happelises ja neutraalses muld-keskkonnas bakterite mõjul, happelises aga mikroseente abil. Lagunemist-muundumist kiirendab ensüümide esinemine varises. Aktiivseteks komponentideks MOA-s on mikroobse ja sellest suurema dimensiooniga mullaelustiku bio- ja mortmassid ning mullaelustiku poolt peenestatud, ekskrementideks muudetud ja osaliselt humifitseerunud osised. Pikaaegsemalt säilivad huumushorisondis mineraalse osaga seotud organo-mineraalsed kompleksid ning peene liiva ja tolmu osistele kinnistunud (tõeline) huumus. Toorhuumuslikes horisontides domineerib veega konserveeritud pooleldi lagunenud varis. Püsiv MOA on ka lagunemisele vastupidav osa taimsest ja loomsest varisest ning füüsiliselt kaitstud (kas struktuuriagregaatide sees või ladestunult tugevasti peenestunud mineraalsete osiste pinnale) osaliselt humifitseerunud MOA. Kauapüsiv stabiilne MOA (tõeline huumus) võib mullas püsida aastasadu tänu sobimatuse tõttu organismide toiduks, kinnistumisele savimineraali kihtide vahele või esinemisele inertse söena. Lisaks öeldule võib MOA esineda lahustunud kujul mullalahuses koostises.

Optimaalne bioloogiline mitmekesisus ja liigirikkus

Sageli on arusaam bioloogilise mitmekesisuse ökoloogilistest seaduspärasustest muldkattes ja ökosüsteemides mitteadekvaatne. Huumusseisundiga seotud talitluste mõistmisel on vähe abi praegusel ajal ehk liialt ületähtsustatud liigirikkuse andmetel (*à la* mida rohkem liike seda parem). Tegelikult on optimaalne seisund siis kui on tagatud mullaliigipõhiste talitluste täitmiseks vajalike organismikoosluste olemasolu ja võimalus nendega seotud toiteahelate talitlemiseks. Looduslike protsesside kulgemises on üsna tavaline, et suurema osa süsteemi taim-muld toimimiseks vajalikest seaduspäraselt järgnevatest talitlustest teeb ära teatud väike osa liikidest. Läbi loodusliku muldkatte toimuva MOA voo aluseks on taimse varise mulda tulek, selle lagundamiseks-muundamiseks vajalike heterotroofsete mikroorganismide olemasolu, redutseerijate talitlemist kontrollivad organismid (kiskjad) ja soodsat muldkeskkonda loovad organismid (insenerid). Ka haritavate muldadel rakenduvad looduslikega sarnased põhimõtted, kuid seejuures võivad suurel määral erineda sarnaseid talitlusi (ökoloogilisi nišše) täitvate organismide liigid. Üldiselt ei ole MOA mineraliseerumise-humifitseerumise järjepidevuse read lineaarsed. Pigem on tegemist toiteahelate võrgustikega, kus mullaliikide lõikes täidavad sarnaseid funktsioone erinevad organismide kooslused. Mistahes mulla orgaanilise aine voo toimimine on tagatud siis, kui toitumisahelate võrgustikus on olemas MOA lagundajad, nende arvukust reguleerivad (nendest toituvad) organismid ning muldkeskkonna ülesehituse ja režiimide kujundajad. Süsteemi toimimiseks on vajalik optimaalne mitte aga võimalikult maksimaalne bioloogiline mitmekesisus.

Liigirikkuse piiritu maksimeerimise taotlus vajab täiendavaid seletusi. Nimelt on muldkattes tegutsevate organismide populatsioonid loodusliku kasvukoha- või mullaliigi-spetsiifilised. Põllumullas saab talitleda hoopis teistsugune, muldade harimisele vastupidav, mullaelustiku kooslus. Loomulikult on põllumullas vähenenud ja teisenenud looduslikule mullale omane liigirikkus. On üldteada, et mullas toimetavate organismide kooslused erinevad nii globaalsel ja regionaalsel tasemel, nii mullaliigi kateenade ja mullaprofiili horisontide suhtes, kui ka struktuuriagregaatide läbilõikes. Vastavalt mulla omadustele võivad ühes mullaliigis domineerida MOA lagundajatena bakterid, teises mikroseened, millega seostuvad ka järgnevad toitumisahela lülid. Seega tuleks mulla liigirikkust käsitleda muldkattes esinevate mullaliikide põhiselt.

Parema arusaamise otstarbel vajab praktika senisest rohkem teavet elusorganismide koosluste dominantide ja nende autökoloogia kohta mullaliikide kaupa. MOA ökoloogia põhjalikumat käsitlust piiravad vähesed teadmised mullaelustiku erimipõhise koosseisu ja ökoloogia kohta. Praktiline põllumajandus ei saa olulist abi terviklikust mullas olevate liikide nimekirjast, hädavajalik oleks hoopiski dominantliikide määramine ja nende ökoloogilise talitluse selgitamine erinevate mullaliikide lõikes kuna mulla saatus oleneb peamiselt ikkagi piiratud arvust organismidest. Üksnes seni hästiuuritud vihmausside ökoloogia tundmine ei selgita kaugeltki piisavalt MOA rolli mullas.

Turvasmuldade pedoökoloogiline käsitlus

Analüüsides turvasmuldade omadusi ja ökoloogiat mullateaduse aspektist, tuleks piirduda vaid turvasmuldkattega, mis moodustab Eesti tingimustes turbalasunditest vaid pealmise *ca* 50 cm tüseduse elusorganismidega ökoloogilistes suhetes oleva turbakihi. Ei ole õige käsitleda (turvas)mullana tihti kuni 5−6 meetrini ulatuvat turbalasundit, mis on tegelikult mittefossiilne maavara. Deklareerides kogu turbalasundi orgaanilist ainet ja temas sisalduvat süsinikku muldkatte osana saame ebaadekvaatselt suurendatud orgaanilise süsiniku varud soomuldi sisaldavate muldkatete kohta. Turvasmuldkattes eristub omakorda (sarnaselt mineraalsete muldadega) ainete ringes aktiivselt osalev viimaste aastate turba kasvukiht ehk turvas-(huumus)kate, mille osaks on ka pindmine varise kiht. Meie arvates tuleks turvas(huumus)katte alastes ökoloogilistes uurimustes piirduda pealmise 30 cm tüseduse kihiga.

Umbrohtumine

Agroökosüsteemide umbrohtumise, kui saaki kahjustava nähtuse, vältimine on põllumehele suurt kulu nõudev tegevus. Eksisteerib selge vastuolu umbrohtude rohke fütomassi ja mitmekesisuse ning põhikultuuri saagi vahel. Üldreeglina on mistahes kultuuri puhul aktsepteeritav vaid väike alla surutud umbrohtude lisandus. Muret tekitab külvamata põlluribade (tegelikult kui umbrohtude seemnepeenarde) kasutusele võtmise propageerimine. Selles osas peaksid propageerijad minema edasi süvitsi. Naiivne oleks siin loota mullaliigile ja tolmeldavatele putukatele sobiva taimkatte iseeneslikku kujunemist. Selles osas saaks toetuda nn kontrollitud mitmekesisuse põhimõtetele. Umbrohtude leviku minimeerimise huvides peaksid mitmekesisuse taotlejad soovitama ka mullaerimile sobilikke taimkatte ribade segusid ja tutvustama nende rajamise tehnoloogiaid. Vaid ühest aspektist lähtuv soovitus ei pruugi olla sobiv praktikasse rakendamiseks.

Maa ja mullaga seotud eetilised aspektid

Põlispõldude (pärandpõldude) muldadesse on aegade jooksul maetud palju meie esivanemate higi ja vaeva, kuid samas on muld olnud ka mistahes lokaalse ala või kogu riigi elukorralduse ja toidutootmise garant. Põlispõldude viljakust on kergem suurendada võrreldes uudismaa mulla samale tasemele aitamisega. Põliste põllumuldade (kui samas ka piirkondlikult viljakamate muldade) roll on paljudes riikides esile tõstetud, muutes seadusandlust nende säilimist soodustavas suunas. Selle läbi on tagatud ka ühiskonna isevarustatuskindlus vajalike toidu, sööda ja tehniliste kultuuridega. Samas on viljakamate muldadega alad põhjustanud kogukondade koondumise nendele aladele ning sellest tuleneva suurema tootmisvajaduse ja kahjuks ka nendest aladest märkimisväärse osa kadumise ehituste alla. Nii on tootmispõllud paratamatult nihkunud vähemsobivate muldadega alade suunas. Vältimaks veelgi intensiivsemat ehituste valgumist viljakatele muldadele peaks väärtuslikud põllumullad võtma riikliku kaitse alla ka Eestis.

Maaparandusobjektide põlu alla võtmine ei ole valdavas osas õigustatud. Eestis on piirkondlikult palju märgade muldadega alasid, kus põllumajandust on raske arendada ning ilma maade kuivenduseta kaotab maaelu seal oma sisu. Teiselt poolt on taunimist väärt tegevused, mis hävitavad või lagastavad eelnevate põlvkondade tehtud töid. Taoline tegevus ei ole paljudel juhtudel mõistlik. Õigem oleks edasi minna ökoloogiliselt ratsionaalsel viisil, taotledes harmoonia saavutamist looduse ja inimtegevuse vahel, mitte aga püüda käesolevaks ajaks väljakujunenud seisundeid tagasi pöörata endiste aegadega sarnasteks.

Huvide konflikt / ***Conflict of interest***

Autor kinnitab, et antud töös puudub rahalistest ja personaalsetest tõekspidamistest lähtuv huvide konflikt.
The author declares that there is no conflict of interest regarding on financial and personal beliefs in this work.

Autorite panus / ***Author contributions***

RK – töö kõik osad (idee, kirjandusallikatest seisukohtade arvamuste otsimine ja analüüs, käsikirja kirjutamine ja lõplik vormistus) on tehtud autori poolt ainuisikuliselt.
RK – all parts of the work (idea, searching for and analyzing opinions from literature sources, writing the manuscript and final formatting) are done by the author alone.

Kasutatud kirjandus

Kõlli, R., Köster T., Kauer, K., Lemetti, I. 2010. Pedoecological regularities of organic carbon retention in Estonian mineral soils. – International Journal of Geosciences, 1:139–148. DOI: 10.4236/ijg.2010.13018

Lal, R. 2016. Encyclopedia of Soil Science. (3rd ed.). – CRC Press, Boca Raton, USA, 3068 p. DOI: 10.1081/e-ess3

Posters of the Global Soil Partnership, FAO 2021; [cited 2021 July 16]. Available from https://www.facebook.com/hashtag/soildoctors#

Short Communication: Pedoecological regularities of soil cover functioning

Raimo Kõlli
Chair of Soil Science, Institute of Agricultural and Environmental Sciences, Estonian University of Life Sciences, Fr. R. Kreutzwaldi 5, 51006 Tartu, Estonia

Summary

The work is dedicated to the analysis of contradictory statements and opinions found in pedoecological scientific publications. The subject matter of the author's statements is distinguished by short theses or keywords in form of subtitles. In the author's opinion, the humus status of soil cover should be analysed by the stages of its formation. By the author's researches, the additional sequestration of carbon into the soil depends to a great extent on the existed soil organic carbon content in the soil. As it has existed discord between consumption and accumulation of soil organic matter, is almost essential to reach optimal equilibration between these opposite processes. In two subdivisions of the work the influence of land use, land-use change and soil tillage on the soil humus status is treated. In analysis, the role of agriculture in carbon turnover should be taken into account not only carbon emission but also its sequestration by agroecosystems, in which cases rather long-lasting equilibration exists between carbon emission and sequestration. The intensity of soil cover degradation by the loss of soil organic carbon seems to be in general lines not true in Estonian pedoecological conditions, which is proved by the absence of downgoing trends in soil organic carbon contents in most agriculturally used soil species. Besides mentioned above in the work are treated as well the influence of soils' permanent and dynamic properties and different components of soil organic matter on soil functioning. Author's opinion is that as real soil

cover (here peat soil cover of peatlands) should be treated only superficial 50 cm layer of peat deposits, but the peat deposited deeper from soil cover, is by its essence a natural fossil resource. For the best functioning agroecosystems, it should have soil type-specific optimal biodiversity and species richness, and minimal weediness. Treated are as well connected with land use ethical statements.

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DYNAMIC MODEL OF SEED GERMINATION ON THE EXAMPLE OF A GENUS *Dracocephalum* L. BASED ON LOGISTIC FUNCTION

Andrei Komarov[1], Nadezhda Naida[2], Edvin Nugis[3]

[1]Agrophysical Research Institute, St. Petersburg, Grazhdansky Prospect 14, Russia
[2]Saint-Petersburg State Agrarian University, Pushkin, Peterburgskoe shosse 2, Russia
[3]Estonian Crop Research Institute, J. Aamisepa 1, 48309 Jõgeva vald, Estonia

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Vastutav autor: Corresponding author: Edvin Nugis

E-mail: edvin.nugis@mail.ee

ORCID:
0000-0003-1430-0509 (AK)
0000-0002-3909-4353 (NN)
0000-0003-4444-7114 (EN)

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ABSTRACT. The aim of this paper is to present the use of mathematical model for an assessment of seed germination on the example of a genus *Dracocephalum* L. based on logistic function. An assessment of the quality of seeds and their species specificity was carried out. For this the method of a mathematical model of seed germination and the "Origin Pro" application package was used. The objects of research were samples of species *Dracocephalum* L. of different geographical origin from the collection of the I.N. Vavilov named All-Russian Crop Research Institute (VIR). Morphometric parameters of seeds of the studied species of the genus *Dracocephalum* L. were identified, which were divided into two groups. The first group with small seeds (2.7–3.0 mm long and 1.6–2.0 mm wide) included varieties of the species *D. moldavica*, and the second group – with very small seeds (2.0 mm in length and 1.0 mm wide) of *D. multicaule* and *D. nutans*. To assess the quality of seeds, we used both standard static indicators for germination, germination energy and seed vigour which are also assessed by both known the Grodzinsky bio test, and new ones based on dynamic parameters for evaluating seed germination. The dynamic model presented in the work reproduces changes in the initial phase of plant growth through the dynamics of seed germination. That is, the change in the state of a living object in motion in this model. When processing the results, a logistic function was applied that reflects the dynamics of change or accumulation of quantitative signs with the transition to new qualitative indicators. It was revealed that the shortest germination time of half of the maximum number of germinated seeds (intensity of germination) equal to 44.0 hours had the sample K-6 ('Aroma-2'). This indicates vigourous and friendly germination of the seeds of this variety. For sample K-7 ('Aroma-2'), this figure is 60 hours and, therefore, the germination rate is less than that for K-6. Similar in these parameters and the intensity of germination in the sample K-8 'Zeya' equal to 53 hours. Sample K-10 ('Arhat') was characterized by a relatively high germination rate, intensity of germination equal to 46 hours. Samples at 32 (*D. nutans*) and at 20 (*D. multicaule*) had approximately the same intensity of germination was equal to 61 and 54 hours, respectively. As a result, comparing the similarly different age characteristics of the seed material, a certain species and variety specificity in the dynamics of growth processes in the seeds of various types of snake head was revealed. The novelty of these studies was the search for new patterns and phenomena in assessing the quality of seeds and their species specificity.

Introduction

It is known that one of the important problems in crop production is the assessment of the quality of planting material, and in the field of agriculture – assessment of the quality of soil and agricultural technologies using bio tests (McDonald, 1998; Komarov, 2002, Nugis *et al.*, 2021). The existing criteria for assessing the quality of seed material are mainly based on determining the indicators of their germination and germination energy (Perry, 1978; Taylor, 2003). Laboratory germination and germination energy are measured by germinating seeds on substrates or on sand in growers with strictly regulated environmental conditions for a fixed time for each type of seed. That is, these scoring parameters are based on standard static metrics. So, for example, for common wheat (*Triticum vulgare* L.). Host germination energy is determined on the 3rd day, and the germination capacity on the 7th day (Hampton, 2002).

As our early research showed (Komarov, 2002), one of the most informative indicators of seed quality based on static indicators is the assessment of seed vigour. The essence of this method, also known as the method of biological samples (Grodzinsky bio test), is described in detail by the author himself (Grodzinsky, 1991). This indicator was used to assess a number of crops, including – *Carthamus tinctorius* L. (Ghassemi-Golezani *et al.*, 2016); *Brassica napus* L. (Amirmoradi, Feizi, 2017; Gu *et al.*, 2019), *Oryza sativa* L. (Ibrahim, Ikhajiagbe, 2021), *Zea mays* L. (Han *et al.*, 2018) and others. An assessment of the influence of various factors on the germination of seeds of various plants is also shown in the works of (Baghel *et al.*, 2019), both for maize seeds (*Zea mays* L.) and for other citation species (Sabelli, Larkins, 2015; Wei, Huang *et al.*, 2018). However, all these methods have one thing in common, which is that the assessment of both the strength of growth and germination is based on static indicators. That is, these estimates are fixed by the time the indicator is determined which contradicts the dynamics of the development of living matter, such as the seeds of living plants. In this regard, the opinion was formed (McDonald, 1998; McDonald, 1999; Ellis, Roberts, 1980; Hampton, 2002) that it is almost impossible to develop any standard methods for assessing the quality of plant seeds for various reasons (prolonged ripening and germination periods, the presence of a dormant period, ecological diversity of species, *etc*.). For these reasons, the quality and viability of seeds of various species have to be determined empirically for each batch of seeds, both immediately before sowing and at various stages of storage. Such routine, but necessary activities, require colossal time and money, limit the creative potential in the search for new patterns and phenomena (Anikina *et al.*, 2021).

At the same time, seeds are living organisms and for them (as for all living organisms) a change in state over time is inherent (growth rate, growth force, germination energy and even germination). Therefore, it would be very tempting to move from static indicators to dynamic ones, which describe the change in the state of the biological system (seed) in time. To substantiate the transition from static to dynamic indicators of seed germination was used. The purpose of these studies was (using the example of the genus *Dracocephalum* L.) to assess the possibility of using a dynamic method for assessing seed germination. To determine the species specification of the genus *Dracocephalum* L., the transition from static to new dynamic parameters were presented. The presented model reveals the possibilities for the development of a method for assessing the quality of seeds of other crops.

Methods

Concerning determination of the bio test parameters a sufficiently large number of seeds (100–200 paces) were used (Grodzinsky, 1991). The seeds were placed in Petri dishes. The bottom of the dishes was previously covered with a layer of filter paper. The seeds evenly placed on the surface of the cup with distilled water were moistened. The volume of water was determined by the number and weight of the analysed test plants. Once the seeds had germinated, the interval between the counting of seeds of each batch was counted which were selected taking into account the intensity of their initial germination processes. The counting of germinated seeds until 50% germinated in the control variant (seed treatment with water) was carried out. The conditions and method of the experiment were based on the assessment of both the parameters of standard static indicators of seed germination and using a dynamic model of seed germination. The parameters of standard static indicators of seed germination by the International Seed Testing Association – ISTA (ISTA, 2021; Handbook, 1995) were developed.

The most common test for germination and seed germination energy as the main parameter of static indicators was used. In addition to standard methods for assessing the dynamic indicators of seed germination was used (Vitkovskaya, 2015; Chetyrbotskiy, Chetyrbotskiy, 2020).

The experiment to assess the dynamics of seed germination was set up in accordance with various regulations (ADSA, 1993; Handbook, 1995; ISTA, 2021). The objects of research were samples of *Dracocephalum* L. species of different geographic origin from the collection of the VIR (All-Russian Crop Research Institute) (Table 1). Since the sizes of seeds in the species of the snake head *Dracocephalum* L. is differ, therefore, they were conditionally divided into two groups. The first group with small seeds (2.7–3.0 mm long and 1.6–2.0 mm wide) includes *D. moldavica* varieties. The mass of 1000 seeds of these varieties is 1.79–2.28 g.

The second group with very small seeds (2.0 mm in length and 1.0 mm in width) includes the species *D. multicaule* and *D. nutans*. The mass of 1000 seeds ranged from 0.54 to 0.65 g.

The evaluated seeds for germination were treated (soaked) with 5–10 ml of distilled water. For example, for small-seeded plants such as Moldavian snake head is 5 ml per 100 paces plants, but for larger (cereals) is 10 ml. To characterize the quality of seeds, various indicators were used. The most important of above were germination, germination energy, seed moisture, seed purity and category were also taken into account. Seed category – original seeds, elite, and reproduction. The seeds of Moldavian snakehead specimens belonged to the reproduction category (1–3 generations), varietal purity was 95%, and moisture content was 12%. The germination and germination energy of the samples was established in the course of the experiment.

From a mixture of seeds, samples were taken four replicates of 100 paces placed in Petri dishes on filter paper Petri dishes in a thermostat at the optimum germination temperature for seeds of the analysed species were placed. Petri dishes were preliminarily washed with hot water and detergent, rinsed with 1% potassium permanganate solution, then with distilled water and alcohol. Each dish was labeled with sample, replication, start date, and counting dates. The accounting was carried out manually, after 2–6 hours. A variable temperature was created in the thermostat of 20 °C – 18 h, 30 °C – 6 h.

The method for assessing the dynamic indicators of seed germination were used. As soon as the seeds germinated, the calculation and assessment of the dynamic indices of seed germination were made. The interval between the counting of seeds of each batch was chosen taking into account the intensity of their initial germination processes every 2–6 hours. To implement the mathematical model of seed germination the Origin Pro software package available to every user of a personal computer was used. The results were processed using MS Excel 2003.

For evaluating of the seed germination which as the basis for processing the results for that a logistic function was used. It should be indicated that in the dynamics of change or accumulation of quantitative indicators the transition to new qualitative indicators is reflected. The logistics function was described by the following formula (Komarov *et al.*, 2007):

$$N = \frac{N_{max}}{1 + e^{-\frac{t-t_c}{t_k}}}, \quad (1)$$

where N – number of germinated seeds at time (t);
t – the time during which a certain number of seeds germinate, expressed in%;
N_{max} – maximum number of germinated seeds;
t_k – the rate of increase in the number of germinated seeds,
t_c – the time at which the number of germinated seeds is equal to half of the maximum number of germinated seeds (which reflects the intensity of germination).

By the germination energy, we meant a fixed period for each plant species without taking into account their variety-specificity. So, the germination energy of the Moldavian snake head on the 3rd day was determined. The seed germination energy under the conditions of this experiment was characterized in the dynamics of the entire period of the experiment. Its was displayed by the *tc* index and in essence which was characterized the intensity of growth processes. Seed quality indicators taking into account their species and varietal heterogeneity or specificity were assessed.

The statistical estimation of data of the areas of germination energy, intensity of germination (*tc*) and speed of seed germination (k) has been carrying out by Student t-test at 0.05 levels.

Results

The morphometric parameters of the seeds of the studied species of the genus *Dracocephalum* L. are shown in Table 1. It should be emphasized that the peculiarity of the structure of the *Lamiaceae* L. fruit to some extent predetermines the specifics of the system for assessing the quality of the seeds of this plant. Seed in these species is not released from pericarp, which performs a protective function, which probably has a certain effect on the qualitative characteristics of seeds, including the intensity of their germination.

Morphometric study of *Eremus* L. showed that their sizes differ in *Dracocephalum* L. species. Thus, dividing them into two different groups was quite justified. Indicators for assessing the quality of seeds obtained as a result of laboratory experiments are shown in Table 2.

Table 1. Morphometric parameters of the seeds for species of the genus *Dracocephalum* L.

No in order	Kind & variety	No. sample according to the VIR catalog	Genesis	Weight of 1000 seeds, g	Seed size, mm	
					length	width
1	*D. moldavica* – Moldavian snakehead, variety Arhat	K-10	St. Petersburg	1.91	2.8	1.6
2	*D. moldavica* – Moldavian snakehead, variety Aroma-2	K-6	Moldova	2.28	3.0	1.9
3	*D. moldavica* – Moldavian snakehead, variety Aroma-2	K-6	Germany	1.86	2.7	1.7
4	*D. moldavica* – Moldavian snakehead, variety Zea	K-7	Kazakhstan	1.79	3.0	2.0
5	*D. multicaule* – Multi-stemmed, snakehead	K-7	Kazakhstan	1.79	3.0	2.0
6	*D. multicaule* – Multi-stemmed, snakehead	Bp-20	Germany	0.54	2.0	1.0
7	*D. nutans* – Hovering snakehead	Bp-32	Switzerland	0.65	2.0	1.0

Table 2. Indicators for assessing the quality of seeds in a dynamic model

No in order	Kind & variety	Germination energy, %	Laboratory germination, %	t_c, *h*	t_k, *h*	$t_c\ t_k^{-1}$	*k*, h^{-1}	R^2
1	*D. moldavica* – Moldavian snakehead, variety 'Arhat'	76 ± 2	78 ± 2	46 ± 0.6	7.05	6.5	0.14 ± 0.01	0.99
2	*D. moldavica* – Moldavian snakehead, variety Aroma-2	77 ± 2	79 ± 2	44 ± 0.6	12.9	3.4	0.08 ± 0.01	0.98
3	*D. moldavica* – Moldavian snakehead, variety Aroma-2	57 ± 1	64 ± 1	60 ± 0.9	15.2	4.2	0.07 ± 0.01	0.99
4	*D. moldavica* – Moldavian snakehead, variety Zea	68 ± 2	72 ± 2	53 ± 1.0	14.7	3.6	0.07 ± 0.003	0.99
5	*D. multicaule* – Multi-stemmed snakehead	87 ± 2	93 ± 2	54 ± 2.0	4.5	13.5	0.22 ± 0.01	0.99
6	*D. nutans* – Hovering snakehead	83 ± 2	88 ± 2	61 ± 0.5	5.9	10.3	0.17 ± 0.01	0.99

$t_c\ t_k^{-1}$ – dynamic growth rate of germinated seeds; *k* – the speed of seed germination; R^2 – coefficient of determination; digits with plus and minus are the standard deviation of data ($P < 0.05$).

It is known that the germination rate of seeds is determined by the peculiarity of their cultivation, duration and storage method including genetic, qualitative traits and other. According to standard indicators (germination), the best indicators with a sample from Germany *D. multicaule* L. – Multi-stemmed snake head (germination rate 93%) were obtained. Somewhat lower (germination rate 88%) or a sample from Switzerland *D. nutans* – Hovering snake head was recorded. Both of these samples are perennial and small-seeded species (0.54–0.65 g per 1000 seeds). For larger-seeded and annual species *D. moldavica* L. – Moldavian snake head, the following row of germination was formed: 79% – sort 'Aroma-2' (Moldova), 78% – sort 'Arhat' (St. Petersburg), 72% – variety 'Zea' (Kazakhstan), 64% – variety 'Aroma-2' (Germany). The germination energy index in a similar way was distributed. The most significant 87% and 83% were for perennial samples No. 5 and No. 6. At the same time, variety 'Arhat' – 76%, 'Aroma-2' (Moldova) – 77%, 'Zea' – 68%, 'Aroma-2' (Germany) – 57%. However, these indicators of germination and germination energy were only to some extent associated with crop yield (Lavrukov, 2012) and do not provide the necessary information content.

Discussion

The dynamic indicators where a mathematical model of seed germination of the genus *Dracocephalum* L. implemented on the basis of a logistic function, provides great information content in terms of seed quality and potential yield we used. Analysis of the model's operation shows (Table 2 and Fig. 1) that according to the tc indicator the germination time of half of the maximum number of germinated seeds is established. The presented tc indicator is very close to the (seed vigour) indicator or the Grodzinsky bio test (Grodzinsky, 1991). It differs in that the tc index determines the LD50 index (50% of germination) relative to all germinated seeds, while the seed vigour index or Grodzinsky bio test determines the LD50 index from the total volume of seeds which includes both germinated (germination) and non-germinated (100% – germination) seeds.

It was found that sample No. 2 ('Aroma-2') had the smallest tc equal to 44.0 hours. Sample No. 1 was somewhat inferior in this indicator germinating by 50% in 46 hours. This indicates vigourous and friendly germination of seeds of these varieties. In addition, this indicator determines the intensity of growth and can become the basis for a preliminary assessment of the potential yield of plants. For sample No. 4 ('Zea'), this figure is 53 hours and for perennial sample No. 5 – 54 hours. The samples No. 3 (60 hours) and No. 6 (61 hours) turned out to be the most "slow" in seed germination.

The dynamics of the process of seed germination is characterized by the speed of germination, acceleration of germination and can be displayed by the angle of inclination on the graph (Fig. 1). Moreover, the larger and steeper the angle of inclination (attack), the more intense the initial stage of growth processes. Indicator k characterizes the rate of seed germination where $1 / k = t_k$ is a value which characterizes the physiological process of growth. At the same time, the physiological postulate is accepted that the less time is required for seed germination and the more intensive the germination process. In terms of t_k, the following features are noted. The smallest t_k value was observed for perennial samples No. 5 = 4.5 hours and No. 6 = 5.9 hours. Annual samples were significantly inferior in physiological parameters of germination where t_k varieties 'Arhat' = 7.05 hours, 'Aroma 2' = 12.9 (sample 2) and 15.2 (sample 3). 'Zea' was almost the "slowest" cultivar where t_k = 14.7 hours.

It is important to note that when describing the dynamic model of germination, very significant statistical indicators are displayed (Table 2, Fig. 1). Thus, the coefficient of determination R^2 for all variants of seed germination was not lower than 0.98. It explains the ability of regression, *i.e.* shows what fraction of the variation (variance) is described by the constructed model. Thus, according to R^2, one can judge how well the constructed model fits the available data and how close the true observations lie to this model.

An important circumstance is that the species of the genus *Dracocephalum* L. from the *Lamiaceae* L. family are not only annuals but also perennial herbaceous plants. Consequently, their seeds can differ morphologically, the type of dormancy, the nature of germination, viability, the duration of its preservation and other biological characteristics. At the same time, the geographical origin of seeds the influence of environmental factors during ripening, can also affect the dynamics of their germination. The most famous and widespread species of this genus is Moldavian snake head, it is widely cultivated as a melliferous, essential oil and ornamental plant (Adewinogo *et al.*, 2021). Multi-stemmed snake head and Hovering snake head (drooping snake head) are perennial plants used mainly

in folk medicine (Melankina, Cicin, 2021). Also, it is generally known that specimens of the Moldavian snakehead species (K-7, K-8 and K-10 from the collection of the VIR) of physiology, differ in biochemistry, anatomical and morphological structure and therefore germinate in different ways. At the same time, specimens of the same species, from different geographical areas, can react to factors, *etc*. in different ways.

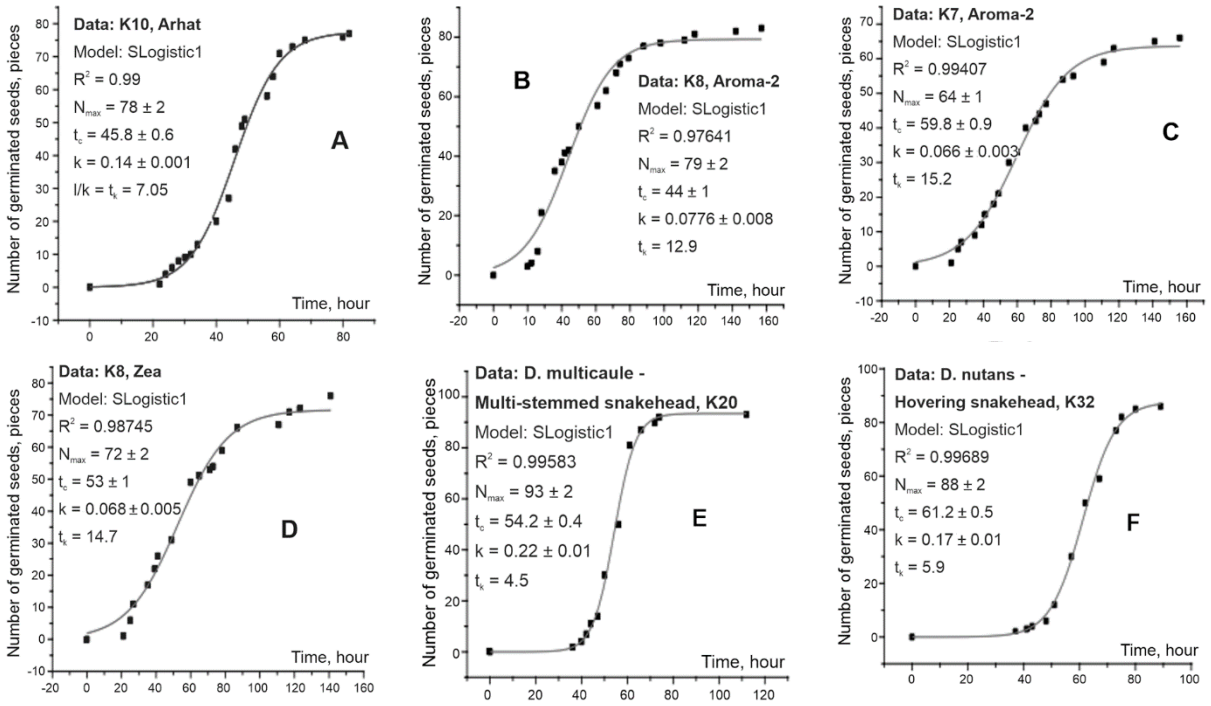

Figure 1. Dynamics of seed germination of snake head species
N – the number of germinated seeds during time *t*; N_{max} – the maximum number of germinated seeds; t_k – the rate of increase in the number of germinated seeds, is associated with a doubling of the number of germinated seeds and, therefore, reflects the rate of seed germination; t_c – the time at which the number of germinated seeds is equal to half of the maximum number of germinated seeds (which reflects the intensity of germination); with this: A – No. 1 *D. moldavica* L. – Moldavian snake head, variety Arhat, data: K 10; B – No. 2 *D. moldavica* L. – Moldavian snake head, variety Aroma-2, data: K 8: C – No. 3 *D. moldavica* L. – Moldavian snake head, variety Aroma-2, data: K 7; D – No. 4 *D. moldavica* L. – Moldavian snake head, variety Zea, data: K 8; E – No. 5 *D. moldavica* L. – Multi-stemmed snake head, data: K 20; F – No. 6 *D. nutans* – Hovering snake head, data: K 32.
where N – is the number of germinated seeds during time t; N_{max} – is the maximum number of germinated seeds; t_k – the rate of increase in the number of germinated seeds, is associated with a doubling of the number of germinated seeds and, therefore, reflects the rate of seed germination; t_c is the time at which the number of germinated seeds is equal to half of the maximum number of germinated seeds (which reflects the intensity of germination).

The structural features of the evaluated seeds include the following. A specialized fruit in *Dracocephalum* L. species – *coenobius* (*Coenobium* L.), when ripe, breaks down into 4 closed single-seeded fragments – erems (*Eremus* L.). (Fedorov, Artyushenko, 2016; Levina, 1987; Yakovlev *et al.*, 2018; Gubanov *et al.*, 2004). In this work, the terms erems and seeds are used interchangeably. The form of erems *Dracocephalum* L. is elongated-oval or elongated-obovate, flattened-trihedral with a convex wider dorsal edge and with flat and somewhat narrower ventral edges. Rafe (*Raphe* L.) in an oval or rounded depression of white colour. The surface of erems is smooth or slightly lumpy, brownish, gray or black in colour. Pericarp consists of 4 layers: exocarp, mechanical layer, parenchymal layer and endocarp. The seed coat grows together with the endocarp only in rafe (*Raphe* L.). It is single-layered of polygonal *Parenchymal* L. cells. Seeds with a straight formed embryo which consists of two cotyledons with pointed lower ends, a root with hypocotyl and a small bud. Endosperm in snake heads is represented by 1–3 rows of cells.

Considering that to describe the performance of any model, it is necessary to take into account the widest possible range of its capabilities and stability (Arseven, 2015), therefore, the species of *Dracocephalum* L. seeds are so heterogeneous in their features and were used to evaluate a dynamic seed germination model. As a result, we believe that since plant seeds are living organisms, it is necessary to describe their germination and the effect of action in dynamics. Thus, the dynamic model is realized which reflects the effect of germination due to the internal reserves of seeds, due to the activation of the endosperm.

Conclusions

The results of our research have shown that the mathematical model for an assessment of seed germination on the example of a genus *Dracocephalum L.* has been fully justified.

The dynamic model in the work reproduces changes in the initial phase of plant growth through the dynamics of seed germination has presented. That is, in this model there is a change in the state of a living object in "motion".

The model had a strictly formulation, which by the corresponding formulas was displayed. The dynamic model was significantly different from all previously used methods. For assessing the initial phases of plant growth based on static parameters.

In static models, the change in the state of plants was considered as objects that practically did not change over time. Since all the estimated indicators (germination, germination energy, *etc*.) were considered fixed in separate time sections were considered fixed.

The intensity of seed germination, which was assessed using a dynamic model, made it possible to select the most "active" seeds. This allowed active seeds to provide an exceptional opportunity for growing plants to take a leading position in the agrocenosis. Dominance in the agrocenosis allowed the plant to more actively obtain the main resources of the environment (moisture, nutrients, solar energy, *etc*.). Thus, this made it possible to ensure the highest productivity.

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Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions

AK 50%, NN 30%, EN 20% – study of the concept and design;
AK 50%, NN 40%, EN 10% − data collection;
AK 70%, NN 20%, EN 10% − analysis and interpretation of data;
AK 60%, NN 10%, EN 30% − writing a manuscript;
AK 40%, NN 10%, EN 50% − critical revision and approval of the final manuscript.

References

Adewinogo, O., Sharma, R., Africa, C.W.J., Marnewick, J.L., Hussein, A.A. 2021. Chemical composition and cosmeceutical potential of the essential oil of *Oncosiphon suffruticosum (L.)* Källersjö Selena. – Plants, 10(1315):1–14. DOI: 10.3390/plants10071315

ADSA (Association of Official Seed Analysts). 1993. Rules for testing seeds. – Journal of Seed Technology, 16(3):1–116.

Amirmoradi, S, Feizi, H. 2017. Can mean germination time predict seed vigour of canola (*Brassica napus* seed lots? – Acta Agrobot, 70(4):1729. DOI: 10.5586/aa.1729

Anikina, A.N, Basalaeva, I.V., Bushkovskaya, L.N. 2021. Lekarstvennõje i jefiromaslichnyje rastenija: osobennosti võrashhivanija na territorii Rossijskoi Federacii [Medicinal and essential oil plants: features of cultivation on the territory of the Russian Federation]. – M.: VILAR, 256 (In Russian).

Arseven, A. 2015. Mathematical modelling approach in mathematics education. – Universal Journal of Educational Research, 3(12):973–980. DOI: 10.13189/ujer.2015.031204

Baghel, L., Kataria, S., Jain, M. 2019. Mitigation of adverse effects of salt stress on germination, growth, photosynthetic efficiency and yield in maize (*Zea mays* L.) through magnetopriming. – Acta Agrobothanica, 72(1):1–16. DOI: 10.5586/aa.1757

Chetyrbotskiy, V.A., Chetyrbotskiy, A.N. 2020. Problemy chislennogo modelirovanija v dinamicheskoj sisteme "pochva- rastenie" [Problems of numerical simulation in the dynamics system "soil-plant"] – Komp'juternyje issledovanija i modelirovanije, 2(12):445–465 (In Russian).

Ellis, R.H., Roberts, E.H. 1980. Towards a Rational Basis for Testing Seed Quality – Seed Production (Ed. P.D. Hebblethwaite), Butterworths, London, pp. 605–645.

Fedorov, A.A., Artyushenko, Z.T. 2016. Atlas opisatel'noi morfologii võsshih rastenij [Atlas of descriptive morphology of higher plants]. – Fruktõ. L., 350 p. (In Russian).

Ghassemi-Golezani, K., Mohammadi, M., Zehtab-Salma, S., Nasrullahzadeh, S. 2016. Changes in seed vigour of safflower (*Carthamus tinctorius* L.) cultivars during maturity in response to water limitation – Acta agriculturae Slovenica, 107(1):15–23. DOI: 10.14720/aas.2016.107.1.02/.

Grodzinsky, M. 1991. Allelopatija rastenij i istoshhenie pochvy, 431 p.

Gu, J., Dalin, Hou D., Li, Y., Chao, H., Zhang, K., Wang, H., Jun Xiang J., Raboanatahiry, N., Wang, B. Li, M. 2019. Integration of proteomic and genomic approaches to dissect seed germination vigour in Brassica napus seeds differing in oil content. – BMC Plant Biology, 19(21):1–20. DOI: 10.1186/s12870-018-1624-7.

Gubanov, I.A., Kiseleva, K.V., Novikov, V.S. 2004. Illjustrirovannyi opredelitel' rasteniy central'noi chasti Rossii [Illustrated plant determinant of the Central part of Russia]. – M.: Tovarishhestvo nauchnyh izdanij MKM, 3(3):520 (In Russian).

Hampton, J.G. 2002. What is seed quality? – Seed Science and Technology, 30:1–10.

Handbook. 1995. Seed Vigour Test Methods (Eds. J.G. Hampton, D.M. TeKrony and ISTA Vigour Test Committee). – Zurich, Switzerland, 3rd Edition, 120 p.

Han, Z., Bin, W., Zhang, J., Guo, S., Zhang, H., Xu, L., Chen, Y. 2018. Mapping of QTLs associated with seed vigour to artificial aging asing two RIL populations in

maize (*Zea mays* L.). – Agricultural Sciences, 9(4) 397–415. DOI: 10.4236/as.2018.94028

Ibrahim, M.S., Ikhajiagbe, B. 2021. The growth response of rice (*Oryza sativa* L. var. FARO 44) in vitro after inoculation with bacterial isolates from a typical ferruginous ultisol. – Bulletin of the National Research Centre, 45:70. DOI: 10.1186/s42269-021-00528-8

ISTA (International Seed Testing Association). 2021. International rules for seed testing. – Seed Science and Technology. Supplement V.27, 2004 p. Available at https://www.seedtest.org/upload/cms/user/s8_ISTA_Rules_ 2021_ 07_seed_health.pdf

Komarov, A.A., Naida, N.M., Lavrukov, M.Yu. 2007. Ocenka dinamiki vshozhesti semjan vidov roda *Dracocephalum* L. [Evaluation of the dynamics of seed germination of species of the genus *Dratsotsephalum* L]. Nauchnoje obespechenie razvitija APK v uslovijah reformirovanija. – Sbornik nauchnyh stat'jei, 1: 3–7 (In Russian).

Komarov, A.A. 2002. Ekspress-metod ocenki soderzhanija fiziologicheski aktivnyh sojedineniy i pochvennoi ustalosti substratov. Sel'skohozjaistvennaja biologija [Express method for assessing the content of physiologically active compounds and soil fatigue of substrates], 5:118–120 (In Russian).

Lavrukov, M.Y. 2012. Influence of the organo-mineral fertilizer "Stimulife" and sodium humate on the growth and development of specimens of the snake head (*Dracocephalum* L.) in the conditions of the Leningrad region. – Defence of the thesis D 220.060. 01. Available at http://spbgau.ru/dissertations/arhiv/node/1563

Levina, R.E. 1987. Morfologija i jekologija plodov [Morphology and ecology of fruits]. – L-l-l: Nauka, 60 p. (In Russian).

McDonald, M.B. 1998. Seed quality assessment. – Seed Science Research, 8:265–275.

McDonald, M.B. 1999. Seed deterioration. Physiology, repair and assessment. – Seed Science and Technology, 27:177–237.

Melankina, E.L., Cicin, A.N. 2021. Lekarstvennye i jefiromaslichnyje rastenija [Medicinal and essential oil plants] – M.: NIC INFRA-M: 368 (In Russian).

Nugis, E., Kuht, J., Komarov, A. 2021. Potato yield forecast by using guttation test method in household laboratory conditions – Agraarteadus, 32(1):86–91. DOI: 10.15159/jas.21.17

Perry, D.A. 1978. Report of the vigour Test Committee. – Seed Science and Technology, 6:159–181

Sabelli, P.A., Larkins, B.A. 2015. Advances in seed biology. – Lausanne: Frontiers Media, 238 p. DOI: 10.3389/ 978-2-88919-675-3

Taylor, A.G. 2003. Seed quality. In Encyclopedia of Applied Plant Sciences (Eds. B. Tomas, D.J. Murphy, B.G. Murray). – Elsevier Academic Press, pp. 1284–1291.

Vitkovskaya, S.E. 2015. Dinamicheskie zakony rosta biomassy i jelementnyi sostav rasteniy jachmenja v polevom jeksperimente [Dynamic laws of the biomass growth and the elemental composition of barley plant in a field experiment]. – Agrohimija, 1:63–72 (In Russian).

Wei, X., Huang, X. 2018. Identification of a seed dormancy gene in soybean sheds light on crop domestication – Science China Life Sciences, 61:1439–1441. DOI: 10.1007/s11427-018-9410-y

Yakovlev, G.P., Goncharov, M.N., Pavydysh, M.N. 2018. – Botanika [Botanics]. – SPb: SpecLit., 879 p. (In Russian).

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AGAR GEL PHENOTYPING OF ROOT TRAITS AS RAPID AND SENSITIVE ASSAY OF WHEAT SEEDLINGS RESPONSE TO EDAPHIC FACTORS: ON EXAMPLE OF CADMIUM

Tetiana Levenets[1], Oleksandr Smirnov[1,2], Mariia Kovalenko[1], Liudmyla Mykhalska[2], Victor Schwartau[2], Nataliya Taran[1]

[1]Educational and Scientific Centre "Institute of Biology and Medicine", Taras Shevchenko National University of Kyiv, 64/13 Volodymyrska St, Kyiv, 01601, Ukraine
[2]Institute of Plant Physiology and Genetics, National Academy of Sciences of Ukraine, 31/17 Vasylkivska St, Kyiv, 03022, Ukraine

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Vastutav autor: / Corresponding author: Oleksandr Smirnov

E-mail: plantaphys@gmail.com

ORCID:
0000-0002-8029-2386 (TL)
0000-0002-2293-5961 (OS)
0000-0003-3861-3796 (MK)
0000-0002-0677-5574 (LM)
0000-0001-7402-5559 (VS)
0000-0002-8669-5899 (NT)

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ABSTRACT. The influence of different concentrations of cadmium on root elongation, exudative activity of roots and seminal root angle of two wheat genotypes: common bread wheat – *Triticum aestivum* L. (cv. 'Favorytka') and emmer wheat – *Triticum dicoccum* Schrank. (cv. 'Holikovska') have been studied in the germination stage. Rapid changes in morphofunctional traits upon first three days of exposure to cadmium on early stages of growth have been studied on phenotyping plates with 25, 50 and 100 μM addition to agar-acid/base indicator medium. Significant inhibition of root elongation, exudative root activity and changes in seminal root angle were observed. Exposure to the highest Cd concentration led to a decrease in primal root length by 50%, decrease in root exudative activity by 88% and decrease in seminal root angle by 24 degrees in *T. aestivum* compared to a decrease by 12%, 83% and 17 degrees in *T. dicoccum*. Unlike root growth retardation, a decrease in exudative activity was observed on all three Cd concentrations. The root growth performance at starting stage of seedlings ontogenesis proposed as an express and sensitive phenotyping test method for determining plant response to edaphic stressors by cadmium toxicity example.

Introduction

Plant roots are involved in obtaining water and nutrients, rapid response to abiotic and biotic stressors in the soil and plant anchoring in the ground. Supervising plant root development and distribution is a fundamental part of insight of plant ontogenesis and evolution, permitting plants to respond to global climate changes and allowing plants to conquer in different ecological niches (Nibau *et al*., 2008).

In addition to measuring linear growth rates of primary and lateral roots, a lot of research is devoted to the root growth angle, which determines the direction of elongation of the roots and the area of distribution in the upper layers of the soil, affects the area in which the roots contact with water and substances dissolved in it (Nelson, Oliver, 2017). Several authors pointed to the significance of root growth angle as a potential trait to enhance crop yield because of the relation of root architectures to increased nutrition within the upper layers of the soil (Lynch, 2011). Thus, the route development and exudative activity of roots determine the ability of a plant to use nutrients that are unevenly distributed in the soil (López-Bucio *et al.*, 2003; Uga *et al.*, 2015).

In monocot species, the embryonic roots (primary and seminal) are especially important during early seedling establishment, but post-embryonic roots soon take over

and are responsible for enhanced foraging (Koevoets *et al.*, 2016). Furthermore root efflux activity is important due to root exudates involving in the increase of bioavailavility and mobilization of nutrients. Organic acids are the most prevalent class of root exudates that have been extensively studied for their role in nutrient mobilization, pathogen resistance, heavy metals tolerance and other abiotic and biotic stresses (McGrail *et al.*, 2020). Heavy metals can inhibit the development of the root system of plants and limit the realization of the genetic potential of a variety and agroecosystems productivity (Rizvi *et al.*, 2020).

Therefore, this work aimed to investigate the roots morphofunctional response of two wheat genotypes (*Triticum aestivum* L. and *Triticum dicoccum* Schrank.) on germination stage under different concentrations of cadmium. The root growth performance at the initial stage of seedlings ontogenesis proposed as an express and sensitive test method for determining plant response to edaphic stressors by cadmium toxicity example.

Material and Methods

The objects of the study were two wheat genotypes – *Triticum aestivum* (cv. 'Favorytka') and *Triticum dicoccum* Schrank. (cv. 'Holikovska') on starting stage of development. Selected cultivars have passed preliminary screening for the level of resistance to changes in the osmotic potential of the growth medium (Smirnov *et al.*, 2020a; Smirnov *et al*., 2020b). Seedlings were grown in vertical quadratic phenotyping plates 120×120 mm (Kartell Labware) in a growth chamber at 25 C without light for 3 days. The control variant of seedlings was grown on a 0.8% (w/v) agar layer prepared with distilled water (Manschadi *et al.*, 2008). Experimental seedlings were grown on a layer of agar with the addition of 25 µM, 50 µM and 100 µM of CdI_2 (pH 6.5).

Wheat seeds of both varieties were soaked in 10% (v/v) hydrogen peroxide and further in aseptic conditions within 6 hours were vernalized in distilled water at 4 °C to stimulate germination then transferred to a Petri dish on wet filter paper and placed in a thermostat at 25 °C for imbibition. Healthy seeds of both varieties were selected randomly. After 12 hours of imbibition, seeds were placed in an agar layer (50 mL of agar per phenotyping plate). For visual control of root exudation, acid-base indicator bromocresol green was used (Kosyan *et al.*, 2016).

Phenotyping of roots architecture and exudative activity (acidification of the medium) was carried out using morphological traits: lengths of primary and seminal roots, the angle between seminal roots (Waidmann *et al.*, 2020) and area of agar layer, which changed colour from blue to yellow under the influence of root exudates (Fig. 1 A, B). Root traits and area of agar layer with changed colour was measured using the ImageJ software, comparing with the scale bar 1 cm (Hohn, Bektas, 2020).

The experiment was repeated three times, with 4-fold biological repeats. The data were subjected to analysis of variance with subsequent Tukey's multiple range test (Two-way ANOVA) with GraphPad Prism 9.0 software. Data are expressed as means of replicates + standard deviation and were considered reliable at a significance level of $P < 0.05$.

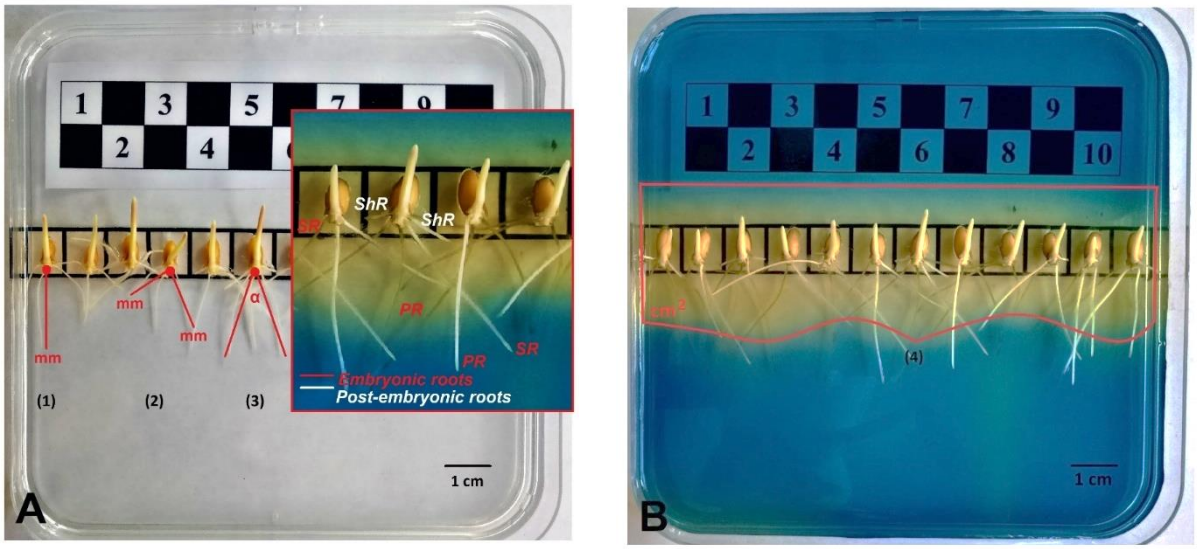

Figure 1. Phenotyping plates with germinated wheat seeds without an acid-base indicator (A) and with indicator addition (B); root traits: primary root length (1), seminal roots length (2), seminal roots angle (3) and root exudation activity as the area of agar gel colour change from blue to yellow (4). The inset to (A) schematically shows the PR – primary root, SR – seminal roots and ShR – shoot-born roots disposition.

Results

In response to cadmium toxicity, we observed growth inhibition of primal (PR) and seminal roots (SR), the degree of which differed between the two genotypes and depended on the concentration of Cd and the time of exposure. In addition, changes in seminal root angle (SRA) and exudative activity were noted (Tables 1–3).

Conditionally, it was possible to identify two opposite patterns of root growth. Reaction of *T. aestivum* cv. 'Favorytka' was distinguished by delay in germination and moderate root growth in the first 24 hours, followed by significant root length increase in the next two days – total increase in PR length on control samples was 398%, increase in SR was 458% of control variant. A high concentration of Cd (100 µM) caused a significant inhibition of the growth processes of PR, after 72 hours, the length of PR was 50% of the control level and moderate inhibition of the SR growth by 18%. Low and medium Cd concentrations (25 µM and 50 µM) did not have any significant effect on PR but had a pronounced stimulating effect on SR, which manifested itself as a 23–30% increase in SR length compared to the control variant.

Table 1. Root traits of wheat seedlings after 24 hours of germination on agar gel with different concentrations of cadmium

Variety	*Triticum aestivum* cv. 'Favorytka'				*Triticum dicoccum* cv. 'Holikovska'			
Variant, n = 36	Concentrations of cadmium, µM							
	0	25	50	100	0	25	50	100
Primary root length, mm	7.91 ± 1.46^{a}*	6.18 ± 1.15^{ab}	8.69 ± 1.22^{a}	5.75 ± 0.91^{b}	12.51 ± 1.74^{a}	13.22 ± 2.46^{a}	11.43 ± 2.22^{a}	11.01 ± 1.91^{a}
Seminal roots length, mm	5.41 ± 1.25^{a}	4.81 ± 0.74^{a}	7.65 ± 1.11^{a}	6.22 ± 0.86^{a}	11.73 ± 1.06^{a}	11.78 ± 1.36^{a}	14.47 ± 1.20^{a}	12.38 ± 1.45^{a}
Seminal root angle, degrees	61 ± 1^{a}	64 ± 8^{a}	63 ± 5^{a}	48 ± 5^{b}	88 ± 5^{a}	85 ± 8^{a}	62 ± 11^{b}	68 ± 6^{b}
Area of exudation activity, cm^2	76.25 ± 15.75	N/A	N/A	N/A	101.75 ± 2.02^{a}	16.75 ± 2.75^{b}	13.01 ± 1.50^{b}	8.5 ± 1.50^{c}

Data represented as mean values with standard deviation. Lower-case letters in the rows of each variety differ significantly by the Tukey's test ($P < 0.05$). N/A – not available

Table 2. Root traits of wheat seedlings after 48 hours of germination on agar gel with different concentrations of cadmium

Variety	*Triticum aestivum* cv. 'Favorytka'				*Triticum dicoccum* cv. 'Holikovska'			
Variant, n = 36	Concentrations of cadmium, µM							
	0	25	50	100	0	25	50	100
Primary root length, mm	16.47 ± 2.15^{a}	17.75 ± 1.96^{a}	16.93 ± 1.72^{a}	11.07 ± 0.82^{b}	19.51 ± 1.71^{a}	21.61 ± 2.43^{a}	19.51 ± 2.45^{a}	17.87 ± 1.63^{a}
Seminal roots length, mm	13.10 ± 1.02^{a}	14.74 ± 1.37^{a}	16.14 ± 1.38^{a}	11.42 ± 0.78^{b}	22.78 ± 1.18^{a}	22.72 ± 1.55^{a}	21.18 ± 1.43^{a}	16.97 ± 1.18^{a}
Seminal root angle, degrees	62 ± 3^{a}	59 ± 4^{a}	52 ± 2^{b}	48 ± 3^{b}	92 ± 2^{a}	86 ± 4^{a}	73 ± 4^{c}	75 ± 2^{c}
Area of exudation activity, cm^2	114.25 ± 4.7^{a}	8.75 ± 2.05^{b}	5.75 ± 1.9^{b}	1.6 ± 1.02^{c}	115.50 ± 2.86^{a}	34.12 ± 4.32^{b}	28.51 ± 2.81^{b}	17.25 ± 2.67^{c}

Data represented as mean values with standard deviation. Lower-case letters in the rows of each variety differ significantly by the Tukey's test ($P < 0.05$).

Table 3. Root traits of wheat seedlings after 72 hours of germination on agar gel with different concentrations of cadmium

Variety	*Triticum aestivum* cv. 'Favorytka'				*Triticum dicoccum* cv. 'Holikovska'			
	Concentrations of cadmium, µM							
Variant, n = 36	0	25	50	100	0	25	50	100
Primary root length, mm	31.15 ± 5.51^{a}	29.36 ± 4.68^{a}	30.52 ± 4.64^{a}	15.59 ± 1.61^{b}	26.21 ± 3.19^{a}	32.37 ± 4.53^{a}	29.24 ± 4.62^{a}	23.05 ± 2.36^{a}
Seminal roots length, mm	24.82 ± 2.28^{a}	30.77 ± 2.81^{b}	32.14 ± 3.31^{b}	20.50 ± 1.38^{c}	34.96 ± 2.05^{a}	35.96 ± 2.51^{a}	29.39 ± 1.97^{a}	22.89 ± 1.48^{b}
Seminal root angle, degrees	62 ± 3^{a}	50 ± 6^{b}	45 ± 2^{b}	38 ± 4^{c}	93 ± 4^{a}	80 ± 6^{ab}	73 ± 5^{b}	76 ± 5^{b}
Area of exudation activity, cm^2	132.0 ± 5.96^{a}	105.50 ± 8.5^{b}	54.25 ± 3.75^{c}	15.2 ± 12.15^{d}	130.5 ± 3.52^{a}	101.01 ± 13.0^{b}	42.02 ± 7.06^{c}	21.25 ± 3.75^{d}

Data represented as mean values with standard deviation. Lower-case letters in the rows of each variety differ significantly by the Tukey's test ($P < 0.05$).

T. dicoccum cv. 'Holikovska' was characterized by rapid growth in the first 24 hours followed by a moderate increase in root length – total increase in both PR and SR of control variant were more than 200%. High concentrations of Cd caused weak unreliable inhibition of PR growth by 12% and pronounced inhibition of SR growth by 35%. Low concentrations of Cd did not influence SR growth, but light unreliable stimulation of PR was observed.

For both cultivars, the first weak manifestations of growth retardation as a result of exposure to high concentrations of cadmium were noted at the time of two days; however, it became possible to unambiguously confirm their manifestations only after 72 hours. Inhibition of root growth processes is typically one of the first manifestations of cadmium toxicity (Ismael *et al*., 2019). The light stimulating effect of low cadmium concentrations was noted previously and is associated with a hyper compensatory response of the antioxidant system of plants (Carvalho *et al*., 20120.

Regarding the angle of root germination – seminal root angle trait, a general tendency was observed, expressed in its decrease as the metal concentration increased. It should be noted that although this parameter of the root system differs significantly between the two species, the degree of their reaction was close to each other. At 25 µM Cd on the third day, the difference between the control and experimental variants was 12 degrees for 'Favorytka' and 13 degrees for 'Holikovska', at concentrations of 100 µM – 24 and 17 degrees, respectively. At medium concentrations, SRA for 'Holikovska' was nearly identical to that at 100 µM, on the contrary, 'Favorytka' was closer to that at 25 µM, which could be attributed to the higher sensitivity of the seminal roots of 'Holikovska' to cadmium addition. In contrast to the root growth

inhibition processes, a visible change in the root angle was noted already after 24 hours at high concentrations of cadmium for the 'Favorytka' and medium-high for 'Holikovska'. The response of SRA could be interlinked with disturbance of auxin homeostasis in roots, which is typically observed under Cd-stress (Uga *et al.*, 2015).

Evaluation of exudative activity showed that the control variant of *T. aestivum* had lower, by 25%, the extent of acidification of the medium in the first 24 h in comparison with *T. dicoccum*, however, there was no significant difference between control samples on the second and third day. Upon exposure to 25 μM of Cd, a sharp decrease in exudative activity was observed, up to the complete absence of any visible changes in the pH of the medium for *T. aestivum* and a decrease in the area of pH change by 83% for *T. dicoccum*. After 72 h samples with minimal cadmium concentrations did not reach the control values, the area of synthetic activity was 79% and 77% of the control, respectively. The subsequent increase in cadmium concentration led to a progressive decrease in the area of excretory activity, a time delay in recovery of excretory activity was noted for *T. aestivum* in comparison with *T. dicoccum*.

Discussion

Current data on the SRA in the early stages of development and the root architecture of adult plants indicate that cultivars with a small root angle tend to develop a compact deep-rooting system (Manschadi *et al*., 2008; Xie *et al*., 2017; Rich *et al*., 2020). Considering that the highest concentrations of bioavailable forms of cadmium are found in the first 20–40 cm of topsoil (Šichorová *et al*., 2004; Wang *et al*., 2019), due to oxidizing condition of topsoil, active use of phosphate-organic fertilizers, other similar agricultural practices and anthropogenic activities in general (Filipović *et al*., 2016; Wei *et al*., 2020), varieties with a small root angle can be considered as potential material for breeding low-cadmium accumulating wheat. In addition, differences in the root morphology of wheat varieties with high- and low-cadmium accumulation have previously been noted: Berkelaar and Hale (2000) reported that of the two durum wheat (*Triticum turgidum* L.) cultivars, which had less root surface area and fewer root tips tended to accumulate less Cd per gram of dry weight, a similar result was later acquired by Kubo *et al.* (2011) for two bread wheat cultivars.

Since the role of low-molecular-weight organic acids (LMWOA) in the mechanisms of extracellular protection against the toxic effects of metals is well known (Osmolovskaya *et al*., 2018), in particular, the excretion of malate by wheat in the response to aluminium (Delhaize *et al*., 1993; Sasaki *et al*., 2006), the relative excretory activity with Cd-stress has been evaluated. The relationship between the release of LMWOA's and resistance to cadmium through the exclusion mechanism was previously observed in a small number of plant species (Zhu *et al*., 2011; Guo *et al*., 2017), as well as in a transgenic species with a modified malate transporter (Ma *et al*., 2020).

In contrast to all other parameters described in the article, the difference in the parameter of exudative activity at concentrations of 0, 25, 50, and 100 μM Cd is very explicit. From a theoretical standpoint, the decrease in the area of pH change, which depends on the active excretion of organic acids by the root system, can be explained by one of the following assumptions or their combination: Cd-stress leads to inhibition of a group of membrane transporters, Cd-stress leads to inhibition of the synthesis of LMWOA's in the roots as such (Chaffai *et al*., 2006), there is active reabsorption of previously excreted acids in the form of Cd-OA conjugates. It is worth noting the available data indicating that when exogenous organic acids are added in medium, they are capable of forming soluble complexes with cadmium, which can be easily absorbed by plants without causing explicit phytotoxic effect (Nigam *et al*., 2000; Zhang *et al*., 2020; Lu *et al*., 2021).

Among other things, as can be seen from the above, as well as from the data given in the tables, such parameters as SRA and acidification of the medium, with all the simplicity of their measurement, exhibit a certain degree of specificity, thus, potentially, can be used to rapid-asset responsivity of plant organisms to low Cd-doses at a short period.

Conclusion

According to the received data on morphofunctional parameters in wheat seedlings upon three-day exposure to cadmium, genotype *Triticum aestivum* cv. 'Favorytka' was estimated to be more Cd-sensitive, as it exhibited much stronger inhibition in primal root growth, up to 50% compared to 12% in genotype *Triticum dicoccum* cv. 'Holikovska'. Significant inhibition in root grow was accompanied by a decrease in seminal root angle by 24 degrees in *T. aestivum*, compared to 17 degrees in *T. dicoccum*, and more prominent, up to complete absence, decrease in root exudative activity. However, a visible inhibition in root exudative activity was observed in both genotypes concerning all cadmium concentrations, and the degree of inhibition largely depended on the metal concentration.

The quality of the proposed phenotyping method, considering all its simplicity, was stated to be satisfactory, as it was found to be sensitive enough to demonstrate the difference in test-objects response depending on tested plant genotype and/or mental concentration. Although the proposed agar-gel phenotyping method has several downsides, such as the inability to model complex interaction between supposed stress-factor (in our case, Cd^{2+}) and soil particles, it still proposes an opportunity for non-invasive monitoring of early stages of root development and rapid, real-time assessment of its response to edaphic stressors. All while being cheap, cost-effective in terms of labour and time, and flexible to modifications.

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Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions

OS – author of the idea, guided the research and is the corresponding author.
TL – performed the phenotyping assays and calculation of the results.
MK – performed data statistical analysis.
LM, VS and NT – performed the literature data analysis and discussion of the results.
All authors read and approved the final manuscript.

References

Berkelaar, E., Hale, B. 2000. The relationship between root morphology and cadmium accumulation in seedlings of two durum wheat cultivars. – Canadian Journal of Botany, 78(3):381–387. DOI: 10.1139/b00-015

Carvalho, M.E.A., Castro, P.R.C., Azevedo, R.A. 2020. Hormesis in plants under Cd exposure: from toxic to beneficial element? –

Journal of Hazardous Materials, 384:121434. DOI: 10.1016/j.jhazmat.2019.121434

Chaffai, R., Tekitek, A., El Ferjani, E. 2006. A comparative study on the organic acid content and exudation in maize (*Zea mays* L.) seedlings under conditions of copper and cadmium stress. – Asian Journal of Plant Sciences, 5(4):598–606. DOI: 10.3923/ajps.2006.598.606

Delhaize, E., Craig, S., Beaton, C.D., Bennet R.J., Jagadish, V.C., Randall, P.J. 1993. Aluminium tolerance in wheat (*Triticum aestivum* L.). – Plant Physiology, 103(3):685–693. DOI: 10.1104/pp.103.3.685

Filipović, V., Cambier, P., Filipović, L., Coquet, Y., Pot, V., Bodineau, G., Jaulin, A., Mercier, V., Houot, S., Benoit, P. 2016. Modeling copper and cadmium mobility in an albeluvisol amended with urban waste composts. – Vadose Zone Journal, 15(12):1–15 vzj2016.07.0056. DOI: 10.2136/vzj2016.07.0056

Guo, H., Feng, X., Hong, C., Chen, H., Zeng, F., Zheng, B., Jiang, D. 2017. Malate secretion from the root system is an important reason for higher resistance of *Miscanthus sacchariflorus* to cadmium. – Physiologia Plantarum, 159(3):340–353. DOI: 10.1111/ppl.12526

Hohn, C.E., Bektas, H. 2020. Genetic mapping of quantitative trait loci (QTLs) associated with seminal root angle and number in three populations of bread wheat (*Triticum aestivum* L.) with common parents. – Plant Molecular Biology Reporter, 38:572–585. DOI: 10.1007/s11105-020-01214-1

Ismael, M.A., Elyamine, A.M., Moussa, M.G., Cai, M., Zhao, X., Hu, C. 2019. Cadmium in plants: uptake, toxicity, and its interactions with selenium fertilizers. – Metallomics, 11((2):255–277. DOI: 10.1039/c8mt00247a

Koevoets, I.T., Venema, J.H., Elzenga, J.T., Testerink, C. 2016. Roots withstanding their environment: exploiting root system architecture responses to abiotic stress to improve crop tolerance. – Frontiers in Plant Science, 7:1335. DOI: 10.3389/fpls.2016.01335

Kosyan, A., Smirnov, O., Taran, N., Burdyga, V. 2016. Test system based on root exudates for high-yielding common buckwheat (*Fagopyrum esculentum* Moench.) form screening. – Bulletin of Taras Shevchenko National University of Kiev. Series: Biology, 72(2):71–75. DOI: 10.17721/1728_2748.2016.72.71-75

Kubo, K., Yoshiaki, W., Hitoshi, M., Masako, S., Masaya, F., Naoyuki, K., Koichi, H., Takashi, N. 2011. Differences in cadmium accumulation and root morphology in seedlings of Japanese wheat varieties with distinctive grain cadmium concentration. – Plant Production Science, 14(2):148–155. DOI: 10.1626/pps.14.148

López-Bucio, J., Cruz-Ramírez, A., Herrera-Estrella, L. 2003. The role of nutrient availability in regulating root architecture. – Current Opinion in Plant Biology, 6(3):280–287. DOI: 10.1016/s1369-5266(03)00035-9

Lu, H., Qiao, D., Han, Y., Zhao, Y., Bai, F., Wang, Y. 2021. Low molecular weight organic acids increase Cd accumulation in sunflowers through increasing Cd bioavailability and reducing Cd toxicity to plants. – Minerals, 11(3):243. DOI: 10.3390/min11030243

Lynch, J.P. 2011. Root phenes for enhanced soil exploration and phosphorus acquisition: tools for future crops. – Plant Physiology, 156(3):1041–1049. DOI: 10.1104/pp.111.175414

Ma, Q.J., Sun, M.H., Lu, J., Hu, D.G., Kang, H., You, C.X., Hao, Y.J. 2020. Phosphorylation of a malate transporter promotes malate excretion and reduces cadmium uptake in apple. – Journal of Experimental Botany, 71(12):3437–3449. DOI: 10.1093/jxb/eraa121

Manschadi, A.M., Hammer, G.L., Christopher, J.T., deVoil, P. 2008. Genotypic variation in seedling root architectural traits and implications for drought adaptation in wheat (*Triticum aestivum* L.). – Plant and Soil, 303:115–129. DOI: 10.1007/s11104-007-9492-1

McGrail, R.K.; Van Sanford, D.A.; McNear, D.H., Jr. 2020. Trait-based root phenotyping as a necessary tool for crop selection and improvement. – Agronomy, 10(9):1328. DOI: 10.3390/agronomy 10091328

Nelson, S.K., Oliver, M.J. 2017. A soil-plate based pipeline for assessing cereal root growth in response to polyethylene glycol (PEG)-induced water deficit stress. – Frontiers in Plant Science, 8:1272. DOI: 10.3389/fpls. 2017.01272

Nibau, C., Gibbs, D.J., Coates, J.C. 2008. Branching out in new directions: the control of root architecture by lateral root formation. – New Phytologist, 179(3):595–614. DOI: 10.1111/j.1469-8137.2008. 02472.x

Nigam, R., Srivastava, S., Prakash, S., Srivastava, M.M. 2000. Effect of organic acids on the availability of cadmium in wheat. – Chemical Speciation & Bioavailability, 12(4):125–132. DOI: 10.3184/ 095422900782775481

Osmolovskaya, N., Dung V.V., Kuchaeva, L. 2018. The role of organic acids in heavy metal tolerance in plants. – Biological Communications, 63(1):9–16. DOI: 10.21638/ spbu03.2018.103

Rich, S.M., Christopher, J., Richards, R., Watt, M. 2020. Root phenotypes of young wheat plants grown in controlled environments show inconsistent correlation with mature root traits in the field. – Journal of Experimental Botany, 71(16):4751–4762. DOI: 10. 1093/jxb/eraa201

Rizvi, A., Zaidi, A., Ameen, F., Ahmed, B., Al Kahtani, M.D., Khan, M.S. 2020. Heavy metal induced stress on wheat: phytotoxicity and microbiological management. RSC Advances, 10:38379–38403. DOI: 10.1039/D0RA05610C

Sasaki, T., Ryan, P.R., Delhaize, E., Hebb, D.M., Ogihara, Y., Kawaura, K., Noda, K., Kojima, T., Toyoda, A., Matsumoto, H., Yamamoto, Y. 2006. Sequence upstream of the wheat (*Triticum aestivum* L.) *ALMT1* gene and its relationship to aluminum resistance. – Plant & Cell Physiology, 47(10):1343–1354. DOI: 10.1093/pcp/pcl002

Šichorová, K., Tlustoš, P., Száková, J., Kořínek, K., Balík, J. 2004. Horizontal and vertical variability of heavy metals in the soil of a polluted area. – Plant, Soil and Environment, 50(12):525–534. DOI: 10. 17221/4069-pse

Smirnov, O., Karpets, L.-A., Zinchenko, A., Kovalenko, M., Belava, V., Taran, N. 2020a. Changes of morphofunctional traits of *Triticum aestivum* and *Triticum dicoccum* seedlings caused by polyethylene glycol-modeling drought. – Journal of Central European Agriculture, 21(2):268–274. DOI: 10.5513/ JCEA01/21.2.2341

Smirnov, O., Zinchenko, A., Karpets, L.-A., Kovalenko, M., Taran, N. 2020b. Short communication: Changes of compatible solutes content in *Triticum aestivum* and *Triticum dicoccum* seedlings in response to drought stress. – Agraarteadus, 31(2):208–211. DOI: 10.15159/ jas.20.19

Uga, Y., Kitomi, Y., Ishikawa, S., Yano, M. 2015. Genetic improvement for root growth angle to enhance crop production. – Breeding Science, 65(2):111–119. DOI: 10.1270/jsbbs.65.111

Waidmann, S., Sarkel, E., Kleine-Vehn, J. 2020. Same same, but different: growth responses of primary and lateral roots. – Journal of Experimental Botany, 71(8):2397–2411. DOI: 10.1093/jxb/eraa027

Wang, F., Huang, C., Chen, Z., Bao, K. 2019. Distribution, ecological risk assessment, and bioavailability of cadmium in soil from Nansha, Pearl River delta, China. – International Journal of Environmental Research and Public Health, 16(19): 3637. DOI: 10.3390/ijerph16193637

Wei, B., Yu, J., Cao, Z., Meng, M., Yang, L., Chen, Q. 2020. The availability and accumulation of heavy metals in greenhouse soils associated with intensive fertilizer application. – International Journal of Environmental Research and Public Health, 17(15): 5359. DOI: 10.3390/ijerph17155359

Xie, Q., Fernando, K.M.C., Mayes, S., Sparkes, D.L. 2017. Identifying seedling root architectural traits associated with yield and yield components in wheat. – Annals of Botany, 119(7):1115–1129. DOI: 10.1093/aob/mcx001

Zhang, S., Chen, H., He, D., He, X., Yan, Y., Wu, K., Wei, H. 2020. Effects of exogenous organic acids on Cd tolerance mechanism of *Salix variegata* Franch. under Cd stress. – Frontiers in Plant Science, 11:594352. DOI: 10.3389/fpls.2020.594352

Zhu, X.F., Zheng, C., Hu, Y.T., Jiang, T., Liu, Y., Dong, N.Y., Yang, J.L., Zheng, S.J. 2011. Cadmium-induced oxalate secretion from root apex is associated with cadmium exclusion and resistance in *Lycopersicon esulentum*. – Plant, Cell & Environment, 34(7):1055–1064. DOI: 10.1111/j. 1365-3040.2011.02304.x

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ECOLOGICAL SUITABILITY PEAS (*Pisum sativum*) VARIETIES TO CLIMATE CHANGE IN UKRAINE

Victor Mazur[1], Oleksandr Tkachuk[1], Hanna Pantsyreva[1], Ihor Kupchuk[1], Myroslava Mordvaniuk[1], Oleksandr Chynchyk[2]

[1]Vinnytsia National Agrarian University, 3 Sonyachna St, Vinnytsia, 21008, Ukraine
[2]State Agrarian and Engineering University, 13 Shevchenko St, Kamianets-Podilskyi, 32300, Ukraine

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Vastutav autor: Corresponding author: Ihor Kupchuk

E-mail: kupchuk.igor@i.ua

ORCID:
0000-0002-9365-8682 (VM)
0000-0002-0647-6662 (OT)
0000-0002-0539-5211 (HP)
0000-0002-2973-6914 (IK)
0000-0001-6615-4705 (MM)
0000-0003-0566-2516 (OC)

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ABSTRACT. The varieties of peas can realize about 50% of their productive potential. One of the main reasons for this is the wrong choice of variety for specific ecological growing conditions. Therefore, the purpose and task of our research are to analyze the current range of peas, included in the State Register of plant varieties suitable for cultivation in Ukraine in terms of their real productivity and resistance to drought and disease in the context of climate change in the direction of drought and temperature rise. Assessment of agroecological stability of pea varieties was carried out by elaboration of the State Register of Plant Varieties Suitable for Distribution in Ukraine for 2020, 2010 and Official Descriptions of Plant Varieties and Suitability Indicators submitted in the official bulletins "Protection of Plant Variety Rights" published in Information and reference system "Variety". The most resistant to disease in Ukraine are varieties of peas 'Verbal', 'Prystan', 'Eco', 'Atanas', 'Haiduk'. Varieties are marked by the highest drought resistance 'Verbal', 'Album', 'Alssas', 'Kampus'. The most productive varieties were peas 'Kosmai', 'Album', 'Haiduk', 'Trendy'. The increase in the average annual air temperature in Ukraine during 2001–2020 by 19.3% (8.2–9.9 °C) led to a decrease in the yield of peas by 13.7%, but an increase in the score of resistance of pea varieties to diseases by 25.0%, the score of drought resistance – by 18.8%. Comparison of indicators of disease resistance, drought resistance and productivity of pea varieties for 2020 and 2010 showed that the score of resistance of pea varieties sown to diseases in the period from 2010 to 2020 increased from 6.3 to 8.4 points, *i.e.* by 25.0%. Drought resistance of pea varieties in 2020 compared to 2010 increased from 6.5 to 8.0 points, which is 18.8%. At the same time, the grain productivity of pea varieties in 2020 compared to 2010 decreased from 3.57 t ha^{-1} to 3.08 t ha^{-1}, which is 13.7%.

Introduction

Among grain legumes grown in Eastern Europe, peas occupy the largest area – about 5 million hectares, which is about 30% of the world's area of this crop. This is due to the high average yield, valuable food and fodder qualities of peas, as well as the important agro-ecological impact of pea plants due to symbiotic nitrogen fixation to increase soil fertility and as an optimal precursor for winter crops (Mazur *et al*., 2019.

In Ukraine, peas are grown in all soil and climatic zones on a total area of 347 thousand hectares with an average yield of 2.28 t ha^{-1} (Pantsyreva, 2018; Telekalo, 2018; Mazur *et al.*, 2020; Palamarchuk, Tkachuk, 2020a). The share of peas in the structure of sown areas is slightly more than 1%, which requires a significant increase in its crops because the potential of the best varieties of peas can reach 5.5 t ha^{-1}. However, under adverse weather conditions during the growing season, there is a significant decrease in its yield.

One of the promising areas to increase sown areas and increase pea productivity is the introduction into production of high-yielding varieties with increased resistance to lodging, shedding, adapted to specific growing conditions, in particular to adverse growing conditions, among which drought has stood out in recent decades.

The variety must be characterized by a high adaptive capacity, which allows restoring to the optimal level of metabolic processes after the stress factor, which is especially important due to changes and instability of the climate. The main properties that determine the level of adaptability of peas include high harvest index, type of stem growth, ripening, resistance to disease, resistance to shedding, high real yield.

According to the results of many years of research, it is established that the high productivity of pea varieties is possible under favourable weather conditions. Given the extreme climate in Ukraine, the constant annual increase in average annual air temperature and reduced rainfall, to realize the potential for productivity in varieties of peas is quite difficult. The level of pea yield and its stability by 48% depends on the influence of weather conditions under the optimal parameters of the influence of other factors.

Meteorological conditions that develop during the growing season, largely determine the effectiveness of a particular agronomic technique, which also affects the productivity of pea crops. The results of research by many scientists (Peltonen-Sainio *et al.*, 2009; Kolesnik, 2012; Karkanis *et al.,* 2016; Witold, Cylwester, 2020) on modern technologies of pea cultivation are aimed at maximizing the biological potential of the crop, which cannot be achieved without taking into account the meteorological conditions of a particular region, which play an important role, and without optimizing pea growing technologies.

The determining factor in the expansion of sown areas under sowing peas is the correct selection of varieties taking into account modern environmental conditions. One of the main indicators in the selection of varieties of legumes for certain soil and climatic conditions is their real yield and manufacturability.

In modern conditions, fundamental and applied research has deepened, in which the problems of the greening of agriculture by optimizing the elements of varietal cultivation technology are the subject of special attention of scientists. In particular, the development of this issue includes many scientific works of Ukrainian scientists (Vdovenko *et al*., 2018a; Mazur *et al*., 2019; Pantsyreva, 2019; Didur *et al.,* 2020; Honcharuk, Pantsyreva, 2020; Mazur *et al*., 2020; Razanov *et al*., 2020b; Petrychenko *et al*., 2021; Puyu *et al.,* 2021).

The main indicators of the manufacturability of legumes are the resistance of plants against lodging, shedding of beans, the suitability of plants for direct combining, the height of attachment of the lower beans, plant height and others (Ermakov *et al*., 1987; Ma *et al.*, 2001; Kolesnik, 2012; Yanovych *et al.,* 2018; Bandura *et al.,* 2019; Kaletnik, Lutkovska, 2020; Kuznietsova *et al.*, 2020; Mazur *et al*., 2020; Pantsyreva *et al.*, 2020; Razanov *et al.,* 2020a; Tkachuk, 2020b; Tkachuk, Telekalo, 2020; Didur *et al.,* 2021;).

It is also necessary to take into account the maturity of varieties, their reaction to weather and soil conditions. Climate change in recent years has led to the fact that some varieties of peas have become severely depressed by drought, and this has affected their resistance to diseases, pests, and most importantly – their productivity.

Therefore, the ecological indicators of suitability of varieties of peas should include their drought resistance, as well as resistance to the most common diseases and pests (Yanovych *et al.,* 2017; Pantsyreva, 2019; Mazur *et al*., 2019; Mazur *et al*., 2020; Pantsyreva *et al.,* 2020; Razanov *et al.,* 2020a; Gunko *et al.,* 2021).

The varieties of peas can realize about 50% of their productive potential. One of the main reasons for this is the wrong variety for specific ecological growing conditions (Melnychuk, Patyka, 2011; Mazur *et al*., 2019; Solona *et al.*, 2020).

The purpose of the research was to develop competitive varietal technologies for growing peas seeds, which provides for the development of elements of the application of a set of alternative fertilizers for their cultivation in terms of short-term and long-term action and basic superstructure factor assessment of soil fertility, hydrothermal conditions.

The task of the paper was to analysis of the assortment of peas, included in the State Register of plant varieties suitable for cultivation in Ukraine in terms of their potential productivity and resistance to drought and disease in the context of climate change in the direction of drought and rising temperatures; formation of a new method for assessing the bioadequate productivity of arable land to determine the possibility of adaptation of plants to bioorganic technologies for growing legumes, in particular peas.

Material and Methods

Assessment of agroecological sustainability of pea varieties was carried out by elaboration of the State Register of Plant Varieties Suitable for Distribution in Ukraine for 2020 and Official Descriptions of Plant Varieties and Suitability Indicators submitted in the official bulletins "Protection of Plant Variety Rights" published in the Information Reference system "Variety" (Palamarchuk *et al*., 2018; Vdovenko *et al.,* 2018b; State Register ..., 2021).

Varieties of legumes in the state qualification examination to determine the indicators of suitability for distribution in Ukraine are assessed, among other things, by grain yield, resistance (tolerance) against disease, to adverse weather conditions and other indicators.

The parameters of agri-environmental sustainability, which are covered in official documents, are the relationship of plants to the effects of disease and drought. Quantitative stability was established on a relative nine-point scale (1–9 points), where 9 points correspond to the highest stability, and 1 point – the lowest stability. The following gradation of grades by points was used: 9 points – the grade is excellent; 7 points – good variety; 5 points – the variety is satisfactory; 3 points – bad grade; 1 point – unsatisfactorily. Pea seed yield levels were also analyzed. We compared the studied indicators with the use of mathematical-statistical correlation-regression analysis.

These indicators of sown peas were established based on the Methodology of examination of plant varieties of cereals, cereals and legumes for suitability for distribution in Ukraine. All experiments are performed on plots of 10–25 m^2 with four repetitions.

Establishment of resistance of pea plants to diseases: peronosporosis (*Peronospora pisi* Syb.), Root rot (*Fusarium* Link), ascochitosis (*Ascochyta pisi* Libert.) and anthracnose (*Colletotrichum pisi* Pat.) was carried out by methods: peronosporosis (*Peronospora pisi* Syb) phase of filling the bulk of beans by the percentage of the affected surface; root rot (*Fusarium* Link) – in the phase of full flowering by the percentage of affected plants and the development of the disease in points; ascochytosis (*Ascochyta pisi* Libert.) – during the period of filling the bulk of beans and before harvesting by the percentage of damage to leaves, stems and beans; anthracnose (*Colletotrichum pisi* Pat.) – in the phase of filling the bulk of beans by the percentage of affected plants and the development of the disease in points.

Assessment of varieties resistance to adverse weather conditions, in particular drought, was carried out by general guidelines. During the growing season, pea varieties are visually assessed for drought resistance. To determine the yield of plants, they are harvested separately or directly by combining, when the humidity was in the range of 30–35%, at grain moisture of 16–17%.

Results and Discussion

In Ukraine, as well as all over the world, the development of crop production is ensured by the creation and implementation of new breeding studies. Selection for resistance to climate change requires constant monitoring of plant growth and development. It is necessary to constantly study and identify reliably resistant varieties of peas – sources of resistance. One of the promising ways to address the issue of creating varieties with long-term resistance to climate change in the direction of warming is the use in the selection of sources characterized by genetic resistance to drought. The gene pool of plants is the basis for the identification of these sources with their subsequent introduction into breeding programs (Peltonen-Sainio *et al.*, 2009; Karkanis *et al.*, 2016; Witold *et al.*, 2020; Puyu *et al.*, 2021).

The results of the research show that in Ukraine there is a steady decline in yields of pea varieties in the period from 2001 to 2020. The ecological reason for this is the increase in the average annual air temperature in Ukraine, which causes the development of pea plants in a less favourable temperature range than required by its biological characteristics. This leads to the fact that the central zone of the Forest-Steppe of Ukraine after some time will be unsuitable for growing peas, and its favourable sowing zones will move to the north. In Ukraine, such a zone is Polissya, where pea crops have long been significantly affected by the disease.

At the same time, the selection of modern varieties of peas is developing in the direction of increasing their drought resistance. During the twenty-year observation period, the drought resistance of pea varieties increased by almost two points. The creation of more drought-resistant varieties of peas reduces their dependence on elevated temperatures and allows to keep the yield of pea seeds at a stable level, but in the long run, the yield of modern varieties of peas, despite increasing their drought resistance, decreases. In parallel with the increase in the score of drought resistance of pea varieties, their resistance to disease increases over the study period. An increase in the average annual air temperature objectively worsens the conditions for the development of fungal diseases in pea crops. Therefore, there was a lower level of disease in pea plants in 2020 compared to 2001. However, the increased score of resistance of pea varieties to diseases did not affect the yield, because, in conditions of elevated temperatures, the damage from them on pea plants is negligible.

Based on this, it follows that the increase in drought resistance and disease resistance of pea varieties did not increase or stabilize their yield. The main factor influencing the level of the yield of pea varieties was the average annual air temperature.

We analyzed the indicators of agroecological resistance varieties of peas to disease and drought, as well as their productivity according to the State Register of Plant Varieties of Ukraine, which were introduced during 2015–2020 and in comparison with pea varieties, which were introduced during 2005–2010.

The most common diseases of peas, resistance to which was analyzed, were downy mildew (*Pernosporosis pisi* Syb.), root rot (*Fusarium* Link), ascochitosis (*Ascochyta pisi* Libert.) and anthracnose (*Colletotrichum pisi* Pat.).

During the period 2015–2020, 39 varieties of sown peas were entered into the State Register of Plant Varieties of Ukraine. The range of scores of resistance to diseases varieties of peas, which were included in the State Register during 2015–2020, was 7.8–8.8 points out of 9 maximum possible. The highest resistance to disease was characterized by varieties of peas 'Verbal', 'Prystan' – 8.8 points; 'Eso', 'Atanas', 'Haiduk' – 8.7 points each. The lowest resistance to disease was found in 'Kentso' pea varieties – 7.8 points; 'Kosmai', 'Impuls', 'Trendy' – 8.0 points each. The average score of resistance varieties of peas to disease was 8.4 points (Table 1).

Drought resistance varieties of sown peas were in the range of 7.0–8.8 points out of 9 maximum possible. The highest drought resistance was noted by 'Verbal' – 8.8 points, 'Album', 'Alssas' – 8.7 points, 'Kampus' – 8.6 points. 'Yump', 'Impuls', 'Malahit' varieties had the lowest drought resistance – 7.0 points each. The average score of drought resistance of all varieties of peas was 8.0 points.

Table 1. Indicators of agroecological sustainability and productivity of pea varieties according to the State Register of Plant Varieties of Ukraine for 2020

Varieties	Stability to diseases, points	Drought stability, points	Real yield, t ha^{-1}
'Abars'	8.3	7.8	2.68
'Album'	8.6	8.7	3.78
'Alex YU.L.'	8.3	8.0	3.19
'Alssas'	8.5	8.7	2.92
'Astronavt'	8.2	8.2	2.96
'Atanas'	8.7	8.3	2.90
'Avenger'	8.2	8.2	2.96
'Bokser'	8.3	8.2	3.18
'Bosfor'	8.5	7.5	2.47
'Darunok stepu'	8.5	8.3	3.29
'Eco'	8.7	8.3	3.53
'Haiduk'	8.7	8.5	3.76
'Hambit'	8.2	8.2	2.95
'Heizer'	8.3	7.7	2.41
'Impuls'	8.0	7.0	3.16
'Kampus'	8.6	8.6	3.23
'Kareni'	8.3	8.0	3.14
'Karpaty'	8.3	8.0	3.37
'Kentso'	7.8	7.8	2.44
'Korvet'	8.5	8.3	2.69
'Kosmai'	8.0	8.0	4.70
'Kruiz'	8.4	8.2	2.64
'Lessna'	8.4	7.6	2.55
'Malahit'	8.3	7.0	2.91
'Mazepa'	8.4	7.8	2.72
'Metsenat'	8.3	8.2	3.00
'Prystan'	8.8	8.5	3.25
'Salamanka'	8.4	8.0	2.91
'Slovan'	8.4	7.8	2.72
'Tip'	8.4	8.1	2.83
'Trendy'	8.0	8.0	3.75
'Velvet'	8.3	8.0	3.19
'Verbal'	8.8	8.8	3.67
'Yump'	8.3	7.0	3.29

Grain productivity of pea varieties in 2020, according to the State Register of Plant Varieties of Ukraine, was 2.44–4.70 t ha^{-1}. 'Kosmai' varieties in 2020 have the highest grain productivity – 4.70 t ha^{-1}, 'Album' – 3.78 t ha^{-1}, 'Haiduk' – 3.76 t ha^{-1}, 'Trendy' – 3.75 t ha^{-1}. The least productive varieties were 'Heizer' – 2.41 t ha^{-1}, 'Kentso' – 2.44 t ha^{-1}, 'Bosfor' – 2.47 t ha^{-1}, 'Lessna' – 2.55 t ha^{-1}. The average yield of all varieties of peas was 3.08 t ha^{-1}.

In 2010, 40 varieties of peas were presented in the State Register of Plant Varieties of Ukraine. The score of resistance of these varieties to diseases was in the range of 5.0–8.0. 'Harde', 'Yezero', 'Kardiff', 'Lavr', 'Maskara', 'Ulus', 'Chehbek', 'CHBL-5' pea varieties had the highest resistance to diseases – 8.0 points each. 'Damyr 3', 'Krasnodarskii 8', 'Lazer', 'Lord', 'Namysto', 'Poltavets-2' pea varieties were characterized by the lowest disease resistance – 5.0 points each. The average score of resistance of all varieties of sown peas, which were in the State Register of Plant Varieties of Ukraine in 2010, was 6.3 points.

Drought resistance of pea varieties, which were in the State Register of Plant Varieties of Ukraine for 2010, was 5.0–8.0 points. The most drought-resistant varieties were 'Zekon', 'Kaddi', 'Kardiff', 'Menhir', 'Maskara', 'Madonna', 'Nord', 'Stepovyk', 'Kharkivskii etalonnyi' – 8.0 points each. The lowest drought resistance varieties 'Krasnodarskii 8', 'Konto', 'Camelot', 'Namysto' – 5.0 points each. The average score of drought resistance of all varieties of sown peas in 2010 was 6.5 points (Table 2).

Table 2. Indicators of agroecological sustainability and productivity of pea varieties according to the State Register of Plant Varieties of Ukraine for 2010

Varieties	Stability to diseases, points	Drought stability, points	Real yield, t ha^{-1}
'CHBL-5'	8.0	6.0	3.08
'Chehbek'	8.0	7.5	3.06
'Damyr 3'	5.0	6.0	3.64
'Deviz'	6.0	7.5	3.87
'Efectnyi'	6.0	6.0	3.60
'Elehant'	6.0	6.0	3.12
'Fargus'	6.0	7.5	3.85
'Glyans'	6.0	6.0	3.90
'Harde'	8.0	6.0	4.10
'Hardi'	6.0	6.0	4.14
'Hotivskii'	7.0	6.0	4.16
'Kaddi'	6.0	8.0	3.86
'Kamelot'	6.0	5.0	3.08
'Kamerton'	6.0	6.0	3.56
'Kardiff"	8.0	8.0	4.05
'Keo'	6.0	6.0	3.50
'Kharkivskii etalonnyi'	6.0	8.0	3.60
'Kombainovanyi'	6.0	6.0	3.54
'Konto'	6.0	5.0	3.08
'Krasnodarskii 8'	5.0	5.0	2.60
'Lavr'	8.0	6.0	3.08
'Lazer'	5.0	6.0	3.64
'Madonna'	6.0	8.0	4.64
'Maskara'	8.0	8.0	4.06
'Menhir'	6.0	8.0	3.62
'MoDus'	6.0	6.0	3.64
'Namysto'	5.0	5.0	2.53
'Nord'	5.0	8.0	3.57
'Petroneun'	6.0	6.0	4.06
'Poltavets-2'	5.0	6.0	3.11
'Rialto'	7.0	6.0	3.07
'Santana'	7.0	7.0	3.09
'Stepovyk'	6.0	8.0	3.58
'Svit'	6.0	7.0	3.10
'Tsarevych'	6.0	6.0	3.10
'Ulus'	8.0	6.0	3.12
'Yavor'	6.0	6.0	4.10
'Yezero'	8.0	6.0	4.10
'Zekon'	6.0	8.0	4.12
'Zinkivskii'	6.0	6.0	3.90

Productivity of pea varieties for 2010 was 2.53–4.64 t ha^{-1}. The most productive varieties were 'Madonna' – 4.64 t ha^{-1}, 'Hotivskii' – 4.16 t ha^{-1}, 'Hardy' – 4.14 t ha^{-1}, 'Zekon' – 4.12 t ha^{-1}, 'Yavor' – 4.10 t ha^{-1}. The lowest yields were 'Namysto' – 2.53 t ha^{-1} and 'Krasnodarskii 8' – 2.60 t ha^{-1}. The average seed yield of pea varieties for 2010 was 3.57 t ha^{-1}.

Of the forty varieties of peas that were in the State Register of Plant Varieties of Ukraine for 2010, currently (2021) there are 9 varieties in this article: 'Hotivskii', 'Glyans', 'Zekon', 'Zinkivskii', 'Madonna', 'Namysto', 'Svit', 'Ulus', 'Tsarevych'. Among them, 'Ulus' had the highest disease resistance score, 'Zekon' and 'Madonna' had the highest drought resistance score, and 'Madonna', 'Hotivskii', 'Zekon', 'Zinkivskii' and 'Glyans' had the highest yield.

Comparison of indicators of disease resistance, drought resistance and productivity of pea varieties for 2020 and 2010 showed that the score of resistance of

pea varieties sown to diseases in the period from 2010 to 2020 increased from 6.3 to 8.4 points, *i.e.* by 25.0%. Drought resistance of pea varieties in 2020 compared to 2010 increased from 6.5 to 8.0 points, which is 18.8%. At the same time, the grain productivity of pea varieties in 2020 compared to 2010 decreased from 3.57 t ha^{-1} to 3.08 t ha^{-1}, which is 13.7%.

A comparison of agroecological indicators of pea varieties that remained in the state register from 2010 to the present with other sowing pea varieties that were in the register at that time showed that the score of disease resistance of these varieties was 1.6% lower than the average of all varieties, the drought resistance score was 1.5% lower than the average of all varieties, but 1.1% higher yield.

Correlation-regression analysis revealed an average positive relationship between the score of disease resistance and the score of drought resistance of varieties of peas, which are in the State Register of Ukraine for 2020 ($r = 0.142$; $P > 0.05$) (Fig. 1). The average positive relationship between the score of disease resistance and the score of drought resistance of pea varieties shows that there was no direct relationship between the studied factors, but there was a tendency to increase the resistance of pea varieties to disease with increasing drought resistance.

Correlation-regression analysis revealed an average positive relationship between the score of drought resistance and the yield of pea varieties that were in the State Register of Ukraine in 2010 ($r = 0.442$; $P < 0.01$) (Fig. 2). The average positive relationship between the drought resistance score and the yield of pea varieties shows that with increasing drought resistance of pea varieties, their yield increases. Given the increase in the average annual air temperature in Ukraine, the conditions of pea development are deteriorating, as peas belong to cold-resistant crops, with moderate moisture, which leads to a decrease in its yield. The direction of breeding science to create more drought-resistant varieties provides high productivity in drought conditions. The coefficient of determination ($R^2 = 0.1954$) shows that increasing the score of drought resistance of pea varieties per unit contributes to increasing its yield by 0.19 t ha^{-1}. The average seed yield of pea varieties for 2010 was 3.57 t ha^{-1}.

At the same time, separate combinations of both positive and positive with negative characteristics of pea varieties have been established. In particular, the 'Album' pea variety combined high seed productivity with the highest drought resistance score, the 'Haiduk' variety with high disease resistance, the 'Kosmai' and 'Trendy' varieties with the highest seed yield with the lowest plant resistance, and the 'Kentso' variety with the lowest productivity and the lowest resistance to diseases.

The pea varieties on the state register as of 2010, such as 'Madonna' and 'Zekon', combining high productivity with high drought resistance, and 'Namysto' and 'Krasnodarskii 8' combined low productivity with the lowest score on disease and drought resistance.

According to the Central Geophysical Observatory of Ukraine. Central Geophysical Observatory of Ukraine, named by Borys Sreznevsky from 2001 to 2010, the average annual air temperature in the middle part of Ukraine was in the range of 8.2–9.9 °C. The average temperature for ten years was 9.0 °C. During the second decade – from 2011 to 2020, the average annual air temperature increased by 0.8 °C and amounted to 9.8 °C with an amplitude of 9.0–10.9 °C (Table 3).

Table 3. Dynamics of average annual air temperature in the Forest-Steppe conditions of the Right Bank of Ukraine during 2001–2020 (Central Geophysical Observatory of Ukraine, named by Borys Sreznevsky)

Years	Temperature, °C	Years	Temperature, °C
2001	8.8	2011	9.2
2002	9.3	2012	9.0
2003	8.2	2013	9.4
2004	8.7	2014	9.4
2005	8.7	2015	10.5
2006	8.4	2016	9.5
2007	9.9	2017	9.8
2008	9.6	2018	9.5
2009	9.4	2019	10.6
2010	9.4	2020	10.9
Average for 2001–2010	9.0	Average for 2011–2020	9.8
Average perennial	7.7	Average perennial	7.7

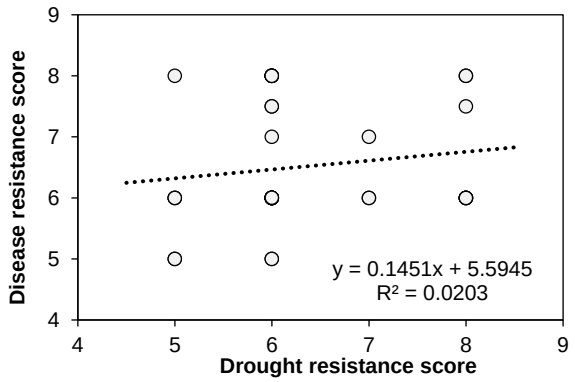

Figure 1. Regression between the score of drought resistance and the score of resistance to diseases of pea varieties included in the State Register of Plant Varieties of Ukraine for 2020

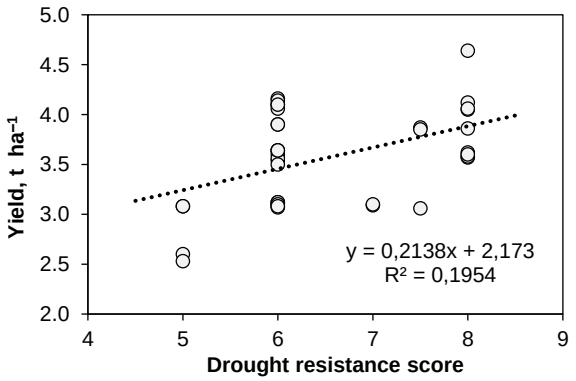

Figure 2. Regression between the score of drought resistance and yield of pea varieties included in the State Register of Plant Varieties of Ukraine for 2010

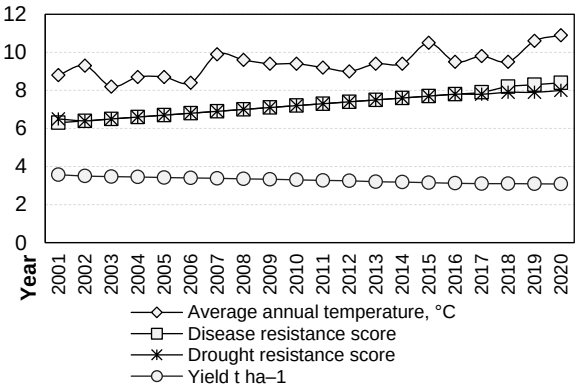

Figure 3. Dynamics of average daily air temperature, the score of disease resistance and drought resistance and yield of pea varieties in Ukraine during 2001–2020.

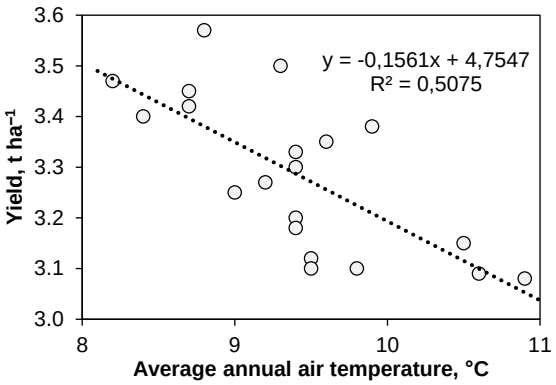

Figure 4. Regression between the average annual air temperature and yield of varieties of peas in 2001–2020

Thus, over the last ten years, the average annual air temperature has risen by 0.8 °C, and compared to the long-term average – by 1.6 °C. Graphic representation of the dependence of changes in average annual air temperature over twenty years on productivity and resistance to disease and drought resistance of pea varieties showed that the growth of average annual air temperature in Ukraine during 2001–2020 by 19.3% led to a decrease in pea yield by 13.7%, but the increase in the score of resistance of pea varieties to diseases by 25.0%, the score of drought resistance – by 18.8% (Fig. 3).

Correlation-regression analysis revealed a strong positive relationship between the average annual air temperature and the score of resistance to diseases of pea varieties ($r = 0.754$; $P < 0.001$); drought resistance score ($r = 0.728$; $P < 0.001$); the strong negative relationship between average annual air temperature and seed yield of pea varieties ($r = –0.712$; $P < 0.001$).

The mathematical relationship between the average annual air temperature and seed yield of pea varieties is described by the correlation-regression chart and the regression equation presented in Figure 4.

The presence of a strong negative relationship between the average annual air temperature and seed yield of pea varieties ($r = –0.712$) shows that with increasing average annual air temperature in Ukraine there was a decrease in the yield of pea varieties under observation for a period of twenty years (2001–2020). The coefficient of determination ($R^2 = 0.5075$) shows that an increase in the average annual air temperature by 1 °C causes a decrease in the average pea yield by 0.5 t ha^{-1} in the twenty-year dynamics of observations.

Conclusion

In 2020 the most diseases resistant in Ukraine are pea varieties 'Verbal', 'Prystan', 'Eso', 'Atanas', 'Haiduk'. 'Verbal', 'Album', 'Alssas', 'Kampus' varieties have the highest drought resistance. The most productive varieties of peas were 'Kosmai', 'Album', 'Haiduk', 'Trendy'. The increase in the average annual air temperature in Ukraine during 2001–2020 by 19.3% led to a decrease in the yield of peas by 13.7%, but an increase in the score of resistance of pea varieties to diseases by 25.0%, the score of drought resistance – by 18.8%.

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Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions

VM, OT – study conception and design;
IK, MM, OC – acquisition of data;
OT, HP, OC – analysis and interpretation of data;
MM, HP – drafting of the manuscript;
IK – editing the manuscript;
VM, HP – critical revision and approval of the final manuscript.

References

Bandura, V., Mazur, V., Yaroshenko, L., Rubanenko, O. 2019. Research on sunflower seeds drying process in a monolayer tray vibration dryer based on infrared radiation. – INMATEN – Agricultural Engineering, 57(1):233–242.

Didur, I., Bakhmat, M., Chynchyk, O., Pantsyreva, H., Telekalo, N., Tkachuk, O. 2020. Substantiation of agroecological factors on soybean agrophytocenoses by analysis of variance of the Right-Bank Forest-Steppe in Ukraine. – Ukrainian Journal of Ecology, 10(5):54–61.

Didur, I., Chynchyk, O., Pantsyreva, H., Olifirovych, S., Olifirovych, V., Tkachuk, O. 2021. Effect of fertilizers for Phaseolus vulgaris L. productivity in Western Forest-Steppe of Ukraine. – Ukrainian Journal of Ecology, 11(1):419–424.

Ermakov, A., Arasimovich, V., Jarosh, N. Peruanskij, Ju., Lukovnikov, G., Ikonnikova, M. 1987. Methods Studies biochemically plants [Metody biokhimicheskogo issledovaniya rastenij]. – Agropromizdat, Leningrad, 430 p. (In Russian).

Gunko, I., Hraniak, V., Yaropud, V., Kupchuk, I., Rutkevych, V. 2021. Optical sensor of harmful air impurity concentration. – Przegląd Elektrotechniczny, 7:76–79. DOI: 10.15199/48.2021.07.15

Honcharuk, I., Pantsyreva H. 2020. Efficiency of growing legumes crops in Ukraine. – In Integration of traditional and innovation processes of development of modern science: collective monograph (3rd ed). (Ed. A. Jankovska). – Baltija Publishing, Riga, Latvia, pp. 42–65. DOI: 10.30525/978-9934-26-021-6-31

Kaletnik, G., Lutkovska, S. 2020. Innovative Environmental Strategy for Sustainable Development. – European Journal of Sustainable Development, 9(2):89–98. DOI: 10.14207/ejsd.2020.v9n2p89

Karkanis, A., Ntatsi, G., Kontopoulou, C.-K., Pristeri, A., Bilalis, D., Savvas, D. 2016. Field pea in European cropping systems: Adaptability, biological nitrogen fixation and cultivation practices. – Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 44(2):325–336. DOI: 10.15835/nbha44210618

Kolesnik, S. 2012. Bacterial fertilizer to optimize nitrogen and phosphorus nutrition soybeans, chickpeas, peas, lentils and commit. – Feed and fodder, 73:145–151.

Kuznietsova, I., Bandura, V., Paziuk, V., Tokarchuk, O., Kupchuk, I. 2020. Application of the differential scanning calorimetry method in the study of the tomato fruits drying process. – Agraarteadus, 31(2): 173–180. DOI: 10.15159/jas.20.14

Ma, Z., Wood, C.W., Bransby, D. I. 2001. Impact of row spacing, nitrogen rate, and time on carbon partitioning of switchgrass. – Biomass Bioenergy, 20(6):413–419. DOI: 10.1016/S0961-9534(01)00008-3

Mazur, V.A., Pantsyreva, H.V., Mazur, K.V., Didur, I.M. 2019. Influence of the assimilation apparatus and productivity of white lupine plants. – Agronomy Research, 17(1):206–219.

Mazur, V.A., Pantsyreva, H.V., Mazur, K.V., Myalkovsky, R.O., Alekseev, O.O. 2020. Agroecological prospects of using corn hybrids for biogas production. – Agronomy Research, 18(1): 177–182. DOI: 10.15159/ar.19.024

Melnychuk, T., Patyka, V. 2011. Microbial preparations bioorganic farming system. – In Proceedings of Third All-Ukrainian Congress of Ecologists with international participation. VNAU, Vinnytsya, Ukraine, 2:423–426.

Palamarchuk, V., Honcharuk, I., Honcharuk T., Telekalo, N. 2018. Effect of the elements of corn cultivation technology on bioethanol production under conditions of the right-bank forest-steppe of Ukraine. – Ukrainian Journal of Ecology, 8(3):47–53.

Palamarchuk, V., Telekalo, N. 2018. The effect of seed size and seeding depth on the components of maize yield structure. – Bulgarian Journal of Agricultural Science, 24(5):785–792.

Pantsyreva, H.V. 2018. Research on varietal resources of herbaceous species of Paeonia L. in Ukraine. – Scientific Bulletin of the NLTU of Ukraine, 28 (8):74–78. DOI: 10.15421/40280815

Pantsyreva, H.V. 2019. Morphological and ecological-biological evaluation of the decorative species of the genus *Lupinus* L. – Ukrainian Journal of Ecology, 9(3):74–77.

Pantsyreva, H.V., Myalkovsky, R.O., Yasinetska, I.A., Prokopchuk, V.M. 2020. Productivity and economical appraisal of growing raspberry according to substrate for mulching under the conditions of Podilia area in Ukraine. – Ukrainian Journal of Ecology, 10(1):210–214.

Peltonen-Sainio, P., Jauhiainen, L., Hakala, K. 2009. Are there indications of climate change induced increases in variability of major field crops in the northernmost European conditions? – Agricultural and Food Science, 18(3–4):206–222. DOI: 10.2137/145960609790059424

Petrychenko, V.F., Lykhochvor, V.V., Olifir, Y.M. 2021. Application of green clover manure in winter wheat growing. – Ukrainian Journal of Ecology, 11(2):91–93.

Puyu, V., Bakhmat, M., Pantsyreva, H., Khmelianchyshyn, Y., Stepanchenko, V., Bakhmat, O. 2021. Social-and-Ecological Aspects of Forage Production Reform in Ukraine in the Early 21st Century. – European Journal of Sustainable Development, 1:221–228.

Razanov, S.F., Tkachuk, O.P., Bakhmat, O.M., Razanova, A.M. 2020a. Reducing danger of heavy metals accumulation in winter wheat grain which is grown after leguminous perennial precursor. – Ukrainian Journal of Ecology, 10(1):254–260. DOI: 10.15421/2020_40.

Razanov, S.F., Tkachuk, O.P., Razanova, A.M., Bakhmat, M.I., Bakhmat, O.M. 2020b. Intensity of heavy metal accumulation in plants of *Silybum marianum* L. in conditions of field rotation. – Ukrainian Journal of Ecology, 10(2):131–136. DOI: 10.15421/2020_75.

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

State Register of Plant Varieties Suitable for Distribution in Ukraine for 2021. – https://sops.gov.ua/reestr-sortiv-roslin. Accessed on 02/03/2021.

Tkachuk, O. 2020a. Growth and development of leguminous perennial herbs in soil pollution with heavy metals. – Sciences of Europe, 3(48):8–13.

Tkachuk, O. 2020b. Height dynamics of perennial leguminous herbs in the context of soil contamination with heavy metals. – Sciences of Europe, 2(49):7–12.

Tkachuk, O., Telekalo, N. 2020. Agroecological potential of legumes in conditions of intensive agriculture of Ukraine. – In Integration of traditional and innovation processes of development of modern science: collective monograph (3rd ed), (Ed. A. Jankovska, – Baltija Publishing, Riga, Latvia. pp. 91–108. DOI: 10.30525/978-9934-26-021-6-33

Vdovenko, S.A., Pantsyreva, G.V., Palamarchuk, I.I., Lytvyniuk, H.V. 2018a. Symbiotic potential of snap beans (*Phaseolus vulgaris* L.) depending on biological products in agrocoenosis of the right-bank forest-steppe of Ukraine. – Ukrainian Journal of Ecology, 8(3):270–274.

Vdovenko, S.A., Prokopchuk, V.M., Palamarchuk, I.I., Pantsyreva, H.V. 2018b. Effectiveness of the application of soil milling in the growing of the squash (*Cucurbita pepo* var. giraumontia) in the right-bank forest steppe of Ukraine. – Ukrainian Journal of Ecology, 8(4):1–5.

Witold, S., Cylwester, M. 2020. Standardised ileal amino acid digestibility in field pea seeds of two cultivars differing in flower colour for broiler chickens: Effects of bird age and microbial protease. – Animals, 10(11):2099. DOI: 10.3390/ani10112099

Yanovych, V., Honcharuk, T., Honcharuk, I., Kovalova, K. 2017. Design of the system to control a vibratory machine for mixing loose materials. – Eastern-European Journal of Enterprise Technologies, 6(3–90):4–13. DOI: 10.15587/1729-4061.2017.117635

Yanovych, V., Honcharuk, T., Honcharuk, I. Kovalova, K. 2018. Engineering management of vibrating machines for targeted mechanical activation of premix components. – INMATEH – Agricultural Engineering, 54(1):25–32.

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EFFECT OF SHADING NET, PLANTING METHODS AND BIO-EXTRACT ON PRODUCTION OF MUSKMELON

Abdulraheem A. Obaid[1,3], Hassan H. Al-Alawy[2], Kadhum Daley Hassan[1], Ghassan Jaafar Hamdi[3]

[1]Department of Horticulture and Landscape Gardening, College of Agriculture, University of Baghdad, 10071, Baghdad, Iraq
[2]Department of Soil Science and Water Resources, College of Agriculture, University of Diyala, 32001, Baqubah, Iraq
[3]Department of Horticulture and Landscape Gardening, College of Agriculture, University of Diyala, 32001, Baqubah, Iraq

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Vastutav autor: Corresponding author: Ghassan Jaafar Hamdi

E-mail: ghassanhamdi38@gmail.com

ORCID:
0000-0001-9312-8238 (GJH)

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ABSTRACT. Growing vegetable transplants under shade nets are currently becoming more popular to protect high intensities of light and high temperature. This study was undertaken to evaluate the influence of shading net at 30% shading and an unshaded control, methods of the planting, direct sowing, transplanting, and foliar application of a biozyme fertilizer at 0 and 0.5 ml L^{-1} production, and quality of muskmelon. These treatments were laid out in a randomized complete block design (RCBD) and were arranged in a split-split plot with three replications. Results showed that 30% shading treatment produced the highest leaf chlorophyll content (57.07 SPAD) and TSS (13.05%). Direct sowing gives a higher value for fruit weight (3583 g), most yield per plant (3772 g) and most total yield (3772 g). Transplanting produced the highest fruit per plant (1.58 fruit). The 0.5 ml L^{-1} fertilizer treatment had the least time to maturity (92.08 days). The interaction between shading treatment, establishment methods and biozyme fertilizer improve the fruit quality and yield of muskmelon.

Introduction

The melon referred to as "Cantaloupe" is classified as a misnomer that is used widely in the vegetable industry as muskmelon (*Cucumis melo* var. *reticulatus*). True cantaloupe (*C. Melo* var. *cantalupensis*) is grown in Europe and is a small fruit with a hard is known for its unique flavour and taste (Mossler, 2010). Muskmelon is a herbaceous annual plant that thrives in dry, sunny, and hot environments (Fontes, Puiatti, 2005).

Due to the extreme heat of the summer season in Iraq, the usage of shade nets has become popular increasingly. Crops are typically protected from excessive sun radiation by netting (Taiz, Zeiger, 2004; Degri, Samalia, 2014) which improves the thermal environment due to the efficiency of photosynthesis can be diminished when some plants are exposed to high amounts of radiation. Photosynthesis, respiration, transpiration and climatic conductance are all variables that impact muskmelon development and production (Teitel *et al.*, 2008; Silva, Costa, 2013). Providing protection from the elements such as wind and preventing the spread of viral illnesses carried by birds and insects can affect the growth and production of muskmelon (Martinez, 1996). Only a few articles showed the influence of shade to achieve maximum growth and yield. The shaded plant had a significantly higher height and internode length than the non-shaded plants (Rungruksatham, Khurnpoon, 2016; Sankhala *et al.*, 2019). While the shaded plant's stem diameter, chlorophyll content from middle leaves and closest fruit were all considerably smaller than the non-shaded plants. Compared to the shaded plant, the non-shaded plant exhibited considerably larger fruit weight, volume, TSS, and thickness (Rungruksatham, Khurnpoon, 2016). In previous decades, many studies were conducted to show the effect of the muskmelon establishment methods on the development of plants and if there was a reflection on the growth and production of muskmelon and can be either direct sowing or transplanted (Andersen, 2018). The earliest harvested melons command top market prices (Mossler, 2010). Producing seedlings for transplanting seeds are usually sown under-protected conditions which improve germination; poor germination which is

a problem in cold soils. In the greenhouse, germination contributes to reducing crop length, early flowering in the field, economies in seed rate, and time saved. Ecological considerations and defence against pests are controlled with direct sowing (Andersen, 2018).

Plant biostimulants, which are natural chemicals other than fertilizers and pesticides that can enhance plant growth, yield, and yield quality when given to the crop in small amounts, are among the most promising solutions to address these increasing issues (Colla, Rouphael, 2015; Du Jardin, 2015).

Thus, the purpose of this work was to study the impact of the shading net, transplanting and foliar application of biozyme on the growth and yield in muskmelon *cv*. 'Gena'.

Materials and Methods

Experiments were conducted using muskmelon plants in a greenhouse at the University of Diyala in Baqubah, Iraq. Between 2 February and 30 May 2020. The soil of the study site is classified as well-drained sandy loam. The chemical properties of the soil were $CaCO_3$ (273.4 g kg^{-1}), $EC_{1:1}$ (6.12 dS m^{-1}), organic matter (1.12 g kg^{-1}), and nitrogen, phosphorous, and potassium as 55, 255, and 9.5 mg kg^{-1}, respectively. Bulk density was 1.45 M mg m^{-3}. Field capacity was 25%. The EC of irrigation water was 0.82 dS m^{-1}.

The experimental design was laid out in a 450 m² area arranged in a split-split plot, in a randomized complete block design, replicated in 3 blocks. The number of experimental units was 24. Each experimental unit included 20 plants and the total number of plants for the experiment was 480.

The first factor was shading which included an unshaded control (S_0) and coloured nets that were white (30% shade) (S_1). The second factor was the planting methods (direct sowing and transplanting) as the subplot. Transplanting and direct sowing were done at the same time. The third factor was the level of biozyme at 0 and 0.5 ml L^{-1}. The composition of the biozyme fertilizer as provided by the producing company is reported in (Table 1). The first spraying was after three weeks from the planting then this process was repeated every 10 days until the fruits attained their maturation stage or maturity.

Table 1. Composition of the fertilizer biozyme (as provided by the producing company)

Nutrient	Percent, wt vol.$^{-1}$	Nutrient	Percent, wt vol.$^{-1}$
Plant hormones	78.87	S	0.44
IAA	32.2	B	0.30
GA3	32.2	Fe	0.49
Zeatins	83.2	Mn	0.12
Nutrient minerals	1.86	Zn	0.37
Mg	0.14	other	19.20

Biozyme TF (French company Arista Life Science)

The soil was fertilized with nitrogen (N), phosphorus (P), and potassium (K) at 150 kg ha^{-1}, respectively, using 10-10-10 granular fertilizer was mixed and placed 20 cm deep in the centre of the bed.

Seedlings were transplanted at the 3–5 leaf stage to withstand against adverse effects of wind and frost. Later, when plants had three true leaves, plants were thinned to 1 seeding per hole. For the transplanting method, the seed was sown in plastic trays, 0.50 × 1 m, with 104-cells per tray, containing peat moss as a medium on 21 January 2020 in a greenhouse and seedlings were ready to transplant when they had 3 true leaves on 2 February 2020.

Traits measured

Data were taken from eight randomly selected plants from each plot to determine index chlorophyll in leaves with a chlorophyll meter (SPAD-502 Plus, Konica Minolta, Japan), early maturity (days), number of fruits per plant, fruit weight (g), total yield (t greenhouse^{-1} (504 m^2) and total soluble solids (TSS) of muskmelon juice were determined with a handheld refractometer (PR-32, Co. Ltd., Tokyo, Japan) with automatic temperature compensation.

Data analysis

The statistics analysis was done using the SAS program; the LSD test was set up to determine the significant differences between means and the confidence level was (0.05).

Results

Table 2 shows that all measured traits in this study was significantly influenced by the single factor of shading (S), methods of planting (G), or foliar spray with biozyme (F). The S1 gave the highest value for leaf chlorophyll content (57.07 SPAD) and TSS (13.05%) which was significantly different from S0 for early maturity, number of fruits per plant, fruit weight, plant yield and total yield there was found a non-significant difference among levels of (S) treatment. The G0 gave a higher value for fruit weight (3583 g), most yield per plant (3772 g) and most total yield (3772 g).

Table 2. Effect of shading methods, establishment methods and biozyme fertilizer on production, and quality of muskmelon

Factors	SPAD index	Early maturity, days	No. of fruits per plant	Fruit weight, g	Plant yield, g	Total yield, t house^{-1}	TSS, %
S0	55.88	89.58	1.33	2406	2782	2.78	11.08
S1	57.07	91.25	1.33	2303	2742	2.74	13.05
LSD	1.227	3.586	0.621	449.4	619.6	0.619	0.271
G0	55.59	88.75	1.08	3583	3772	3.77	12.18
G1	56.37	92.08	1.58	1125	1752	1.75	11.94
LSD	2.92	4.627	0.327	332.3	247.6	0.247	0.595
F0	55.87	88.75	1.25	2385	2645	2.64	11.69
F1	56.09	92.08	1.42	2325	2879	2.88	12.43
LSD	1.285	2.354	0.544	407	596.5	0.597	0.934

S_0 – non-shading, S_1 – 30% shading, G_0 – direct sowing, G_1 – transplanting, F_0 – without foliar spraying and F_1 – foliar spraying

The G1 gave the highest value for fruit per plant (1.58 fruit), significantly different from G0. The F1 had less time to maturity (92.08 days) which was significantly different from F0. However, the leaf chlorophyll content, number of fruits per plant, fruit weight, plant yield, total yield, and TSS there were found a non-significant difference among levels of (F) treatment.

Table 3 shows the interaction between two factors (S*G, S*F or G*F), there was a significant difference among treatments for all measured traits. The S1*G1 has observed the highest value of leaf chlorophyll content (57.45 SPAD) which was significantly differenced from others. The S0*G0 was given the highest value of fruits weight (3740 g) and less time to maturity (87.5 days) which was significantly different from others. The S0*G1 gave the highest value of fruit per plant (1.67 fruit). The S1*G0 gave the highest value of yield plant (3803 g), higher total yield (3.8 t house^{-1}), and highest TSS (13.63%) which was significantly differenced from others. The S1*F1 gave the highest leaf chlorophyll content (57.08 SPAD) and TSS (13.18%), significantly different from others. For the other measured traits, there were found non-significant between S*F interaction. The G0*F0 gave less time to maturity (87.5 days) and heavier fruit (3663 g). The highest value of fruit per plant and TSS was observed in G1*F1 (1.67 fruit and 12.47%). The highest value of yield per plant and total yield was observed in G1*F0 which was significantly different from others.

For the three-factor interactions (S*G*F), there was a significant difference among treatments for all measured traits (Table 4). The treatment S1*G1*F0 was observed the highest value of leaf chlorophyll content (57.57 SPAD), which was significantly differenced from others. The treatment S0*G0*F0 gave less time to maturity (86.67 days), which was significantly different from others. The highest fruit weight was observed in the treatment S0*G0*F0 (3787 g). The highest yield, total yield, and TSS was observed in the treatment S1*G0*F1 (3973 g, 3.97 t house^{-1}, and 13.8%, respectively). However, the treatment S1*G1*F0 was given the lowest value (1478 g and 1.47 t house^{-1}, respectively). The lowest value of TSS was observed in the treatment S0*G1*F0.

Table 3. Effect of the interaction shading × establishment methods, shading × biozyme fertilizer and establishment methods × biozyme fertilizer on production, and quality of muskmelon

Factors	SPAD index	Early maturity, days	No. of fruits per plant	Fruit weight, g	Plant yield, g	Total yield, t house^{-1}	TSS, %
S0G0	54.48	87.5	1	3740	3740	3.74	10.73
S0G1	55.28	91.67	1.67	1072	1823	1.82	11.42
S1G0	56.7	90	1.17	3428	3803	3.8	13.63
S1G1	57.45	92.5	1.5	1178	1680	1.64	12.47
LSD	2.884	4.649	0.494	392.9	493.8	0.494	0.588
S0F0	54.67	88.33	1.33	2372	2733	2.73	10.47
S0F1	55.1	90.83	1.33	2441	2830	2.83	11.68
S1F0	57.07	89.17	1.17	2397	2556	2.55	12.92
S1F1	57.08	93.33	1.5	2209	2928	2.93	13.18
LSD	1.395	3.038	0.619	458.4	660.5	0.661	0.938
G0F0	55.33	87.5	1	3663	3663	3.66	11.97
G0F1	56.4	90	1.5	1106	1626	1.62	11.42
G1F0	55.85	90	1.17	3505	3880	3.88	12.4
G1F1	56.33	94.17	1.67	1145	1877	1.88	12.47
LSD	2.877	4.613	0.579	464.8	611.9	0.612	1.005

S_0 – non-shading, S_1 – 30% shading, G_0 – direct sowing, G_1 – transplanting, F_0 – without foliar spraying and F_1 – foliar spraying

Table 4. Effect of the interaction shading × establishment methods × biozyme fertilizer and establishment methods × biozyme fertilizer on production, and quality of muskmelon

Factors	SPAD index	Early maturity, days	Number of fruits per plant	Fruit weight, g	Plant yield, g	Total yield, t house^{-1}	TSS, %
S0G0F0	54.10	86.67	1.00	3693	3693	3.69	10.5
S0G0F1	54.87	88.33	1.00	3787	3787	3.78	10.6
S0G1F0	55.23	90.00	1.67	1050	1773	1.77	10.4
S0G1F1	55.33	93.33	1.67	1095	1873	1.87	12.4
S1G0F0	56.57	88.33	1.00	3633	3833	3.83	13.4
S1G0F1	56.83	91.67	1.33	3223	3973	3.97	13.8
S1G1F0	57.57	90.00	1.33	1162	1478	1.47	12.4
S1G1F1	57.33	95.00	1.67	1195	1882	1.88	12.5
LSD	3.034	5.167	0.834	640	890	0.891	1.366

S_0 – non-shading, S_1 – 30% shading, G_0 – direct sowing, G_1 – transplanting, F_0 – without foliar spraying and F_1 – foliar spraying

Discussion

It is important to note that the nature of the growth of the root system is of great importance in determining its efficiency in absorbing water and nutrients from the soil and the available depth of the soil for these roots. Using the seeds in cultivation directly in the soil allows the formation of a deep root system that has greater efficiency in providing the plant with the requirements of growth and production. High solar radiation in the Middle East causes heat stress that increases the rate of respiration of plants and thus loses a percentage of water and sugars manufactured in the plant, which negatively affects the inhibition of growth rate. In this study, the weight of fruits increased when seeds were directly sowed in the soil. This may be due to the formation of a deep root system that is highly efficient in absorbing water and nutrients from the soil, thus stimulating an increase in the metabolism process within the plant and then depressing more of it in the developing fruits. The muskmelon is usually directly planted by using the seeds since the roots will partially be damaged during transportation from containers to soil and which will affect the development of the roots naturally (Andersen, 2018).

The positive effect of shading on chlorophyll, TSS, and the positive combination effect on the yield indicators, maybe due to the impact of shading that reduced the excess solar radiation than the plant needs to reduce excess heat (Taiz, Zeiger, 2004; Pacharane, 2016; Abu-Zahra, Ateyyat, 2016; Diliprao, 2018; Utkhede *et al.*, 2019). Therefore, reducing solar radiation makes the ideal temperature for growth. Other results indicated that the 30% shading improved most of the vegetative characteristics and the yield of muskmelon plants compared to the plants exposed to

full solar radiation. A significantly negative effect in the early maturity of the fruits, when compared to untreated plants, resulted from the continuity of the vegetative growth of the plants for the longest time (Francisco *et al.,* 2011). Other previous studies have indicated the importance of foliar spraying in improving the growth and yield of vegetable plants. In limited experimental investigations, considering the impact of biostimulants under open-field and green-house settings, a rise in early and total marketable fruit yields has been observed for various crops. (Halpern *et al.,* 2015; Ali *et al.,* 2016; Rouphael *et al.,* 2017).

Conclusion

1. Planting of the muskmelon in plastic house by the transplant method had a significant effect on the number of the fruits, at the expense of decreased; weight of the fruit to levels that exceeded their positive impact on the number of fruits. Moreover, this effect caused decreasing in the plant's yield.
2. Shading of the plants had a significant effect on the index of chlorophyll (spad-502) and TSS in the fruits and significantly superior by their treatments combination such as increasing the yield and improving the quality of the fruit.
3. Plants treated with biozyme had a negative effect that delayed fruits maturity compared with the untreated plants.

Recommendation

Using the seeds directly in the planting of the muskmelon is recommended since it improves their growth and productivity, as well the shading which reduces solar radiation and thermal stress on plants in the spring season.

Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions

AO 25%, HA 25%, KH 25%, GH 25% – study conception and design;
HA 50%, AO 50% – acquisition of data;
AO 50%, AH 25%, KH 25% – analysis and interpretation of data;
AO 25%, HA 25%, KH 25%, GH 25% – critical revision and approve the final manuscript.

References

Abu-Zahra, T.R., Ateyyat, M.A. 2016. Effect of various shading methods on cucumber (*Cucumis Sativus* L.) growth and yield production. – International Journal of Environment and Sustainability, 5(1):10–17. DOI: 10.24102/ijes.v5i1.659

Ali, N., Farrell, A., Ramsubhag, A., Jayaraman, J. 2016. The effect of *Ascophyllum nodosum* extracts on the growth, yield and fruit quality of tomato under tropical conditions. – Journal of Applied Phycology, 28:1353–1362. DOI: 10.1007/s10811-015-0608-3

Andersen, C.R. 2018. Home gardening series. Muskmelon. – University of Arkansas Division of Agriculture Research & Extension, FSA6071, Fayetteville, 4 p.

Colla, G., Rouphael, Y. 2015. Biostimulants in horticulture. – Scientia Horticulturae, 196:1–2. DOI: 10.1016/j.scienta.2015.10.044

Diliprao, U.A. 2018. Response of Muskmelon to spectral modification and irrigation levels under shading nets'. – MS. Thesis. Mahatma Phule Krishi Vidyapeeth, Rahuri. Indian, 263 p.

Du Jardin, P. 2015. Plant biostimulants: Definition, concept, main categories and regulation. – Scientia Horticulturae, 196:3–14. DOI: 10.1016/j.scienta. 2015.09.021

Degri, M.M., Samalia, A.E. 2014. Impact of intercropping tomato and maize on the infestation of tomato fruit borer (*Helicoverpa armigera*). – Journal of Agricultural and Crop Research, 2:160–164.

Fontes, P., Puiatti, M. 2005. Cultura do melão. In: Olericultura: teoria e prática (Ed. P.C.R. Fontes). – Viçosa: Universidade Federal de Viçosa, pp. 407–428.

Francisco, H.F.P., Puiatti, M., Finger, F.L., Cecon, P.R. 2011. Growth assimilates partition and yield of melon charenthais under different shading screens. – Horticultura Brasileira, 29:91–97. DOI: 10. 1590/ S0102- 05362011000100015

Halpern, M., Bar-Tal, A., Ofek, M., Minz, D., Muller, T., Yermiyahu, U. 2015. The use of biostimulants for enhancing nutrient uptake. – Advances in Agronomy, 130:141–174. DOI: 10.1016/bs.agron.2014. 10.001

Martinez, C.A. 1996. Fotoinibição da fotossíntese. – Viçosa: UFV, 69 p. (In Portugese)

Mossler, M. 2010. Crop profile for muskmelon in Florida. – University of Florida. USA, 16 p.

Pacharane, S.B. 2016. Effect of different shadenet colours and foliar application of potassium on growth, yield and quality of muskmelon. – M.S. Thesis. Mahatma Phule Krishi Vidyapeeth, Rahuri. India, 143 p.

Rouphael, Y., De Micco, V., Arena, C., Raimondi, G., Colla, G., De Pascale, S. 2017. Effect of *Ecklonia maxima* seaweed extract on yield, mineral composition, gas exchange, and leaf anatomy of zucchini squash grown under saline conditions. – Journal of Applied Phycology, 29:459–470. DOI: 10.1007/s10811-016-0937-x

Rungruksatham, P., Khurnpoon, L. 2016. Effect of shade net and fertilizer application on growth and quality in muskmelon (*Cucumis melo.* L. var. reticulatus) after harvest. – International Journal of Agricultural Technology, 12(7.1):1407–1417.

Sankhala, G.K., Verma, P., Nandre, B.M., Vadodaria, J.R., Joshi, P.C., Vani, F.B. 2019. Effect of different shadenet on growth, flowering, yield and quality of muskmelon (*Cucumis melo* L.) cv. GMM3. –

International Journal of Agriculture Sciences, 11(5):7950–7952.

Silva, H.R., Costa, N.D. 2003. Exigências de clima e solo e época de plantio. In: Melão produção: aspectos técnicos (H.R. Silva, N.D. Costa). – Brasília: Embrapa Informação Tecnológica, pp. 23–28. (In Portugese)

Taiz, L., Zeiger, E. 2004. Fisiologia Vegetal (Eds. E.R. Santarém *et al.*) 3. ed. – Porto Alegre: Artmed, 719 p. (In Portugese)

Teitel, M., Liron, O., Haim, Y., Seginer, I. 2008. Flow through inclined and concertina shape screens. – Acta Horticulturae, 801:99–106. DOI: 10.17660/Acta Hortic.2008.801.5

Utkhede, A.D., Gadge, S.B., Gorantiwar, S.D. 2019. Response of muskmelon to spectral modification of shading nets under different drip irrigation regimes. – International Journal of Current Microbiology and Applied Sciences, 8(2):419–428. DOI: 10.20546/ijcmas.2019.802.047

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GENOTYPE AND NITROGEN EFFECTS ON GRAIN YIELD AND YIELD-RELATED TRAITS OF MAIZE (*Zea mays* L.) HYBRIDS

Ganga Paudel[1], Maya Bhatta[1], Mohan Mahato[2], Darbin Joshi[2], Jiban Shrestha[3]

[1]Prithu Technical College, Institute of Agriculture and Animal Science, Tribhuvan University, Bangaun, Ward No. 3, Lamahi Municipality, Dang, 22414, Nepal
[2]International Maize and Wheat Improvement Center (CIMMYT), Khumaltar, Ward No. 15, Lalitpur Metropolitan City, Lalitpur, 44700, Nepal
[3]Nepal Agricultural Research Council, National Plant Breeding and Genetics Research Centre, Khumaltar, Ward No. 15, Lalitpur Metropolitan City, Lalitpur, 44700, Nepal

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Vastutavautor: Corresponding author: Ganga Paudel

E-mail: gangapaudel73@gmail.com

ORCID:
0000-0002-1631-3621 (GP)
0000-0001-6355-2505 (MB)
0000-0002-1883-7402 (MM)
0000-0003-1566-3598 (DJ)
0000-0002-3755-8812 (JS)

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ABSTRACT. Genotype and nitrogen application are important determinants of grain yield in maize. This experiment was carried out in split-plot design with two factors (maize hybrids as the main factor and nitrogen rates as the sub factor) arranged in randomized complete block design (RCBD) with three replications. The maize hybrids including Rampur Hybrid-2, Rampur Hybrid-4 and Rampur Hybrid-6 were main plots, and four nitrogen rates of 0, 140,160, and 180 kg N ha^{-1} were sub-plot. Results revealed that hybrids had significant effects on the days to 50% tasselling, cob circumference, number of kernel rows per cob and grain yield. Similarly, nitrogen rates had significant effects on all parameters except on the days to 50% tasselling and silking. The highest values of cob length (18.31 cm), no of kernel rows per cob (13.22), no of kernels per cob (33.36), cob circumference (13.90 cm) was recorded from the plot fertilized with 180 kg N ha^{-1}. Rampur Hybrid-2 produced the highest yield (6.19 t ha^{-1}), whereas the lowest yield was found in Rampur Hybrid-6. Similarly, 180 kg N ha^{-1} produced a significantly higher yield (7.06 t ha^{-1}) which was followed by 160 kg ha^{-1} (6.71 t ha^{-1}), 140 kg ha^{-1} (6.30 t ha^{-1}) and the lowest yield (3.93 t ha^{-1}) with 0 kg N ha^{-1}. Therefore, among the hybrids evaluated, Rampur Hybrid-2 could be an appropriate hybrid variety for the cultivation at Dang district and similar conditions in Nepal. This study suggests that maize production can be maximized by cultivating Rampur Hybrid-2 with the use of 180 kg N ha^{-1} in the inner Terai region of Nepal.

Introduction

In terms of area and productivity, maize is Nepal's second most important crop after rice. In Nepal, the maize production area is currently 8.915 million hectares with a productivity of 2.50 t ha^{-1} (MOAD, 2016). According to Oad *et al*. (2004), the biggest obstacles to boosting grain yield, include an insufficient supply of fertilizers. Among the plant nutrients, nitrogen (N) management is one of the most essential factors for increasing crop yield and profitability (Amanullah, 2016). N is the most yield-restraining nutrient in crop production worldwide Guo *et al.* (2016). Nitrogen is a major component of amino acids, which function as the building blocks of proteins. It is a vital nutrient for maize, and its role in photosynthesis and other biological activities such as water and mineral absorption, vacuole storage, and xylem transport is a key determinant of grain yield (Asibi *et al*., 2019). Nitrogen (N) fertilizer affects dry matter production in maize via regulating leaf area development, leaf area maintenance, photosynthetic ability, and, as a result, yield, and grain quality (Muchow, Sinclair, 1994). Nitrogen improves grain yield in all hybrids, mostly by increasing the number of kernels, which increases productivity (Uribelarrea *et al*., 2004; Khaliq *et al*., 2009). Nitrogen (N) deficit results in pale, yellowish-green maize plants with thin stalks. Because nitrogen is a mobile nutrient in plants, symptoms appear first on the older, lower leaves and proceed up the plant if the deficiency is not corrected. A V-shaped

yellowing appears on leaves, starting at the tip and moving down the midrib toward the leaf base (Sawyer, 2004). The increase in maize grain production after nitrogen fertilization is mostly due to an increase in the number of ears per plant, total dry matter distributed to the grain, and average ear weighing (Nxumalo *et al*., 1993). Hybrid maize varieties are more nitrogen-responsive than local varieties of maize (Shrestha *et al*., 2018b). Maize grain production and quality are affected by nitrogen application rate and fertilizer N source. In hybrid maize varieties, nitrogen fertilizer at a rate of 150 kg ha^{-1} enhanced grain production and yield attributing factors such as the number of cobs per hectare and thousand-grain weight (Sharma *et al*., 2019). Urea is becoming more popular because it offers several advantages over other forms of nitrogen fertilizer in terms of manufacturing, transportation, and marketing (Biswas, Ma, 2016). Another source of N is Di-ammonium phosphate.

Crop yield is also heavily influenced by variety. To acquire the best yield, cultivars that are suitable to specific agro-ecological locations, seasons, and maturity should be chosen (Adhikari *et al*., 2021). The reason for differences in grain yield and yield attributing traits among the maize genotypes was due to their variation in their genetic makeup. Prasai *et al*. (2015) reported significant differences among maize cultivars for grain yield and yield attributing traits. Dhakal *et al*. (2017) observed the difference in the days to tasseling and silking among maize genotypes. Shrestha *et al*. (2021) found that promising maize hybrids namely KWM-91 × KWM-93 produced the maximum values of grain yield (9.99 t ha^{-1}) followed by KWM-93 × KWM-91 (9.63 t ha^{-1}) and KWM-92 × KWM-93 (9.40 t ha^{-1}) at Khumaltar, Lalitpur, Nepal. Similarly, Kandel and Shrestha (2020) found that their two years of field experiments showed that P3396, Shresta, and Rampur Hybrid 6 in 2018 and P3396, Shresta, and Ganga Kaveri in 2019 was promising maize hybrid in inner terai condition in Nepal.

The hybrid variety with appropriate nitrogen doses is most important to maximize maize yield. The optimum N fertilizer rates and maize hybrids have not been determined for the newly developed hybrids in the district. Therefore, this study was carried out to determine the optimum nitrogen rates and maize hybrid.

Table 1. Physico-chemical properties of the soil of the experimental location

S.N.	Properties	Content	Category
1	Physical properties		
	Sand (%)	21.6	
	Silt (%)	58.80	
	Clay (%)	19.60	
	Soil texture		Silt loam
2	Chemical properties		
	pH	6.67	Slightly Acidic
	Total Nitrogen (%)	0.10	Medium
	Available Phosphorus (P_2O_5 kg ha^{-1})	45	Medium
	Available Potassium (K_2O kg ha^{-1})	190.78	Medium
	Organic matter (%)	2.1	Low

Materials and Methods

Experimental location

The experiment was conducted in Lamahi municipality, Dang district in Lumbini province of the inner Terai region of Nepal from June to September 2017. Geographically, it is located at 27.9904° N Latitude and 82.3018° E Longitude and has an elevation of 725 masl. The Physico-chemical properties of the soil of the experimental site are given in Table 1. The meteorological data for the growing season of 2017 is presented in Figure 1.

The soil analysis results showed (Table 1) the soil was silt loam, pH 6.67 and low in organic matter (2.1%).

Plant materials

The plant materials used in the experiment were received from National Maize Research Program, Rampur, Chitwan, Nepal. The details of plant materials are given in Table 2. These three maize hybrids are recommended for the Terai region of Nepal. The experimental location is in the Terai region of Nepal. These hybrids were favoured for cultivation because of their higher productivity by farmers. The effects of different rates of nitrogen on these maize hybrids were not evaluated in Lamahi, Dang district; therefore, these hybrids were selected for this study.

Table 2. The details of maize hybrids used in the experiment

S. N.	Name of hybrids	Parentage	Type
1	Rampur Hybrid-2	RML-4/NML-2	Single crops hybrid
2	Rampur Hybrid-4	RML-32/RML-17	Single crops hybrid
3	Rampur Hybrid-6	RML-4/RML-17	Single crops hybrid

Experimental design and cultural practices

Twelve treatments were laid out in a split-plot design with two factors (Hybrids as the main factor and nitrogen rates as the subfactor) arranged in a randomized complete block design (RCBD) with three replications. The maize hybrids of Rampur Hybrid-2, Rampur Hybrid-4 and Rampur Hybrid-6 were main plots, and four nitrogen rates of 0, 140,160, and 180 kg N ha^{-1} were sub-plot. Field data were collected from the two middle rows of each plot leaving the outside rows and a distance of 25 cm at the ends of each middle row to serve as borders. Each plot size measured 2.4 m × 4 m (9.6 m^2) consisting of four rows of 0.60 m apart and 4 m in length. The individual plots and replication were separated by 0.5 m. We tested four levels of N (0, 140, 160 and 180 kg N ha^{-1}) on three maize hybrids (Rampur Hybrid-2, Rampur Hybrid-4, and Rampur Hybrid-6).

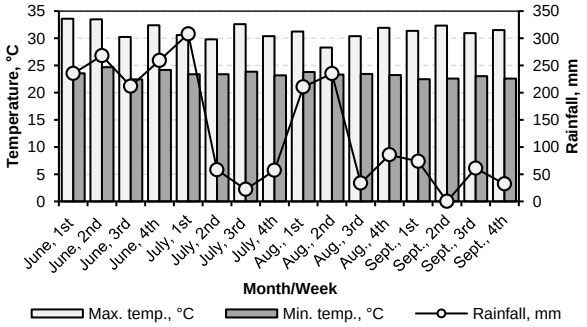

Figure 1. Climatic records of the experimental location

The fertilizer was applied into soil rowsby hands. The nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) were applied via Urea, Diammonium Phosphate (DAP), and Muriate of Potash (MOP). Half dose of the Nitrogen (0, 70, 80 and 90 kg N ha^{-1}) and a full dose of phosphorus (60 kg P_2O_5 ha^{-1}) and potassium (40 kg K_2O ha^{-1}) were applied at the basal dose at the time of seed sowing. The remaining N was applied in two splits; first dose (0, 35, 40, and 45 kg N ha^{-1}) at six-leaf stages and second dose (0, 35, 40, and 45 kg N ha^{-1}) at the ten-leaf stage. During the maize growing season, two manual weeding and hoeing operations were carried out. On 18 days after sowing, the first weeding was done, and 36 days later, the second weeding was done. Irrigation was used at three different periods of growth: knee-high stage, tasseling stage, and milking stage. Other crop management practices such as irrigation and pest management were carried out as per the recommendation of the National Maize Research Program (NMRP) Rampur, Chitwan, Nepal.

Data collection and observations

Field data were collected from the two middle rows of each plot leaving the outside rows and a distance of 25 cm at the ends of each middle row to serve as borders. Data obtained included days to 50% silking, days to 50% tasseling, plant height, cob length, and cob circumference, ear weight, kernel rows per cob, and the number of kernels per row. The moisture content was determined on all harvested cobs in representative cobs (central two rows). Wile-Model 55-Grain Moisture Meter was used to take the reading on the moisture content of grain.

The following formula (Eq.1) was used to compute grain yield (t ha^{-1}) at 12% moisture content using fresh ear weight:

$$GY = \frac{FW \times (100 - GMP) \times S \times 10\,000}{(100 - DMP) \times NPA}, \quad (1)$$

where
GY – grain yield, kg ha^{-1};
FW – fresh weight of ear in kg per plot at harvest, kg plot^{-1};
GMP – grain moisture percentage at harvest, %;
DMP – desired moisture percentage, *i.e.*, 12%;
NPA – net harvest plot area, m^2;
S – shelling coefficient, *i.e.*, 0.8.

Grain yield was converted to t ha^{-1} from kg ha^{-1}.

Data analysis

All collected data were entered into Microsoft Excel 2016 and analyzed by using GENSTAT (version14th edition; VSN International, Hemel Hempstead,UK). All the data collected were statistically analyzed using the analysis of variance (ANOVA) procedure described by Gomez and Gomez (1984) for Split plot design experiments. Separation of treatment means for the significant difference was performed by using the Fisher's least significant difference (LSD) procedure at 0.05 probability level (Obi, 1986).

Results and Discussion

Effect of genotypes

The plant height, days to 50% silking, cob length, and no. of kernels per row were non-significant. The plant height varied from 167.03 (Rampur Hybrid-4) to 168.08 (Rampur Hybrid-6) and days to 50% silking varied from 61 days (Rampur Hybrid-4) to 63.17 (Rampur Hybrid-2). The cob length differed from 16.32 cm (Rampur Hybrid-6) to 16.49 cm (Rampur Hybrid-2). The number of kernels per row varied from 29.10 (Rampur Hybrid-4) to 31.93 (Rampur Hybrid-2). The days to 50% tasselling, cob circumference, no. of kernel rows per cob and grain yield were found significant (Table 3). Significantly, the maximum days to 50% tasselling was found in Rampur Hybrid-2 (58.67 days) and the minimum days to 50% tasselling (58 days) in Rampur Hybrid-6. The cob circumference was significantly biggest (13.61 cm) in Rampur Hybrid-2 and the smallest (13.09 cm) in Rampur Hybrid-4. The maximum no. of kernel rows per cob was found in Rampur Hybrid-2 (13.36) and the minimum no. of kernel rows per cob (13.07) in Rampur Hybrid-6. The maximum grain yield was found in Rampur Hybrid-2 (6.19 t ha^{-1}) and Rampur Hybrid 6 produced the minimum grain yield (5.80 t ha^{-1}) (Table 4).

Table 3. Mean squares from ANOVA for grain yield and other agronomic traits of maize hybrids

Sources	df	Plant height, cm	Days to 50% tasselling	Days to 50% silking	Cob length, cm	Cob circum-ference, cm	No. of kernel rows per cob	No. of kernels per row	Grain yield, t ha^{-1}
Replication	2	6.04	14.08**	23.69	0.17	1.88*	0.94	0.90	0.01
Hybrid (H)	2	4.20	7.58*	15.44	0.10	0.80	3.83	30.16	0.44
Error (a)	4	60.21	0.66	5.23	2.46	0.25	0.64	37.09	0.11
Nitrogen (N)	3	2462.35**	2.54	7.29	25.66**	2.95**	1.65*	56.59**	17.94**
H × N	6	12.36	0.76	1.18	1.06*	0.05	0.88	0.65	0.006
Error (b)	18	17.60	1.13	4.27	0.33	0.15	0.45	3.10	0.03
Total	35								

df – degree of freedom, * statistically significant at the level of 0.05, ** statistically significant at level 0.01

The above ANOVA (Table 3) showed that days to 50% tasselling was significant with the use of genotype. The use of genotypes showed the non-significant for the plant height, days to 50% silking, cob circumference, no. of kernel rows per cob, no. of kernels per row and grain yield. The days to 50% tasselling, days to 50% silking were non-significant with the application of nitrogen. The no. of kernel rows per cob

showed a significant effect with the application of nitrogen. The traits namely plant height, cob circumference, cob length, no. of kernels per row and grain yield were found highly significant for plant height, cob circumference, no. of kernels per row and grain yield. The interaction (nitrogen × genotype) effect for cob length was found significant but non-significant for plant height, days to 50% tasselling, and days to 50% silking, cob circumference, no. of kernel rows per cob, no. of kernels per row and grain yield.

Table 4. Effect of various levels of nitrogen and genotypes on growth, grain yield and yield attributing traits in maize hybrids

Traits	Plant height, cm	Days to 50% tasselling	Days to 50% silking	Cob length, cm	Cob circumference, cm	No. of kernel rows per cob	No. of kernels per row	Grain yield, t ha^{-1}
Maize hybrids								
Rampur Hybrid-2	167.07	58.67^{a}	63.17	16.49	13.61^{a}	13.36^{a}	31.93	6.19^{a}
Rampur Hybrid-4	167.03	57.08^{b}	61.00	16.48	13.09^{b}	12.27^{b}	29.10	5.99^{b}
Rampur Hybrid-6	168.08	58.00^{ab}	62.66	16.32	13.37^{ab}	13.07^{a}	31.75	5.80^{c}
CV%	4.64	1.41	3.67	9.56	3.78	6.24	19.69	5.54
P value	0.93	0.02	0.16	0.959	0.02	0.05	0.51	0.04
LSD (0.05)	–	0.93	–	–	0.35	0.59	–	0.18
Nitrogen levels								
N @ 0 kg ha^{-1} (Control)	147.07^{d}	58.55	63.55	14.28^{cd}	12.60^{c}	12.27^{b}	27.53^{c}	3.93^{d}
N @ 140 kg ha^{-1}	161.71^{c}	58.11	62	16.12^{c}	13.24^{b}	13.03^{a}	30.71^{b}	6.30^{c}
N @ 160 kg ha^{-1}	176.08^{b}	57.66	62.11	17.01^{ab}	13.68^{a}	13.07^{a}	32.11^{ab}	6.71^{b}
N @ 180 kg ha^{-1}	184.71^{a}	57.33	61.44	18.31^{a}	13.90^{a}	13.22^{a}	33.36^{a}	7.06^{a}
CV%	2.51	1.84	3.32	3.51	2.95	5.22	5.70	3.17
P value	0.00	0.12	0.20	0.00	0.00	0.03	0.00	0.00
LSD (0.05)	4.16	–	–	0.99	0.39	0.67	1.75	0.19

Means with the same letter in the column are not significantly different at P = 0.05 by DMRT. LSD –least significant difference, and CV – coefficient of variance

Effect of nitrogen levels

Nitrogen levels showed no significant differences for days to 50% tasselling and days to 50% silking. Plant height, cob length, cob circumference, no. of kernel rows per cob, no. of kernels per row and grain yield were significantly affected by different levels of nitrogen (Table 3). The plant height (184.71 cm) was significantly highest with the application of nitrogen level of 180 kg N ha^{-1} and the lowest plant height (147.07 cm) was produced with the application of 0 kg N ha^{-1}. The plant height significantly increased with the increase in the rate of nitrogen from 0 to 180 kg ha^{-1}. Significantly longest cob length (18.31cm) was recorded with the application of a nitrogen level of 180 kg N ha^{-1} and the lowest cob length (14.28 cm) was produced with the application of 0 kg N ha^{-1}. The cob length significantly increased with the increase in the rate of nitrogen from 0 to 180 kg ha^{-1}. The cob circumference (184.71 cm) was the biggest with the application of nitrogen level of 180 kg N ha^{-1} and the smallest cob circumference (147.07 cm) was produced with the application of 0 kg N ha^{-1}. The cob circumference significantly increased with the increase in the rate of nitrogen from 0 to 180 kg ha^{-1}. The maximum no. of kernel rows per cob (13.22) was recorded with the application of nitrogen level of 180 kg N ha^{-1} and the minimum no. of kernel rows per cob (12.27) was produced with the application of 0 kg N ha^{-1}. No. of kernel rows per cob significantly increased with the increase in the rate of nitrogen from 0 to 180 kg ha^{-1}. The no. of kernels per row (33.36) was the maximum with the application of nitrogen level of 180 kg N ha^{-1} and the minimum no. of kernels per row (27.53) was produced with the application of 0 kg N ha^{-1}. The no. of kernels per row significantly increased with the increase in the rate of nitrogen from 0 to 180 kg ha^{-1}. The grain yield (7.06 t ha^{-1}) was the highest under nitrogen level of 180 kg N ha^{-1} and the lowest (3.93 t ha^{-1}) was produced under 0 kg N ha^{-1} The grain yield significantly increased with the increase in the rate of nitrogen from 0 to 180 kg ha^{-1} (Table 4).

Correlation study

Estimates of the phenotypic correlation for traits are shown in Table 5. Grain yield was negatively correlated with days to 50% tasselling (r = –0.253) and days to 50% silking (r = –0.291). Days to 50% tasselling were positively correlated with days to 50% silking (r = 0.73**). Grain yield was positively and significantly correlated with plant height (r = 0.883**), cob length (r = 0.812**), cob circumference (r = 0.689**), No. of kernel rows per cob (r = 0.397*), No. of kernels per row (r = 0.593**).

Table 5. Pearson's correlation coefficient among growth, grain yield and its attributing traits of maize hybrids

Traits	PH	TD	SD	CL	CC	NKRPC	NKR	GY
PH	1							
TD	–0.297	1						
SD	–0.222	0.73**	1					
CL	0.805**	–0.177	–0.214	1				
CC	0.659**	–0.005	–0.045	0.500**	1			
NKRPC	0.362*	0.043	–0.092	0.166	0.430**	1		
NKR	0.587**	–0.375*	–0.461**	0.433**	0.444**	0.078	1	
GY	0.883**	–0.253	–0.291	0.812**	0.689**	0.397*	0.593**	1

PH–plant height, cm; TD– days to 50% tasselling; SD–days to 50% silking; CL–cob length, cm, CC–cob circumference, cm, NKRPC – no. of kernel row per cob, NKR– no. of kernels per row, GY– grain yield, t ha^{-1}. * – significant at P <0.05, ** – significant at P <0.01

Discussion

Hybrid maize is a heavy feeder with a higher nutritional response (Sarkar *et al*., 2000). Commercial maize hybrids demand high nitrogen levels and fertile soils, according to Muza *et al*. (2004) and Shrestha *et al*. (2018a), hybrids respond well to nitrogen fertilizer. The highest grain yield (7.06 tha^{-1}) was obtained when the nitrogen level was 180 kg N ha^{-1}, whereas the lowest grain yield (3.93 t ha^{-1}) was obtained when the nitrogen level was zero kg N ha^{-1}. Increased nitrogen rate from 0 to 180 kg ha^{-1} resulted in a considerable increase in grain yield (Table 4). Maize received increased nutrition because of nitrogen application, resulting in higher grain production. The increased grain production due to nitrogen application could be linked to the plant's enhanced growth. The increased growth resulted in a significant rise in yield parameters such as the number of cobs per plant, grains per cob, cob length and girth, and test weight, all of which contributed to a higher grain yield with nitrogen application. Sahoo and Mahapatra (2004) have also reported on the favourable effects of nitrogen on maize grain yield. The results of this experiment showed a positive response of various yield attributes to increased nitrogen fertilization, which was consistent with the findings of several researchers (Chillar, Kumar, 2006; Bindhani *et al*., 2007; Prodhan *et al*., 2007) who found a higher green cob yield with increased nitrogen application. Nitrogen has a major effect on the crop's vegetative and reproductive growth. Increased nitrogen rates improved yield attributes, which could be related to the fact that nitrogen treatment to maize plants kept the leaves greener for longer, allowing for more dry matter accumulation and so improving yield attributes (Asaduzzaman *et al*., 2014)

Various hybrids differed in terms of growth, yield, and yield-related traits. The grain yields of the hybrids were different. Of all the hybrids, Rampur Hybrid-2 (6.19 t ha^{-1}) produced the maximum grain yield. The findings of Kandel *et al*. (2018) and Prasai *et al.* (2015), who reported considerable differences in grain yield between maize varieties, are supported by these data. Differences in days to tasselling and silking among maize genotypes were found by Prasai *et al.* (2014), Dhakal *et al.* (2017). Hussain *et al*. (2011) found that maize varieties differed in plant height. Maize genotypes had distinct genetic makeup, resulting in variation in grain yields in different locations. The most important and complex quantitative trait in maize is grain yield, which is affected by numerous genes. Both genetic and environmental factors may have contributed to the increase in maize yield under varied environmental conditions. Researchers have found a lot of variation in maize populations, including top-crosses and open-pollinated cultivars (Sampoux *et al.,* 1989). These findings are consistent with those of Grzesiak (2001), who found significant genotypic variability across maize genotypes grown in various locations.

The correlation coefficient is used to measure the degree of relationship as well as the degree of interconnection between traits (Bocanski *et al*., 2009; Nagabhushan *et al*., 2011). Selection based on yield components is thought to be more successful than selection based solely on yield (Shamsuddin, Ali, 1989). Plant height, ear height, and the number of kernel rows per ear all indicate a positive and significant correlation with maize grain yield, according to the study (Sadek *et al*., 2006). Grain yield was negatively correlated with days to 50% tasselling and days to 50%silking. Grain yield and days to blooming have a significant negative correlation, according to De Souza *et al.* (1997). Grain yield was positively correlated with plant height, cob length, cob circumference, number of kernel rows per cob, and number of kernels per row. Alvi *et al*. (2003) and Nzuve *et al*. (2014) reported similar findings. There was a positive correlation between days to 50% tasselling and days to 50% silking. This result is similar to the findings of Chase and Nanda (1967). If these traits have a strong and positive correlation, it means that genotypes are being chosen for grain yield indirectly.

Conclusion

Nitrogen fertilizer had profound effects on growth, grain yield and yield attributing traits of hybrids of maize. Nitrogen rate @180 kg ha^{-1} produced the higher grain yield in Rampur Hybrid-2. Therefore, the use of this level of nitrogen in this hybrid is beneficial to get the higher maize production.

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Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions

GP, MB – Carry out experiment, collection, analysis and interpretation of data and wrote the manuscript;
MM, DJ – Provided guidance of experiment, critical revision of the manuscript and wrote the manuscript;
JS – Critical revision of the manuscript, data analysis and wrote the manuscript;
All the authors read and approved the final manuscript.

References

Adhikari, K., Bhandari, S., Aryal, K., Mahato, M., Shrestha, J. 2021. Effect of different levels of nitrogen on growth and yield of hybrid maize (*Zea mays* L.) varieties. – Journal of Agriculture and Natural Resources, 4(2):48–62. DOI: 10.3126/janr.v4i2.33656

Alvi, M.B., Rafique, M., Shafique, M., Hussain, A., Mohmood, T., Sarwar, M. 2003. Characters association and path analysis of grain yield and yield components in maize. – Pakistan Journal of

Biological Science, 6(2):136–138. DOI: 10.3923/pjbs.2003.136.138

Amanullah.2016. Rate and timing of nitrogen application influence partial factor productivity and agronomic NUE of maize (*Zea mays* L) planted at low and high densities on calcareous soil in northwest Pakistan. – Journal of Plant Nutrition, 39:683–690. DOI: 10.1080/01904167.2015.1087031

Asaduzzaman, Md., Biswas, M., Nazrul Islam, Md., Rahman, Md.M., Begum, R., Sarkar, Md.A.R., Asaduzzaman, Md. 2014. Variety and N-fertilizer rate influence the growth, yield and yield parameters of baby corn (*Zea mays* L.). – Journal of Agricultural Science, 6(3):118–131. DOI: 10.5539/jas.v6n3p118

Asibi, A.E., Chai, Q., Coulter, J.A. 2019. Mechanisms of nitrogen use in maize. – Agronomy, 9(12):775. DOI: 10.3390/agronomy9120775

Bindhani, A., Barik, K.C., Garnayak, L.M., Mahapatra, P.K. 2007. Nitrogen management in baby corn (*Zea mays* L.). – Indian Journal of Agronomy, 52:135–138.

Biswas, D.K., Ma, B.L. 2016. Effect of nitrogen rate and fertilizer nitrogen source on physiology, yield, grain quality, and nitrogen use efficiency in corn. – Canadian Journal of Plant Science, 96(3):392–403.

Bocanski, J., Srećkov, Z., Nastasić, A. 2009. Genetic and phenotypic relationship between grain yield and components of grain yield of maize (*Zea mays* L.). – Genetika, 41(2):145–154. DOI: 10.2298/GENSR0902145B

Chase, S.S., Nanda, D.K.1967. Number of leaves and maturity classification in *Zea mays* L. – Crop Science, 7:431–433.

Chillar, R.K., Kumar, A. 2006. Growth and yield behaviour of sweet corn (*Zea mays* L. saccharata) under varying plant population and nitrogen level. In Extended Summaries of Golden Jubilee National Symposium on conservation Agriculture and Environment. Held during 26–28 October, 2006, Banaras Hindu University, Varanasi, India, pp. 277–278.

De Souza, O.I., Egli, D.B., Bruening, W.P. 1997. Water stress during seed filling and leaf senescence in Soybean. – Agronomy Journal, 89(5):807–812. DOI: 10.2134/agronj1997.00021962008900050015x

Dhakal, B., Shrestha, K.P., Joshi, B.P., Shrestha, J. 2017. Evaluation of early maize genotypes for grain yield and agro-morphological traits. – Journal of Maize Research and Development, 3(1):67–76. DOI: 10.3126/jmrd.v3i1.18923

Gomez, K.A., Gomez, A.A. 1984. Statistical procedures for agricultural research. 2nd ed. – New York. John Wesley and Sons, 680p.

Grzesiak, S. 2001. Genotypic variation between maize (*Zea mays* L.) single-cross hybrids in response to drought stress. – Acta Physiologiae Plantarium, 23(4):443–456.

Guo, C., Li, P., Lu, J., Ren, T., Cong, R., Li, X. 2016. Application of controlled release urea in rice: reducing environmental risk while increasing grain yield and improving nitrogen use efficiency. – Communications in Soil Science and Plant Analysis, 47: 1176–1183. DOI: 10.1080/00103624.2016.1166235

Hussain, N., Khan, M.Y., Baloch, M.S. 2011. Screening of maize varieties for grain yield at Dera Ismail Khan. – The Journal of Animal and Plant Sciences, 21(3):626–628.

Kandel, B.P., Shrestha, K. 2020. Performance evaluation of maize hybrids in inner-plains of Nepal. – Heliyon, 6(12):e05542.

Kandel, B.P., Adhikari, N.R., Adhikari, B.B., Tripathi, M. 2018. Performance of hybrid maize in Chitwan Nepal. – Bangladesh Journal of Plant Breeding and Genetics, 31:43–51.

Khaliq, T., Ahmad, A., Hussain, A., Ali, M.A. 2009. Maize hybrids response to nitrogen rates at multiple locations in semiarid environment. – Pakistan Journal of Botany, 41(1):207–224.

MOAD.2016. Food and Nutrition Security: A Status Report. Reported by Ministry of Agricultural Development and Central Bureau of Statistics to the Food and Agricultural Organizations, Nepal.

Muchow, R.C., Sinclair, T.R. 1994. Nitrogen response of leaf photosynthesis and canopy radiation use efficiency in field-grown maize and sorghum. – Crop Science, 34(3):721–727. DOI: 10.2135/cropsci1994.0011183X003400030022x

Muza, L., Waddington, S.R., Banziger, M. 2004. Preliminary results on the response of nitrogen use efficient OPV and hybrid maize to N fertilizer on smallholder fields in Zimbawe. – In: Integrated approaches to higher maize productivity in the new millennium: Proceedings of the seventh eastern and southern Africa regional maize conference, Nairobi, Kenya, CIMMYT African Livelihoods Program, p. 245.

Nagabhushan, N.M., Mallikarjuna, C.H., Shashibhaskar, M.S., Prahalada, G.D. 2011. Genetic variability and correlation studies for yield and related characters in single cross hybrids of maize (*Zea mays* L.). – Current Biotica, 5:157–163.

Nxumalo, E.M., Pali-Shikhulu, J., Dlamini, S.M. 1993. Assessment of nitrogen fertilizer use in commercial hybrids. SADC-Land and Water Research Programme. – Proceedings of the Fourth Annual Scientific Conference, Windhoek, Namibia, p. 322–329.

Nzuve, F., Githiri, S., Mukunya, D.M., Gethi, J. 2014. Genetic variability and correlation studies of grain yield and related agronomic traits in maize. – Journal of Agricultural Science, 6(9):166–176. DOI:10.5539/jas.v6n9p166

Oad, F.C., Buriro, U.A., Agha, S.K. 2004. Effect of organic and inorganic fertilizer application on maize fodder production. – Asian Journal of Plant Sciences, 3:375–377. DOI: 10.3923/ajps.2004.375.377

Obi, I.U.1986. Statistical methods of detecting differences between treatment means. – SNAAP press limited, Enugu, Nigeria, 45p.

Prasai, H.K., Sharma, S., Kushwaha, U.K.S., Joshi, B.P. 2014. Varietal improvement of early maize for

far western hills of Nepal. – Proceedings of the 27th National Summer Crops Workshop,Vol.II, held on18–20th April,2013 at National Maize Research Program, Rampur, Chitwan, Nepal, p.174–177.

Prasai, H.K., Kushwaha, U.K.S., Joshi, B.P., Shrestha, J. 2015.Performance evaluation of early maize genotypes in far western hills of Nepal. – Journal of Maize Research and Development, 1(1):106–111. DOI: 10.3126/jmrd.v1i1.14248

Prodhan, H.S., Bala, S., Khoyumthem, P. 2007. Response to rate of nitrogen and effect of plant density on yield of baby corn. – Journal of Interacademicia, 11:265–269.

Sadek, S.E., Ahmed, M.A., Abd El-Ghaney, H.M. 2006. Correlation and path coefficient analysis in five parents inbred lines and their six white maize (*Zea mays* L.) single crosses developed and grown in Egypt. – Journal of Applied Sciences Research, 2(3):159–167.

Sahoo, S.C., Mahapatra, P.K. 2004. Response of sweet corn (*Zea mays* L.) to nitrogen levels and plant population. – Indian Journal of Agricultural Sciences, 74(6):337–338.

Sampoux, J.P., Gallais, A., Lefort-Buson, M. 1989.S1 value combined with topcross value for forage maize selection. – Agronomie, 9(5):511–520.

Sarkar, A.K., Singh, K.P., Singh, B.P., Singh, R.P. 2000. Long term effects of fertilizers, manures and amendments on crop production and soil fertility. – Technical Bulletin of Soil Science and Agricultural Chemistry (BAU) No.2/2000, pp. 31–45.

Sawyer, J. 2004. Integrated pest management, nutrient deficiencies and application injuries in field crops. – Unpublished report IPM, 42, IOWA State University, USA.

Shamsuddin, A.K.M., Ali, M.M. 1989. Genotypic and phenotypic correlation and path analysis in spring wheat. – Bangladesh Journal of Agricultural Science, 16(1):75–78.

Sharma, R., Adhikari, P., Shrestha, J., Acharya, B.P. 2019. Response of maize (*Zea mays* L.) hybrids to different levels of nitrogen. – Archives of Agriculture and Environmental Science, 4(3):295–299.

Shrestha, J., Chaudhary, A., Pokhrel, D. 2018a. Application of nitrogen fertilizer in maize: a review. – Peruvian Journal of Agronomy, 2(2):22–26. DOI: 10.21704/pja.v2i2.1201

Shrestha, J., Subedi, S., Acharya, R., Sharma, S., Subedi, M. 2021. Variability for growth and yield traits in single cross hybrids of maize (*Zea mays* L.). – Agraarteadus, 32(2):In Press. DOI: 10.15159/ jas.21.31

Shrestha, J., Yadav, D.N., Amgain, L.P., Sharma, J.P. 2018b. Effects of nitrogen and plant density on maize (*Zea mays* L.) phenology and grain yield. – Current Agriculture Research Journal, 6(2):175–182.

Uribelarrea, M., Below, F.E., Moose, S.P. 2004. Grain composition and productivity of maize hybrids derived from the Illinois protein strains in response to variable nitrogen supply. – Crop Science, 44(5): 1593–1600. DOI: 10.2135/cropsci2004.1593

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EFFECT OF PROBIOTIC SUPPLEMENT ON NUTRIENT DIGESTIBILITY AND PRODUCTION TRAITS ON BROILER CHICKEN

Julia Poberezhets, Roman Chudak, Ihor Kupchuk, Vitalii Yaropud, Volodymyr Rutkevych

Vinnytsia National Agrarian University, 3, Sonyachna St., UA 21008, Vinnytsia, Ukraine

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Vastutav autor: Corresponding author: Ihor Kupchuk

E-mail: kupchuk.igor@i.ua

ORCID:
0000-0002-1727-6105 (JP)
0000-0003-4318-6979 (RC)
0000-0002-2973-6914 (IK)
0000-0003-0502-1356 (VY)
0000-0002-6366-7772 (VR)

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ABSTRACT. The aim of the research was to investigate feed nutrient digestion and slaughter indicators of broiler chickens fed a probiotic supplement based on lactic acid bacteria. The experiment lasted for 42 days. Four groups of one-day-old broiler chickens of the Ross-308 cross were selected by the method of analogous groups, each group contained 50 birds. Broilers were kept in group cages considering all zoohygienic requirements. The control group consumed a basic diet (BD), *i.e.*, a complete feed. The experimental groups were additionally fed different doses of a probiotic supplement (by percentage mass of feed). The broiler chickens fed the probiotic supplement had increased digestibility of dry matter, protein, fibre and nitrogen-free extractives (NFE) compared with the control group. The application of probiotic supplement in broiler feeding increases the availability of essential amino acids, *i.e.* lysine, histidine, arginine, threonine, valine, methionine, isoleucine compared with the control. The absorption of Ca, P, Mg, and Mn increased with the probiotic supplement. The probiotic supplement application in the diet of broiler chickens increased the pre-slaughter live weight by 16.7%, the un-gutted body weight by 15.0% and gutted body weight by 17.3%. Probiotic supplement had a positive effect on the digestibility of feed nutrients, increased the absorption of amino acids and minerals in the body broiler chickens.

Introduction

Numerous feed additives such as probiotics, prebiotics, phytobiotics, enzymes, vitamins *etc*. have been used in animal diets in recent years (Park *et al.*, 2014; Mookiah *et al.*, 2014; Anggraeni *et al.*, 2020). However, they do not always have a positive effect on product quality. This issue is important because of advanced technologies for new feed application, the application of chemical and microbiological synthesis products in animal nutrition (Dunkley, 2008; Alavi *et al.*, 2012; Meremäe *et al.*, 2015; Sobolev *et al.*, 2019). Probiotics have become widespread among feed additives of natural origin. They create an unfavourable pH environment for pathogenic and opportunistic microflora and stimulate the growth and biological activity of normal intestinal microflora, having a positive effect on the composition of the microbiocenosis, probiotic microorganisms also produce biologically active substances and amino acids (Liu *et al*., 2012; Salim *et al.*, 2013; Park *et al.*, 2014).

The microbiological industry is actively developing the creation of new and effective feed additives, including probiotic additives based on lactic acid bacteria *(Lactobacillus* and *Enterococcus).* It is known that the hydrolysis of feed nutrients to monomers is carried out using enzymes and acids, and symbiotic microorganisms that are in the digestive tract (Chudak *et al.*, 2020). Some research results have shown the promise of using such probiotic supplements in the diets of farm animals (Dunkley, 2008; Urdzik, 2010; Mookiah *et al.*, 2014; Park *et al.*, 2014; Balukh, 2016; Poberezhets, 2020). However, how the new probiotic supplements that are made according to improved recipes affect the productivity of broiler chickens has not yet been fully studied. Moreover, digestibility of nutrients depends on the species and the animal age, chemical composition,

preparation methods for fee- ding, feeding level and other factors. The aim of this study was to investigate feed nutrient digestion and slaughter indicators of broiler chickens fed a probiotic supplement based on lactic acid bacteria *(Lactobacillus* and *Enterococcus).*

Material and Methods

Formation of groups

The study was carried out on the research farm of Vinnytsia National Agrarian University (Ukraine). The experiment lasted for 42 days, by the method of analogue groups four groups were selected (I – control group, II, III, IV – experimental groups) of one-day broiler chickens "Ross-308" with 50 birds per group, the mean body weight was 62 ± 2 g (Hamungalu *et al.*, 2020).

Ethical statement

The protocol and procedures used in this research were ethical for the animals tested and complied with Directive 2010/63 / EC of the European Parliament.

Description of housing conditions

Broilers were kept in TBB-AV cage batteries (manufactured by VO TECHNA, Kyiv, Ukraine) with a nipple watering system with a stocking density of 20 birds per m^2. The dimensions of the cage were: 1,200 × 1,604 × 408 mm. The cage consisted of flooring, side mesh walls and doors. The floor of the cages was made of a galvanized metal mesh (diameter of the coated wire, 2.2 mm) with holes the size of (16 × 25) mm, which eliminated the possibility of manure soiling, as well as injury to the legs of the bird. Temperatures were as follows: from days 1 to 5 – 32–35 °C, from days 6 to 42 days – 20 °C. Relative humidity 60–70%. Lighting intensity 10–20 lux.

Feed ration and composition

Compound feed TM "Multigain" of joint-stock company "Kyiv-Atlantic-Ukraine" Myronivka, Kyiv region was used. The full-ration compound feeds for broilers PC 5-4 / 7 (Table 1) was used.

The control group consumed a basic diet (BD) as complete feed. The experimental groups were additionally fed different doses (percentage to mass of feed) of a probiotic supplement (Table 2).

Probiotic supplements

Feed additive "Entero-active" is a homogeneous loose mixture without solid lumps coloured from light grey to dark grey colour. The probiotic contains lactic acid bacteria of the genus *Lactobacillus bulgaricus* – 2.0×10^{10} CFU per kg and *Enterococcus faecium* – 2.0×10^{10} CFU per kg. The probiotic "Entero-active", due to the formation of lactic and acetic acids, creates an unfavourable pH environment for pathogenic microflora, stimulates the growth of intestinal normal flora, which has a positive effect on the composition of the microbiocenosis. In addition, probiotic microorganisms produce biologically active substances, enzymes and amino acids.

This feed additive was created in the PE "BTU-centre" Ladyzhyn, Vinnytsia region. The owner of the patent for feed additive "Entero-active" is Vinnytsia National Agrarian University (Podolian *et al.*, 2011). All rights to the results of the study on the impact of Enteroactive on lethal properties belong to Vinnytsia National Agrarian University. The obtained results of scientific research were used during the development of technical conditions: Probiotic "Entero-active" TR (IS) U 15.7-00497236-001: 2012 (Chudak *et al.*, 2012).

Table 1. Composition of compound feed for broiler chickens aged 4–5 weeks

Composition of the diet, %					
Corn	30	Soybean oil	3.0	Vitamin and mineral mixture	1.0
Wheat	27.5	Fodder yeast	3.4	Antioxidant	0.0125
Soybean meal	15.0	Defluorinated phosphate	1.55	Mould inhibitor	0.009
Sunflower meal	12.0	Limestone	1.2	Coccidiostat	0.0097
Fishmeal	5.0	Table salt	0.3	Granule fixer	0.0108
Chemical composition, %					
Crude protein	21.0	Phosphorus	0.7	Linoleic acid	3.21
Crude fiber	5.0	Chlorides	0.307	Sodium	0.2
Methionine + cystine	0.89	Crude fat	6.2	Methionine	0.45
Lysine	1.15	Tryptophan	0.26		
Calcium	0.9	Threonine	0.17		
Vitamins and trace elements, mg kg^{-1}					
Vitamins				Salts	
A	3.00	PP	20.0	Copper	4.8
D3	0.04	E	20.0	Iron	20.0
B1	2.0	K3	2.5	Cobalt	0.48
B24.0B6	2.5	Pantothenic acid	10.0	Zinc	48.0
B12	0.01	Folic acid	0.5	Iodine	0.8
		Biotin	0.05	Selenium	0.28

Table 2. Composition of experimental diets

Group	Duration, days	Feeding characteristics by age, days		
		1–10	11–28	29–42
Control	42	BD (complete feeds)		
II	42	BD + 0.062% Probiotic supplement	BD + 0.025% Probiotic supplement	BD + 0.0125 % Probiotic supplement
III	42	BD + 0.125% Probiotic supplement	BD + 0.05% Probiotic supplement	BD + 0.025% Probiotic supplement
IV	42	BD + 0.25% Probiotic supplement	BD + 0.1% Probiotic supplement	BD + 0.05% Probiotic supplement

The probiotic supplement was fed in the dry form. The preparation and verification of the homogeneity of the mixture of feed and probiotic additives was carried out in the laboratory of Technological Processes of food and processing industry of Vinnytsia National Agrarian University. Mixing took place in the chamber of a vibrating machineVM-5.0 the manufacturer is Ukraine (in the absence of grinding bodies) to homogeneity in the range of 96–98% (Clark *et al.,* 2007).

Measurements and analysis of samples

During the physiological trial, which lasted forfive days, the birds were kept in separate cages. The digestibility of feed nutrients was determined by the difference between their content in the consumed feed and the excreted manure (Kozyr *et al*., 2002). Consumed feed and manure were analysed. Compound feed samples were taken daily for analysis. Feed samples were taken in accordance with DSTU ISO 6497: 2005. Twice a day, morning and evening, manure was collected, which was preserved with toluene and stored in a closed glass container in the refrigerator at +5 °C (Ibatullin *et al.,* 2017). Assessment of morphological and biochemical parameters of the blood were made at the end of the experiments. Four animals were selected by average live weight per group from each group, from which blood was taken in the morning before feeding (Levchenko *et al.,* 2002).The amino acid composition was determined with Automatic Amino acid Analizator (AAA) T-339 (Microtechna, Czech Republic) automatic analyser using LG ANB cation exchange resin with SO_3 active group (Kozyr *et al.,* 2002). Haematological parameters were determined as follows: haemoglobin content – hemoglobin cyanide method using a hemoglobinometer type HG-202 (APEL, Japan), erythrocytes and leukocytes – counted using Goryaev's camera (grid contains 225 large squares; 15 rows of 15 large squares each), to study the feeding efficiency (such as slaughter qualities) of the experimental birds were carried out at the end of the experiment after slaughter – four birds from each group by average live weight per group (Ibatullin *et al.,* 2017).

Slaughter was by cutting the sublingual vein after stunning. Slaughter qualities were investigated according to the following indicators: pre-slaughter live weight of poultry after 12 hours of fasting; mass of ungutted carcass – mass of carcass exsanguinated and without plumage; mass of half-gutted carcass – carcass exsanguinated, without plumage and intestines; the mass of the gutted carcass – the mass of the exsanguinated carcass, without plumage, head, legs, wings, intestine; mass of edible and inedible parts (Ibatullin *et al.,* 2017).

During the experiment, the preservation of livestock was recorded according to the count of dead birds.

Statistical analysis

Processing of experimental data and statistical analysis of the results were performed on a PC using MS Excel 2019 software (Microsoft, USA) and Statistica 12.6 (Dell Technologies, USA) using built-in statistical functions. Statistical functions are functional software modules that implement individual statistical formulas (calculation of average values, correlation coefficient, *etc*.), and can be used in formulas. The small sample method was used. The method of small samples provided for the determination of the arithmetic mean values (x) and the deviation of the arithmetic mean values (± SD). The data in the tables are presented in the form of x ± SD (mean ± standard deviation). Statistical evaluation of differences was performed using Student's t-test. The difference was considered significant if the calculated criterion for the reliability of the difference (experimental) is equal to or exceeds the standard value of the Student's t-test.The results of the average values were considered statistically significant at * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$ (Rudenko, 2012).

Results

It was found that feed consumption per kg of growth decreased by 7.7% in the III group, and by 12.9% in the IV group (compared to control group). There was no significant effect of the probiotic supplement for group II (Table 3).

Poultry fed additional Entero-active probiotic increased feed conversion in proportion to the dosage of probiotic supplements. However, feed consumption per kg of gain were lower in all of the groups than in the control group.

Table 3. Effect of probiotic supplement on feed consumption, kg

Indicators	Group			
	Control	II	III	IV
Feed consumption during the experiment:				
- total for the group	192.2	189.4	193.8	195.0
- per bird	3.84	3.78	3.88	3.90
Feed consumption per 1 kg gain:				
- total for the group	1.95	1.89	1.80	1.70
- compared (±) to the control group	–	–0.06	0.15	0.25
- compared (%) to the control group	–	3.07	7.7	12.9

The highest digestibilities of protein and nitrogen-free extractives (NFE) were observed when the average dose of the additive was additionally fed; they were higher by 3.4% and 4.0% ($P < 0.001$) than the control. The broilers of the II and IV groups had increased digestibility of protein, although a significant difference with the control was not found (Table 4).

Table 4. Effect of probiotic supplement on coefficients of feed nutrients' digestibility, % ± SD

Traits	Group			
	Control	II	III	IV
Dry matter	77.9 ± 0.39	79.7 ± 1.01	80.3 ± 0.24**	80.2 ± 0.45**
Protein	84.1 ± 0.32	85.6 ± 0.70	87.5 ± 0.11***	84.8 ± 0.95
Fat	94.8 ± 0.08	94.6 ± 0.30	95.0 ± 0.10	93.5 ± 0.22**
Fibre	6.1 ± 2.05	26.3 ± 3.43**	22.1 ± 1.14***	37.2 ± 2.26***
NFE	86.6 ± 0.24	88.1 ± 0.57*	90.6 ± 0.16***	87.9 ± 0.17**

* significant at $P < 0.05$ compared with control group; ** significant at $P < 0.01$ compared with control group; *** significant at $P < 0.001$ compared with control group. NFE – nitrogen-free extractives

Feeding the probiotic maximum dose increased the dry matter digestibility ($P < 0.01$), the average dose also increased the dry matter digestibility ($P < 0.01$) relative to the control group. The maximum dose of the additive caused the highest digestibility of fibre by broilers ($P < 0.001$). However, in groups II and III the fibre digestibility was higher than in the control by 20.2% ($P < 0.01$) and 16.0 % ($P < 0.001$), respectively. Group II consumed the lowest dose of probiotic supplement; they outperformed NFE digestibility in the control group by 1.5% ($P < 0.05$). The consumption of probiotics in group IV increased NFE digestibility ($P < 0.01$). However, it caused a decrease of fat digestibility ($P < 0.01$). Probiotics application for broiler chicken feeding had a positive effect on the digestibility of amino acids (Table 5). The broiler chickens fed the average dose of the supplement had the highest digestibility of amino acids. The digestibility of such essential amino acids as lysine, histidine, arginine, valine, methionine, isoleucine and leucine in group III significantly exceeded the control group values ($P < 0.001$). In group II the absorption of phenylalanine was lower ($P < 0.001$) than the control sample.

Feeding the minimum dose of probiotics caused a decrease in the coefficients of digestion of amino acids compared to control values. The highest digestibility of aspartic and glutamic acids was found in group III, which was higher ($P < 0.001$) compared to the control group. The digestibilities of threonine ($P < 0.001$), serine ($P < 0.001$), proline ($P < 0.001$), glycine ($P < 0.001$), alanine ($P < 0.001$) and cystine ($P < 0.001$) were higher in group III compared to the control. The highest content of tyrosine was observed in group IV ($P < 0.01$). The retention of mineral elements in the feed of broiler chickens are listed (Table 6).

Table 5. Effect of probiotic supplement on digestibility of amino acids by broiler chickens, % ± SD

Amino acids	Group			
	Control	II	III	IV
Lysine	87.0 ± 0.24	84.3 ± 0.74*	91.8 ± 0.15***	88.5 ± 0.21**
Histidine	90.5 ± 0.22	87.7 ± 0.49**	94.3 ± 0.09***	91.8 ± 0.45*
Arginine	88.1 ± 0.09	82.7 ± 0.90**	93.0 ± 0.21***	91.4 ± 0.24***
Aspartic acid	83.4 ± 1.52	79.0 ± 1.52*	88.7 ± 0.14***	86.0 ± 0.30**
Threonine	81.9 ± 0.29	76.1 ± 0.93**	89.4 ± 0.29***	85.5 ± 0.28***
Serine	82.8 ± 0.49	72.9 ± 1.25***	88.8 ± 0.19***	85.8 ± 0.40**
Glutamic acid	83.9 ± 0.34	86.2 ± 0.65*	93.6 ± 0.12***	90.9 ± 0.21***
Proline	85.9 ± 0.334	79.5 ± 0.53***	90.2 ± 0.10***	88.2 ± 0.21**
Glycine	76.9 ± 0.44	61.1 ± 1.88***	83.2 ± 0.45***	78.1 ± 0.42
Alanine	76.1 ± 0.75	58.4 ± 2.29***	82.7 ± 0.48***	74.5 ± 0.43
Cystine	89.8 ± 0.10	85.2 ± 1.16**	92.2 ± 0.19***	88.3 ± 0.55
Valine	84.5 ± 0.35	71.4 ± 1.49***	88.6 ± 0.36***	86.2 ± 0.43*
Methionine	93.9 ± 0.07	92.9 ± 0.43	96.5 ± 0.40***	92.9 ± 0.28*
Isoleucine	78.4 ± 0.29	75.0 ± 0.95*	86.0 ± 0.30***	82.1 ± 0.35***
Leucine	85.8 ± 0.26	75.7 ± 0.81***	89.9 ± 0.11***	87.9 ± 0.23***
Tyrosine	86.6 ± 0.49	75.2 ± 0.85***	88.7 ± 0.51*	91.2 ± 0.60**
Phenylalanine	88.9 ± 0.45	57.0 ± 1.30***	89.5 ± 0.23	88.0 ± 0.28

* significant at $P < 0.05$ compared with control group; ** significant at $P < 0.01$ compared with control group; *** significant at $P < 0.001$ compared with control group.

Table 6. Effect of probiotic supplement on retention of mineral feed elements, % ± SD

Mineral elements	Group			
	Control	II	III	IV
Calcium	17.9 ± 1.53	39.9 ± 2.82***	40.1 ± 0.91***	41.4 ± 1.49***
Phosphorus	60.8 ± 1.42	67.7 ± 1.95*	66.8 ± 1.02*	66.4 ± 2.18
Magnesium	31.8 ± 1.14	32.7 ± 3.95	40.8 ± 0.68***	44.0 ± 1.69**
Manganese	7.2 ± 2.45	31.8 ± 3.29**	26.0 ± 1.13***	40.3 ± 1.36***

* significant at $P < 0.05$ compared with control group; ** significant at $P < 0.01$ compared with control group; *** significant at $P < 0.001$ compared with control group.

Broilers additionally fed probiotic additive had increased retention of Ca and Mn in the all treatment groups ($P < 0.001$ and $P < 0.001$) compared to the control group.

A significant difference in increase in the phosphorus absorption was observed in groups II and III ($P < 0.05$) compared to the control group. The probiotic supplement had a positive effect on Mg content in groups III and IV ($P < 0.001$) compared to the control.

The effect of probiotic supplement on morphological analysis of the blood in broilers are presented in Table 7.

Table 7. Effect of probiotic supplement on morphological parameters of broiler blood

Parameters	Group			
	Control	II	III	IV
Leukocytes, G l^{-1}	18.1 ± 0.96	20.8 ± 0.92	20.1 ± 0.80	21.0 ± 1.88
Erythrocytes, T l^{-1}	3.0 ± 0.17	2.9 ± 0.08	2.8 ± 0.07	2.8 ± 0.04
Haemoglobin, g l^{-1}	106.5 ± 5.28	122.0 ± 4.97	121.5 ± 2.60*	116.0 ± 2.49
ESR, mm h^{-1}	1.7 ± 0.55	1.5 ± 0.33	1.7 ± 0.55	1.5 ± 0.33

* results of the mean values ± SD were considered significant at $P < 0.05$ compared with control group. ESR – erythrocyte sedimentation rate

The highest number of leukocytes relative to the control group was recorded in group IV, it was higher by 16.0%, but no significant difference was found. The erythrocyte level of the treatment groups did not differ, neither was the erythrocyte sedimentation rate (ESR) affected by the experimental diets. The highest haemoglobin contents were observed in groups II and III ($P < 0.05$). The probiotic additive had a positive effect on the slaughter indicators of broiler chickens (Table 8).

Broilers in groups III and IV had a higher pre-slaughter live weight ($P < 0.001$) compared to the control and group II. The broilers in groups III and IV had an increased weight of ungutted and gutted carcasses compared with chickens in the control group and group II. The weight of semi-gutted carcass was not affected by the probiotic supplementation.

Table 8. Effect of probiotic supplement on slaughter qualities indicators ± SD of broiler chickens

Indicators	Group			
	Control	II	III	IV
Pre-slaughter weight, g	2 064.5 ± 15.3	2 104.0 ± 14.8	2 258.0 ± 26.7***	2 410.7 ± 95.6**
Ungutted carcass weight, g	1 867.2 ± 8.3	1 923.0 ± 55.9	2 031.0 ± 24.8***	2 148.0 ± 93.1**
Semi gutted carcass weight, g	1 650.5 ± 53.0	1 652.5 ± 73.0	1 793.2 ± 30.0	1 918.0 ± 101.6
Gutted carcass weight, g	1 406.0 ± 18.2	1 412.5 ± 89.5	1 540.5 ± 29.5**	1 650.0 ± 82.14*
Mortality of broiler chickens, %	4.0	3.0	2.5	2.0

* significant at $P < 0.05$ compared with control group; ** significant at $P < 0.01$ compared with control group; *** significant at $P < 0.001$ compared with control group.

Discussion

This research showed that probiotic supplement application caused a reduction of feed consumption and increased broiler productivity. The results are consistent with the study by Podolian (2016) showing the effective action of a probiotic feed additive on live weight, the growth and slaughter indices of cross Ross-308 broiler chickens. The feed consumption per kg of growth was higher in the control group chickens. However, it was found that the administration of probiotic feed additive increased the live weight, the undressed carcass weight, half-dressed carcass weight and dressed carcass weights compared to the control group. Cengiz e*t al*. (2015) have also reported a positive effect on the productivity and growth of broilers fed probiotic additives.

It is conjectured that the better slaughter rates of broilers fed probiotic supplement was caused by increased feed intake and improved digestibility of feed nutrients, amino acids and minerals (Rajesh *et al*., 2020). According to He *et al*. (2019), the probiotic is able to improve the activity of digestive enzymes of poultry. Slaughter rates of broilers of groups III and IV increased, in particular preslaughter live weight and gutted carcasses live weight.

The results are consistent with research results that were carried out with other broilers. The positive effect of probiotics on slaughter rates has been previously mentioned, in particular, that their use increases slaughter qualities and improves the development of internal organs and digestive organs (Patreva, Shevchenko, 2010; Otchenashko, 2012). The addition of probiotics (500 mg/kg in the first phase and 300 mg/kg in the second phase) could improve broilers' growth performance, nutrient retention, and serum antioxidant capacity, improve their intestinal health *via* improving jejunal mucosal barrier function and intestinal morphology.

Previous studies (Urdzik, 2010; Balukh, 2016) confirm the positive effect probiotic additives have on amino acid absorption and retention of mineral feed elements in poultry. The findings on increased nutrient digestibility under the influence of probiotic additives are consistent with previous studies (Belova *et al*., 2009; Urdzik, 2010; Fedorchenko, 2017; Azemraw, Sewalem, 2017).

Haemoglobin increased in the blood of broiler chickens that consumed a probiotic during the experiment. The results are consistent with studies that have shown a positive effect of probiotic feed additives on the animals' haemaglobin (Mashkin, 2010; Poberezhets, 2020).

The positive effect of probiotics on slaughter yield has been noted previously (Patreva, Shevchenko, 2010; Otchenashko, 2012) in particular, that their use increases slaughter live, weight of ungutted and gutted carcasses.

Translocation of probiotic bacteria from the intestine to the blood and the following bacteraemia is one of the critical issues that should be considered when probiotics are supplemented in the diet (Lopetuso *et al*., 2017). According to Zaghari *et al*. (2020), probiotic bacteria do not enter the bloodstream following use of a probiotic feed additive for poultry feeding. So there is no likelihood of complications from high microbial count and septicaemia arising from the presence of these bacteria and bacteriocin produced by them in the blood of broiler chickens. Thus, probiotic feed additives have a positive effect on the productivity, digestibility of nutrients in broiler feed and are safe for poultry.

Conclusion

This study has shown the use probiotic supplement had a positive effect on the digestibility of feed nutrients, increased the absorption of amino acids and minerals in the body and enhanced metabolic processes in broiler chickens. In addition, the feed consumption per kg of growth was lower when probiotic supplement was used. Additionally, the pre-slaughter live weight increased and the weight of ungutted carcasses and gutted carcasses also increased.

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Conflict of interest
The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions
JP – study conception and design;
JP, VY, VR, IK – acquisition of data;
JP, RC – analysis and interpretation of data;
IK, JP – drafting of the manuscript;
IK – editing the manuscript;
RC, JP – critical revision and approval of the final manuscript.

References

Alavi, S.A.N., Zakeri, A., Kamrani, B., Pourakbari, Y. 2012. Effect of prebiotics, probiotics, acidifier, growth promoter antibiotics and synbiotics on humural immunity of broiler chickens. – Global Veterinaria, 8:612–617.

Anggraeni, A.S., Suryani, A.E., Sofyan, A., Sakti, A.A., Istiqomah L., Karimy M.F., Darma I.N.G. 2020. Nutrient digestibility of broiler chicken fed diets supplemented with probiotics phytase-producing. – IOP Conference Series: Earth and Environmental Science, 462:01200. DOI: 10.1088/1755-1315/462/1/012003.

Azemraw, W., Sewalem, M. 2017. Review on application of probiotics in poultry. – British Journal of Poultry Sciences, 6(3):46–52. DOI: 10.5829/idosi.bjps.2017.46.52

Balukh, N. 2016. Probiotyk ta ferment u ratsionakh broileriv [Probiotic and enzyme in broiler diets]. – Theoretical and Applied Veterinary Medicine, 4(1): 23–26. [in Ukrainian].

Belova, N., Yezhova, O., Kornilova, V., Maslov, M. 2009. Vlyianye probyotykov y vytamyna S na yspolzovanye pytatelnыkh veshchestv korma [The effect of probiotics and vitamin C on the use of feed nutrients]. – Poultry keeping, 5: 16–18. [in Ukrainian]

Chudak, R.A., Podolian, J.M. 2012. Probiotyk «Entero-aktyv» [Probiotic "Entero-active"]. – Vinnytsia National Agrarian University. Technical requirements (Industry standard) of Ukraine. TR (IS) U 15.7-00497236-001: 2012. 2012 Aug 1. [in Ukrainian]

Cengiz, Ö., Köksal, B.H., Tatlı, O., Sevim, Ö., Ahsan, U., Üner, A.G., Ulutaş, P.A., Beyaz, D., Büyükyörük, S., Yakan, A., Önol, A.G. 2015. Effect of dietary probiotic and high stocking density on the performance, carcass yield, gut microflora, and stress indicators of broilers. – Poultry Science, 94(10):2395–2403. DOI: 10.3382/ps/pev194

Chudak, R.A., Ushakov, V.M., Poberezhets, Y.M., Lotka, H.I., Polishchuk, T.V., Kazmiruk, L.V. 2020. Effect of *Echinacea pallida* supplementation on the amino acid and fatty acid composition of Pharaoh quail meat. – Ukrainian Journal of Ecology, 10(2):302–307. DOI: 10.15421/2020_101.

Clark, P.M., Behnke, K.C., Poole, D.R. 2007. The effects of marker selection and mix time on the coefficient of variation (the uniformity of mixing) of broiler feed. – Journal of Applied Poultry Research, 16(3):464–470. DOI: 10.1093/japr/16.3.464

DSTU ISO 6497:2005. Animal feeding stuffs. Sampling methods. (ISO 6497:2002, IDT). – https://www.ukrainelaws.com/p-41349-dstu-iso-64972005.aspx. Accessed on 22/10/2021

Dunkley, C. 2008. The use of probiotics and prebiotics in poultry feeds. – Feed and Nutrition, pp. 25–28.

Fedorchenko, A. 2017. Probiotyky dlia broilera [Probiotics for broiler]. – Our Poultry, 3:35–48. [in Ukrainian]

Hamungalu, O., Zaefarian, F., Abdollahi, M.R., Ravindran, V. 2020. Performance response of broilers to feeding pelleted diets is influenced by dietary nutrient density. – Animal Feed Science and Technology, 268:114613. DOI: 10.1016/j.anifeedsci.2020.114613

He, T., Long, S., Mahfuz, S., Wu, D. Wang, X., Wei, X., Piao, X. 2019. Effects of probiotics as antibiotics substitutes on growth performance, serum biochemical parameters, intestinal morphology, and barrier function of broilers. – Animals, 9(11):985. DOI: 10.3390/ani9110985

Ibatullin, I.I., Zhukorskyi, O.M., Bashchenko, I. 2017. Metodolohiia ta orhanizatsiia naukovykh doslidzhen u tvarynnytstvi [Methodology and organization of scientific research in animal husbandry]. – Ahrar. Nauka: Kyiv, Ukrainian, pp. 312–327. [in Ukrainian]

Kozyr, V.S., Svezhentsov, A.I. 2002. Praktychni metody doslidzhen u tvarinnycztvi [Practical methods of research in animal husbandry]. – Art Press: Kyiv, Ukrainian, pp. 350–354 p. [in Ukrainian]

Levchenko, V.I., Vlizlo, V.V., Kondrahin, I.P., Melnichuk, D.O., Apuhovska, L.I., Galjas, V.L., Golovaha, V.I., Sahnjuk, V.V., Tomchuk, V.A., Grishhenko, V.A., Cvilihovskij, M.I. 2002. Veterinarna klinichna biochimiya [Veterinary clinical biochemistry]. – Bila Tserkva National Agrarian University: Bila Tserkva, Ukraine, pp. 388–400. [in Ukrainian].

Liu, X., Yan, H., Lv, L., Xu, Q., Yin, C., Zhang, K., Wang, P., Hu, J. 2012. Growth performance and meat quality of broiler chickens supplemented with *Bacillus licheniformis* in drinking water. – Asian-Australasian Journal of Animal Sciences, 25(5):682–689. DOI: 10.5713/ajas.2011.11334

Lopetuso, L., Graziani, C., Guarino, A., Lamborghini, A., Masi, S., Stanghellini, V. 2017. Gelatin tannate and tyndallized probiotics: a novel approach for treatment of diarrhea. – European Review For Medical and Pharmacological Sciences. 21(4):873–883.

Mashkin, Y.O. 2010. Hematolohichni pokaznyky krovi kurchat-broileriv pid vplyvom «Protekto-Aktyv» [Hematological parameters of the blood of broiler chickens under the influence of "Protecto-Active"]. – Modern poultry farming, 1–2:26–28. [in Ukrainian]

Meremäe, K., Mäesaar, M., Kramarenko, T., Häkkinen, L., Roasto, M. 2015. The prevalence, counts and antimicrobial susceptibility of thermophilic *Campylobacter* spp. in fresh chicken meat at Estonian retail level. – Agraarteadus, 2(26):68–75.

Mookiah, S., Sieo, C.C., Ramasamy, K., Abdullah, N., Ho, Y.W. 2014. Effects of dietary prebiotics, probiotic and synbiotics on performance, caecal bacterial populations and caecal fermentation concentrations of broiler chickens. – Journal of the Science of Food and Agriculture, 94(2):341–348. DOI: 10.1002/jsfa.6365

Otchenashko, V.V. 2012. Vykhid produktiv zaboiu ta kharchova tsinnist miasa perepeliv za vykorystannia kombikormiv z riznymy rivniamy enerhii [Yield of slaughter products and nutritional value of quail meat using compound feeds with different energy levels]. – Modern poultry farming, 5:5–9. [in Ukrainian]

Park, J.H., Kim, I.H. 2014. Supplemental effect of probiotic *Bacillus subtilis* B2A on productivity, organ weight, intestinal *Salmonella* microflora, and breast meat quality of growing broiler chicks. – Poultry Science, 93(8):2054–2059. DOI: 10.3382/ps.2013-0381

Patreva, L.S., Shevchenko T.V. 2010. Vplyv probiotyka «Baikal EM-1» na morfolohichnyi sklad tushok kachok [Influence of probiotic "Baikal EM-1" on the morphological composition of duck carcasses]. – Agricultural Science and Food Technology. Animal Feeding and Feed Technology, 4(44):143–145. [in Ukrainian]

Poberezhets, J. 2020. The effect of probiotic on hematological parameters and chemical content of broiler chickens meat. – Slovak International Scientific Journal, 45:44–50.

Podolian, J.M., Chudak, R.A., Bolokhovsky, V.V., Bolokhovskaya, V.A., Blagodir, A.M. 2011. Kormova dobavka «Entero-aktyv» [Feed additive "Entero-active"]. – Vinnytsia National Agrarian University. Ukraine patent UA 59058. 2011 May 10.

Rajesh, Jha., Das, R., Oak, S., Mishra, P. 2020. Probiotics (Direct-Fed Microbials) in poultry nutrition and their effects on nutrient utilization, growth and laying performance, and gut health: A systematic review. – Animals (Basel), 10(10):1863. DOI: 10.3390/ani10101863

Rudenko, V.M. 2012. Matematychna statystyka [Mathematical statistics]. – Center for Educational Literature: Kyiv, Ukrainian, pp. 234–245. [in Ukrainian]

Salim, H.M., Kang, H.K., Akter, N., Kim, D.W., Kim, J.H., Kim, M.J., Na, J.C., Jong, H.B., Choi, H.C., Suh, O.S., Kim, W.K. 2013. Supplementation of direct-fed microbials as an alternative to antibiotic on growth performance, immune response, cecal microbial population and ileal morphology of broiler chickens. – Poultry Science, 92:2084–2090. DOI: 10.3382/ps. 2012-02947

Sobolev, O.I., Gutyj, B.V., Soboliev, S.V., Borshch, O.O., Liskovich, V.A., Prystupa, O.I., Demus, N.V., Paladiychuk, Fedorovych, O.V., Fedorovych, E.I., Khariv, I.I., Vasiv, R.O., Levkivska, N.D., Leskiv, K.Y., Guta, Z.A.. 2019. Chemical composition, energy and biological value of broiler chicken meat caused by various doses of selenium. – Ukrainian Journal of Ecology, 9(4):622–627. DOI: 10.15421/ 2019_799

Syrovatko, K.M., Vuhliar, V.S. 2021. The effect of additives with essential oils on the productivity of young pigs. – Regulatory Mechanisms in Biosystems, 12(1):92–95. DOI: 10.15421/022114

Urdzik, R.M. 2010. Probyotyky vmesto antybyotykov - stymuliatorov rosta. [Probiotics instead of antibiotics - growth stimulants]. – Effective poultry farming, 3:26–29. [in Ukrainian]

Zaghari, M., Sarani, P., Hajati, H. 2020. Comparison of two probiotic preparations on growth performance, intestinal microbiota, nutrient digestibility and cytokine gene expression in broiler chickens. – Journal of Applied Animal Research, 48(1):166–175. DOI: 10.1080/09712119.2020.1754218

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CASE STUDY: INFLUENCE OF PROBIOTICS-BASED PRODUCTS ON PHYTOPATHOGENIC BACTERIA AND FUNGI IN AGROCENOSIS

Pavlo Pysarenko, Maryna Samoilik, Anna Taranenko, Yurii Tsova, Maksym Sereda

Department of Agrotechnology and Ecology, Poltava State Agrarian University, 1/3 Skovorody St, Poltava 36003, Ukraine

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Vastutav autor: Corresponding author: Anna Taranenko

E-mail: anna.taranenko@pdaa.edu.ua
Phone: +380 953 388 252

ORCID:
0000-0002-4915-265X (PP)
0000-0003-2410-865X (MSa)
0000-0002-1305-939X (AT)
0000-0002-2796-3830 (YT)
0000-0002-6151-2144 (MSe)

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ABSTRACT. In recent years bacterial diseases of agricultural plants have reached a new level of epiphytoty and they appear as an essential factor that influences crop yield. It is important to use products, which provide the eradication of pathogenic agents and the prevention of their development and propagation. The objective of our study is to define the effect of probiotics, based on *Bacillus subtillis*, on bactericidal and fungicidal activities, and to develop the recommendations for probiotics application in a biological system of plant protection. The results show that studied solutions Sviteco-PPW, Sviteco-OPL and Sviteco-Agrobiotic-01 affect phytopathogenic bacteria. Sviteco-Agrobiotic-01 either is the most active product, in its native state or diluted. It has demonstrated high antagonizing activity against all studied phytopathogenic bacteria. Hence, Sviteco-Agrobiotic-01 has the best potential to be used in the biological protection system of grain crops, grain legumes, vegetables from the most dangerous and widely spread pathogenic bacteria. Research results don't show a significant effect of studied probiotics on phytopathogenic fungicidal activity.

Introduction

Pathogenic organisms, invaders or weeds are the main factors that do not allow to obtain high crop yield. Ecological conditions of ecosystem development are changing significantly and that is why scientists are more likely to consider either plant resistance support or to take advantage of the natural potential of agroecosystems. On the other hand, the harmful impact of plant protection products on the agroecosystem and, more precisely on humans, stimulate the industry to use biological or microbiological methods of plant protection against pathogens. These approaches are ecologically safe for the ecosystems and human beings (Patyka *et al.* 2014a, Patyka *et al.* 2014b).

Microbiological techniques of plant protection against diseases and pathogens have an important role in ecologically sustainable agriculture. The demand for such drugs is growing in recent years. Biological methods of protection permit significantly reduce the costs of the production technology. Moreover, combined methods of protection prevent the uprise of resistances that are only observed upon the usage of chemical pesticides.

There is a sustainable market of different products based on probiotic cultures, which indicates the benefit of them. The scientific research proves the mechanisms of their action. The capacity of spore-forming bacteria to perform probiotic activity has led to the development of probiotic-based products, which are considered to be a new generation of antagonists (Green *et al.*, 1999). The unique feature of this bacterial group is the high G+C ratio (from 32% to 69%) (Nakano *et al.*, 1998).

Bacillus is a genus with about 77 species that create a large group of Gram-positive chemoorganotrophic rod-shaped aerobes or facultative anaerobes forming endospores (List of Prokaryotic names with Standing in Nomenclature). The representatives of this genus have

a high and diverse spectrum of biological activity. Very often it is also characterized by antagonizing activity against pathogens.

The crucial features of probiotic strains are a high antagonism to pathogens and opportunistic microorganisms, the resistance to low pH of the environment, low adhesive activity, the absence of genes of antibiotic resistance and virulence.

As for today, we know about microbiological manure based on nitrogen-assimilating and phosphate-mobilizing bacteria. Many strains used in these fertilizers have an antagonizing effect on phytopathogenic flora. Therefore, a new and perspective way of disease prevention and crop yield increase is the application of probiotics.

The research aimed to determine the influence of microbiology products, based on *Bacillus subtilis* on bactericidal and fungicidal activity and their further usage in the biological system of agrophytocenosis protection.

Materials and Methods

Our experiment envisaged the study of three probiotic-based products: Sviteco-PPW, Sviteco-OPL, Sviteco-Agrobiotic-01 (Chrisal NV, Lommel, Belgium), based on *Bacillus subtillis.* Was made the determination of their antibacterial and fungicidal activity on phytopathogenic bacteria.

The bacterial sensibility was determined using a serial dilution method on a solid medium – potato dextrose agar. The product has been applied using a disc diffusion method (instead of a disc with an antibiotic we have used a drop of a probiotic drug). Petri dish with potato dextrose agar (PA) was inoculated with 0.1 ml of a bacterial suspension of studied bacteria (the concentration of suspension was 1×109 CFU ml^{-1}) and then we used a spreader to homogenize the pathogen culture. Afterwards have added 0.1 ml of a tested drug in different concentrations. After 24–48 hours in an incubator at 28 °C, we have made the accounting of inhibition zones. Every experiment has been repeated three times. The absence of inhibition zones indicated the resistance of pathogens to this concentration of a product. Zones with a diameter higher than 15 mm signify the low sensitivity to a product. Inhibition zones with a diameter of 15–25 mm are characteristic of sensible bacteria. Highly sensible bacteria show the inhibition zones with a diameter of more than 25 mm (Dankevych *et al.,* 2014). Bactericidal action of solutions was determined using test cultures: *Pseudomonas syringae* – UKM B-1027[T] (IMB 8511); *Pseudomonas fluorescens, Pectobacterium carotovorum* – UKM B-1095[T] (IMB 8982); *Xanthomonas campestris pv. campestris* – UKM B-1049 (IMB 8003); *Clavibacter michiganensis* subsp. *michiganensis* 10_2; *Agrobacterium tumefaciens* (*Rhizobium vitis*) 8628.

The fungicidal activity was determined using a wort agar (Merck, Germany). Phytopathogenic strains of *Fusarium oxysporum* and *Alternaria* sp. were used to determine the fungicidal action of the products. For this experiment, we have used products in a 100% concentration and diluted state (1:10, 1:100, 1:1000 and 1:10000). The conclusion about the biocide activity was made from inhibition zones on the third and fifth day of incubation.

Results

Identification of influence of probiotics on bactericidal activity

Obtained results indicate, that Sviteco-Agrobiotic-01 is the most effective among the three tested products. Both in native state and diluted it has shown high antibacterial activity against all tested phytopathogenic bacteria (Table 1).

Table 1. Effect of probiotics on phytopathogenic bacteria (diameter of the inhibition zones, mm)

Phytopathogenic bacteria	Native state	Concentration					
		$1:10^{-1}$	$1:10^{-2}$	$1:10^{-3}$	$1:10^{-4}$	$1:10^{-5}$	$1:10^{-6}$
		Sviteco-PPW					
P. syringae	20	15	0	0	0	0	0
P. fluorescens	0	0	0	0	0	0	0
P. carotovorum	0	0	0	0	0	0	0
X. campestris pv. campestris	Full BA	40	28	0	0	0	0
C. michiganensis	Full BA	35	22	5	0	0	0
A. tumefaciens	0	0	0	0	0	0	0
		Sviteco-OPL					
P. syringae	15	13	10	BsA-18	BsA-9	0	0
P. fluorescens	0	0	0	0	0	0	0
P. carotovorum	30	20	0	0	0	0	0
X. campestris pv. campestris	50	40	15	13	0	0	0
C. michiganensis	50	35	24	15	0	0	0
A. tumefaciens	20	13	0	0	0	0	0
		Sviteco-Agrobiotic-01					
P. syringae	50	30	25	25	10	weak BsA	0
P. fluorescens	30						
P. carotovorum	50	25	22	27	0	0	0
X. campestris pv. campestris	40	35	30	15	10	0	0
C. michiganensis	60	30	18	15	13	0	0
A. tumefaciens	50	35	15	5	0	0	0

BA – bactericidal action, BsA – bacteriostatic action

It was found, that bacterial species *Pseudomonas syringae*, *Xanthomonas campestris* and *Clavibacter michiganensis* is sensible even to a solution diluted 1:10000. Sviteco-Agrobiotic-01 diluted in 1000 times has shown high antibacterial activity against *Pseudomonas syringae* and *Pseudomonas fluorescens*; moderate antibacterial activity on *Xanthomonas campestris* and *Clavibacter michiganensis*; weak activity against *Agrobacterium tumefaciens*. To limit the spread of phytopathogenic bacteria *Pseudomonas syringae* and *Pectobacterium carotovorum* Sviteco-Agrobiotic-01, diluted 1:1000, can be used.

Sviteco-PPW and Sviteco-OPL have shown selective antibacterial activity against certain pathogens. Hence, Sviteco-PPW has antibacterial activity on *Pseudomonas syringae* only in a native (non-diluted) state and in a 1:10 dilution. *Xanthomonas campestris* and *Clavibacter michiganensis* were not sensible to a product neither in the native state nor in 1:10 or 1:100 dilutions. There was no toxic action observed against *Pseudomonas fluorescens* or *Agrobacterium tumefaciens*.

Sviteco-OPL has a selective activity to phytopathogenic bacteria mostly in a native state. The exception is the antibacterial activity on *Xanthomonas campestris* and *Clavibacter michiganensis*, which has been revealed even using a 1:1000 dilution.

Thus, 1:100 or 1:1000 dilutions of Sviteco-Agrobiotic-01 can be used to develop biological methods of plant protection against all tested phytopathogenic bacteria. Sviteco-OPL can be employed to protect plants only against *Xanthomonas campestris* and *Clavibacter michiganensis*.

Identification of influence of probiotics on fungicidal activity

The results of our study of fungicidal activity prove that probiotics have no toxic action against all tested phytopathogenic fungi (Table 2).

Table 2. Effect of probiotics on phytopathogenic bacteria (diameter of the inhibition zones, mm)

Micromycete	Native state	Concentration			
		$1:10^{-1}$	$1:10^{-2}$	$1:10^{-3}$	$1:10^{-4}$
Sviteco-PPW					
Fusarium oxysporum	0	0	0	0	0
Alternaria sp.	0	0	0	0	0
Sviteco-OPL					
Fusarium oxysporum	15	0	0	0	0
Alternaria sp.	15	0	0	0	0
Sviteco-Agrobiotic-01					
Fusarium oxysporum	10	0	0	0	0
Alternaria sp.	10	0	0	0	0

During the examination of Sviteco-PPW all the dilution and in the native state has no zones of growth inhibition. Products Sviteco-OPL and Sviteco-Agrobiotic-01 show fungicidal activity only in a native state. However, the diameter of inhibition zones was not bigger than 15 mm, which indicates the pathogen resistance to this probiotics. Hence, products, based on probiotics, do not affect to the development of *Fusarium oxysporum* and *Alternaria* sp.

Discussion

Scientific research (Vandenberghe *et al.*, 2017) showed probiotic microorganisms, as bioprotectants, bio-controllers, biofertilizers, or biostimulants, are beneficial microorganisms that offer a promising alternative and reduce health and environmental problems. These microorganisms are involved in either a symbiotic or free-living association with plants and act in different ways, sometimes with specific functions, to achieve satisfactory plant development. The use of probiotics as an alternative soil fertilization source in agriculture improves nutrient supply and conserves field management and causes no adverse effects.

Another research (Barriuso *et al.*, 2008; Zhang *et al.*, 2008) confessed salt tolerance in plants, a decrease in the disease index of 61.2%, and a reduction in mortality due to salt stress of 72.4% after application *Bacillus* sp. strain. Additionally, significant differences were found in the growth of plants and photosynthesis. Showed an increase in dry biomass, total soluble sugars and proline content in wheat crops (Upadhyay *et al.*, 2012).

The study of the potential of *Bacillus* sp. as a probiotic was made by Khadieva *et al.* (2018). The strains were resistant to a wide range of the ambient pH, characterized by antagonistic properties against phytopathogenic micromycetes, as well as against pathogenic and opportunistic enterobacteria. Therefore, were concluded to be promising strains for use as probiotics. *Bacillus subtilis* strain showed strong ability against many common plant fungal pathogens in vitro (Gong *et al.*, 2006).

The research results of Avdeeva *et al.* (2015) has defined high antagonizing activity of *B. Subtilis* against *Shigella flexnery, Proteus vulgaris, P. Vulgaris, Staphylococcus aureus* as well as a moderate level of antagonism on *Salmonella thyphimurium, Ecsherichia coli* and a low level of antagonism against *S. enteri3a, S. Derby, Pseudomonas aeruginosa*. Hrabova *et al.* (2015) have found out the antagonizing effect of 100 strains of genus *Bacillus* against ancient and actual strains of phytopathogenic bacteria and fungi. It was identified that the level of antagonizing activity against phytopathogenic bacteria has varied depending on the genus of pathogens. The average level of antagonism against fungi has been revealed among 30% of bacilli. The strain *Bacillus sp.* has been isolated. It has a high and moderate level of antagonism against bacterial and fungal phytopathogens. Hence, this strain is considered to have a lot of potential for biological drug development for plant growth.

High antimicrobial activity of *B. Subtilis* has been studied by Cutting (2011); Karlsson *et al.* (2017); Khadieva *et al.* (2018). They have characterized the perspective of these cultures to be used as probiotics. The resistance to a wide range of pH has been confirmed along with the identification of antagonizing effect on phytopathogenic micromicelles.

Thus, studies of scientists confirm our research of antagonizing effect of probiotic cultures. So, the application of these probiotic-based drugs to control phytopathogens is a perspective and innovative approach.

Prospects for future research is field investigation of probiotic products depending on the type of crops and method of application.

Conclusion

Research results show that studied probiotics affect phytopathogenic bacteria. Sviteco-Agrobiotic-01 has a high antibacterial activity on bacteria species *Pseudomonas syringae, Pseudomonas fluorescens, Pectobacterium carotovorum* subsp. *carotovorum* in a 1:1000 dilution; or on *Xanthomonas campestris* pv. *campestris and Clavibacter michiganensis subsp. michiganensis* in a 1:100 dilution. Sviteco-PPW and Sviteco-OPL have a selective antibacterial activity in a 1:100 dilution.

Studied products Sviteco-PPW, Sviteco-OPL and Sviteco-Agrobiotic-01 haven't fungicidal activity against fungal test cultures: *Fusarium oxysporum* and *Alternaria* sp.

Therefore, among studied products, Sviteco-Agrobiotic-01 has the best potential to be used in the biological protection system of grain crops, grain legumes, vegetables from the most dangerous and widely spread pathogenic bacteria.

Conflict of interest

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

Author contributions

PP, MSa – editing and approving the final manuscript.
AT – the corresponding author, writing of the manuscript.
YT, MSe – design/sampling/analysis.
All authors read and approved the final manuscript.

References

Avdeeva, L.V., Nechypurenko, O.O., Kharhota, M.A. 2015. Probiotic features of carotene producing strains Bacillus sp. 1.1 and B. amyloliquefaciens UCM B-5113. [Probiotichni vlastivosti karotinsintezuval"nih shtamiv bacillus sp.1.1 ta b. Amyloliquefaciens ukmv-5113]. – Mikrobiolohichnyi Zhurnal, 77(2): 22–27. (In Ukrainian)

Barriuso, J., Ramos Solano, B., Gutiérrez Mañero, F.J. 2008. Protection against pathogen and salt stress by four plant growth-promoting rhizobacteria isolated from *Pinus* sp. on *Arabidopsis thaliana*. – Phytopathology, 98(6):666–672. DOI: 10.1094/ PHYTO-98-6-0666

Cutting, M. 2011. Bacillus probiotics. – Food Microbiology, 28(2):214–220. DOI: 10.1016/j.fm. 2010.03.007

Dankevych, L.A., Zakharova, O.M., Melnichuk, M.D., Votselko, S.K., Patyka, V.P. 2014. REP-PCR analysis of rape´s bacterial diseases agents. [REP-PLR analiz zbudnykiv bakterial"nyx xvorob ripaku]. – Mikrobiolohichnyi Zhurnal, 76(4):17–25. (In Ukrainian)

Gong, M., Wang, J.-D., Zhang, J., Yang, H., Lu, X.-F., Pei, Y., Cheng, J.-Q. 2006. Study of the antifungal ability of *Bacillus subtilis* strain PY-1 in vitro and identification of its antifungal substance (Iturin A). – Acta Biochimica et Biophysica Sinica, 38(4):233–240. DOI: 10.1111/j.1745-7270.2006.00157.x

Green, D.H., Wakeley, P.R., Page, A., Barnes, A., Baccigalupi, L., Ricca, E., Cutting, S.M. 1999. Characterization of two *Bacillus* probiotics. – Applied and Environmental Microbiology, 65:4288–4291. DOI: 10.1128/AEM.65.9.4288-4291.1999

Hrabova, H.Y., Drahovoz, I.V., Kriuchkova, L.O., Pasichnyk, L.A., Avdeeva, L.V. 2015. *Bacillus* strains's screening - active antagonists of bacterial and fungal phytopathogens [Skrining shtammov bakterij roda bacillus – aktivnyh antagonistov fitopatogenov bakterial"noj I gribnoj prirody]. – Mikrobiolohichnyi Zhurnal, 77(6):47–54. (in Russian)

Karlsson, I., Friberg, H., Kolseth, A.K., Steinberg, C., Persson, P. 2017. Agricultural factors affecting Fusarium communities in wheat kernels. – International Journal Food Microbiol., 252:53–60. DOI: 10.1016/j.ijfoodmicro.2017.04.011.

Khadieva, G.F., Lutfullin, M.T., Mochalova, N.K., Lenina, O.A., Sharipova, M.R. Mardanova, A.M. 2018. New *Bacillus subtilis* strains as promising probiotics. – Microbiology, 87:463–471. DOI: 10.1134/S0026261718040112

Nakano, M.M., Zuber, P. 1998. Anaerobic growth of a "strict aerobe" (*Bacillus subtilis*). – Annual Review Microbiology, 52:165–190. DOI: 10.1146/annurev. micro.52.1.165

Patyka, V.P., Pasichnyk, L.A. 2014a. Phytopathogenic bacteria in the system of modern agriculture. – Mikrobiolohichnyi Zhurnal, 76(1):21–26.

Patyka, V.P., Taranenko, S.V., Taranenko, A.O., Kalinichenko, A.V. 2014b. Microbial biom of different soils and soil-climatic zones of Poltava region. [Mikrobnyj biom riznyx gruntiv j gruntovo-klimatychnyx zon Poltavs"koyi oblasti] – Mikrobiolohichnyi Zhurnal, 76(5):20–25. (In Ukrainian)

Vandenberghe, L.P., Garcia, L.M, Rodrigues, C., Camara, M.C., Pereira, G.V., Oliveira, J., Soccol, C.R. 2017. Potential applications of plant probiotic microorganisms in agriculture and forestry. – AIMS Microbiology, 3(3):629–648. DOI: 10.3934/ microbiol.2017.3.629

Upadhyay, S.K., Singh, J.S., Saxena, A.K., Singh D.P. 2012. Impact of PGPR inoculation on growth and antioxidant status of wheat under saline conditions. – Plant Biology, 14:605–611. DOI: 10.1111/j.1438-8677.2011.00533.x

Zhang, H., Kim, M.S., Sun, Y., Dowd, S.E., Shi H., Paré, P.W. 2008. Soil bacteria confer plant salt tolerance by tissue-specific regulation of the sodium transporter HKT1. – Mol. Plant Microbe Interact, 21(6):737–744. DOI: 10.1094/MPMI-21-6-0737

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BIOLOGICAL ACTIVITY OF CHERNOZEMS TYPICAL OF DIFFERENT FARMING PRACTICES

Serhii Rieznik[1], Dmytro Havva[1], Andrii Butenko[2], Konstantin Novosad[1]

[1]Department of Soil Science, State Biotechnological University, Dokuchaevske Vill, Kharkiv Dist, Kharkiv Reg, Ukraine
[2]Sumy National Agrarian University, 160 H. Kondratieva St, UA40021, Sumy, Ukraine

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Vastutav autor: Corresponding author: Andrii Butenko

E-mail: andb201727@ukr.net

ORCID:
0000-0002-2703-1021 (SR)
0000-0001-6516-7846 (DH)
0000-0001-9639-9826 (AB)
0000-0003-2043-9160 (KN)

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ABSTRACT. The study aimed to determine the impact of different farming practices (organic and intensive) on the dynamics of potential biological activity of typical chernozem (mollisol). Comparative-profile-genetic, microbiological and mathematical-statistical methods were used for the research. The data obtained during the study of soil biological activity for 2018–2020 were analyzed. The highest population density of Collembola was observed in the variant of fallow soil in the layer of 10–20 cm (111 indiv. $dm^{3\,-1}$) with the lowest amount of Oribatida (32 indiv. $dm^{3\,-1}$). Under conditions of agrogenic use of soils, the predominance of Oribatida over Collembola was recorded. When using green manure in a soil layer of 0–10 cm, the number of Oribatida is 125 indiv. $dm^{3\,-1}$, while Collembola – 50 indiv. $dm^{3\,-1}$. Agrogenic use of chernozems reduces the number of microscopic fungi. The intensive farming system is the reason for the decrease in the number of all ecological and trophic groups of microorganisms in the 0–10 cm layer while increasing their number in the layer of 20–30 cm. Variants of the organic system of agriculture, especially with the use of green manure, contribute to the increase in the number of actinomycetes and amylolytic microbiota, as well as a short-term sharp increase in the number of oligonitrophilic microbiota. Agricultural use of soils reduces the activity of enzymes such as invertase, protease, dehydrogenase and cellulase. However, the activity of urease and catalase – increases in the soils of the organic system of agriculture. Discriminant analysis of biological activity identified three groups of soils, corresponding to different farming systems. This confirms the possibility of using the studied indicators for soil biodiagnostics.

Introduction

At the present stage of soil genesis, the most influential factor there is a human agricultural activity, as evidenced by the huge area ploughed lends and unprecedented rates of soil degradation not only in Ukraine but also around the world (National report..., 2010; FAO, 2020). Agrogenic soil formation is fundamentally different from natural, especially the rate of transformation of organic and mineral parts of the soil. Human agricultural activity often leads to the suppression of soil biosphere functions and harms the ecosystem. The most striking example is arable land, where there is a radical change in the entire biogeocenosis. Intensive tillage, application of mineral fertilizers and pesticides, change of vegetation and alienation of a significant part of biomass and nutrients contribute to the development of degradation processes of soil cover, such as the formation of the arable horizon, erosion, destruction of structural aggregates, compaction, decarbonization, desertification, salinization, reduction of biological diversity *etc*. (FAO and ITPS, 2017; Tikhonenko, 2011; Medvedev, 2008).

In soil biodiagnostics, the most complex sections are biochemical and microbiological characteristics of soils. Microbial communities are a certain ecolotrophic combination of microorganisms of different species that directly affect soil fertility. It is established that a significant part of microorganisms take a active part in the transformation of organic matter and mineral part of the soil. A close positive relationship between crop yields and soil biological activity has been noted by

many researchers (Karpenko *et al.*, 2020; Volkohon *et al.*, 2017). The microorganisms studied by us take an active part in the processes of mineralization-synthesis of organic substances in the soil. For example, the number of ammonifying and amylolytic microbiota, which reflect the intensity of mineralization processes, are good indicators of microbiological processes occurring in the soil (Volkohon *et al.*, 2019). Also, various researchers have found that in arable soils there is a decrease in the number of microscopic fungi, but increases the number of phytopathogenic fungi and actinomycetes (Pesakovic *et al.*, 2009; Stanojković *et al.*, 2011).

Nowadays, scientists, not only in Ukraine but all over the world, agree that living organisms are the most informative indicators of changes occurring in the soil (Paz-Ferreiro *et al.*, 2016). Therefore, the study of soil biological activity under different farming practices is especially relevant.

Materials and Methods

Typical deep medium loamy chernozems on the loess (molik, mollisol) located on the territory of Zinkiv district of Poltava region were selected for research (forest-steppe zone, Ukraine). The soils are located on the plateau of the watershed between the rivers Psel and Vorskla.

The selection of individual soil samples took place during 2018–2020 in the fields of farms operating under two radically different systems of agriculture. Organic technology farms abandoned ploughing in 1975, herbicides and other agrochemicals in 1978, and mineral fertilizers a few years later. On another farm, working on traditional technology, a system of different tillage is used: deep loosening, ploughing, disking and cultivation. The technology of growing crops involves the use of seeds, fertilizers and plant protection products only from the best domestic and foreign producers. New agricultural machinery is used in farms and elements of precision agriculture are introduced into production: GPS-monitoring systems, autopiloting, remote sensing methods, yield monitoring, variable sowing rates and differentiated fertilizer application.

The first soil profile is located on a field with an area of 143 hectares, wherein the crop rotation link a vetch yara (*Vicia sativa* L.) is grown for green manure – is a variant of the organic farming system (green manure). The crop rotation is shown in Table 1, and technological operations in Table 2.

The second soil profile is located on a plot that has not been cultivated for over 30 years – it is variant fallow. Legumes, cereals and other wild plants grow in this area. The variant of fallow is controlled.

The third soil profile is located on a field with an area of 94 hectares, where the compost made from cattle manure is applied at a dose of 20 t ha^{-1} – is a variant of the organic farming system (compost).

The fourth soil profile is located on a field with an area of 125 hectares, where use the full range of plant protection products and fertilizers (intensive).

Table 1. Crop rotation and fertilizer system during the research period

Variant	Year		
	2018	2019	2020
Organic farming system (green manure)	Vetch yara on green manure	Winter wheat (green manure, 15 t ha^{-1} of green mass)	Wintering peas – moved corn to silage
Fallow	Weeds		
Organic farming system (compost)	Corn for grain (20 t $ha^{-1}$of compost from cattle manure)	Oat	Soybeans
Intensive farming system	Corn for grain ($N_{130}P_{30}K_{30}$)	Sunflower ($N_{35}P_{15}K_{30}$)	Corn for grain ($N_{130}P_{30}K_{30}$)

The selection of individual soil samples was carried out in the first decade of May, August and November during 2018–2020. Soil sampling was performed from depths of 0–10, 10–20, 20–30, 30–40 cm. Soil sampling for the study of mesofauna was performed with cylinders with a volume of 1 dm^3. Catch of springtails and oribatides samples were performed in simple Tulgren funnels, followed by their fixation in aqueous-alcohol solution with the addition of 3% glycerol. The number of microarthropods was recalculated by 1 dm^3 in the corresponding soil layer, this method was described by Gilyarov (1975) and Bater (1996).

The number of microorganisms was determined by the method of deep sowing of soil suspension on dense nutrient media, all methods described by Volkohon *et al.* (2010), Shchukovs′kyy *et al.* (2002) and Titova *et al.* (2012). The number of representatives of different ecological and trophic groups of microorganisms was taken into account by sowing dilutions of soil suspension on the following elective nutrient media: meat-peptone agar (MPA), starch-ammonia agar (SAA), peptone-glucose agar – Waxman's agar (PGA), hangry agar (HA), Ashby's agar (ASH), nitrite agar (NA).

The activity of the following soil enzymes was studied: catalase, urease, dehydrogenase, protease and cellulase, all methods described by Khaziev (2005) and Titova *et al.* (2012).

The activity of the enzyme catalase was determined by the gasometric method by Galstyan (Khaziev, 2005). The essence of the method is to determine the amount of oxygen released during the decomposition of hydrogen peroxide. The activity of the enzyme invertase was determined by a modified photocolorimetric (UNICO 1205, USA) method of Khaziev (Khaziev, 2005). The essence of the method is to determine the optical density of the solution after the reduction of copper by glucose and fructose, released during the hydrolysis of sucrose. Urease activity was determined by the colourimetric method of Scherbakova (Khaziev, 2005), by determining the amount of ammonium released using Nessler's reagent (BASF, Germany). Dehydrogenase activity was determined by Galstyan's method, by photocolorimetric determination of the amount of formed triphenylformazan (TFF). Protease activity was determined by the method of Galstyan-Harutyunyan (Khaziev, 2005), a method based on the ability of proteases to decompose the protein substrate

into amino acids, followed by photocolorimetric (UNICO 1205, USA) determination of their amount using ninhydrin (Biochem, France). Cellulase activity was determined based on the ability of the enzyme to decompose biopolymers to glucose, the amount of which is determined iodometrically by back titration with sodium hyposulfite (Merck).

Mathematical analysis of the data was performed with Microsoft Excel 2010 and Statgraphics 18.1 trial. Multifactor ANOVA and Discriminant Analysis were used.

Table 2. Technological operations for the period 2018–2020

2018	2019	2020
	Variant organic farming system (green manure)	
- harvest of the predecessor in 2017 - earnings of crop residues by a disk cultivator to a depth of 6–8 cm - disking (12–14 cm) - early spring cultivation (4 cm) - pre-sowing cultivation (4 cm) - sowing of vetch yara (continuous sowing) - disking of green manure to a depth (6–8 cm) in two tracks - pre-sowing cultivation (5 cm) - sowing of winter wheat	- early spring harrowing - harvesting by direct combining - harvesting of straw - earnings of crop residues by a disk cultivator (10–12 cm) - cultivation (6–8 cm) - pre-sowing cultivation (5 cm) - sowing of winter peas	- cultivation (6–8 cm) - earnings of crop residues by a disk cultivator to a depth of 12–14 cm - pre-sowing cultivation (6 cm) - sowing corn for silage because the peas are gone - two inter-row cultivation - collection of green mass on a silo - cultivation (12–14 cm)
	Variant organic farming system (compost)	
- harvest of the predecessor in 2017 - earnings of crop residues by a disk cultivator (6–8 cm) - disking (12–14 cm) - rolling by heavy ring- spur rollers (spring) - export and application of humus (compost) - cultivation to a depth of 6–8 cm - pre-sowing cultivation (6 cm) - sowing of corn - harrowing of ladders - three inter-row cultivation, and the last with hilling - harvesting - earnings of crop residues by a disk cultivator (6–8 cm) - cultivation to a depth of 12–14 cm	- spring provocative cultivation (3–4 cm) - pre-sowing cultivation (4 cm) - sowing of oats - post-emergence harrowing - harvesting by a separate method - harvesting of straw - earnings of crop residues by a disk cultivator (10–12 cm)	- early spring harrowing - pre-sowing cultivation (4 cm) - soybean sowing - pre-sowing cultivation (4 cm) - new soybean sowing - post-emergence harrowing - three inter-row cultivation - harvesting by direct combining - earnings of crop residues by a disk cultivator (12–14 cm) - deep loosening to a depth of 26 cm
	Variant intensive farming system	
- harvest of the predecessor in 2017 - disking (12–15 cm) - deep loosening 35–37 cm (autumn) - application of urea 250 kg ha^{-1} (spring) - cultivation (12–15 cm) - discussing (8–10 cm) - sowing of corn together with the introduction of a diamophos of 120 kg ha^{-1} 10:26:26 - introduction of soil herbicide - care 1–2: application of insurance herbicide + foliar fertilization - care 3: application of insecticide (on the panicle) - harvesting by direct combining - disking (12–15 cm) - ploughing (25–28 cm)	- application of Ammonium Sulfate 100 kg ha^{-1} - cultivation (12–15 cm) - harrowing - sowing of sunflower with the introduction of complex fertilizers 115 kg ha^{-1} 8:24:24 - introduction of soil herbicide - care 1: herbicide around the perimeter of the field and inter-row tillage - care 2: application of graminicide, fungicide, growth regulator and feeding on the leaves (4–5 pairs of true leaves) - care 3: application of insecticide, fungicide and foliar fertilization (asterisk) - harvesting by direct combining - disking (12–15 cm) - deep loosening (35–37cm) - application of urea 250 kg ha^{-1} – cultivation (12–15 cm)	- harrowing - sowing of corn together with the introduction of a diamophos of 125 kg ha^{-1} 9:25:25 - introduction of soil herbicide - care 1: application of insurance herbicide + foliar fertilization (3–5 leaves) - care 2: foliar fertilization (7–8 leaves) - care 3: application of insecticide (on the panicle) - harvesting by direct combining - disking (12–15 cm) - deep loosening (35–37cm) - application of urea 250 kg ha^{-1} - cultivation (12–15 cm)

Results and Discussion

Results (Table 3) indicate a decrease in the number of collembolas and a simultaneous increase in the number of oribatids in the soils of agrocenoses, and their ratio (Acari / Collembola) is 0.5–1.4, which according to other researchers (Ponge *et al.*, 2003; Kalynovskyi, 2014; Coulson *et al.*, 2015) is characteristic of forest cenoses and disturbed soils. Under the fallow area, on the contrary, the number of colembols is 2.2–3.4 times greater. The application of organic fertilizers, especially green manures, in the variants of the organic system of agriculture contributes to the increase in the number of collembolas and oribatids compared to the variant of intensive farming practices.

Studies have shown that the number of microarthropods has a weak correlation with ecolotrophic groups of microorganisms. There was also a moderate correlation between the number of oribatides and cellulase activity r = 0.43 and a significant correlation between the number of colembols and invertase activity r = 0.53.

The largest number of microscopic fungi was recorded in the soil layer of 0–10 cm variant of fallow (PGA = 5.39 CFU*10^3 per 1 g dry soil). Agricultural use of soils reduces the number of micromycetes by 1.5–2.0 times.

Table 3. The average number of microarthropods in typical chernozems under different farming practices (2018–2020)

Variant	Depth, cm	Collembola, indiv. $dm^{3\ -1}$	Oribatida, indiv. $dm^{3\ -1}$
Green manure	0–10	50	125
	10–20	47	70
	20–30	30	51
	30–40	22	51
Compost	0–10	55	75
	10–20	56	53
	20–30	39	28
	30–40	29	27
Fallow	0–10	101	43
	10–20	111	32
	20–30	71	27
	30–40	59	27
Intensive	0–10	50	82
	10–20	56	89
	20–30	37	86
	30–40	49	53
Farm system	S.E.	4.02	4.17
	F-Ratio	9.1	14.32
	P-Value	>0.001	>0.001
	$LSD_{0.5}$	11.18	11.59
Soil layer	S.E.	3.9	4.05
	F-Ratio	28.74	27.23
	P-Value	>0.001	>0.001
	$LSD_{0.5}$	10.85	11.26

Organic farming, especially the application of green manures, increases the number of amylolytic microbiota (Green manure, 0–10 cm – 2.84 CFU*10^6 per 1 g dry soil).

Mathematical and statistical analysis (Table 4) showed no significant difference between the options for the number of actinomycetes, ammonifying and oligotrophic microbiota (P-Value: MPA = 0.9964, ASH = 0.6772, HA = 0.9678, NA = 0.937, SAA actinomycetes = 0.0746). A significant difference was recorded only in the number of micromycetes and amylolytic microbiota ($P < 0.05$).

The number of aerobic microbiota decreases sharply from a depth of 20–30 cm. An intensive farming system causes a decrease in the number of microorganisms in the soil layer 0–10 cm and an increase in their number in the soil layer 20–30 cm compared to other options. This is due to ploughing and mixing different layers of soil with plant debris. Our data are consistent with the results of research by other scientists: Bulyhin *et al.* (2018), Tsova (2016), Araujo *et al.* (2010).

Table 4. The average number of ecological and trophic groups of microorganisms in chernozems typical of different farming practices (2018–2020)

Variant	Depth, cm	PGA	SAA actinomycetes	SAA	MPA	ASH	HA	NA
		CFU*10^3 per 1 g dry soil		CFU*10^6 per 1 g dry soil				
Green manure	0–10	2.75	25.43	2.84	2.62	2.91	4.99	0.69
	10–20	2.14	19.00	1.86	2.69	1.42	4.55	0.44
	20–30	1.08	10.09	0.72	0.63	0.88	1.01	0.26
	30–40	0.86	4.32	0.42	0.53	0.51	0.76	0.20
Compost	0–10	3.06	21.52	2.08	2.45	2.07	4.19	0.58
	10–20	2.15	16.47	1.72	2.48	1.92	4.11	0.50
	20–30	1.09	7.13	0.73	0.92	0.83	0.52	0.25
	30–40	0.63	5.28	0.44	0.62	0.54	0.37	0.20
Fallow	0–10	5.39	16.06	1.78	2.45	1.72	4.26	0.58
	10–20	2.96	11.25	1.07	2.63	1.23	4.69	0.45
	20–30	1.75	5.48	0.63	0.64	0.74	0.61	0.23
	30–40	0.91	3.63	0.30	0.46	0.48	0.47	0.19
Intensive	0–10	3.20	14.02	1.55	2.06	1.70	3.50	0.50
	10–20	2.55	12.61	1.60	2.54	1.55	4.49	0.50
	20–30	1.46	6.05	0.92	1.17	1.11	0.71	0.41
	30–40	1.13	5.73	0.49	0.79	0.75	0.43	0.26
Farm system	S.E.	0.16	1.00	0.09	0.17	0.14	0.54	0.03
	F-Ratio	2.77	2.32	4.36	0.02	0.51	0.09	0.14
	P-Value	0.0411	0.0746	0.0048	0.9964	0.6772	0.9678	0.937
	$LSD_{0.5}$	0.45	2.78	0.23	–	–	–	–
Soil layer	S.E.	0.16	0.97	0.09	0.16	0.14	0.52	0.03
	F-Ratio	49.29	42.42	51.86	31.61	21.17	11.25	29.31
	P-Value	0,0000	>0.001	>0.001	>0.001	>0.001	>0.001	>0.001
	$LSD_{0.5}$	0.44	2.7	0.26	0.46	0.39	1.46	0.09

The obtained data indicate a decrease in the activity of such enzymes as invertase, protease, dehydrogenase and cellulase under agricultural use of chernozems typical compared to the fallow (Table 5). However, in organic farming, the activity of urease and catalase is much higher than in fallow. The activity of enzymes with depth decreases. Only in the case of an intensive system of agriculture because of mixing and rotation of the formation (ploughing), there is a homogenization of the 0–30 cm layer, which leads to a partial alignment of indicators at these depths. A feature of the intensive farming system is not a typical increase in urease activity at a depth of 10–20 cm, which is a consequence of the introduction of urea (14.6 mg NH_3 per 10 g of soil for 24 hours). The application of organic fertilizers in the variants of the organic system of agriculture (especially the use of green manure) increases the activity of all studied enzymes in comparison with the soil of the variant of the intensive system of agriculture, similar results were obtained in studies Kwiatkowski *et al.* (2020), Fließbach *et al.* (2007), Woźniak (2019).

Table 5. Enzymatic activity of chernozems under different farming practices, the average for the years 2018–2020

Variant	Depth, cm	Catalase, cm^3 O_2 per 1 g of soil for 1 min	Invertase, mg of glucose per 1 g of soil for 24 hours	Urease, mg NH_3 per 10 g of soil for 24 hours	Dehydrogenase, mg of TFF per 10 g of soil for 24 hours	Protease, mg of glycine per 1 g of soil for 24 hours	Cellulase, µg of glucose per 10 g of soil for 48 hours
Green manure	0–10	7.54	29.89	25.61	11.68	17.10	5.93
	10–20	7.36	20.94	18.55	9.43	5.42	5.84
	20–30	7.00	12.82	14.03	6.11	3.59	2.60
	30–40	5.79	7.78	12.20	4.28	4.08	2.10
Compost	0–10	6.35	22.47	16.07	11.83	11.65	6.20
	10–20	6.24	18.83	16.15	9.37	5.91	5.22
	20–30	6.12	11.45	13.28	7.32	3.55	2.60
	30–40	5.46	8.44	11.93	5.90	2.44	1.76
Fallow	0–10	5.63	35.83	14.62	12.37	21.96	6.37
	10–20	4.92	19.41	11.96	9.92	6.70	5.30
	20–30	5.02	15.56	12.05	7.82	3.81	3.08
	30–40	4.39	9.40	10.47	4.73	2.04	1.86
Intensive	0–10	4.28	15.92	13.71	8.88	4.72	6.13
	10–20	4.03	16.12	14.60	9.11	3.66	3.76
	20–30	3.97	15.78	12.34	8.68	3.23	3.13
	30–40	3.57	10.64	12.20	6.84	1.70	2.34
Farm system	S.E.	0.11	0.5	0.59	0.18	0.27	0.16
	F-Ratio	88.65	6.35	6.79	3.58	26.97	1.99
	P-Value	0.0000	0.0003	0.0002	0.0138	0.0000	0.1151
	$LSD_{0.5}$	0.29	1.39	1.64	0.51	0.76	0.43
Soil layer	S.E.	0.1	0.49	0.57	0.18	0.27	0.15
	F-Ratio	38.48	225.49	50.77	289.18	232.63	127.13
	P-Value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	$LSD_{0.5}$	0.28	1.35	1.59	0.49	0.74	0.42

Discriminant analysis (Fig. 1) of indicators of biological activity of chernozem soils makes it possible to distinguish different farming systems by a set of predictors, the values of the canonical correlation are 0.24–0.73 under conditions of statistical significance $P < 0.05$. As a result of mathematical and statistical analysis, only those indicators were selected that significantly affect the differentiation of chernozems of different uses ($F < 4.0$), and normalized coefficients of discriminant functions were determined.

Equation of discriminant functions:

1) 1,03302*Catalase + 0,343788*Urease – 0,567763*Dehydrogenase + 0,227503*Protease – 0,346053*PGA – 0,484932*MPA + 0,280742*ASH + 0,504131*HA – 0,398958*Collembola + 0,0209006*Oribatida
2) 0,337853*Catalase –0,681677*Urease + 0,0231899*Dehydrogenase + 0,666935*Protease + 0,0159984*PGA –0,554784*MPA –0,214321*ASH + 0,717943*HA + 0,741564*Collembola – 0,851151*Oribatida
3) 0,266271*Catalase –0,434354*Urease + 1,18612*Dehydrogenase –0,677315*Protease –0,603386*PGA + 0,629841*MPA–0,0744966*ASH –0,491181*HA –0,051398*Collembola –0,52884*Oribatida

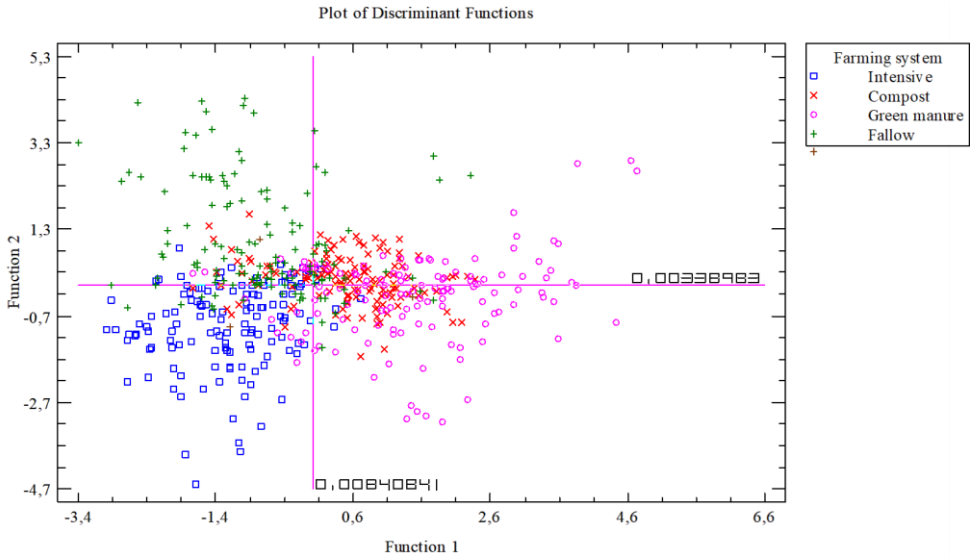

Figure 1. Discrimination of chernozems is typical according to different farming practices on the basis of indicators of biological activity of chernozems (built on Function 1 and Function 2)

According to the equations of functions, the most indicative is the data on the activity of catalase and dehydrogenase, the number of micromycetes, oligocarbophilic and ammonifying microbiota and microsarthropods. Some of these indicators are actively used by other researchers in attempts to mathematically model the relationship of microbiological activity with indicators of fertility and soil formation processes and the impact of weather conditions on them (Steinweg *et al.*, 2012; Demyanyuk *et al.*, 2017; Demydenko, 2021; Hryhoriv *et al.*, 2021; Kvitko *et al.*, 2021).

As a result of the performed discriminant differentiation, 66.5% of the data sample by agricultural systems were reliably classified. For the most part, classification errors occurred between samples of the organic farming system using green manure and compost. According to the above figure, among the clusters of predictors, three groups of indicators are quite clearly distinguished, which are variants of the intensive system of agriculture, fallow and organic system of agriculture

Conclusions

Mathematical modelling development of chernozem soils under different farming practices indicates significant changes in soil formation processes under the influence of human agricultural activity and allows distinguishing "agrochernozem" from natural analogues.

It is recommended to use 10 indicators of potential biological activity for bioindication of chernozem soils, namely: the number of microarthropods, micromycetes, ammonifying and oligotrophic microbiota, catalase activity, dehydrogenase, urease and protease.

Agrogenic soils are characterized by a decrease in the number of colembols with a simultaneous increase in the number of oribatids.

Agrogenic soils are characterized by a decrease in the number of micromycetes and *vice versa* by an increase in the number of actinomycetes and amylolytic microbiota.

Soils in the conditions of the intensive system of agriculture are characterized by a decrease in the activity of soil enzymes in comparison with a fallow. Whereas the organic farming system helps to increase the activity of urease and catalase, even in comparison with fallow land.

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

SR – writing a manuscript, analysis and interpretation of data;
SR, DH – acquisition of data, author of the idea, guided the research;
AB – analysis and interpretation of data and is the corresponding author;
KN – critical revision and approve the final manuscript.

References

Araujo, A.S., Melo, W.J. 2010. Soil microbial biomass in organic farming system. – Ciencia Rural, 40:2419–2426. DOI: 10.1590/S0103-84782010001100029

Bater, J.E. 1996. Micro- and Macro-arthropods, In: Methods for the examination of organismal diversity in soils and sediments (Ed. G.S. Hall). – Cab International. United Kingdom, pp. 163–174.

Bulyhin, S., Tonkha, O. 2018. Biological evaluation of the rationality of soil usage in agriculture. – Agricultural Science and Practice, 5(1):23–29. DOI: 10.15407/agrisp5.01.023

Coulson, S.J., Fjellberg, A., Melekhina, E.N., Taskaeva, A.A., Lebedeva, N.V., Belkina, O.A., Seniczak, S., Seniczak, A., Gwiazdowicz, D.J. 2015. Microarthropod communities of industrially disturbed or imported soils in the High Arctic; the abandoned coal mining town of Pyramiden, Svalbard. – Biodiversity and Conservation, 24:1671–1690. DOI: 10.1007/s10531-015-0885-9

Demyanyuk, O.S., Gaidarzhi, V.I., Vasilieva, O.B. 2017. Modelyuvannya produktyvnosti ahroekosystemy zalezhno vid pokaznykiv biolohichnoyi aktyvnosti gruntu ta hidrotermichnykh umov [Modeling of productivity of agroecosystem depending on indicators of biological activity of soil and hydrothermal conditions]. – Zbalansovane pryrodokorystuvannya [Balanced nature management], 1:143–148. (In Ukrainian)

Demydenko, O.V. 2021. Korelyatsiyni zv'yazky fiziolohichnykh hrup mikroorhanizmiv z pokaznykamy rodyuchosti chornozemu opidzolenoho za riznykh system udobrennya [Correlation relations of physiological groups of microorganisms with fertility indicators of podzolic chernozem under different fertilizer systems]. – Visnyk ahrarnoyi nauky [Bulletin of Agricultural Science], 4(817):20–27 (In Ukrainian). DOI: 10.31073/agrovisnyk202104-03

FAO and ITPS. 2017. Global assessment of the impact of plant protection products on soil functions and soil ecosystems. – FAO and ITPS, Rome: FAO. 40 p.

FAO. 2020. A protocol for measurement, monitoring, reporting and verification of soil organic carbon in agricultural landscapes – GSOC-MRV Protocol. Rome. DOI: 10.4060/cb0509en

Fließbach, A., Oberholzer, H.-R., Gunst, L., Mäder, P. 2007. Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. – Agriculture, Ecosystems & Environment, 118(1–4): 273-284. DOI: 10.1016/j.agee.2006.05.022

Gilyarov, M.S. 1975. Uchet melkikh chlenistonogikh (mikrofauny) i nematode [Accounting for small arthropods (microfauna) and nematodes]. – Metody pochvenno-zoologicheskikh issledovaniy [Methods of soil-zoological research], Moscow: Science. 280 p. (In Russian)

Hryhoriv, Ya.Ya., Butenko, A.O., Kovalenko, V.M., Zakharchenko, E.A., Kriuchko, L.V., Pshychenko, O.I., Radchenko, M.V., Trotska, S.S., Terokhina, N.O. 2021. Productivity of oat (*Avena sativa* L.) with different methods of cultivation on soddy-podzolic

soils. – AMA, Agricultural Mechanization in Asia, Africa and Latin America, 51(03):1793–1799.

Kalynovskyi, N. 2014. The effects of forest site conditions and stands' age on litter microarthropod density and community structure in Zhytomyr Polissya. Northern Ukraine. – Forestry Ideas, Bulgaria, 20, 1(47): 57–66.

Karpenko, O.Yu., Rozhko, V.M., Butenko, A.O., Samkova, O.P., Lychuk, A.I., Matviienko, I.S., Masyk, I.M., Sobran, I.V., Kankash, H.D. 2020. Influence of agricultural systems and basic tillage on soil microorganisms number under winter wheat crops of the Right-Bank Forest-Steppe of Ukraine. – Ukrainian Journal of Ecology, 10(5):76–80. DOI: 10.15421/2020_209.

Khaziev, F.Kh. 2005. Metody pochvennoy enzimologai [Methods of soil enzymology]. – Institute of Biology of the Ufa Scientific Centre. Moscow: Science, 252 p. (In Russian).

Kwiatkowski, C.A., Harasim, E., Feledyn-Szewczyk, B., Antonkiewicz, J. 2020. Enzymatic Activity of Loess Soil in Organic and Conventional Farming Systems. – Agriculture, 10(4):135. DOI: 10.3390/ agriculture 10040135

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

Medvedev, V.V. 2008. Struktura pochvy (metody, genezis, klassifikatsiya, evolyutsiya, geografiya, monitoring, okhrana) [Soil structure (methods, genesis, classification, evolution, geography, monitoring, protection). – Kharkiv: "13 printing house", 406 p. (In Russian)

Natsional′na dopovid′ pro stan rodyuchosti gruntiv Ukrayiny [National report on the state of relatives and landowners of Ukraine]. 2010, Kyiv: VIK Print LLC 111 p. (In Ukrainian)

Paz-Ferreiro, J., Fu, S. 2016. Biological indices for soil quality evaluation: perspectives and limitations. – Land Degradation & Development, 27:14–25. DOI: 10.1002/LDR.2262

Pesakovic, I.M., Djukic, A., Mandic, G., Rakicevic, L., Miletić, K. 2009. Mineral fertilizers as a governing factor of the regulation of the number of fungi in soil. – Zbornik Matice Srpske Za Prirodne Nauke, 116: 201–207. DOI: 10.2298/ZMSPN0916201P

Ponge, J.F., Gillet, S., Dubs, F., Fedoroff, E., Haese, L., Sousa, J.P., Lavelle, P. 2003. Collembolan communities as bioindicators of land use intensification. – Soil Biology and Biochemistry, 35: 813–826. DOI: 10.1016/S0038-0717(03)00108-1

Shchukovs′kyy, M.A., Velychko, L.L., Novosad, K.B., Kazyuta, O.M., Vasyl′yeva, L.I., Tykhonenko, D.G., (Ed.). 2002. Mikrobiolohiya gruntiv. Posibnyk do laboratorno-praktychnykh zanyat′ [Soil microbiology. Manual for laboratory and practical classes]. – Kharkiv: KhNAU named after V.V. Dokuchaeva. 136 p. (In Ukrainian)

Stanojković, A.B., Đukić, D., Mandić, L., Miličić, B. 2011. The influence of mineral and bacterial fertilization on the number of fungi in soil under maize. – Zbornik Matice Srpske Za Prirodne Nauke, 205–212. DOI: 10.2298/ZMSPN1120205S

Steinweg, J.M., Dukes, J.S., Wallenstein, M.D. 2012. Modeling the effects of temperature and moisture on soil enzyme activity: linking laboratory assays to continuous field data. – Soil Biology and Biochemistry, 55:85–92. DOI: 10.1016/j.soilbio.2012.06.015

Tikhonenko, D.G. 2011. Elementarni gruntovi protsesy (EGP) pry akumulyatyvnomu gruntotvorenni [Elementary soil processes (ESP) in accumulative soil formation]. – Visnyk Kharkivs′koho natsional′noho ahrarnoho universytetu imeni V. V. Dokuchayeva. Seriya "Gruntoznavstvo, ahrokhimiya, zemlerobstvo, lisove hospodarstvo, ekolohiya gruntiv" [Bulletin of V.V. Dokuchaev Kharkiv National Agrarian University. Series "Soil Science, Agrochemistry, Agriculture, Forestry, Soil Ecology"]. Kharkiv: KhNAU named after V.V. Dokuchaeva, 1:18–21. (In Ukrainian)

Titova, V.I., Kozlov, A.V. 2012. Metody otsenki funktsionirovaniya mikrobotsenoza pochvy, uchastvuyushchego v transformatsii organicheskogo veshchestva: Nauchnometodicheskoye posobiye [Methods for assessing the functioning of the microbial nosis of the soil involved in the transformation of organic matter: scientific methodical manual]. – Nizhny Novgorod: Nizhny Novgorod Agricultural Academy, 64 p. (In Russian)

Tsova, Yu.A. 2016. Dynamika chysel′nosti hruntovykh hrybiv v zalezhnosti vid ahroekolohichnykh umov [Dynamics of the number of soil fungi depending on agroecological conditions]. – Visnyk Dnipro-petrovs′koho derzhavnoho ahrarno-ekonomichnoho universytetu [Visnyk of Dnipropetrovsk State Agrarian and Economic University]. 4(42): 102–107. (In Ukrainian)

Volkohon, V.V., Pyrih, O.V., Brytan, T.Yu. 2017. Trends in biological processes in leached chernozem under cultivation of spring barley with various species and rates of fertilizers. – Agricultural microbiology, 26:3–12. DOI: 10.35868/1997-3004. 26.3-12. (In Ukrainian)

Volkohon, V.V., Pyrig, O.V., Volkohon, K.I., Dimova, S.B. 2019. Methodological aspects of determining the trend of organic matter mineralization synthesis processes in croplands. – Agricultural Science and Practice, 6(1):3–9. DOI: 10.15407/agrisp6.01.003

Volkohon, V.V., Nadkernychna, O.V., Tokmakova, L.M., Mel′nychuk, T.M., Chaykovs′ka, L.O. 2010. Eksperymental′na hruntova mikrobiolohiya: monohrafiya [Experimental soil microbiology: monograph]. – Kiev: Agrarian Science, 464 p. (In Ukrainian)

Woźniak, A. 2019. Chemical properties and enzyme activity of soil as affected by tillage system and previous crop. – Agriculture, 9(12):262. DOI: 10.3390/agriculture9120262

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IS ESTONIAN BARLEY READY TO TACKLE CLIMATE CHANGE-INDUCED WATER REGIMES?

Siim Samuel Sepp[1], Ülle Tamm[1], Evelin Loit[2]

[1]Estonian Crop Research Institute, 1 J. Aamisepa St, 48309 Jõgeva, Estonia
[2]Estonian University of Life Sciences, Chair of Crop Science and Plant Biology, 1 Fr. R. Kreutzwaldi St, 51006 Tartu, Estonia

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Vastutav autor: / Corresponding author: Siim Samuel Sepp

E-mail: siim.sepp@etki.ee
Phone: +372 5558 5149

ORCID:
0000-0003-1181-7924 (SSS)
0000-0002-0258-2951 (ÜT)
0000-0001-6635-8740 (EL)

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ABSTRACT. The objective was to examine the effect of drought and flood on barley plants' biomass and growth rate in early vegetative development while comparing the stress adaption of different varieties. A greenhouse trial was conducted in the Estonian Crop Research Institute (ECRI) in 2021, where five Estonian grown spring barley varieties were grown in optimal, drought and flood treatments for six weeks to measure plants' projected leaf area (PA) and relative growth rate (RGR) through phenotyping. Both drought and flooding stress have a strong negative impact on plant biomass in early vegetative growth phases, causing PA at the end of the trial to decrease 26% and 49% respectively. Meanwhile, RGR throughout the trial decreased 6% in drought treatment and 16% in flood treatment. This indicates the greater impact of flood stress on plant's growth compared to drought stress. Genetic variation related to adaption to extreme water regimes in varieties is rather low, especially in drought stress conditions. In drought treatment, the variation coefficient (CV) was 14%, and in flood treatment 25%. Even as most varieties' PA and RGR varied between treatments, the difference between varieties in specific stress treatments was minimal. Estonian grown spring barley varieties are susceptible to extreme water regime related stress caused by potential climate change. This indicates the importance of assessing water-related stress tolerance in breeding material, adapting more accurate innovative evaluation approaches, and integrating climate-resilient genetic material into breeding programs, to hedge the risk caused by unfavourable growth environments in Estonian barley production.

Introduction

Even though global population growth is projected to slow down by the end of the 21st century (Vollset *et al.*, 2020), the persistence and irreversibility of anthropogenic negative influence on the global ecosystem must be acknowledged. In the meantime, forecasted climate change and increasing demand for food will put even more pressure on plant breeders to develop cultivars with higher yields, quality, and climate resilience. In addition to changes in temperature and atmospheric gas composition, precipitation patterns will also be altered, affecting global and local hydrological cycles (Konapala *et al.*, 2020). This altogether increases the likelihood of extreme weather conditions with excessive or lacking precipitation, resulting in drought or flood induced abiotic stress in plants. Exposure of crops to abiotic stress thereby limits the biomass and yield of crops, which is something we can't afford.

At present, a great amount of crop plants' genetic diversity to adapt to the environment has been lost due to the long-term yield-oriented selection bottleneck (Dawson *et al.*, 2015). To improve adaption to abiotic stress, the suitable genetic material must be screened for and transferred to new varieties. With the help of non-destructive phenotyping, adaption of plants' phenotypes to abiotic stress can be observed in time on a larger scale, making it possible to evaluate breeding material and to connect its phenotype with a responsible QTL (quantitative trait locus) or a gene.

In this experiment, a cost-effective greenhouse phenotyping platform was used to measure the relative growth rate (RGR) and projected leaf area (PA) of Estonian grown barley varieties in extreme water regimes. Evaluating varieties' adaption to extreme water regimes gives an overview of their climate

resilience at present, making it possible to prepare better for future challenges.

The objective was to examine the effect of drought and flood on barley plants' biomass and relative growth rate in early vegetative development while comparing the stress adaptions of different varieties.

Material and Methods

A six-week trial (04.01.–16.02.2021) was conducted in controlled greenhouse conditions at the Estonian Crop Research Institute (ECRI) in Jõgeva, Estonia (58.759097° N, 26.406711° E). Five common Estonian grown spring barley varieties of various origins were used: 'Maali' (ECRI), 'Tuuli' (ECRI), 'Katniss' (Nordic Seed A/S), 'Feedway' (Nordic Seed A/S) and 'Bente' (Nordsaat Saatzucht GmbH).

An experiment was carried out with five replicates per genotype in each of the three treatments: control, drought and flood. Single plants were grown next to each other in two-litre plastic pots with 1.7 kg of the growth substrate, in a randomized design. For growth substrate, a mix of soil, peat and sand was used in a volume ratio of 3:2:1.

Three seeds were sown into each pot and trimmed to a single plant two weeks later. For light conditions, 16: 8 h light regime was secured with plant growth lamps and temperature between 15–25 °C. At the end of the experiment, the shoots were cut from basal conjunction to determine wet and dry biomass.

Induced stress lasted for two weeks in drought treatment and a week in flood treatment. For the first 14 days after sowing (DAS), all treatments were kept at a water level of 20% gravimetric water content (GWC). In the control treatment, 20% GWC was sustained throughout the experiment. To induce drought, watering was reduced until 10% GWC was achieved, starting from 14 DAS and kept until 28 DAS. For flood treatment, a water level of 1cm above soil level was sustained from 14 DAS to 21 DAS. Both stress treatment's water level of 20% GWC was restored post-stress until the end of the experiment at 42 DAS. This method is based on the trial conducted by Honsdorf *et al.* (2014), and modified to add flood treatment conditions.

Phenotyping was done weekly from 14 DAS to 42 DAS. Every week, three pictures of each plant were captured (front, side 90° and top). Captured photos were analysed in the program EasyLeafArea, where green pixels were separated from the background and summed. To calculate RGR, the formula:

$$RGRPA = \frac{\ln\left(\frac{PA_2}{PA_1}\right)}{t2 - t1} \quad \text{was used,} \quad (1)$$

where PA is projected area (pix) at time t (Armonienė *et al.*, 2018).

For descriptive statistics of PA and RGR, average and standard error were calculated. Tukey HSD was used to calculate the significant difference between varieties and treatments. One-way ANOVA and variation coefficient (CV) were used to determine variation in treatments and varieties. All data analysis and statistical tests were done in R (R Core Team 2021).

Results and Discussion

Relative growth rate (RGR) and projected area (PA)(pix) of five Estonian grown barley varieties were measured through phenotyping in control and extreme water regime conditions.

Effect of stress

In both drought and flood treatment, PA was significantly lower than control treatment from the end of stress until the end of the experiment ($P < 0.001$). When the decrease in the first post-stress week of drought plants was only 7%, it slumped for the second and third post-stress week to 31% and 42% (Fig. 1). By the end of the experiment, PA in drought treatment was 26% lower in the control treatment. In flood treatment, PA decreased 28% by the first post-stress week, decreasing even more in the following weeks to 52% and 55% accordingly. At 42 DAS flood treatment, PA was 49% lower compared to the control treatment. Variation between both stress treatments and control treatment at 42 DAS was 97%, while variation within groups was 3% ($P < 0.001$).

In the meantime, RGR decreased 6% overall in drought treatment and 16% in flood treatment ($P < 0.001$). Although the decrease of RGR was greater in flood than drought treatment, in both treatments the significant effect of stress appeared only during the stress and the following week. By the last week of the experiment, RGR in both flood and drought exceeded control treatment by 48% and 21% ($P < 0.001$), compensating the former stress with faster growth. Here we can conclude that flood had a more severe effect to plant biomass growth than drought, as a greater decrease in PA and RGR indicate.

Different physiological processes targeted by stress cause the difference. As known, growth reduction in drought treatment can be explained by dehydration of cells due to the plant's limited access to water, harming basic growth-related physiological processes like cell/leaf expansion and metabolic activities. Meanwhile, excess water in flood treatment leaves plants' roots in anoxic conditions, inhibiting their respiration and energy availability, which is necessary to provide water and nutrients for the growth and metabolism of above-ground parts.

The effect of abiotic stress on the biomass of barley varieties from different backgrounds has been measured before by Honsdorf *et al.* (2014) and Zhao *et al.* (2010) with drought and Yordanova and Popova (2001), Bertholdsson (2013) and Luan *et al.* (2018) with the flood, where uneven severity depends strongly on the origin of varieties, developmental stage of exposure and other methodical approaches. Overall, that points to the presence of genetic variation and even resistant varieties in-between different gene pools

tested, which can be exploited for climate-resilient breeding in other regions.

Here we can conclude that there is the widespread vulnerability of juvenile barley to potential climate change-induced flood and drought stress, which could inhibit achieving sustainable development goals if action is not taken in time.

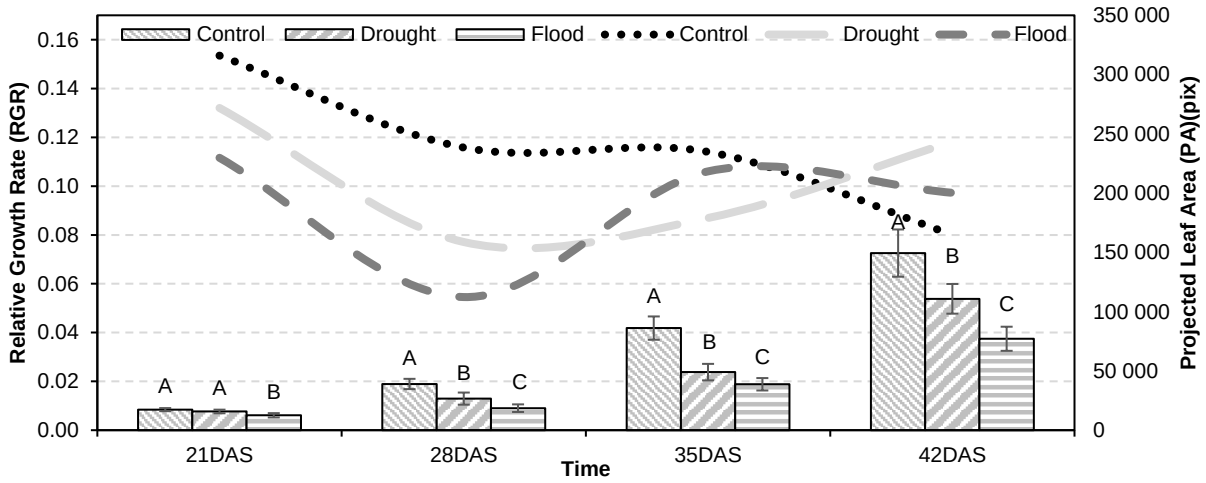

Figure 1. Average projected leaf area (PA-columns) and relative growth rate (RGR-lines) of control, drought, and flood treatments (all varieties). (I represent ± SE (standard error); different capital letters represent statistical difference $P < 0.05$ between treatments; DAS – days after sowing)

Varieties in stress treatments

The effect of stress caused by extreme water regimes depends on the plant's genotype. Drought stress did not decrease PA of all varieties. The PA of varieties 'Tuuli' and 'Maali' did not differ significantly from the control treatment ($P > 0.05$), while 'Tuuli''s average PA value exceeded the control treatment by 9%. A negative effect of drought was observed with varieties 'Katniss' (28%), 'Feedway' (40%) and 'Bente' (34%) ($P < 0.001$). The latter's PA was significantly decreased from the end of stress exposure to the end of the experiment (28–42DAS), in the situation where 'Tuuli' and 'Maali' were significantly lower than the control treatment only the week after the stress (35DAS). Flood stress decreased PA in all varieties from the second post-stress week until the end of the trial. PA decreased in varieties: 'Maali' (67%), 'Tuuli' (42%), 'Bente' (41%), 'Katniss' (45%) and 'Feedway' (46%) ($P < 0.001$).

Variation between varieties in flood treatment was 85% and in drought, treatment was 79% ($P < 0.05$). Meanwhile, the variation coefficient (CV) between varieties in drought treatment was 14% and 25% in flood treatment ($P < 0.05$). Wild barley introgression varieties tested for drought by Honsdorf *et al.* (2014) showed a variation coefficient of 72%. The higher variation in response to flood treatment in this experiment indicates greater genetic variation related in genotypes than in drought treatment, while still staying relatively low for both treatments compared to wild relatives. That points out the stronger negative effect of flood stress to plant growth together in combination with to some extent greater genetic variance in the phenotypic response.

A similar pattern to PA occurred with RGR, wherein drought treatment 'Tuuli' and 'Maali' did not differ significantly ($P > 0.05$), while other varieties had 28–44% lower RGR compared to the control treatment ($P < 0.05$). On the other hand, 'Tuuli' and 'Maali' did not show the highest PA in the control treatment of all varieties, pointing out their robustness in their biomass growth. In flood treatment, RGR decreased unevenly across all varieties between 14–35DAS in between 29–58% ($P < 0.05$), without a single variety indicating resistance.

For the most part, varieties in treatments did not differ from each other in stress treatments (Fig. 2). In drought treatment, PA of 'Tuuli' was 37% higher than 'Feedway' and in flood treatment, PA of 'Bente' was 36% higher than 'Tuuli' and 49% higher than 'Maali' ($P < 0.05$).

Varieties' low CV with the scarce significant difference in RGR and PA affirm relatively narrow genetic variation in their genotypes for these specific abiotic stress responses, common to modern top-yield varieties. Low genetic variation for early flood and drought tolerance was also pointed out with local varieties in neighbouring Finland by Hakala *et al.* (2012), where all other climate change risk-related traits had variation in local genotypes. That points out the demand and need for more climate-resilient breeding material for spring barley in the region.

A better overview of individual varieties' growth in control and stress treatment is seen while comparing the performance in both. As seen, 'Maali' had the second highest average PA in control and drought treatment compared to other varieties, despite great variation in-between replications (Fig. 3). At the same time, the variety 'Feedway' had one of the lowest PA in control and drought treatment.

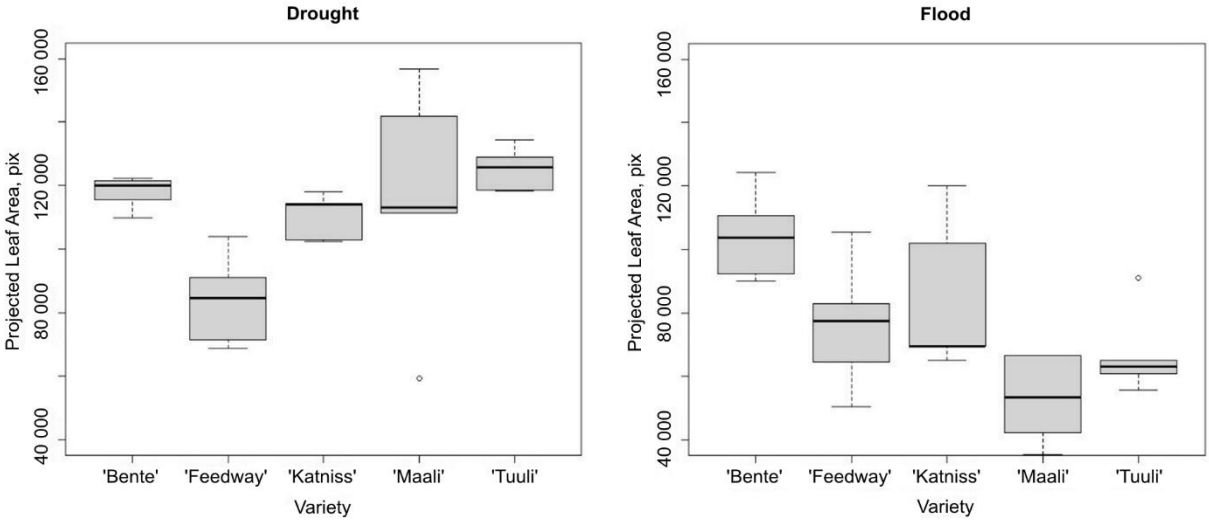

Figure 2. Projected leaf area (PA) of varieties at 42 DAS in drought and flood treatment. I represent 95% confidence interval, the bottom and top of the box are the 25th and 75th percentiles, the inner line as the 50th percentile (median), and outliers are shown as open circles.

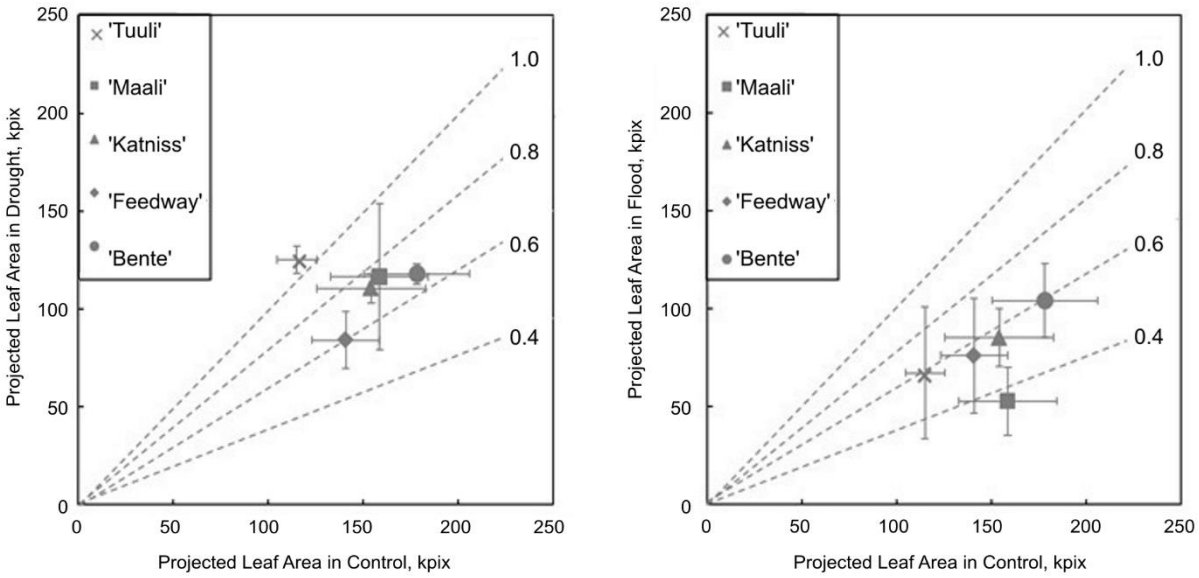

Figure 3. Projected leaf area (PA) of varieties in control and drought treatment and in control and flood treatment. I represent ± SE (standard error).

In flood and control treatment, 'Bente' performed above varieties' average, meanwhile 'Tuuli' stayed below. Indeed, it also shows the complexity of breeding material evaluation for abiotic stress resistance, which could benefit from the use of stress indexes and yield data in future studies, to get output that is even more accurate.

Based on the results, we can state that Estonian grown spring barley varieties are overwhelmingly susceptible to extreme water regimes caused by water-related abiotic stress, an effect, which is likely caused by their narrow gene pool common to high-performing varieties. Even though breeding for extreme weather events still has a limited capacity (Olesen *et al.,* 2011), it will become more relevant with pessimistic climate change scenarios already becoming reality.

For more accurate evaluation in future studies, plants' grain yield data can also be collected, which makes it possible to better understand the effect of abiotic stress growth in time and its relation to grain yield formation (Ciancio *et al.,* 2021). In addition, adapting other phenotyping stress indexes and developing genetic markers combined with gene expression measurements will make it feasible to precisely determine the nature of yield-limiting bottlenecks in plant physiology. Thus, having a deeper insight into limitations of growth and yield-formation, more efficient selection of crossing parents can be done.

Conclusion

The spring barley varieties tested were vulnerable to potential climate change-induced water regime changes in juvenile growth. Genetic variation of abiotic stress

response-related genes is relatively low, drawing attention to the need for more climate-resilient breeding material. To achieve climate-smart barley production, better screening of abiotic resistance and integration of resistance-related traits must be adopted in plant breeding.

Conflict of interest

The authors declare that there are no conflicts of interest.

Author contributions

SSS, ÜT – study conception and design, analysis and interpretation of data.
SSS – acquisition of data, drafting of the manuscript.
SSS, ÜT, EL – critical revision and approval of the final manuscript.

References

Armoniené, R., Odilbekov, F., Vivekanand, V., Chawade, A. 2018. Affordable imaging lab for noninvasive analysis of biomass and early vigour in cereal crops. – BioMed Research International; Hindawi, 2018:ID5713158, 9 p. DOI: 10.1155/2018/5713158

Bertholdsson, N.-O. 2013. Screening for barley waterlogging tolerance in Nordic barley cultivars (*Hordeum vulgare* L.) using chlorophyll fluorescence on hydroponically-grown plants. – Agronomy, 3(2): 376–390. DOI: 10.3390/agronomy 3020376

Ciancio, N., Miralles, D.J., Striker, G.G., Abeledo, L.G. 2021. Plant growth rate after, and not during, waterlogging better correlates to yield responses in wheat and barley. – Journal of Agronomy and Crop Science, 207(2):304–316. DOI: 10.1111/jac.12472

Dawson, I.K., Russell, J., Powell, W., Steffenson, B., Thomas, W.T.B., Waugh, R. 2015. Barley: A translational model for adaptation to climate change. – New Phytologist, 206(3):913–931. DOI: 10.1111/nph.13266

Hakala, K., Jauhiainen, L., Himanen, S.J., Rötter, R., Salo, T., Kahiluoto, H. 2012. Sensitivity of barley varieties to weather in Finland. – The Journal of Agricultural Science, 150(2):145–160. DOI: 10.1017/S0021859611000694

Honsdorf, N., March, T.J., Berger, B., Tester, M., Pillen, K. 2014. High-throughput phenotyping to detect drought tolerance qtl in wild barley introgression lines. – PLOS ONE, 9(5):e97047. DOI: 10.1371/journal.pone.0097047

Konapala, G., Mishra, A.K., Wada, Y., Mann, M.E. 2020. Climate change will affect global water availability through compounding changes in seasonal precipitation and evaporation. – Nature Communications, 11(1):3044. DOI: 10.1038/s41467-020-16757-w

Luan, H., Guo, B., Pan, Y., Lv, C., Shen, H., Xu, R. 2018. Morpho-anatomical and physiological responses to waterlogging stress in different barley (*Hordeum vulgare* L.) genotypes. Plant Growth Regulation, 85(3):399–409. DOI: 10.1007/s10725-018-0401-9

Olesen, J.E., Trnka, M., Kersebaum, K.C., Skjelvåg, A.O., Seguin, B., Peltonen-Sainio, P., Rossi, F., Kozyra, J., Micale, F. 2011. Impacts and adaptation of European crop production systems to climate change. – European Journal of Agronomy, 34(2):96–112. DOI: 10.1016/j.eja.2010.11.003

R Core Team. 2021. The R Project for Statistical Computing. [webpage] https://www.r-project.org/ (Accessed 20.05.2021).

Zhao, J., Sun, H., Dai, H., Zhang, G., Wu, F. 2010. Difference in response to drought stress among Tibet wild barley genotypes. – Euphytica, 172(3):395–403. DOI: 10.1007/s10681-009-0064-8

Vollset, S.E., Goren, E., Yuan, C.-W., Cao, J., Smith, A.E., Hsiao, T., Bisignano, C., Azhar, G.S., Castro, E., Chalek, J., Dolgert, A.J., Frank, T., Fukutaki, K., Hay, S.I., Lozano, R., Mokdad, A.H., Nandakumar, V., Pierce, M., Pletcher, M., Murray, C.J.L. 2020. Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100: A forecasting analysis for the Global Burden of Disease Study. – The Lancet, 396(10258):1285–1306. DOI: 10.1016/S0140-6736(20)30677-2

Yordanova, R.Y., Popova, L.P. 2001. Photosynthetic response of barley plants to soil flooding. – Photosynthetica, 39(4):515–520. DOI: 10.1023/A:1015643710177

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VARIABILITY FOR GROWTH AND YIELD TRAITS IN SINGLE CROSS HYBRIDS OF MAIZE (*Zea mays* L.)

Jiban Shrestha, Sudeep Subedi, Ramesh Acharya, Shiva Sharma, Mahesh Subedi

Nepal Agricultural Research Council, National Plant Breeding and Genetics Research Centre, Khumaltar, 15 Lalitpur Metropolitan City, 44700, Nepal

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Vastutav autor: Corresponding author: Jiban Shrestha

E-mail:
jibshrestha@gmail.com (JS)
sudeepsubedi111@gmail.com (SuSu)
samyam.ramesh@gmail.com (RA)
shiva.sharma79069@gmail.com (ShSh)
m.subedig@gmail.com (MS)

ORCID:
0000-0002-3755-8812 (JS)
0000-0002-4478-704X (SuSu)
0000-0002-1683-4988 (MS)

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ABSTRACT. Sixteen single-cross hybrids of maize were evaluated in a randomized complete block design with three replications to investigate genetic variability and correlation among growth and yield traits at Khumaltar, Lalitpur, Nepal from March 13 to September 05, 2021. The hybrids were grouped into four clusters using Euclidean Average Linkage method. The cluster analysis showed the presence of genetic variability in the evaluated hybrids. The maximum distance between cluster centroids (194.28) was found between cluster 2 and cluster 4, indicating genetic dissimilarity. Grain yield had the maximum values of phenotypic coefficient of variation (PCV) (35.02%), followed by ear height (17.82%) and plant height (12.22%). Similarly, grain yield had the maximum values of genotypic coefficient of variation (GCV) (26.24%) followed by the number of kernel rows/cob (8.77%) and days to 50% silking (8.72%). Days to 50% silking and days to 50% tasseling had the highest values of heritability (86%) followed by cob diameter (84%) and no. of kernel rows in cob (68%). The leaf area per plant had the maximum values of genetic advance (GA) (74.87 cm^2), followed by plant height (27.80 cm) and days to 50% silking (9.66 days). Similarly, the maximum values of genetic advance as percent of the mean (GAM) was found for grain yield (40.50%) followed by days to 50% silking (16.70%) and days to 50% tasseling (16.17%). The hybrids namely KWM-91 × KWM-93 produced the maximum values of grain yield (9.99 t ha^{-1}) followed by KWM-93 × KWM-91 (9.63 t ha^{-1}) and KWM-92 × KWM-93 (9.40 t ha^{-1}). Grain yield showed positive and significant phenotypic correlation with days to 50% silking (r = 0.41), days to 50% tasseling (r = 0.39), plant height (r = 0.37), cob diameter (r = 0.49) and the number of kernel rows in cob (r = 0.38). Therefore, utilization of present genetic variability along with indirect selection for traits having significant association with grain yield, high heritability and GAM could aid in the improvement of maize productivity.

Introduction

Maize (*Zea mays* L.) is Nepal's second most important cereal crop, with an area of 9 40 886 ha and a yield of 26 53 243 t (MoALD, 2020). It contributes 3.15% to the national gross domestic product (GDP) and 9.5% to agricultural GDP. It covers 27.39% area of total food crops and contributes 24.97% of total cereal production (MoALD, 2020). There is a considerable gap between the yield potential of the improved varieties and the national average yield. So far, seven hybrid maize varieties have been released in the country. Maize breeding efforts are focusing on developing high-yielding hybrid maize varieties to boost the yield potential furthermore.

The understanding of germplasm diversity among elite breeding materials has a major impact on crop improvement (Hallauer *et al*., 1988). Crop improvement relies on variability (Welsh, 1981). Maize germplasm has been found to have a large genetic diversity in terms of growth, development, and grain yield, and this variability has fueled the search for the development of new genotypes with desirable characteristics (Betran *et al*., 2003; Liu *et al*., 2003). Khan *et al*. (2018) and Khalil *et al*. (2011) found variation among the traits in maize hybrids. Similarly, Hallauer and Schos (1973) and Grzesiak (2001) found significant genotype diversity among maize genotypes for various traits. The genetic makeup of maize genotypes influences maize

growth, development, and productivity. Furthermore, critical environmental factors like soil fertility and climatic change-related parameters can have a major impact on maize growth and productivity (Oseni, Masarirambi, 2011). Grain yield is determined by a combination of genetic and environmental factors. Genetic variability across maize genotypes is a major determinant of grain yield (Tahir *et al*., 2008). Heritability and the genetic advance of the individual trait determine the efficiency with which genotypic variability can be utilized by selection. Understanding the association between yield and its component traits can help breeders to improve the effectiveness of selection (Kalla *et al*., 2001; Zeeshan *et al*., 2013).

The present study was conducted to quantify the variability, heritability, genetic advance, and the correlation between yield and its contributing traits among single-cross maize hybrids.

Material and Methods

Plant materials

Sixteen single-cross hybrids of maize were selected and used for this study (Table 1). National Plant Breeding and Genetics Research Centre (NPBGRC), Khumaltar, Lalitpur, Nepal, was the source of genotypes.

Table 1. List of single-cross hybrids of maize used in the experiment

S. No.	Maize hybrids
1	KML-1A × RML-4
2	KWM-91 × KWM-93
3	Rampur Hybrid-2
4	KWM-93 × KWM-91
5	Khumal Hybrid-2
6	KML-2A × KYM-86
7	KML-4A × KYM-86
8	KML-5A × RML-4
9	KML-8A × RML-4
10	KML-4A × RML-4
11	Super-951
12	KML-3B × RML-4
13	KML-5A × KYM-33
14	KML-8A × KYM-33
15	KML-4B × KYM33
16	KWM-92 × KWM-93

Experimental site

The study was conducted at the research field of the National Plant Breeding and Genetics Research Centre in Khumaltar, Lalitpur, Nepal from March 13 to September 05, 2021. It is located at 27°40'0" north latitude, 85°20'0" east longitude, and 1350 m above sea level. The soil of the research plot was clay loam type. The climatic data of the site during the experiment period (2021) is given in Table 2.

Table 2. Climate data of the experimental location in 2021

Month	Maximum temperature, °C	Minimum temperature, °C	Precipitation, (mm)	Sun Hours, h
March	24	10	75.4	364.8
April	27	13	222.9	351.5
May	27	14	447.9	347.5
June	27	16	705	324.7
July	25	17	1097.5	314.8
August	26	16	995.6	320.3
September	25	15	599.6	330.2

(Source: Meteorology station, National Agronomy Research Centre, Khumaltar, Lalitpur)

Experimental design and cultural practices

The experiment was laid out in a randomized complete block design (RCBD) with three replications. Individual plots comprised four rows of five meters each, with a 60 cm × 25 cm spacing (row to row × plant to plant). One week before sowing, well-decomposed farmyard manure was incorporated @ 6 t ha^{-1} into the soil and the chemical fertilizer @ 180:60:40 kg N:P_2O_5:K_2O [(nitrogen (N), phosphorus (P), and potassium (K)] ha^{-1} was applied *via* Urea, Diammonium Phosphate (DAP), and Muriate of Potash (MOP). During final land preparation, as a basal dose, a half dose of N, full dose of P_2O_5 and K_2O was applied. The remaining half dose of N was divided into two parts and administered 45 and 90 days after sowing. Two manual weeding and hoeing operations were completed during the maize growing season. The first weeding was performed 18 days after sowing, and the second weeding 36 days later. The irrigation was applied at three important growth stages: knee-high stage, tasseling stage, and milking stage.

Data collection and observations

Data were collected for all traits from ten plants chosen at random from each experimental plot. The phenological traits (days to 50% silking, days to 50% tasseling) of these selected plants, as well as biometrical variables (plant and ear height, leaf area per plant, cob length, and cob diameter), yield, and yield attributing traits (Number of kernel rows in cob), were observed. The following formula (Eq. 1) was used to compute grain yield (kg ha^{-1}) at 12% moisture content using fresh ear weight:

$$\text{Grain yield, t ha}^{-1} = \frac{\text{F.W., kg plot}^{-1} \times (100 - \text{HMP}) \times \text{S} \times 10\,000}{(100 - \text{DMP}) \times \text{NPA} \times 1000}, \quad (1)$$

where
F.W. – the fresh weight of ear per plot (kg) at harvest;
HMP – moisture percentage of grain at harvest;
DMP – desired moisture percentage, *i.e.* 12%;
NPA – the area of net harvest plot, m^2;
S – shelling coefficient, *i.e.* 0.8.

The phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) provide information on the level of variability in a population, whereas heritability depicts the component of a character that is passed down to future generations (Girma *et al*., 2018; Pal *et al*., 2016). The phenotypic coefficients of variation (Eq. 3) and genotypic coefficients of variation (Eq. 2) were estimated using the formula given by Singh and Chaudhary (1985). The estimation of heritability (in the broad sense) (Eq. 4) was carried out using the formula given by Johnson *et al*. (1955). Similarly, genetic advance (Eq. 5) was calculated using the formula given by Burton (1952), and genetic advance as a percentage of the mean (GAM) (Eq. 6) was calculated using the formula given by Johnson *et al*. (1955).

$$\text{GCV}, \% = \frac{\sqrt{\delta^2 \text{g}}}{\text{x}} \times 100, \quad (2)$$

$$\text{PCV}, \% = \frac{\sqrt{\delta^2 \text{p}}}{\text{x}} \times 100, \quad (3)$$

where
δ^2g – genotypic variance;
δ^2p – phenotypic variance;
x – Sample mean.

$$\text{Heritability in board sense } (\text{h}^2\text{bs}) = \frac{\delta^2 \text{g}}{\delta^2 \text{p}}, \quad (4)$$

$$\text{Genetic advance } (\text{GA}) = (\text{K})(\delta^2 \text{p})\ (\text{h}^2), \quad (5)$$

where
GA – expected genetic advance;
K – selection differential that varies depending upon the selection intensity and stands at 2.056 for selecting 5% of the genotypes;
δp – phenotypic standard deviation;
h^2 – heritability (in the broad sense).

According to Shukla *et al.* (2006), the expected genetic advance as a percentage of the mean (GAM) was estimated as below (Eq. 6);

$$\text{GAM} = \frac{\text{GA}}{\text{x}} \times 100, \quad (6)$$

where x – grand mean.

The correlation coefficient aids in determining the degree of relationship as well as the degree to which traits are interdependent (Bocanski *et al*., 2009; Nagabhushan *et al*., 2011). By examining genotypic and phenotypic differences in yield and yield components of many crop genotypes, a breeder will be able to determine how much the environment influences yield (Ullah *et al*., 2012). The correlation between traits in this study was assessed using Pearson's correlation coefficient approach.

Multivariate analysis is the most used method for assessing genetic variability. Crop plant genetic diversity is required to maintain high levels of productivity (Tripathi *et al*., 2013). Multivariate analysis of various agro-morphological traits has successfully been employed by numerous researchers to delineate the inherent diversity in the germplasm (Nachimuthu *et al*., 2014; Ravikumar *et al*., 2015). Cluster analysis with Euclidean distance is an effective statistical technique for evaluating genetic diversity. The Euclidean average linkage Method was used in this study.

Statistical analysis

The experimental data were processed using MS Excel 2010, and the data was analyzed using R-studio 3.5.0 and SPSS 20. The data were analyzed using a randomized complete block design (RCBD) with one-way ANOVA. The least significant difference (LSD) was used to compare the treatment means at a 5% level of significance (Gomez, Gomez, 1984). The Pearson correlation coefficient of growth, yield and its attributing traits was worked out using SPSS 20.

Results and Discussion

Agro-morphological variability

The presence of significant variation in genotypes for most of the traits was given in Table 3. The non-significant difference was found for ear height, cob length and the number of kernel rows in cob, whereas a significant difference ($P < 0.05$) was found for plant height and grain yield. Days to 50% silking, days to 50% tasseling, leaf area per plant and cob diameter had highly significant differences ($P < 0.01$) (Table 3). The maximum coefficient of variation (17.5%) was found in ear height followed by grain yield (13.1%). The minimum coefficient of variation (2.3%) was found in cob diameter (Table 3).

The hybrids namely KWM-91 × KWM-93 produced the maximum grain yield (9.99 t ha^{-1}) followed by KWM-93 × KWM-91 (9.63 t ha^{-1}) and KWM-92 × KWM-93 (9.40 t ha^{-1}) (Figure 1).

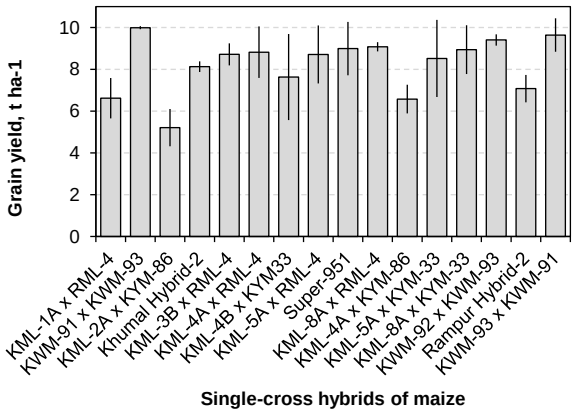

Figure 1. Bar diagram showing mean and standard deviation of grain yield of sixteen single-cross hybrids of maize

These findings support those of Akbar *et al.* (2009), Prasai *et al*. (2015), Shrestha (2016), Adhikari *et al*. (2018), Dhakal *et al*. (2018), Shrestha *et al*. (2019), Kafle *et al.* (2020), Shrestha *et al.* (2018) and Bastola *et al*. (2021) who found significant changes in grain

production between maize genotypes. The genetic makeup of maize genotypes varied, which resulted in variances in grain yield.

Table 3. Mean sum of squares for different traits of sixteen single-cross hybrids of maize

Traits	Mean	SE	CV, %	LSD (0.05)	Signifi-cance
Plant height, cm	267.10	17.67	9.4	53.27	*
Ear height, cm	143.20	17.77	17.5	53.57	NS
Days to 50% silking	57.81	1.41	3.5	4.26	***
Days to 50% tasseling	55.91	1.31	3.3	3.97	***
Leaf area per plant, cm^2	676.6	24.25	5.1	73.11	***
Cob length, cm	21.95	0.91	5.9	2.74	NS
Cob diameter, cm	4.92	0.08	2.3	0.24	***
Number of kernel rows in cob	14.50	0.61	6.0	1.86	NS
Grain yield, t ha^{-1}	8.25	0.76	13.1	2.29	*

NS – not significant, *-significant at P <0.05, ***-significant at P <0.001, SE – standard error of the mean, CV – coefficient of variation, LSD – least significance difference

Phenotypic and genotypic coefficients of variation

The GCV values were smaller than PCV values for all traits studied, showing that the characters were more influenced by their surrounding environments. Deshmukh *et al*. (1986) grouped the PCV and GCV values as low (0–10%), moderate (10–20%), and high (>20%). The maximum values of GCV were observed in grain yield (26.24%), followed by the number of kernel rows in cob (8.77%). The minimum values of GCV were observed in ear height (3.07%) followed by cob length (3.40%) (Table 4). Similarly, the maximum values of PCV were observed in grain yield (35.02%), followed by ear height (17.82%). The minimum PCV values were observed in cob diameter (5.86%) followed by cob length (6.79%) (Table 4). Similar findings were found by Kandel *et al.* (2017) and Sharma *et al.* (2018). The difference between phenotypic and genotypic variance was larger in the leaf area showing that these features were substantially impacted by the environment. The results were the same as those of Ojo *et al.* (2006) and Kashiani *et al*. (2010).

Heritability and genetic advance

Heritability estimates are classified as low (5–10%), medium (10–30%) and high (30–60%) (Dabholkar, 1992). The maximum values of broad-sense heritability values were observed in days to 50% silking (86%), days to 50% tasseling (86%) and cob diameter (84%). The minimum value of heritability value was found in ear height (3%) (Table 4)**.** Alemu *et al*. (2017) found similar results. Cob diameter produced the maximum values of heritability, according to Swamy *et al.* (1971) and Lias *et al.* (1987). Most of the factors had high estimates of heritability, showing that variations were handed down to progeny, implying that a high-yielding variety may be generated by choosing suitable genotypes. Because of the high values of heritability, there were more alternatives for picking plant material that had the desired characteristics.

Estimation of genetic advance (at 5% selection intensity), and the corresponding genetic advance as a per cent of the mean (GAM) were estimated for each measured character. The leaf area per plant had the maximum values of genetic advance (GA) (74.87 cm^2), followed by plant height (27.80 cm) and days to 50% silking (9.66 days) (Table 4). Similarly, the maximum values of genetic advance as per cent of the mean (GAM) was found for grain yield (40.50%) followed by days to 50% silking (16.70%) and days to 50% tasseling (16.17%) (Table 4). In our study, high values of heritability did not associate with genetic advances. Najeeb *et al.* (2009) found that high values of heritability are not always associated with high genetic advances. Since high values of heritability do not always indicate high genetic advance, it is recommended to consider heritability in conjunction with genetic advance to predict the effect of selecting superior plant varieties.

Table 4. Estimation of PCV, GCV, heritability, genetic advance and GAM for growth, yield and its attributing traits of sixteen single-cross hybrids of maize

Traits	Vg	Vp	PCV, %	GCV, %	h^2bs, %	GA	GAM, %
Plant height, cm	440.45	1065.15	12.22	7.86	41	27.80	10.41
Ear height, cm	19.35	651.05	17.82	3.07	3	1.56	1.09
Days to 50% silking	25.43	29.43	9.38	8.72	86	9.66	16.70
Days to 50% tasseling	22.27	25.75	9.08	8.44	86	9.04	16.17
Leaf area per plant, cm^2	2071	3247	8.42	6.73	64	74.87	11.07
Cob length, cm	0.56	2.22	6.79	3.40	25	0.77	3.52
Cob diameter, cm	0.07	0.08	5.86	5.38	84	0.50	10.18
Number of kernel rows in cob	1.62	2.38	10.65	8.77	68	2.16	14.88
Grain yield, t ha^{-1}	9.34	10.7	35.02	26.24	56	3.78	40.50

Vg – genotypic variance, Vp – phenotypic variance, h^2bs – heritability in the broad sense, GCV – genotypic coefficient of variation, PCV – phenotypic coefficient of variation, GA – genetic advance at 5% intensity of selection, GAM – genetic advance as per cent of mean

Cluster analysis

The statistical distances between clusters are an indicator of genetic diversity. The inter-cluster distances were larger than the intra-cluster distances which indicated wider genetic diversity among the genotypes of different groups. The 16 single-cross hybrids of maize were grouped on four clusters based on growth and yield traits (Table 5, Figure 2). Among all the clusters, cluster 2 was the largest containing 6 hybrids followed by clusters 1 (5 hybrids), 3 (4 hybrids) and 4 (1 hybrid) (Table 5). Mounika *et al.* (2018) found similar results after grouping 47 maize inbred lines into seven clusters. In a study by Alom *et al*. (2003), twenty-five maize genotypes were categorized into seven clusters based on morphological traits. Similarly,

Rafique *et al.* (2018) used morphological traits to separate 40 maize inbred lines into ten clusters. Azam (2012) discovered five clusters from 49 maize genotypes. Cluster analysis can be effective for locating high-yielding genotypes, according to Ali *et al.* (2008).

Hybrids of cluster 4 had the maximum values of plant height (318.00 cm), ear height (177.30 cm), leaf area per plant (800.20 cm^2), cob length (23.84 cm), number of kernel rows in cob (16.00) and grain yield (9.40 t ha^{-1}). The hybrids of cluster 2 had the minimum values of plant height (245.03 cm), ear height (126.32 cm), leaf area per plant (627.85 cm^2), cob length (21.63 cm), number of kernel rows in cob (13.83) and grain yield (7.90 t ha^{-1}) (Table 6). Chakma et al. (2012) obtained similar results.

Distance between cluster centroids ranged from 49.83 to 194.28 (Table 7). The minimum distance (49.83) between cluster centroids was found between cluster 3 and cluster 2 indicating genetic similarity and the maximum distance was found in the cluster 4 (KWM-92 × KWM-93) and cluster 2 (KML-2A × KYM-86, KML-4A × KYM-86, KML-5A × RML-4, KML-8A × RML-4, KML-4A × RML-4, Super-951) (194.28) indicating genetic dissimilarity (Table 7).

The maximum distance of cluster 1 from centroid was 37.98 and the minimum distance of cluster 4 (0.00) (Table 8). Debnath (1987) found that the inter-cluster distance was greater than the intra-cluster distance in maize genetic variability. Abedin and Hossain (1990) found similar results in maize. To generate a wide spectrum of genotype variation, Yadav *et al.* (2011), Vennila *et al.* (2011), and Latif *et al.* (2011) recommended employing a distantly dispersed cluster genotypes in hybridization procedures.

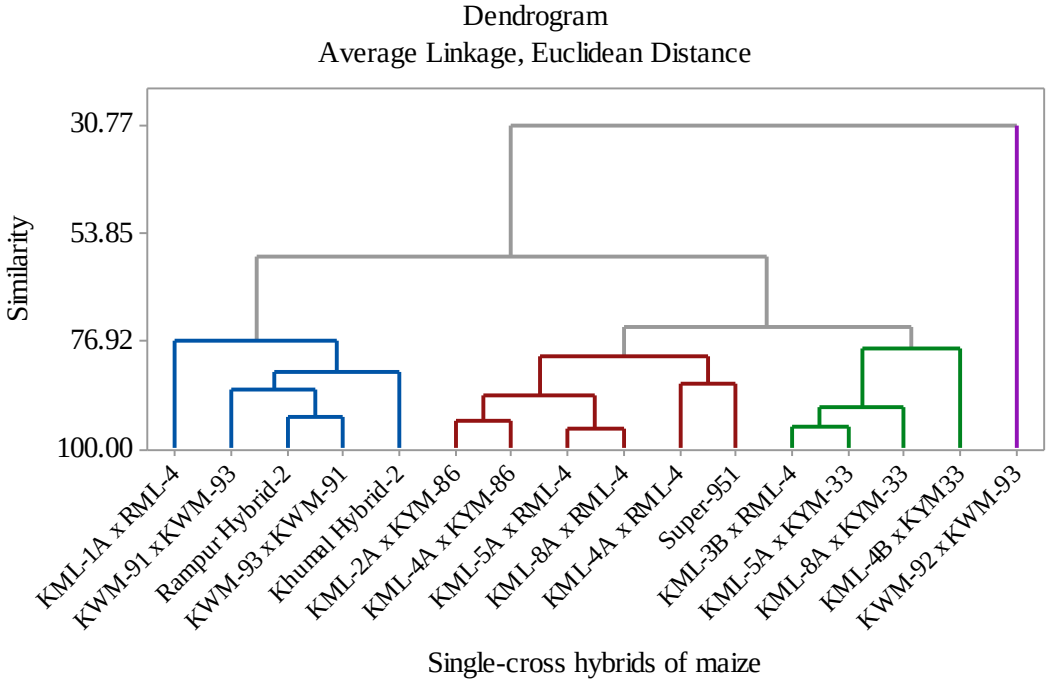

Figure 2. Dendrogram of sixteen single-cross hybrids of maize using Euclidean average linkage method

Table 5. Grouping of sixteen single-cross hybrids of maize by Euclidean average linkage method

Cluster 1	Cluster 2	Cluster 3	Cluster 4
KML-1A × RML-4, KWM-91 × KWM-93, Rampur Hybrid-2, KWM-93 × KWM-91, Khumal Hybrid-2	KML-2A × KYM-86, KML-4A × KYM-86, KML-5A × RML-4, KML-8A × RML-4, KML-4A × RML-4, Super-951	KML-3B × RML-4, KML-5A × KYM-33, KML-8A × KYM-33, KML-4B × KYM33	KWM-92 × KWM-93

Table 6. Cluster means for nine traits of sixteen single-cross hybrids of maize

Variable	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Centroid
Days to 50% tasseling	60.80	51.50	55.88	58.00	55.91
Days to 50% silking	63.00	53.17	57.50	61.00	57.81
Plant height, cm	287.64	245.03	261.73	318.00	267.08
Ear height, cm	159.80	126.32	139.39	177.30	143.23
Leaf area per plant, cm^2	713.69	627.85	672.50	800.20	676.61
Cob Length, cm	21.78	21.63	22.18	23.84	21.95
Cob Diameter, cm	4.90	4.74	5.17	5.17	4.92
Number of kernel rows in cob	14.60	13.83	15.00	16.00	14.50
Grain yield, t ha^{-1}	8.29	7.90	8.45	9.40	8.25

Table 7. Distances between cluster centroids in sixteen single-cross hybrids of maize

Clusters	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Cluster 1	0	102.42	53.29	93.44
Cluster 2			49.83	194.28
Cluster 3				144.68
Cluster 4				0

Table 8. Different statistics of Euclidean distance and cluster analysis of sixteen single-cross hybrids of maize

Cluster	No. of observations	Within clusters sum of square	Average distance from centroid	Maximum distance from centroid
Cluster 1	5	3194.15	23.32	37.98
Cluster 2	6	2981.63	21.51	29.82
Cluster 3	4	1820.05	19.15	33.94
Cluster 4	1	0	0	0

Correlation coefficient

The coefficient of variation represents the degree of variability present in a wide range of qualities, but it excludes the heritable component. In maize, traits like plant height, ear height, and the number of kernel rows per ear are reported to have a positive and substantial link with grain yield, according to the study (Sadek *et al*., 2006). The values of the phenotypic correlation of traits are shown in Table 9. Cob length was negatively correlated with days to 50% silking, days to 50% tasseling and the Number of kernel rows in cob. This result was similar to Selvaraj and Pothiraj (2011) who reported a negative correlation between cob length and the number of kernel rows in cob. The positive and significant phenotypic correlation was found between grain yield and days to 50% silking (r = 0.409), days to 50% tasseling (r = 0.386), plant height (r = 0.367), cob diameter (r = 0.490) and the number of kernel rows in cob (r = 0.382) respectively. Alvi et al. (2003), Prakash et al. (2006), Sharma et al. (2021), and Bartaula et al. (2019) reported similar findings. The ear height and plant height were both positively and strongly correlated with grain yield (Nzuve *et al*., 2014). If there is a positive and high correlation between such traits, it would show an indirect selection of genotypes for grain yield.

Table 9. Pearson's correlation coefficient among growth, yield and its attributing traits of sixteen single-cross hybrids of maize

Traits	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. Days to 50% tasseling	1								
2. Days to 50% silking	0.993**	1							
3. Plant height, cm	0.609**	0.635**	1						
4. Ear height, cm	0.569**	0.592**	0.715**	1					
5. Leaf area per plant	0.545	0.559**	0.619**	0.552**	1				
6. Cob length, cm	–0.025	–0.055	0.104	0.04	0.24	1			
7. Cob diameter, cm	0.419*	0.401*	0.215	0.188	0.291	0.424	1		
8. No. of kernel rows in cob	0.445*	0.475**	0.296	0.294	0.199	–0.086	0.294	1	
9. Grain yield, t ha^{-1}	0.386*	0.409*	0.367*	0.218	0.127	–0.082	0.490**	0.382**	1

* – correlation is significant at the 0.05 level, ** – correlation is significant at the 0.01 level

Conclusion

Significantly differed traits were observed except ear height, the number of kernel rows in cob and cob length, implying that maize hybrids have genetic diversity that can be used to increase yield. In all traits, PCV was bigger than GCV, indicating that there was an environmental influence. Days to 50% silking, days to 50% tasseling, plant height, cob diameter and the number of kernel rows in cob were found to have a maximum correlation with grain yield; these traits may boost grain yield. The cluster analysis revealed that the hybrids had genetic variability. The maximum distance between cluster centroids was found between cluster 2 and cluster 4, showing genetic dissimilarity. The hybrids namely KWM-91 × KWM-93 followed by KWM-93 × KWM-91 and KWM-92 × KWM-93 was identified as a superior hybrid for grain yield. The grain yield production can be maximized by growing these maize hybrids.

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Conflict of interest

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

Author contributions

JS – the lead investigator and also responsible for data collection from the field, literature search and write-up.
SS, RA, SS, MS – responsible for the literature review, reviewing the initial draft and providing critical feedback on the manuscript.
All the authors read and approved the final manuscript.

References

Abedin, J., Hossain, M.A. 1990. Variability in maize composites. – Bangladesh Journal of Agricultural Research, 15(1):24–31.

Adhikari, B.N., Shrestha, J., Dhakal, B., Joshi, B.P., Bhatta, N.R. 2018. Agronomic performance and genotypic diversity for morphological traits among early maize genotypes. – International Journal of Applied Biology, 2(2):33–43. DOI: 10.20956/ijab.v2i2.5633

Akbar, M., Saleem, M., Ashraf, M.Y., Hussain, A., Azhar, F.M. Ahmad, R. 2009. Combining ability studies for physiological and grain yield traits in maize at two temperatures. – Pakistan Journal of Botany, 41(4):1817–1829.

Alemu, B., Tesfaye, K., Haileselassie, T., Lule, D. 2017. Broad sense heritability and genetic advance for grain yield and yield components of chickpea (*Cicer arietinum* L.) genotypes in western Ethiopia. – International Journal of Genetics and Molecular Biology, 9(4):21–25. DOI: 10.5897/IJGMB2017.0158

Ali, Y., Atta, B.M., Akhter, J., Monneveux, P., Lateef, Z. 2008.Genetic variability, association and diversity studies in wheat (*Triticum aestivum* L.) germplasm. – Pakistan Journal of Botany, 40(5):2087–2097.

Alom, A.K.M.M., Masum, A.S.M.H., Nahar, N., Matin, M.A., Pasha, A.K.M.J. 2003. Genetic divergence in maize (*Zea mays* L.). – Pakistan Journal of Biological Sciences, 6:1910–1911. DOI: 10.3923/pjbs.2003.1910.1911

Alvi, M.B., Rafique, M., Shafique, M., Hussain, A., Mohmood, T., Sarwar, M. 2003. Characters association and path analysis of grain yield and yield components in maize. – Pakistan Journal of Biological Science, 6(2):136–138.

Azam, M.G. 2012. Morphological and molecular diversity analysis in maize inbreds. – MS. Thesis, Department of Genetics and Plant Breeding, BSMRAU, Salna, Gazipur, pp. 58–59.

Bartaula, S., Panthi, U., Timilsena, K., Acharya, S.S., Shrestha, J. 2019. Variability, heritability and genetic advance of maize (*Zea mays* L.) genotypes. – Research in Agriculture Livestock and Fisheries, 6(2): 163–169. DOI:10.3329/ralf.v6i2.42962

Bastola, A., Soti, A., Pandey, U., Rana, M., Kandel, M., Shrestha, J. 2021. Evaluation of white grain maize varieties for growth, yield and yield components. – Journal of Agriculture and Natural Resources, 4(1):265–272. DOI: 10.3126/janr.v4i1.33281

Betran, F.J., Ribaut, J.M., Beck, D., Gonzalez De León, D. 2003. Genetic diversity, specific combining ability, and heterosis in tropical maize under stress and nonstress environments. – Crop Science, 43(3): 797–806. DOI: 10.2135/cropsci2003.7970

Bocanski, J., Srećkov, Z., Nastasić, A. 2009. Genetic and phenotypic relationship between grain yield and components of grain yield of maize (*Zea mays* L.). – Genetika, 41(2):145–154. DOI: 10.2298/GENSR0902145B

Burton, G.H. 1952. Quantitative inheritance in grasses. – Proceedings 6th International Grassld. Congress, 1:277–283.

Chakma, S.P., Huq, H., Mahmud, F., Husna, A. 2012. Genetic diversity analysis in rice (*Oryza sativa* L.). – Bangladesh Journal of Plant Breeding and Genetics, 25(1):31–39. DOI: 10.3329/bjpbg.v25i1.17010

Dabholkar, A.R. 1992. Elements of Biometrical Genetics. – Concept Publishing Company, New Delhi 110059, p. 431.

Debnath, S.C. 1987. Genetic variability in maize (*Zea mays* L.). – Bangladesh Journal of Agricultural Research, 12(4):217–221.

Deshmukh, S.N., Basu, M.S., Reddy, P.S. 1986. Genetic variability, character association and path coefficients of quantitative traits in Virginia bunch varieties of groundnut. – Indian Journal of Agricultural Sciences, 56:816–821.

Dhakal, B., Shrestha, K.P., Joshi, B.P., Shrestha, J. 2018. Evaluation of early maize genotypes for grain yield and agromorphological traits. – Journal of Maize Research and Development, 3(1):67–76. DOI: 10.3126/jmrd.v3i1.18923

Girma, B.T., Kitil, M.A., Banje, D.G., Biru, H.M. Serbessa, T.B. 2018. Genetic variability study of yield and yield related traits in rice (*Oryza sativa* L.) genotypes. Advances in Crop Science and Technology, 6(4):381. DOI: 10.4172/2329-8863.1000381

Gomez, K.A., Gomez, A.A. 1984. Statistical procedures for agricultural research. – New Delhi, India: Wiley India (P) Ltd.

Grzesiak, S. 2001. Genotypic variation between maize (*Zea mays* L.) single-cross hybrids in response to drought stress. – Acta Physiologic Plantarium, 23(4): 443–456

Hallauer, A.R., Schos, J.H. 1973. Change in quantitative traits associated with inbreeding in synthetic variety of maize. – Crop Science, 13(3):327–330.

Hallauer, A.R., Russell, W.A., Lamkey, K.R. 1988. Corn Breeding. In: Corn and Corn Improvement, 3rd ed. – Agronomy Monographs 18, ASA-CSSA-SSSA, Madison, Wisconsin, USA, pp. 469–564.

Johnson, H.W., Robinson, H.F., Comstock, R.E. 1955. Estimates of genetic and environmental variability in soybeans. – Agronomy Journal, 47:314–318. DOI: 10.2134/agronj1955.00021962004700070009x

Kafle, S., Adhikari, N.R., Sharma, S., Shrestha, J. 2020. Performance evaluation of single-cross maize hybrids for flowering and yield traits. – Fundamental and Applied Agriculture, 5(4):590–597. DOI: 10.5455/faa.130574

Kalla, V., Kumar, R., Basandrai, A.K. 2001. Combining ability analysis and gene action estimates of yield and yield contributing characters in maize (*Zea mays* L.). – Crop Research, 22(1):102–106.

Kandel, B.P., Poudel, A., Sharma, S., Subedi, M. 2017. Variability studied in yield attributing traits of early

maize genotypes in western hill of Nepal. – Nepalese Journal of Agriculture Science, 15:13–18.

Kashiani, P., Saleh, G., Abdullah, N.A.P., Abdullah, S.N. 2010. Variation and genetic studies on selected sweet corn inbred lines. – Asian Journal of Crop Science, 2(2):78–84. DOI: 10.3923/ajcs.2010.78.84

Khalil, I.A., Rahman, H., Rehman, N.U., Arif, M., Khalil, I.H., Iqbal, M., Ullah, H., Afridi, K., Sajjad, M. Ishaq, M. 2011. Evaluation of maize hybrids for grain yield stability in north-west of Pakistan. – Sarhad Journal of Agriculture, 27(2):213–218.

Khan, M.U., Shah, S.M.A., Rahman, H., Iqbal, A., Aslam, E. 2018. Evaluation of Maize Hybrids for Yield and Maturity Traits. – Sarhad Journal of Agriculture, 35(1):7–12.

Latif, M.A., Rahman, M.M., Kabir, M.S., Ali, M.A., Islam, M.T., Rafii, M.Y. 2011. Genetic diversity analyzed by quantitative traits among rice (*Oryza sativa* L.) genotypes resistant to blast disease. – African Journal of Microbiology Research, 5(25):4483–4391. DOI: 10.5897/AJMR11.492

Lias, S.J., Xu, Z.B., Wen, S.P. 1987. Analysis of combining ability for major quantitative character in maize in some maize inbred lines. – Ningxia Agriculture and Forestry Science and Technology, 5:10–12.

Liu, K., Goodman, M., Muse, S., Smith, J.S., Buckler, E.D., Doebley, J. 2003. Genetic structure and diversity among maize inbred lines as inferred from DNA microsatellites. – Genetics, 165(4):2117–2128.

MoALD. 2020. Statistical Information on Nepalese Agriculture 2075/76 (2018/19). Singha Durbar, Kathmandu Nepal, Ministry of Agriculture and Livestock Development, AgriBusiness Promotion and Statistics Division.

Mounika, K., Ahamed, M.L., Nafeez, U.S. 2018. Principal component and cluster analysis in inbred lines of maize (*Zea mays* L.). – International Journal of Current Microbiology and Applied Sciences, 7(06): 3221–3229. DOI: 10.20546/ijcmas.2018.706. 379

Nachimuthu, V.V., Robin, S., Sudhakar, D., Raveendran, M., Rajeswari, S., Manonmani, S. 2014. Evaluation of rice genetic diversity and variability in a population panel by principal component analysis. – Indian Journal of Science and Technology, 7(10):1555–1562. DOI: 10.17485/ijst/2014/v7i10.14

Nagabhushan, N.M., Mallikarjuna, C.H., Shashibhaskar, M.S., Prahalada, G.D. 2011. Genetic variability and correlation studies for yield and related characters in single cross hybrids of maize (*Zea mays* L.). – Current Biotica, 5:157–163.

Najeeb, S.O.F.I., Rather, A.G., Parray, G.A., Sheikh, F. A., Razvi, S.M. 2009. Studies on genetic variability, genotypic correlation and path coefficient analysis in maize under the high altitude temperate conditions of Kashmir. – Maize Genetics Cooperation Newsletter, 83, 46 p.

Nzuve, F., Githiri, S., Mukunya, D.M., Gethi, J. 2014. Genetic variability and correlation studies of grain yield and related agronomic traits in maize. – Journal of Agricultural Science, 6(9):166–176. DOI: 10.5539/jas.v6n9p166

Ojo, D.K., Omikunle, O.A., Oduwaye, O.A., Ajala, M.O., Ogunbayo, S.A. 2006. Heritability, character correlation, and path coefficient analysis among six inbred-lines of maize (*Zea mays* L.). – World Journal of Agricultural Science, 2(3):352–358.

Oseni, T.O., Masarirambi, M.T. 2011. Effect of climate change on maize (*Zea mays* L.) production and food security in Swaziland. – American-Eurasian Journal of Agricultural & Environmental Sciences, 11:385–391.

Pal, S., Sharma, H.R., Rai, A.K., Bhardwaj, R.K. 2016. Genetic variability, heritability and genetic gain for yield and quality traits in cucumber (*Cucumis sativus* L.) genotypes. – The Bioscan, 11(3):1985–1990.

Prakash, O., Shanthi, P., Satyanarayana, E., Sai, K.R. 2006. Studies on inter relationship and path analysis for yield improvement in sweet corn genotypes (*Zea mays* L.). – International Journal of Plant Science Research, 33:1–4.

Prasai, H.K., Kushwaha, U.K.S., Joshi, B.P., Shrestha, J. 2015. Performance evaluation of early maize genotypes in far western hills of Nepal. – Journal of Maize Research and Development, 1(1):106–111. DOI: 10.3126/jmrd.v1i1.14248

Rafique, M., Malhi, A.R., Altaf, M., Saleem, S., Khakwani, K. 2018. Cluster analysis and genetic diversity of maize inbred lines. – International Journal of Agriculture Innovations and Research, 6(5):2319–1473.

Ravikumar, B.N.V.S.R., Naga Kumari, P., Venkata Ramana Rao, P., Girija Rani, M., Satyanarayana, P.V., Chamundeswari, N., Mohan Vishuvardhan, K., Suryanarayana, Y., Bharathalakshmi, M., Vishnuvardhan Reddy, A. 2015. Principal component analysis and character association for yield components in rice (*Oryza sativa* L.) cultivars suitable for irrigated ecosystem. – Current Biotica, 9(1):25–35.

Sadek, S.E., Ahmed, M.A., Abd El-Ghaney, H.M. 2006. Correlation and path coefficient analysis in five parents inbred lines and their six white maize (*Zea mays* L.) single crosses developed and grown in Egypt. – Journal of Applied Sciences Research, 2(3):159–167.

Selvaraj, C.I., Pothiraj, N. 2011. Interrelationship and path-coefficient studies for qualitative traits, grain yield and other yield attributes among maize (*Zea mays* L.). – International Journal of Plant Breeding and Genetics, 5(3):209–223. DOI: 10.3923/ijpbg. 2011.209.223

Sharma, B.K., Sharma, S., Kandel, B.P., Shrestha. J. 2018. Varietal evaluation of promising maize genotypes. – Azarian Journal of Agriculture, 5(4):120–124.

Sharma, H.P., Upadhyaya, J., Shrestha, J. 2021. Analysis of correlation and agro-morphological traits in single cross hybrids of maize. – Russian Journal of

Agricultural and Socio-Economic Sciences, 9(117): 43–49. DOI: 10.18551/rjoas.2021-09.16

Shrestha, J. 2016. Evaluation of quality protein maize genotypes for grain yield in mid hill districts of Nepal. – International Journal of Life Sciences, 10(1):7–9. DOI: 10.3126/ijls.v10i1.14514

Shrestha, J., Yadav, D.N., Amgain, L.P., Sharma, J.P. 2018. Effects of nitrogen and plant density on maize (*Zea mays* L.) phenology and grain yield. – Current Agriculture Research Journal, 6(2):175–182. DOI: 10.12944/CARJ.6.2.06

Shrestha, J., Gurung, D.B., Koirala, K.B., Rijal, T.R. 2019. Performance evaluation of maize in Jumla district of Nepal: from yielding perspective. – International Journal of Applied Biology, 3(2):35–45.

Shukla, S., Bhargava, A., Chatterjee, A., Sirivastava, J.,Singh, N., Singh, S.P. 2006. Mineral profile and variability in vegetable amaranth (*Amaranthus tri-color*). – Plant Foods for Human Nutrition, 61(1): 23–28. DOI: 10.1007/s11130-006-0004-x

Singh, R.K., Chaudhary, B.D. 1985. Biometrical methods in quantitative analysis. Kalayani Publishers, New Delhi. 304 pp.

Swamy, R.T., Ramamurty, A., Patil, S.J., Aradhya, R.S., Mahadevappa, M. 1971. Genetic variability and heterosis in maize. – Maderas Agricultural Journal, 58:620–623.

Tahir, M., Tanveer, A., Ali, A., Abbas, M., Wasaya, A. 2008. Comparative yield performance of different maize (*Zea mays* L.) hybrids under local conditions of Faisalabad-Pakistan. – Pakistan Journal of Life and Social Sciences, 6(2):118–120.

Tripathi, A., Bisen, R., Ahirwal, R.P., Paroha, S., Sahu, R., Ranganatha. A.R.G. 2013. Study on genetic divergence in sesame (*sesamum indicum* L.) Germplasm based on morphological and quality traits. – The Bioscan, 8(4):1387–1391.

Ullah, M.Z., Hasan, M.J., Chowdhury, A.Z.M.K.A., Saki, A.I., Rahman, A.H.M.A. 2012. Genetic variability and correlation in exotic cucumber (*Cucumis sativus* L.) varieties. – Bangladesh Journal of Plant Breeding and Genetics, 25(1):17–23. DOI: 10.3329/ bjpbg.v25i1.17008

Vennila, S., Anbuselvam, Y., Palaniraja, K. 2011. Genetic divergence analysis using yield and quality traits in rice (*Oryza sativa* L.). – International Journal of Recent Scientific Research, 2(7):237–239.

Welsh, J. 1981. Fundamental of Plant Breeding and Genetics. – New York: JhonWelicy and sons, p. 304.

Yadav, V.K., Singh, Y., Soni, S.K., Yadav, A.K. 2011. Genetic divergence analysis in salt tolerance rice (*Oryza sativa* L.) genotypes. – Plant Archives, 11(2):593–595.

Zeeshan, M., Ahsan, M., Arshad, W., Ali, S., Hussain, M., Khan, M.I. 2013. Estimate of correlated responses for some polygenic parameters in yellow maize (*Zea mays* L.) hybrids. – International Journal of Advanced Research, 1(5):24–29.

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EVALUATION OF COMMON BEAN (*Phaseolus vulgaris* L.) GENOTYPES AGAINST ANTHRACNOSE (*Colletotrichum lindemuthianum* Sacc. and Magn.)

Sujata K.C.[1], Hira Kaji Manandhar[2], Sundar Man Shrestha[2], Basistha Acharya[3], Jiban Shrestha[4]

[1]National Wheat Research Program, Bhairahawa, Ward No. 2, Omsatiya Rural Municipality, Rupandehi, Lumbini Province, 32900, Nepal
[2]Agriculture and Forestry University, Rampur, Chitwan, Bharatpur 15, Bharatpur Metropolitan City, 44209, Nepal
[3]Nepal Agricultural Research Council, Directorate of Agricultural Research, Khajura, Ward No. 4, Janaki Rural Municipality, Banke, Nepal
[4]Nepal Agricultural Research Council, National Plant Breeding and Genetics Research Centre, Khumaltar, Ward No. 15, Lalitpur Metropolitan City, Lalitpur, 44700, Nepal

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Vastutavautor: Corresponding author: Sujata K.C.

E-mail:
kc.sujata08@gmail.com (SKC)
hirakaji@gmail.com (HKM)
smshrestha@afu.edu.np (SMS)
basisthacharya1@gmail.com (BA)
jibshrestha@gmail.com (JS)

ORCID:
0000-0002-5368-8182 (SKC)
0000-0001-7243-0841 (HKM)
0000-0001-6696-2462 (SMS)
0000-0002-2444-1674 (BA)
0000-0002-3755-8812 (JS)

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ABSTRACT. Twelve genotypes of common bean were evaluated against anthracnose under natural epiphytotic conditions. This study was carried out in a randomized complete block design with three replications at the research field of Agriculture Research Station (ARS), Vijaynagar, Jumla, Nepal from June to September 2018. The area under the disease progress curve (AUDPC) and disease severity were calculated. In laboratory conditions, artificial inoculation was carried out on detached leaves of twelve genotypes using a pure culture suspension of *Colletotrichum lindemuthianum* (1.2×10^6 conidia ml^{-1}) in a completely randomized design with three replications. The results showed that bean genotypes varied significantly for disease severity both in the field and laboratory conditions. In the field, bean genotypes showed resistance to highly susceptible reactions. Their AUDPC value ranged from 120.55 to 502.31. The lowest mean AUDPC value was recorded in KBL-1 (120.55) followed by KBL-3 (123.79) and KBL-2 (124.44). Similarly, the lowest severity value was recorded with KBL-1 (0.51), KBL-2 (0.52) and KBL-3 (0.53). Detached leaf assay in laboratory experiment showed that the lowest mean AUDPC was found in KBL-2 (16.67) and KBL-3 (16.67). Therefore, KBL-2 and KBL-3 could be utilized as resistant varieties to anthracnose disease under Jumla and similar field conditions.

Introduction

Beans are a good source of protein with 2–3 times the amount of cereal grains (Siddiq *et al*., 2010). Starch, dietary fibre, minerals and vitamins are all abundant in foods with a high dry matter content (Kutos *et al*., 2003; Costa *et al*., 2006). Beans also include a wide range of phytochemicals, antioxidant activity and a wide range of flavonoids, including anthocyanins, flavonoids, proanthocyanidins, flavonols, phenolic acids and isoflavones (Beninger, Hosfield, 2003; Choung *et al*., 2003; Granito *et al*., 2008; Lin *et al*., 2008). Dry edible beans are grown and eaten in large quantities all over the world (Sathe, 2002). Bean is an indigenous crop of the Jumla and Karnali zones of Nepal (Subba *et al*., 2016). It can also be interpreted as local Rajma. Jumli simi, the indigenous bean's name, is gaining popularity.

Indigenous bean plants come in a wide range of colour, shape, size and growth habit (Subba *et al*., 2016). Local Jumli simi cultivars are high in minerals and have a high antioxidant potential. Because of its high polyphenol content, Jumli simi is a nutritious food. When compared to light-coloured beans, dark-coloured beans are found to have higher phytochemicals and antioxidant activity (Subba *et al*., 2016).

Both biotic and abiotic constraints are responsible for reducing the production of common beans. Among them, anthracnose caused by *Colletotrichum lindemuthianum* (Sacc. & Magn.) is an important disease of the beans (Muimba-Kankolongo, 2018). It is the major yield-limiting disease impacting seed quality and marketability (Schwartz, Pastor-Corrales, 1989). The disease can cause 95–100% yield loss when the infected seed is used for cultivation and favourable weather conditions occur during the crop cycle (Yesuf, Sangchote, 2007). The disease is particularly important in relatively cool, wet areas of tropical and temperate regions (Schwartz, Pastor-Corrales, 1989). In Nepal, it causes a huge loss in the temperate and sub-tropical areas (Manandhar *et al*., 2016). The disease symptoms are seen in all the above-ground parts including leaf, stem, pods and seeds (Agrios, 2005). On leaves, symptoms generally occur on the underside as linear, dark brick-red to black lesions on the leaf veins. As the disease progresses, discolouration appears on the upper leaf surface. Leaf symptoms often are not obvious and may be overlooked when examining bean fields (Kelley, Vallejo, 2004). The most striking symptoms develop on the pods. Small, reddish-brown to black blemishes and distinct circular, reddish-brown lesions are typical symptoms on bean pods. Since, the disease is mostly visible in the fields from flowering (R6) to pod filling stage (R8), disease scoring is mostly recommended during this stage (Manandhar *et al.*, 2016).

Adopting various methods such as the use of disease-free certified seeds, use of resistant varieties, crop rotation (of 2 to 3 years), field sanitation and chemical application, this disease can be managed (Tesfaye, Pretorius, 2005). Crop rotation, intercropping, field sanitation and plant debris removal, altering planting dates, applying compost and blending diverse cultivars have all been shown to reduce disease severity (Joshi *et al*., 2009). However, because these treatments have both economic and environmental limitations, the most cost-effective and environmentally sustainable option is to use host plant resistance to reduce anthracnose disease in beans.

Plant resistance is also the most efficient, simple, secure and cost-effective alternative for small, resource-poor farmers (Opio *et al*., 2006), Since, Jumla was declared as an organic district by the District Development Committee of Jumla in 2007, plant resistance can be an effective option for disease management where the use of chemicals is prohibited. In comparison to other management practices, Pastor-Corrales (1995) found that using genetically resistant cultivars is the most effective, least expensive and the easiest method for farmers to implement. Therefore, this study was conducted to determine the level of anthracnose resistance in promising common bean pipeline genotypes appropriate for the high hills of Nepal.

Materials and Methods

Field experiment

Field screening was carried out from June to September 2018 at the research field of Agriculture Research Station Vijaynagar, Jumla (27°38'51.8" north longitude and 84°20'52.5" east latitude with an elevation of 2 370 masl). The experimental site falls in the temperate climate zone of the high hills where the maximum summer temperature goes up to 26 °C, the minimum temperature reaches –6 °C. The experimental location receives the highest amount of rainfall up to 180 mm. The meteorological data during the experiment is given in Figure 1.

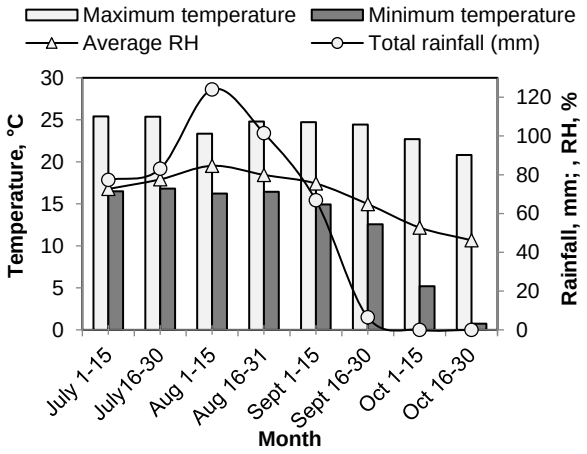

Figure 1. Meteorological data of Jumla during experiment in 2018 at Vijaynagar, Jumla, Nepal (RH – relative humidity)

Twelve bean genotypes were evaluated in a randomized complete block design with three replications in a 6 m^2 plot size with the spacing of 50 cm × 10 cm (row to row and plant to plant spacing) for each entry. The list of genotypes used in this experiment is given in Table 1. The source of these genotypes is Agriculture Research Station (ARS), Jumla, Nepal.

Fertilizer was applied at a rate of 100:60:40 kg N: P_2O_5:K_2O [N (100 kg ha^{-1}); Urea and Di-Ammonium Phosphate, P_2O_5 (60 kg ha^{-1}; Di-Ammonium Phosphate) and K_2O (40 kg ha^{-1}; Murate of Potash)] with the full dose of phosphorus and potassium as a basal dose. Nitrogen was applied in two split with half dose as basal and the remaining half dose was top dressed just after first weeding (one month after sowing). Staking of trailing beans was done according to the need. The crop was grown under rain-fed condition. On the first week of June 2018, the crop was planted. All plots were surrounded by a spreader area of one meter in width planted with the highly susceptible local variety (Farmer's variety).

Table 1. List of bean genotypes used in the experiment in 2018 at Vijaynagar, Jumla, Nepal

Genotype	Growth habit	Flower colour	Seed colour	Pod colour	Seed shape
PB0001	Bushy	Light pink to white	Dark red with white streaks	Green	Kidney
PB0002	Trailing	Dark pink	Creamy white with purple streaks	Green with dark-purple streaks	Elongated
PB0048	Trailing	Very light pink to white	Dark red	Green	Elongated
KBL-1	Trailing	Dark pink	Black	Green	Elongated
KBL-2	Trailing	White	Dark red	Reddish green	Elongated
KBL-3	Trailing	Very dark pink	Dark purple with white streaks	Green	Elongated
KBL-4	Trailing	Dark pink	Creamy to very light brown	Green	Flattened, elongated
KBL-5	Bushy	Pink	Light brown	Green	Elongated
KBL-6	Trailing	White	White	Green	Elongated
KBL-7	Trailing	Whitish pink to dark	Creamy to very light brown	Green	Oval
KBL-8	Bushy	Very light pink to white	White with dark red streaks	Green	Kidney
KBL-9	Trailing	Dark pink	Light to dark grey	Green	Elongated

Disease assessment

Disease severity. Disease scoring was done by using a 1–9 scale given by (CIAT, 1987) which was converted to disease severity percentage. Disease severity (Eq. 1) was calculated by using the formula given by (Wheeler, 1969).

$$DS,\% = \frac{SNR}{TNR \times MR} \times 100 \quad (1)$$

where,

DS – disease severity,
SNR – a sum of all numerical ratings,
TNR – total number of plants observed and
MR – maximum rating.

Before analysis severity percentage data were arcsine transformed to improve variance inequality.

AUDPC values. AUDPC value was calculated by using the following formula (Eq. 2) as given by Das *et al.* (1992).

$$AUDPC = \sum_{i=1}^{n-1} [\{\frac{(Y_i + Y_{i+1})}{2}\} \times (t_{(i+1)} - t_i)] \quad (2)$$

where,

AUDPC – area under the disease progress curve,
Y_i – disease severity on the i^{th} date,
t_i – time on which Y_i is recorded and
n – number of time observations were taken.

Based on the mean AUDPC values, the genotypes were categorized into 4 groups of resistance levels as below (Magar *et al*., 2015):

Mean AUDPC value	Resistance category	Code
1–30	Resistant	R
31–60	Moderately resistant	MR
61–90	Susceptible	S
>90	Highly susceptible	HS

Anthracnose disease scoring was carried out on a scale of 1–9 (CIAT, 1987).

Laboratory experiment

Detached leaf assay

A modified detached leaf technique was used to screen the common bean genotypes (Tu, 1986).

Inoculum preparation. A small piece of the infected pod was surface sterilized in 1% sodium hypochlorite solution for 25–30 seconds, washed three times in sterilized distilled water under aseptic conditions, excess water was drained out and the sample was placed in sterilized moist blotter paper and incubated at 22 ± 1 °C for seven days in Biological Oxygen Demand (B.O.D) incubator. A stereomicroscope was used to inspect the incubated materials and a single acervulus was transferred to a Potato Dextrose Agar (PDA) plate in a laminar flow hood. Commercial PDA manufactured by HiMedia Laboratories Pvt. Ltd., Mumbai, India was used for inoculum preparation purposes. The culture was obtained after ten days and then sub-cultured in PDA. Using a hemocytometer, the concentration of the conidial suspension was adjusted to 1.2×10^6 conidia ml^{-1} (Mahuku, Riascos, 2004).

Inoculation. Bean plants of test genotypes grown in a screen house were used for this assay where apical leaflets from one-week-old plants were washed with sterilized distilled water and placed abaxial surface up in Petri dishes containing two layers of water-soaked blotting papers and glass slides (to avoid rotting). The spore suspension was brushed gently onto the leaves as described by (Tu, 1986). The plate was covered with a transparent lid and the inoculated leaflets were incubated at 22 ± 1 °C with 12 hours light cycle. On the 7th day after inoculation, the severity of the disease was scored based on the percentage of veins diseased. The disease scoring was carried out on a scale from 0 to 3 (Table 2).

Table 2. Scoring scale for anthracnose disease based on leaf area affected (Inglis *et al*., 1988).

Scale	Plant parts affected
0	No disease
1	1–10% veins with lesions
2	11–25% veins and veinlets with lesions
3	26% or more veins and veinlets with lesions

Disease severity and AUDPC were calculated s as mentioned previously.

The Pearson correlation coefficient was estimated.

Data analysis

The analysis of variance (ANOVA) was performed for all parameters in GenStat (version 15.0, VSN International Ltd., England & Wales). Duncan's Multiple Range Test (DMRT) was used for mean separation and was performed at a 5% level of significance (Gomez, Gomez, 1984).

Results and Discussion

Field experiment

Disease severity

Twelve bean genotypes varied significantly in the severity of anthracnose at 63, 70, 77, 84 and 91 DAS (Table 3). Anthracnose severity was found 0.51 to 1.27. On 91 DAS, The lowest disease severity was obtained in KBL-1(0.51) followed by KBL-2 (0.52), KBL-3 (0.53) and PB-0001 (0.53) (Table 3).

Table 3. Severity of anthracnose disease on bean genotypes in 2018 under field condition at Vijaynagar, Jumla, Nepal

Genotype	63 DAS	70 DAS	77 DAS	84 DAS	91 DAS
KBL-1	0.35^{a}	0.38^{a}	0.42^{a}	0.46^{ab}	0.51^{a}
KBL-2	0.36^{ab}	0.39^{ab}	0.44^{ab}	0.46^{ab}	0.52^{ab}
KBL-3	0.36^{ab}	0.40^{b}	0.44^{ab}	0.44^{a}	0.53^{b}
PB0001	0.34^{a}	0.40^{b}	0.45^{bc}	0.48^{b}	0.53^{b}
KBL-4	0.38^{bc}	0.44^{cd}	0.47^{cde}	0.52^{c}	0.61^{c}
KBL-6	0.39^{c}	0.42^{c}	0.46^{bcd}	0.52^{c}	0.62^{c}
KBL-7	0.38^{bc}	0.44^{d}	0.48^{de}	0.52^{c}	0.62^{c}
KBL-9	0.40^{c}	0.45^{d}	0.49^{e}	0.54^{c}	0.65^{d}
PB0002	0.38^{bc}	0.59^{e}	0.79^{f}	0.84^{d}	0.97^{e}
PB0048	0.40^{c}	0.59^{e}	0.77^{f}	0.88^{e}	0.97^{e}
KBL-5	0.72^{d}	0.91^{g}	1.03^{g}	1.15^{f}	1.27^{f}
KBL-8	0.72^{d}	0.87^{f}	1.04^{g}	1.15^{f}	1.27^{f}

DAS: Days after sowing, Means in a column followed by different letter's are significantly different at P <0.05. Mean values derived from arcsine transformation of percentage data.

Area Under the Disease Progress Curve (AUDPC)

Resistance category of bean genotypes based on total AUDPC, mean AUDPC and AUDPC day^{-1} are given in Table 4. The genotype KBL-1 had the lowest mean AUDPC value (120.5). Similar observations were recorded for AUDPC day^{-1} values with the lowest AUDPC day^{-1} was observed in KBL-1 (17.2) which was at par with KBL-3 and KBL-2. Among them, four genotypes (PB-0001, KBL-2, KBL-3, KBL-1) were categorized into resistant, four genotypes (KBL-6, KBL-9, KBL-7, KBL-4) into moderately resistant, two moderately susceptible (PB-0048 and PB-0002) and two susceptible (KBL-8, KBL-5) categories based on mean AUDPC values (Table 4).

Table 4. Resistance category of bean genotypes based on total AUDPC, mean AUDPC and AUDPC day^{-1} in 2018 at Vijaynagar, Jumla, Nepal

Genotype	Total AUDPC	Mean AUDPC	AUDPC day^{-1}	Resistance category
KBL-8	2009.2	502.3	71.7	S
KBL-5	1973.0	493.2	70.5	
PB0048	1292.9	323.2	46.2	MS
PB0002	1265.2	316.3	45.2	
KBL-9	661.1	165.3	23.6	
KBL-7	617.0	154.2	22.0	MR
KBL-4	604.0	151.0	21.6	
KBL-6	598.9	149.7	21.4	
PB0001	513.3	128.3	18.3	
KBL-2	497.8	124.4	17.8	R
KBL-3	495.2	123.8	17.7	
KBL-1	482.2	120.5	17.2	

S – Susceptible, MS – moderately susceptible, MR – moderately resistant, R – Resistant, AUDPC – area under disease progress curve

Grain yield

The effect of anthracnose on the grain yield of different genotypes is given in Figure 2. Grain yield varied significantly among the genotypes. The highest grain yield was found in KBL-9 (6.02 t ha^{-1}) followed by KBL-2 (5.41 t ha^{-1}) while the lowest yield was obtained in PB-0048 (3.46 t ha^{-1}) followed by KBL-6 (3.61 t ha^{-1}) (Fig. 2).

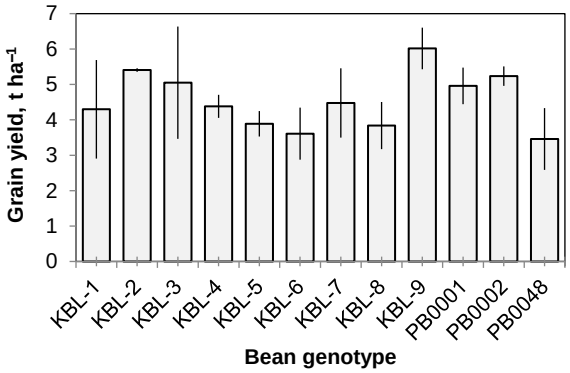

Figure 2. Bar graph illustrating the mean and standard deviation (error bars) of grain yield of bean genotypes in 2018 under field conditions at Vijaynagar, Jumla, Nepal

Laboratory experiment

Final AUDPC and mean AUDPC in detached leaf assay

Final AUDPC and mean AUDPC differed significantly (P<0.01) among genotypes (Table 5). The final AUDPC was found the lowest in KBL-3 (50.0) and KBL-2 (50.0) which was followed by KBL-9 (66.7) and PB-0001(66.7). The minimum mean AUDPC was found in KBL-3 (16.67) and KBL-2 (16.67) followed by PB0001 (22.2) and KBL-9 (22.2) (Table 5).

Table 5. Final AUDPC and mean AUDPC of bean genotypes in detached leaf assay in 2018 at Vijaynagar, Jumla, Nepal

Genotype	Final AUDPC	Mean AUDPC
KBL-5	222.2	74.0
KBL-8	233.3	77.8
KBL-9	66.7	22.2
PB0048	177.8	59.2
KBL-6	144.4	48.1
KBL-4	133.3	44.4
KBL-7	88.9	29.6
PB0002	233.3	77.8
KBL-2	50.0	16.7
KBL-3	50.0	16.7
KBL-1	88.9	29.6
PB0001	66.7	22.2

AUDPC – Area under disease progress curve

Correlation analysis

The correlation studies showed highly significant correlations between different parameters (Table 6). Grain yield showed a negative and significant correlation with mean AUDPC (r = –0.452), disease incidence (r = –0.512) and disease severity (r = –0.442) (Table 6). The correlation values between mean AUDPC and disease incidence (r = 0.960), mean AUDPC and disease severity (r = 0.991), and disease incidence and disease severity (r = 0.959) were significantly positive.

Table 6. Pearson's correlation coefficient between parameters of different genotypes of bean grown in the field in 2018 at Vijaynagar, Jumla, Nepal

Parameter	Mean AUDPC	Disease incidence	Disease severity
Mean AUDPC			
Disease incidence	0.960**		
Disease severity	0.991**	0.959**	
Yield	–0.452*	–0.512*	–0.442*

* – significant at P <0.05, ** – significant at P <0.01

Discussion

Common bean provides an important source of fibre, protein and energy to the people of Jumla district. Bean is one of the important pulse crops with good economic value and high export. They are usually used as dal, soup and porridge. In common bean growing areas, the incidence of anthracnose disease has posed a serious threat to bean production (Choudhary *et al*., 2018; Gonçalves-Vidigal *et al*., 2020). Jumla is known as an organic district, the use of pesticides for the control of insect pests and diseases is prohibited in this district. Therefore the development of a disease-resistant variety of beans is important for this district. Agriculture Research Station (ARS), Jumla have been evaluating many local and exotic bean genotypes for disease screening. Due to lack of laboratory and manspower, successful resistant breeding works have not been achieved yet rather than screening works. This study can contribute to developing a potential resistant variety to boost productivity. The leaf detachment assay showed that the final AUDPC and mean AUDPC were found the lowest in KBL-3 and KBL-2. The field screening showed the KBL-2, KBL-3 and PB-0001 had lower disease severity. Variation of the genotypes against anthracnose disease was reported by Prasad *et al*. (2016). The leaf detachment assay could be used to screen beans for anthracnose disease in an efficient and time-saving manner. Detached leaf assay is an alternative to inoculating whole plants that allow breeders to test for diseases or races without destroying the plant, reduces the time between inoculation and disease assessment and confines the pathogen to the lab (Miller-Butler *et al*., 2019).

In the development of resistant plant lines, screening for and selecting resistant plant sources is important (Geetha *et al*., 2013; Sharma *et al*., 2012). In our study, based on mean AUDPC values, genotypes were categorized into four categories; four (PB-0001, KBL-2, KBL-3, KBL-1) were categorized into resistant, four genotypes (KBL-6, KBL-9, KBL-7, KBL-4) into moderately resistant, two moderately susceptible (PB-0048 and PB-0002) and two susceptible (KBL-8, KBL-5) categories.KBL-9 which showed a moderately resistant reaction to the disease produced the highest yield which was also reported as a high yielder by Bhujel *et al.* (2014). In the case of yield, the result wasn't regarding the resistance category as the highest yield was obtained in the moderately resistant one. This might be because, in common beans, yield is a complex character brought about by other pod quality traits as well (Singh *et al.*, 2015). According to Nkalubo (2006), yield differences differed significantly between different accession types but not between resistant classes.

In our study, there was a positive correlation between AUDPC and disease severity. Similar results were observed by (Viriyasuthee *et al*., 2019). A negative correlation between seed yield and AUDPC, disease severity score and percent disease severity was recorded in faba bean (Zebire, Tadesse, 2018). The grain yield showed significant and negative correlations with AUDPC values in Lay Gorebela and Mush in faba bean (Wondwosen *et al*., 2019).

Conclusion

According to the findings, the disease-resistant promising bean genotypes namely KBL-2 and KBL-3 can be recommended for Jumla conditions in terms of both anthracnose disease resistance and grain yield potential. The bean genotypes found promising under Jumla conditions can be considered for multi-location experiments in other high hill areas. This finding will help the bean farmers in enhancing the yield of common beans and minimizing economic loss.

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

Author contributions
SKC – conceived and designed the experiments; performed the experiments as part of thesis research; analyzed and interpreted the data; wrote the paper.
HKM – guided and helped to design the experiment as a major advisor, provided editorial suggestions in the preparation of manuscript, revision and approval of the final manuscript.
SMS, BA – guided in performing experiments as a member advisor, provided editorial suggestions in the preparation of manuscript, revision and approval of the final manuscript
JS – revised manuscript; wrote the paper.

References

Agrios, G.N. 2005. Plant Pathology (Fifth ed.). – Burlington, USA: Elsevier.

Allen, D.J., Ampofo, J., Wortman, C.S. 1996. Pests, diseases and nutritional disorders of the common bean in Africa: A field guide. – International Centre for Tropical Agriculture: Wageningen, The Netherlands: technical centre for Agricultural and Rural Cooperation, 132 p

Beninger, C.W., Hosfield, G.L. 2003. Antioxidant activity of extracts, condensed tannin fractions and pure flavonoids from *Phaseolus vulgaris* L. seed coat color genotypes. – Journal of Agricultural and Food Chemistry, 51:7879–788.

Bhujel, R.B., Rana, C.B., Mahat, P.M., Subedi, S., Shrestha, L.L. 2014. Evaluation of bean (*Phaseolous vulgaris* L.) as an important pulse and cash crop in Jumla and similar high hills region of Nepal. – Proceedings of the 27th National Summer Crops Workshop, Nepal Agricultural Research Council, pp. 22–27.

Choudhary, N., Bawa, V., Paliwal, R., Singh, B., Bhat, M.A., Mir, J.I., Gupta, M., Sofi, P.A., Thudi, M., Varshney, R.K., Mir, R.R. 2018. Gene/QTL discovery for Anthracnose in common bean (*Phaseolus vulgaris* L.) from North-western Himalayas. – PLoS One, 13(2):p.e0191700. DOI: 10.1371/journal.pone.0191700

Choung, M.G., Choi, B.R., An, Y.N., Chu, Y.H., Cho, Y.S. 2003.Anthocyanin profile of Korean cultivated kidney bean (*Phaseolus vulgaris* L.). – Journal of Agricultural and Food Chemistry, 51:7040–7043.

CIAT. 1987. Inform annual 1987: Bean Program. – Working Paper 72. CIAT, CIAT African Workshop Series, Colombia.

Costa, G.E.A., Queiroz-Monici, K.S., Reis, S.M.P.M., Oliveira, A.C.2006. Chemical composition, dietary fibre and resistant starch contents ofraw and cooked pea, common bean, chickpea and lentil legumes. – Food Chemistry, 94:327–330.

Das, M.K., Rajaram, S., Mundt, C.C., Kronstad, W.E. 1992. Inheritance of slow-rusting resistance to leaf rust in wheat. – Crop Science, 32(6):1452–1456. DOI: 10.2135/cropsci1992.0011183X003200060028x

Geetha, S.B., Subbareddy, S., Satishchandra, P., Moses, R., Chandra, S. 2013. Morphological and molecular screening of French bean (*Phaseolus vulgaris* L.) germplasm using SCAR markers for *Colletotrichum lindemuthianum* (Sacc. and Magn.) Scrib. causing anthracnose resistance. – Archives of Phytopathology and Plant Protection, 46(1):84–97. DOI: 10.1080/03235408.2012.734717

Gomez, K.A., Gomez, A.A. 1984.Statistical procedures for agricultural research. – John Wiley & Sons.

Gonçalves-Vidigal, M.C., Gilio, T.A.S., Valentini, G., Vaz-Bisneta, M., VidigalFilho, P.S., Song, Q., Oblessuc, P.R., Melotto, M. 2020. New Andean source of resistance to anthracnose and angular leaf spot: Fine-mapping of disease-resistance genes in California Dark Red Kidney common bean cultivar. – PloS one, 15(6):p.e0235215. DOI: 10.1371/journal.pone.0235215

Granito, M., Palolini, M., Perez, S. 2008. Polyphenols and antioxidant activity of *Phaseolus vulgaris* stored under extreme conditions and processed. – LWT, 41:994–999.

Inglis, D.A., Haedorn, D.J., Rand, R.E. 1988. Use of dry inoculums to evaluate beans for resistance to anthracnose and angular leaf spot. – Plant Disease, 72:771–774. DOI: 10.1094/PD-72-0771

Joshi, D., Hooda, K.S., Bhatt, J.C., Mina, B.L., Gupta, H.S. 2009. Suppressive effects of composts on soil-borne and foliar diseases of French bean in the field in the western Indian Himalayas. – Crop Protection, 28(7):608–615.

Kelly, J.D., Vallejo, V.A. 2004. A comprehensive review of the major genes conditioning resistance to anthracnose in common bean. – HortScience, 39(6): 1196–1207.

Kutos, T., Golob, T., Kac, M., Plestenjak, A. 2003. Dietary fibre content of dry and processed beans. – Food Chemistry, 80:231–235

Lin, L.Z., Harnly, J.M., Pastor-Corrales, M.S. Luthria, D.L. 2008. Thepolyphenolic profiles of common beans (*Phaseolus vulgaris* L.). – Food Chemistry, 107:399–410.

Magar, P.B., Khatri-Chhetri, G.B., Shrestha, S.M., Rijal, T.R. 2015. Screening of maize genotypes against southern leaf blight (*Bipolaris maydis*) during summer in Rampur, Chitwan, Nepal. – Journal of the Institute of Agriculture and Animal Science, 33–34: 115–122.

Mahuku, G.S., Riascos, J.J. 2004. Virulence and molecular diversity within Colletotrichum lindemuthianum isolates from Andean and Mesoamerican bean varieties and regions. – European Journal of Plant Pathology, 110(3):253–263. DOI: 10.1023/B:EJPP.0000019795.18984.74

Manandhar, H.K., Timila, R.D., Sharma, S., Joshi, S., Manandhar, S., Gurung, S.B., Sthapit, S.R., Palikhey, E., Pandey, A., Joshi, B.K., Manandhar, G. 2016. A field guide for identification and scoring methods of diseases in the mountain crops of Nepal. – Bioversiy International, NARC, DoA and LI-BIRD, Nepal, pp. 1–186.

Miller-Butler, M.A., Smith, B.J., Curry, K.J., Blythe, E.K. 2019. Evaluation of detached strawberry leaves for anthracnose disease severity using image analysis and visual ratings. – HortScience, 54(12):2111–2117. DOI: 10.21273/HORTSCI14321-19

Muimba-Kankolongo, A. 2018. Leguminous Crops. In Food Crop Production by Smallholder Farmers in Southern Africa, pp. 173–203.

Nkalubo, S. 2006. Study of anthracnose (*Colletotrichum lindemuthianum*) resistance and its inheritance in Ugandan dry bean germplasm. – M.Sc. Thesis, University of Kwazulu-Natal Pietermantz burgh, South Africa.

Opio, M.F., Mawejje, D., Nkalubo, S. 2006. Progress report on bean anthracnose research in Uganda. – MUARICbulletin.

Pastor-Corrales, M.A., Otoya, M.M., Molina, A., Singh, S.P. 1995. Resistance to Colletotrichum lindemuthianum isolates from Middle America and Andean South America in different common bean races. – Plant Disease, 79:63–67.DOI: 10.1094/PD-79-0063

Prasad, R.C., Paudel, M.N., Ghimire, N.H., Joshi, B.K. 2016. Cultivar mixtures in bean reduced disease infection and increased grain yield under mountain environment of Nepal. – Agronomy Journal of Nepal, 4:128–135.

Sathe, S.K. 2002. Dry bean protein functionality. – Critical Reviews in Biotechnology, 22(2):175–223. DOI: 10.1080/07388550290789487

Schwartz, H.F., Pastor-Corrales, M.A.1989. Bean Production Problems. – Colombia: CIAT.

Sharma, P.N., Kumar, A., Sharma, O.P., Sud, D., Tyagi, P.D. 1999. Pathogenic variability in *Colletotrichum lindemuthianum* and evaluation of resistance in *Phaseolus vulgaris* in the north-western Himalayan region of India. – Journal of Phytopathology, 147(1): 41–45.

Sharma, P.N., Kajal, B., Rana, J.C., Ruby, N., Sharma, S.K., Anju, P. 2012. Screening of common bean germplasm against *Colletotrichum lindemuthianum* causing bean anthracnose. – Indian Phytopathology, 65(1):99–102.

Siddiq, M., Ravi, R., Dolan, K.D. 2010. Physical and functional characteristics of selected dry bean (*Phaseolus vulgaris* L.) flour. – LWT-Food SciTechnol, 43:232–237.

Singh, A., Singh, A.P., Ramaswamy, H. S. 2015. Effect of processing conditions on quality of green beans subjected to reciprocating agitation thermal processing. – Food Research International, 78:424–432. DOI:10.1016/j.foodres.2015.08.040

Subba, S., Poudel, P.K., Kharel, G.P. 2016. Study on phytochemicals present in Jumli Simee and effect of cooking on them. – Golden Gate Journal of Science & Technology, 1–8.

Tesfaye, B., Pretorius, Z.A. 2005. Seed treatment and foliar application of fungicide for the control of bean anthracnose. – Pest management journal of Ethiopia, 9:57–62.

Tu, J.C. 1986. A detached leaf technique for screening beans (*Phaseolus vulgaris* L.) in vitro against anthracnose (*Colletotrichum lindemuthianum*). – Canadian Journal of Plant Science, 66(3):805–809. DOI: 10.4141/cjps86-100

Viriyasuthee, W., Saksirirat, W., Saepaisan, S., Gleason, M.L., Jogloy, S. 2019. Variability of Alternaria leaf spot resistance in Jerusalem artichoke (*Helianthus tuberosus* L.) accessions grown in a humid tropical region. – Agronomy, 9(6):268. DOI: 10.3390/agronomy9060268

Wheeler, B.E.J. 1969. An introduction to Plant diseases. – John Wiley and Son Ltd, London, 374 p.

Wondwosen, W., Dejene, M., Tadesse, N., Ahmed, S. 2019. Evaluation of faba bean (*Viciafaba* L.) varieties against faba bean gall disease in North Shewa Zone, Ethiopia. – Review of Plant Studies, 6(1):11–20. DOI:10.18488/journal.69.2019.61.11.20

Yesuf, M., Sangchote, S. 2007. Survival and transmission of *Colletotrichum lindemuthianum* from naturally infected common bean seeds to the seedlings. – Tropical Science, 47(2):96–103.

Zebire, D.A., Tadesse, K.A. 2018. Evaluation of faba bean (*Vicia faba* L.) varieties for yield and reaction to chocolate spot disease at Chencha, Southern Ethiopia. – African Journal of Plant Science, 12(8):155–163. DOI: 10.5897/AJPS2017.1557

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EFFECT OF DIFFERENT LEVELS OF NITROGEN AND FARMYARD MANURE ON THE GROWTH AND YIELD OF SPINACH (*Spinacia oleracea* L.)

Parbati Thapa[1], Ram Kumar Shrestha[1], Kishor Kafle[1], Jiban Shrestha[2]

[1]Institute of Agriculture and Animal Science, Lamjung Campus, Sundarbazar 07, Sundarbazar Municipality, 33600, Nepal
[2]Nepal Agricultural Research Council, National Plant Breeding and Genetics Research Centre, Khumaltar15, Lalitpur Metropolitan City, 44700, Nepal

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Vastutav autor: Corresponding author: Parbati Thapa

E-mail:
parbatimgr03@gmail.com (PT)
shresthark_2004@yahoo.com (RKS)
kaflekishor999@gmail.com (KK)
jibshrestha@gmail.com (JS)

ORCID:
0000-0002-7543-9072 (PT)
0000-0003-0809-055X (RKS)
0000-0001-9483-103X (KK)
0000-0002-3755-8812 (JS)

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ABSTRACT. The application of nitrogen (N) and farmyard manure (FYM) greatly affects the growth and production of spinach. The objective of this study was to evaluate the effect of various levels of nitrogen and farmyard manure on the growth and yield of spinach. This study was conducted in the research field of the Institute of Agriculture and Animal Science, Lamjung, Sundarbazar, Lamjung, Nepal from November 2019 to January 2020. The treatments were: 0 kg N ha^{-1}, 30 kg N ha^{-1}, 60 kg N ha^{-1}, 60 kg N ha^{-1} + 10 t FYM ha^{-1}, 60 kg N ha^{-1} + 20 t FYM ha^{-1}, 90 kg N ha^{-1} and 120 kg N ha^{-1}. These treatments were laid out in a randomized complete block design (RCBD) with three replications. The results showed that higher N levels gave better results for all parameters studied. The increasing N fertilization rates increased the vegetative characters and yield of spinach. The maximum plant height (22.68 cm), leaf width (6.69 cm), number of leaves (12.93), fresh weight of leaves (17.07 g) and leaf length (14.94 cm) were recorded with the application of the highest level of nitrogen (120 kg N ha^{-1}). The spinach yield (3.2 t ha^{-1}) was the highest with the application of 120 kg N ha^{-1}. However, the growth and yield traits were not significantly differed with the application of 60 kg N ha^{-1} + 20 t FYM ha^{-1}. Therefore, this study suggests that spinach production can be maximized by the application of 60 kg N ha^{-1}+ 20 t FYM ha^{-1}.

Introduction

Soil fertility is one of the key factors that have a direct effect on the yield of horticultural crops (Sherchan, Karki, 2006). Spinach (*Spinacia oleracea* L.) due to its shallow root system is more susceptible to nutrient deficiency than any other crops (Schenk *et al*., 1991). Heavy feeder Spinach demands high nutrients nitrogen (N) in particular, to grow rapidly and to ensure a high and profitable yield (Zaman *et al*., 2018). The productivity of spinach in Nepal (10.10 t ha^{-1}) is comparatively lower than that of its neighbouring countries (MOALD, 2017). Inadequate application of the nutrients including N and organic matter in the soil is believed to be the main reason for low spinach yields in Nepal (Sherchan, Karki, 2006).

Nitrogen is one of the most yield-limiting nutrients in plants (Dehariya *et al*., 2019). It is a constituent of protein that builds cell material and chlorophyll which are known to enable photosynthesis. This most vital biochemical process accelerates the growth process in spinach (Torres-Olivar *et al*., 2014). Smolders and Merckx (1992) demonstrated the linear relationship between the relative growth rate and the N level in the spinach for exponentially growing plants. Abdelraouf (2016) and Zaman *et al.* (2018) found that higher N levels resulted in a higher number of leaves, leaf area,

plant height, and yield in spinach. Different Iranian spinach varieties also showed significantly greater vegetative attributes and yield attributes at the application of higher N compared to no application of N (Ahmadi *et al*., 2010). When N deficiency occurs, it affects the function of enzymes, causes the breakdown of nucleic acids and proteins, hastens senescence, and inhibits plant growth resulting in reduced quality and quantity of spinach. N deficiency in spinach plants is often expressed as stunted growth and leaf yellowing (Torres-Olivar *et al*., 2014). The amount of N and chlorophyll per unit leaf area was decreased by 60% by N deficit in spinach (Evans, Terashima, 1988). There was a two-fold decrease in the number of leaves per plant in the control application of N compared to 130 kg N ha^{-1}(Shormin, Kibria, 2018). The deficiency of N in the plant can be attenuated by the application of inorganic and organic sources of N into the soil. Mineral nutrients due to their readily available N are widely popular. Readily available farmyard manure (FYM) in rural areas for marginal farmers contains all the nutrients needed for crop growth including N (0.5–1.5%) is also used widely for soil N fertility enhancements. Along with N, FYM makes other elements more readily available to the plants increasing soil fertility status of soil (El-Habet, 2018).

Most Nepalese farmers have low financial resources to purchase a sufficient amount of inorganic fertilizers to supply N nutrients adequately which hinder achieving the desired yield. Further, financially well-being farmers lack proper knowledge about the optimum dosages of N fertilization in spinach. They tend to rely on the misconception of using higher dosages of N fertilizer for higher productivity. This irrational use of N causes toxic compound accumulation on edible products which may be harmful to humans and cause environmental pollution. Moreover, it increases the cost of production and causes economic loss (Canali *et al*., 2008). Thus, knowledge of the judicious use of N is required to overcome these challenges. A study by Hashimi *et al*. (2019) indicated that application of the N and FYM singly or combined on soil improve soil N and positively influenced the overall growth parameters and yield parameters in spinach. However, little research is conducted on the effective level of N usages for spinach in the context of Nepal. So, it is best to have rational knowledge about the optimum dosage of N fertilizer as well as look for an alternative approach to alleviate such problems.

The objective of this study was to determine the effects of different levels of nitrogen and FYM on vegetative growth and yield characteristics of the spinach plant.

Materials and Methods

Description of the study area

This experiment was carried out in the research field of the Institute of Agriculture and Animal Science (IAAS), Lamjung Campus, Sundarbazar, Lamjung, Nepal from November 1 2019 to January 1 2020 to investigate the effect of N and FYM on the growth and yield of spinach plant. The research field is located at 28.13°N latitude, 84.42°E longitude and 630.02 m altitude. The maximum and the minimum temperature recorded during the experiment was given in Figure 1. Similarly, the average relative humidity and rainfall were 44%, and 3 mm respectively.

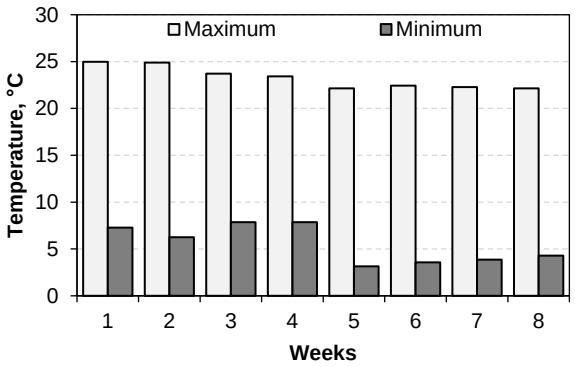

Figure 1. Meteorological data during the experiment (November 1, 2019, to January 1, 2020).

Baseline soil samples were taken from the different homogenous units of the field by driving the auger to a plough depth of 15 cm. 20 samples were collected and thoroughly mixed and foreign materials like roots, stones, pebbles and gravels were removed. Then the thoroughly mixed sample was divided into four equal parts. The two opposite quarters were discarded and the remaining two quarters were remixed out until we reached the required amount of sampled soil. Finally, it was air-dried under room conditions and the sample was analyzed at National Soil Science Research Centre, Khumaltar, Lalitpur, Nepal for soil physicochemical analysis (Table 1).

Table 1. Soil physical and chemical properties of the experimental site

Soil Component	Values	Remarks
pH	5.93	Acidic
N%	0.18	Medium
P, kg ha^{-1}	35.5	Medium
K, kg ha^{-1}	1098.8	High
OM	3.63	Medium
Sand	56.0	
Slit	29.7	
Clay	14.3	
Soil texture	Sandy Loam	

Description of experimental materials

The spinach variety 'All Green' was used for the experiment. This variety can be grown 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 was obtained from the same Agrovet.

Treatments, experimental design and cultural practices

There were seven different levels of treatments: T1: 0 kg N ha^{-1}, T2: 30 kg N ha^{-1}, T3: 60 kg N ha^{-1}, T4:

60 kg N + 10 t FYM ha^{-1}, T5: 60 kg N + 20 t FYM ha^{-1}, T6: 90 kg N ha^{-1}and T7: 120 kg N ha^{-1}. The area of 98 m^2 field was divided into 21 plots with each plot having an area of 4 m^2 and the spacing between each plot was 0.5 m. Three replications of the treatments were arranged in Randomized complete block design (RCBD). Before sowing seeds of spinach var. (30 × 20 cm spacing), P (20 kg ha^{-1}; Di-Ammonium Phosphate) and K (40 kg ha^{-1}; Murate of Potash) and 50% of N (Urea and Di-Ammonium Phosphate) and as per treatment listed full dosages of FYM was supplied. The remaining N (Urea) was supplied in equal proportion in the 2nd and 4th weeks after sowing as per treatment level. The farmyard manure (FYM) used in this experiment was cattle FYM. It was matured after 5 months of decomposition. The FYM consisted of 1.33% total nitrogen, 0.23% available phosphorous, 0.5% K_2O, 2.38% exchangeable K, 0.14% exchangeable Fe, 0.78% exchangeable Ca and 0.38% exchangeable Mg.

Data observation

Fifty-six days after sowing, observations were carried out in randomly selected five plants per plot in the following parameters: plant height (cm), number of leaves per plant, leaf length (cm), leaf width (cm), leaf fresh weight per plant (g), yield per hectare (t ha^{-1}) (Eq. 1). The plant height was measured as a distance from the ground level to the maximum vertical point of the foliage. The leaf length was measured as the distance between the petiole and leaf apex. Leaf width was measured as the average of three expansions in the 25%, 50%, and 75% parts of the leaf.

The fresh weight of leaves was taken and yield per hectare was computed by using the following formula:

$$\text{Yield, t ha}^{-1} = \frac{\text{Leaves weight, g plant}^{-1} \times \text{total plant popul. ha}^{-1}}{1000 \times 1000} \quad (1)$$

Data analysis

Data were recorded and entered into MS-Excel 2016. The data were analyzed using SPSS 16.0 and R studio. Data were statistically analyzed according to RCB design, One-way ANOVA was used to analyze data. The differences among treatments were separated using Duncan at a 5% level of significance.

Results and Discussion

Growth Attributes

Table 2 illustrates the results of the effects of various levels of N and FYM on plant height, number of leaves, leaf length and leaf width. Plants were the tallest at 120 kg N ha^{-1} (22.68 cm) and the value was not significantly different from those at 90 kg N ha^{-1}, 60 kg N + 20 t FYM ha^{-1}. More or less similar trends appeared in the case of the number of leaves and leaf length in the plants. In 8th weeks after sowing, the significantly higher no. of leaves (12.93) was observed when the plants were grown with 120 kg N ha^{-1} which was statistically par with 90 kg N ha^{-1} (12.16) and 60 kg N + 20 t FYM ha^{-1} (11.4). Leaf length was also found the longest at 120 kg N ha^{-1} (14.94cm) which was statistically par with 90 kg N ha^{-1} and 60 kg N + 20 t FYM ha^{-1}. Similarly, significantly wider leaves were observed at 120 kg N ha^{-1} (6.69 cm) which was statistically par with 90 kg N ha^{-1} (5.94 cm), 60 kg N + 20 t FYM ha^{-1} (5.39 cm) and 60 kg N + 10 t FYM ha^{-1} (5.35 cm). Hence, the values for these parameters improved with the addition of the nutrients tended to level off at 60 kg N+ 20 t FYM ha^{-1}. Compared to the Control of no N and FYM application, an increase in the value of mean plant height and mean number of the leaves were found to be 40% and 68% higher at 60 kg N + 20 t FYM ha^{-1}. Similarly, mean leaf length and mean leaf width was found to be 56% and 14% higher respectively at 60 kg N + 20 t FYM ha^{-1} over control treatment of no nutrient addition.

Table 2. Effect of different levels of nitrogen and FYM on the growth attributes of spinach (*Spinacia oleracea* L.)

Treatments	Plant height, cm	No. of leaves	Leaf length, cm	Leaf width, cm	Fresh weight per leaf, g	Yield, t ha^{-1}
0 kg N ha^{-1}	15.18 ± 2.76^{c}	6.77 ± 1.38^{d}	7.62 ± 1.90^{d}	4.65 ± 0.93^{c}	8.94 ± 1.82^{d}	1.68 ± 0.34^{d}
30 kg N ha^{-1}	16.35 ± 2.36^{bc}	8.55 ± 1.52^{cd}	8.41 ± 2.57^{cd}	5.02 ± 1.49^{bc}	11.29 ± 2.00^{cd}	2.12 ± 0.37^{cd}
60 kg N ha^{-1}	19.17 ± 1.80^{ab}	9.79 ± 1.23^{bc}	9.68 ± 0.83^{cd}	5.28 ± 0.74^{ab}	12.92 ± 1.63^{bc}	2.42 ± 0.30^{bc}
60 kg N +10 t FYM ha^{-1}	20.01 ± 1.40^{ab}	10.13 ± 2.61^{bc}	10.73 ± 2.26^{bcd}	5.35 ± 1.09^{ab}	13.37 ± 3.44^{bc}	2.51 ± 0.64^{bc}
60 kg N + 20tFYM ha^{-1}	21.28 ± 1.80^{a}	11.40 ± 0.91^{ab}	11.91 ± 1.72^{ab}	5.39 ± 0.29^{a}	15.04 ± 1.20^{ab}	2.82 ± 0.22^{ab}
90 kg N ha^{-1}	21.67 ± 2.05^{a}	12.16 ± 1.18^{ab}	13.50 ± 1.35^{ab}	5.94 ± 1.56^{ab}	16.06 ± 1.56^{ab}	3.01 ± 0.29^{ab}
120 kg N ha^{-1}	22.68 ± 1.47^{a}	12.93 ± 0.61^{a}	14.94 ± 1.37^{a}	6.69 ± 1.32^{a}	17.07 ± 0.80^{a}	3.20 ± 0.15^{a}
Mean	19.48	10.25	10.97	5.47	13.53	2.53
SEM±	4.17	2.00	3.50	1.20	0.986	0.184
CV %	10.48	13.82	17.06	19.99	12.60	12.60
LSD (0.05)	3.63	2.52	3.33	1.95	3.039	0.569
F test	**	**	**	**	**	**

Means in a column followed by different lowercase letter/s are significantly different according to Duncan multiple range test at P = 0.05. ** Highly significant at 0.01 level of significance, SEM± – standard error of the mean, CV – coefficient of variation. Mean in a column followed by ± standard deviation.

The obtained results align with the findings of Mirdad (2009) where plant height and number of leaves per plant with the addition of high N level resulted in significant increments in these characters of spinach plants. Similarly, Zaman *et al.*(2018), Solangi *et al.* (2015) and Shormin and Kibria (2018) recorded taller plant height and higher number of leaves per plant with the higher application of 150 kg N ha^{-1} compared to other lower levels of N treatment. Zheng (2009) reported that N plays a pivotal role in cellular carbon

and N metabolism, which must be tightly coordinated to sustain optimal growth and development for plants. Application of N to spinach might have favoured vegetative growth increasing plant vigour and shoot growth rate increasing spinach growth attributes overall. Nevertheless, beyond the optimum level of N, it will be harmful to plants as it creates osmotic imbalances due to luxury nitrogen absorption (nitrogen accumulation) in plant tissue leading to toxic effects of nitrates on the plants (Ng'etich *et al*., 2014). It also can create favourable conditions for the development of various diseases due to its lush foliage and succulent (Torres-Olivar *et al*., 2014). Gülser (2005), Nemadodzi *et al* (2017) and Rodríguez-Hidalgo *et al*. (2010) reported that N treated plant has significantly higher leaf length compared to no nutrient treatments. Cytological development and differentiation for the development of the leaf are dependent on the availability of N and it has a significant effect on the leaf size (Roggatz *et al*., 1999). Thus, the observed increase in leaf length might be due to adequate N for plant growth rate. Also, a significant response was shown in leaf width at a different level of N treatments and the highest leaf width value was obtained at 120 kg N ha^{-1} (6.69 cm). Güsewell (2004) suggested that adequate input of N increases the level of cytokinin in the plant. This increased level of cytokinin may have stimulated shoot growth rate resulting in leaf length and leaf breadth of the plant. Our findings confirm with Cruz and Boval (2009) where leaf width increases along with nutrient increment.

Crop yield

The results showed the significant differences ($P<0.01$) were observed in the fresh weight of leaves and yield of spinach at different levels of treatments. However, the significantly higher fresh weight observed in 120 kg N ha^{-1} (17.07 g) compared to control, showed non-significant differences with 90 kg N ha^{-1} (16.06 g) and 60 kg N + 20 t FYM ha^{-1} (15.04 g) (Table 2). Concomitant to the fresh yield, spinach yield was obtained significantly higher at treatment 120 kg N ha^{-1} (3.20 t ha^{-1}) over control treatment but was significantly par with a yield of 90 kg N ha^{-1} (3.01 t ha^{-1}) and 60 kg N + 20 t FYM ha^{-1} (2.82 t ha^{-1}) (Table 2). These results indicated that adding nutrients to boost yield trait has a beneficial impact to some degree, but that it eventually levels out at 60 kg N + 20 t FYM ha^{-1}. The increase in the yield and fresh weight of spinach at 60 kg N + 20 t FYM ha^{-1} were 67.8% and 68.2% higher compared to control where the application of N and FYM was not done.

These results are in line with Zaman *et al.*(2018) where they showed an increase in fresh weight of leaves and yield along with increasing N fertilizer rates, which was added to the spinach plants. The highest weight of the fresh leaves and yield was observed at 240 kg N ha^{-1}. Similar to our findings, Hashimi *et al.* (2019) reported that spinach yield was significantly higher than other lower level N treatments, but no significant difference was observed at 150 kg N ha^{-1} and 5 t CM + 80 kg N ha^{-1}, concluding that the non-significant difference in yield is correlated with increased N nutrients supply from FYM source. This is supported by Sajirani *et al*. (2012) where they reported a higher yield in spinach in the combination of N and FYM. Conforming preceding statements, Stagnari *et al*. (2007) result showed that N fertilizers significantly increased yield concerning the untreated control even when sources were different. Since photosynthesis rates are N-dependent, an increase in photosynthetic rates has a direct impact on plant growth and biomass accumulation (Zheng, 2009). This rapid plant growth may have resulted in significantly increased plant height, the number of leaves, and the fresh weight of leaves, all of which led to increased yield. But the application of N above the optimum level may not improve the crop growth, or even damages the plant. Greenwood *et al.* (1980) indicated that although the yield of each crop initially increased with an increase in N fertilizer compared to the control, the yield later remained the same or decline with further increment.

Conclusion

The growth and yield of spinach were influenced by different levels of nitrogen and FYM. The increasing application rate of N fertilization up to 120 kg N ha^{-1} increased the growth and yield of spinach, however, these traits are not significantly differed from the application of 60 kg N + 20 t FYM ha^{-1}. Therefore, the application of 60 kg N + 20 t FYM ha^{-1} was found to be the optimum level for the cultivation of spinach.

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Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions

PT – study conception and design, analysis and interpretation of data, literature search, drafting of the manuscript and approval of the final manuscript.
RKS, KK, JS – critical revision on the initial draft and approval of the final manuscript.
All the authors read and approved the final manuscript.

References

Ahmadi, H., Akbarpour, V., Shojajaeian, A. 2010. Effect of different levels of nitrogen fertilizer on yield, nitrate, accumulation and several quantitative attributes of five Iranian spinach accessions. – American-Eurasian Journal of Agricultural and Environmental Science, 8(4):468–473.

Abdelraouf, E.A.A. 2016. The effects of nitrogen fertilization on yield and quality of spinach grown in

high tunnels. – Alexandria Science Exchange Journal: An International Quarterly Journal of Science Agricultural Environments, 37:488–496. DOI: 10.21608/asejaiqjsae.2016.2517

Canali, S., Montemurro, F., Tittarelli, F., Masetti, O. 2008. Effect of nitrogen fertilization reduction on yield, quality and N utilisation of processing spinach. – Journal of Food, Agriculture and Environment, 6(3–4):242–247.

Cruz, P., Boval, M. 2009. Effect of nitrogen on some morphogenetic traits of temperate and tropical perennial forage grasses. In Grassland Ecophysiology and Grazing Ecology (Eds.G. Lemaire, J. Hodgson, A. de Moraes, C. Nabinger, P.C.deF., Carvalho).– CABI PublishingUK, pp. 151–168. DOI: 10.1079/9780851994529.0151

Dehariya, P., Mishra, D. K., Dhakad, R., Kumar, A. 2019. Studies on Different Levels of Nitrogen Application on Growth and Yield of Amaranthus (*Amaranthus tricolor* L.). – International Journal of Current Microbiology and Applied Sciences, 8(04): 1423–1427. DOI:10.20546/ijcmas.2019.804.165

El-Habet, H. 2018. Effect of organic and inorganic fertilizers on rice and some nutrients availability under different water regimes. – Journal of Agricultural Science and Food Research, 9(4):1–16.

Evans, J.R., Terashima, I. 1988. Photosynthetic characteristics of spinach leaves grown with different nitrogen treatments. – Plant and Cell Physiology, 29(1):157–165. DOI: 10.1093/oxfordjournals.pcp.a077462

Greenwood, D.J., Cleaver, T.J., Turner, M.K., Hunt, J., Niendorf, K.B., Loquens, S.M.H. 1980. Comparison of the effects of potassium fertilizer on the yield, potassium content and quality of 22 different vegetable and agricultural crops. – The Journal of Agricultural Science, 95(2):441–456. DOI: 10.1017/S0021859600039496

Gülser, F. 2005. Effects of ammonium sulphate and urea on NO_3- and NO_2-accumulation, nutrient contents and yield criteria in spinach. – Scientia Horticulturae, 106(3):330–340. DOI: 10.1016/j.scienta.2005.05.007

Güsewell, S. 2004. N :P ratios in terrestrial plants : variation and functional significance. – New Phytologist, 164(2):243–266.

Hashimi, R., Afghani, A.K., Karimi, M.R. 2019. Effect of organic and inorganic fertilizers levels on spinach (*Spinacia oleracea* L.) production and soil properties in Khost Province, Afghanistan. – International Journal of Applied research, 5(7):83–87.

Mirdad, Z.N. 2009. Spinach (*Spinacia oleracea* L.) growth and yield responses to irrigation dates, mineral nitrogen-sources and levels–application. – Journal of Agriculture and Environmental Science, 8(1):43–69.

MOALD. 2017. Statistical Information in Nepalese Agriculture. Ministry of Agriculture and Livestock, 290. https://nepalindata.com/resource/statistical-information-nepalese-agriculture-207374-201617/ Accessed on 07/06/2021.

Nemadodzi, L.E., Araya, H., Nkomo, M., Ngezimana, W., Mudau, N.F. 2017. Nitrogen, phosphorus, and potassium effects on the physiology and biomass yield of baby spinach (*Spinacia oleracea* L.). – Journal of Plant Nutrition, 40(14):2033–2044. DOI: 10.1080/01904167.2017.1346121

Ng'etich, O.K., Aguyoh, J.N., Ogweno, J.O. 2014. The effect of integrated application of farmyard manure and calcium ammonium nitrate on growth and yield attributes of African nightshade (*Solanum Scabrum* Mill.). – Asian Journal of Agriculture and Food Science, 02(02):158–165.

Rodríguez-Hidalgo, S., Artés-Hernández, F., Gómez, P.A., Fernández, J.A., Artés, F. 2010. Quality of fresh-cut baby spinach grown under a floating trays system as affected by nitrogen fertilization and innovative packaging. – Journal of the Science of Food and Agriculture, 90(6):1089–1097. DOI: 10.1002/jsfa.3926

Roggatz, U., McDonald, A.J.S., Stadenberg, I., Schurr, U. 1999. Effects of nitrogen deprivation on cell division and expansion in leaves of *Ricinus communis* L. – Plant, Cell and Environment, 22(1):81–89. DOI:1046/j.1365-3040.1999.00383.x

Sajirani, E.B., Shakouri, M.J., Mafakheri, S. 2012. Response of spinach (*Spinacia oleracea*) yield and nutrient uptake to urea and manure. – Indian Journal of Science and Technology, 5(1):1953–1955. DOI:10.17485/ijst/2012/v5i1.27

Schenk, M., Heins, B., Steingrobe, B. 1991. The significance of root development of spinach and kohlrabi for N fertilization. – Plant and Soil, 135(2):197–203. DOI: 10.1007/BF00010907

Sherchan, D.P., Karki, K.B. 2006. Plant nutrient management for improving crop productivity in Nepal. – Food and Agriculture Organization, Improving Plant Nutrient Management for Better Farmer Livelihoods, Food Security and Environmental Sustainability, p.257.

Shormin, T., Kibria, M. G. 2018. Effects of nitrogen from different inorganic fertilizers on growth and yield of indian spinach (*Basella Alba* L.). IOSR Journal of Pharmacy and Biological Sciences, 13(5): 43-48.

Smolders, E., Merckx, R. 1992. Growth and shoot:root partitioning of spinach plants as affected by nitrogen supply. – Plant, Cell and Environment, 15(7):795–807. DOI: 10.1111/j.1365-3040.1992.tb02147.x

Solangi, M., Suthar, V., Wagan, B., Siyal, A.G., Sarki, A., Soothar, R.K.2015. Evaluate the effect of nitrogen and phosphorus fertilizer doses on growth and yield of spinach (*Spinacia Oleracea* L.). –Science international (Lahore), 28(1):379–383.

Stagnari, F., Di Bitetto, V., Pisante, M. 2007. Effects of N fertilizers and rates on yield, safety and nutrients in processing spinach genotypes. – Scientia Horticulturae, 114(4):225–233. DOI: 10.1016/j.scienta.2007.06.016

Torres-Olivar, V., Villegas-Torres, O.G., Domínguez-Patiño, M.L., Sotelo-Nava, H., Rodríguez-Martínez, A., Melgoza-Aleman, R.M., Valdez-Aguilar, L.A, Alia-Tejacal, I. 2014. Role of nitrogen and nutrients in crop nutrition. – Journal of Agricultural Science and Technology B, 4(1B):29–37.

Zaman, Q., Hamid, F., Islam, S., Ahmad, F., Ahmad, N. 2018. Impact of various levels of nitrogen and phosphorus on growth and yield of spinach (*Spinacea oleracea* L.) under conditions of Mansehra (Pakistan). – Open Academic Journal of Advanced Science and Technology, 2(1):5–8. DOI: 10.33094/5.2017.2018.21.5.8

Zheng, Z.L. 2009. Carbon and nitrogen nutrient balance signaling in plants. – Plant Signaling and Behavior, 4(7):584–591. DOI:10.4161/psb.4.7.8540

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JUSTIFICATION OF THE MECHATRONIC SYSTEM FOR PIGSTY MICROCLIMATE MAINTENANCE

Vitalii Yaropud[1], Iryna Hunko[1], Elchyn Aliiev[2], Ihor Kupchuk[1]

[1]Vinnytsia National Agrarian University, 3 Sonyachna St., Vinnytsia, 21008, Ukraine
[2]Dnipro State Agrarian and Economic University, 25 Voroshylova St., Dnipro, 49027, Ukraine

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Vastutav autor: Corresponding author: Ihor Kupchuk

E-mail: kupchuk.igor@i.ua

ORCID:
0000-0003-0502-1356 (VY)
0000-0003-2868-4056 (IH)
0000-0003-4006-8803 (EA)
0000-0002-2973-6914 (IK)

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ABSTRACT. The main parameters of the microclimate of pig farms are regulated by the norms of technological design. Naturally, such microclimate parameters at real energy prices require high costs, but these are the most favourable conditions for the life of suckling piglets. According to the presented analysis, the problem of research is the need to provide a microclimate in the room for comfortable keeping of pigs, which is currently achieved through high energy. The purpose of the development is to increase the efficiency of the microclimate of pig farms by using a mechatronic control system, rational use of utilized air energy and soil thermal potential with reduced energy costs of the ventilation system. The problem is solved by creating such a mechatronic system to ensure the microclimate of pig farms, which can: switch the direction of airflow to ensure the operation of the system in winter and summer; to control the movement of air, which must be disposed of according to the parameters of its quality; to provide a local microclimate in each place where animals are kept; rational use of soil thermal energy as a source of alternative energy; to carry out automatic pumping of the water necessary for humidification of air, and its utilization. The article presents the results of research of parameters of the developed mechatronic system of providing microclimate of pig premises, which were carried out in three stages: research of heat exchanger of side-evaporating type; substantiation of the ventilation system of polluted air intake; substantiation of the ventilation system for injecting clean air taking into account it's geothermal heating/cooling. The advantage of the proposed mechatronic system of the microclimate of pig farms is that it allows increasing the efficiency of microclimate by rational use of energy of utilized air (due to the use of side-evaporator type heat exchanger based on Maisotsenko cycle) and soil heat potential (geothermal energy) at low operating costs of the ventilation system through the additional provision of mechatronic elements. The presented results of numerical simulation of the indirect evaporative heat exchanger allow us to state that the cooling effect obtained in indirect evaporative channels can be quite high in comparison with traditional air conditioning patterns. The presented heat exchanger based on the Maisotsenko cycle (M-cycle) of considered heat carrier flow scheme is characterized by its high cost-effectiveness, low specific cost, small operational costs and structural simplicity, which is confirmed in the works. The models obtained in the Star CCM +software package can be used for optimization analysis of air-cooling with variations in the Reynolds number, humidity, channel length and geometric dimensions of channels. Because of analytical investigations of the contaminated air intake ventilation system, the method was developed and on its basis – the algorithm was implemented for the determination of geometrical arrangement of holes in the air duct of the mechatronic system for pigsty microclimate maintenance.

Introduction

Pigsty microclimate is determined by the combination of air temperature, relative humidity, chemical and mechanical composition. Each of these parameters individually has a significant impact on livestock productivity and should be maintained within a strict framework conditioned by livestock physiological needs and capabilities (Van Wagenberg, 2005; Gunko *et al.*, 2021).

In livestock breeding, microclimate is primarily understood as the climate of livestock building, which is defined as the totality of the air environment's physical state, its gas, microbial and dust contamination, taking into account the state of the building itself and the process equipment. In other words, microclimate means meteorological conditions in closed livestock buildings, the concept of which includes temperature, humidity, chemical composition and air velocity, as well as dust content and illumination intensity. Optimal microclimate allows increasing livestock productivity, reducing the feed expenditures per production unit, contributes to better maintenance of livestock health. Microclimate in the building depends on local (zonal) climate and season, thermal and moisture resistance of buildings' enclosing structures, ventilation conditions, the intensity of the building' illumination and heating, sewerage conditions and manure removal quality, livestock management technology, species and age composition of livestock (Huynh *et al.*, 2005). Basic parameters of pigsty microclimate are regulated by technological designing standards (Godyń *et al.*, 2020). The room temperature for breeding boars should be indoors – from 13 °C to 18 °C, for pregnant sows – from 13 °C to 18 °C, for suckling – from 18 °C to 22 °C, for repair young stock – from 18 °C to 22 °C, for weaned piglets up to 30 days – from 24 °C to 30 °C, in 60 days – 22 °C, for piglets on rearing – from 15 °C to 20 °C, for fattening young animals depending on age – from 12 °C to 20 °C. At local heating of piglets in the first week of life the temperature in a lair should be 30 °C, in the second – 28 °C, in the third – 26 °C, in the fourth – 24 °C, in the fifth – 24 °C. Naturally, such microclimate parameters at real energy prices require high costs, but these are the most favorable conditions for the life of suckling piglets.

At below-critical temperatures, the body has no time to produce heat, based on forage energy, so hypothermia occurs followed by possible colds and even death. At above-critical temperature, convective heat exchange between the body and the environment decreases sharply, so the risk of overheating and heatstroke arises. When temperature conditions are violated (hypothermia, overheating), natural resistance decrease, as well as pulmonary and gastrointestinal diseases are observed (Godyń *et al.*, 2020). However, sharp temperature fluctuations during the day produce a stronger negative impact on the body than permanently elevated or reduced temperatures, and this primarily affects the young stock. Protective humoral factors in first day's livestock are poorly developed, their skin and mucous membranes being very sensitive to pathogenic microbes (Renaudeau *et al.*, 2010).

Ambient humidity also significantly affects livestock body thermoregulation, and particularly its heat elimination, and high relative humidity (85% and above) produces a negative effect on the body and heat elimination at both high and low ambient temperatures (Johnston *et al.*, 2013). High humidity suppresses metabolism and redox processes in the body and reduces pigs' resistance. When livestock is kept in the building with high humidity during the cold season, such diseases as bronchitis, pneumonia, gastrointestinal diseases are often observed in young livestock. High humidity contributes to the preservation of microorganisms, particularly pathogenic and fungal microflora, in the building, this frequently giving rise to skin diseases – ringworm, eczema, scabies and others. In addition, high humidity and low temperature increases the consumption of feed per unit of output, livestock appetite is deteriorating (Kozlovski, 1984).

Air velocity ensures air exchange in the building, enhancing the cooling capacity of the air. Therefore, low air velocities lead to microclimate deterioration, with high ones being able to cause colds at low temperatures (Il'in *et al.*, 2011). Increasing air velocity along animals' body surfaces reduces the "perceived body temperature" – that is, the temperature the animals feel. When using this method, one must monitor the cooling effect, as there is the risk of hypothermia in livestock. Increasing air velocity reduces body temperature, so even during the warm season, one needs to ensure that livestock does not over cool. Normally, excessive air velocity causes drafts. Hence, the evaluation of the cooling effect depending on air velocity is as follows. For 0.2 m s^{-1} air velocity along the animal body, the perceived temperature decrease is 4 °C, for that of 0.5 m s^{-1} – 7 °C, and 1.5 m s^{-1} – 10 °C (Forcada, Abecia, 2019; Song *et al.*, 2013).

In its turn, optimal microclimate maintenance in pigsties is associated with significant heat and electricity consumption, which makes up to 15% of producers' costs. During the heating period, pigsties heat-generating devices for various purposes consume up to 90% of total fuel and energy costs, while in summer air coolers consume up to 50% thereof. In addition, even a partial reduction of these costs will result in a significant reduction in energy-related production expenditures, thus reducing its self-cost. Ever-increasing energy cost complicates the situation and exacerbates the issue of energy-saving technologies implementation, as well as actualizes the economic problem of reducing the specific energy consumption for the manufacture of livestock products (Kaletnik *et al.*, 2020; Braun *et al.*, 2020).

Existing equipment meant for pigsty microclimate maintenance either entirely meets the requirements outlined in the Table 1 while consuming large amounts of energy, or is cost-saving but unable to maintain optimal microclimate parameters (Ivanov, Novikov,

2020). For example, disadvantages of known equipment (Patent UA 129759, 2018) may include the non-use of utilized air's thermal energy and lack of automatic switching of the microclimate system for summer (supply air-cooling) and winter (supply air heating) periods. This leads to an increase in energy consumption for pigsty microclimate maintenance. Except when using this equipment (Patent UA 102567, 2009), utilized air thermal energy is used inexpediently, while this can be used to cool the supplied air in summer and heat the same in winter. Lack of airflow's local regulation does not allow creating an individual microclimate for different livestock groups. Disadvantages of (Patent UA 144887, 2020) and (Patent US 2017/0016645, 2017) equipment include the absence of the system for microclimate parameters' automatic regulation, insufficient degree of airflow cooling and heating, which can be compensated by the use of alternative energy sources. Each of these units operates exclusively to cool or heat the supply airflow, *i.e.* no provision is made for switching between operating modes. In addition, these units' structural and process flow diagrams provide for no automatic pumping of water required for air humidification and its disposal.

According to the presented analysis, the problem of research is the need to provide a microclimate in the room for comfortable keeping of pigs, which is currently achieved through high energy consumption therefore, the development project is aimed at increasing the efficiency of pigsties microclimate by using a mechatronic control system, expedient use of utilized air energy and thermal soil potential (geothermal energy) with reduced energy costs for ventilation system functioning.

The designated problem was solved by the generation of such mechatronic system for pigsty microclimate maintenance, which provides for the opportunity to:

- switch between airflow directions to ensure the system's operation in winter (0 °C) and summer (25 °C) periods;
- control air movement, which must be disposed of according to its quality parameters (hydrogen sulfide, carbon dioxide and ammonia content);
- maintain local microclimate in each stall, where livestock are kept;
- expediently to use thermal soil energy as an alternative energy source;
- carry out automatic pumping of water required for air humidification and its disposal.

Methods

To solve the designated problem, a structural and process flow diagram of the mechatronic system for pigsty microclimate maintenance has been developed (Fig. 1).

The mechatronic system for pigsty microclimate maintenance operates as follows. The operator on control unit (5) sets given ranges of local microclimate parameters (temperature, humidity, airflow rate) for each stall, where livestock are kept. The operator of control unit (5) also sets air quality limits in terms of hydrogen sulfide, carbon dioxide and ammonia content. Next goes the launch of the mechatronic system for pigsty microclimate maintenance. Information on temperature, humidity and air quality values (hydrogen sulfide, carbon dioxide and ammonia) from temperature, humidity and air quality sensors (9), temperature and humidity sensors (14), external temperature and humidity sensors (36) is transmitted to control unit (5) via electrical wire devices (10). These data are compared between each other and with the data set by the operator.

The operator must set the temperature in the pigsty higher than the temperature on the outside of the pigsty (winter period), the control unit transmits a signal to rotating servo-operated rotating valve (18), with the valve having been set to the position that allows connecting contaminated air intake ventilation system (1) with inner working air pipe (20) of the indirect evaporative heat exchanger (3). In its turn, clean air charging ventilation system (2) is connected to inner recycled air pipe (22) of the indirect evaporative heat exchanger (3). Control unit (5) starts blower fan (24) in the direction of air supply from the pigsty to its outer side, and exhaust fan (25) in the opposite direction of air supply from the outside of the pigsty.

Depending on the air quality above the place where the pigs are kept, as determined using temperature, humidity and air quality sensors (9) and the limit values set by the operator, control unit (5) via electrical wires transmits the signal to servo-operated intake valves (8). Measured air quality parameters should be less than the limit values set by the operator, servo-operated intake valve (8) is closed. Otherwise, the servo-operated intake valve (8) opens at an angle that is directly proportional to the corresponding difference between air quality parameters and limit parameters. Air is sucked into air intake nozzles (7) and formed into the stream that moves along central air intake duct (6) of contaminated air intake system (1). Next, the airflow enters nozzles (16) and central cavity (17) of four-way valve (4). After that, the airflow enters inner working air pipe (20) and then to cross-channel set (23) of the indirect evaporative heat exchanger (3). This airflow passes through working channels (26), where it is cooled and its humidity is reduced along with condensate generation. This process occurs due to heat exchange through the walls connecting working channels (26) and wet channels (27). Next, cooling airflow is supplied to the pigsties outside through the outer working air pipe (19).

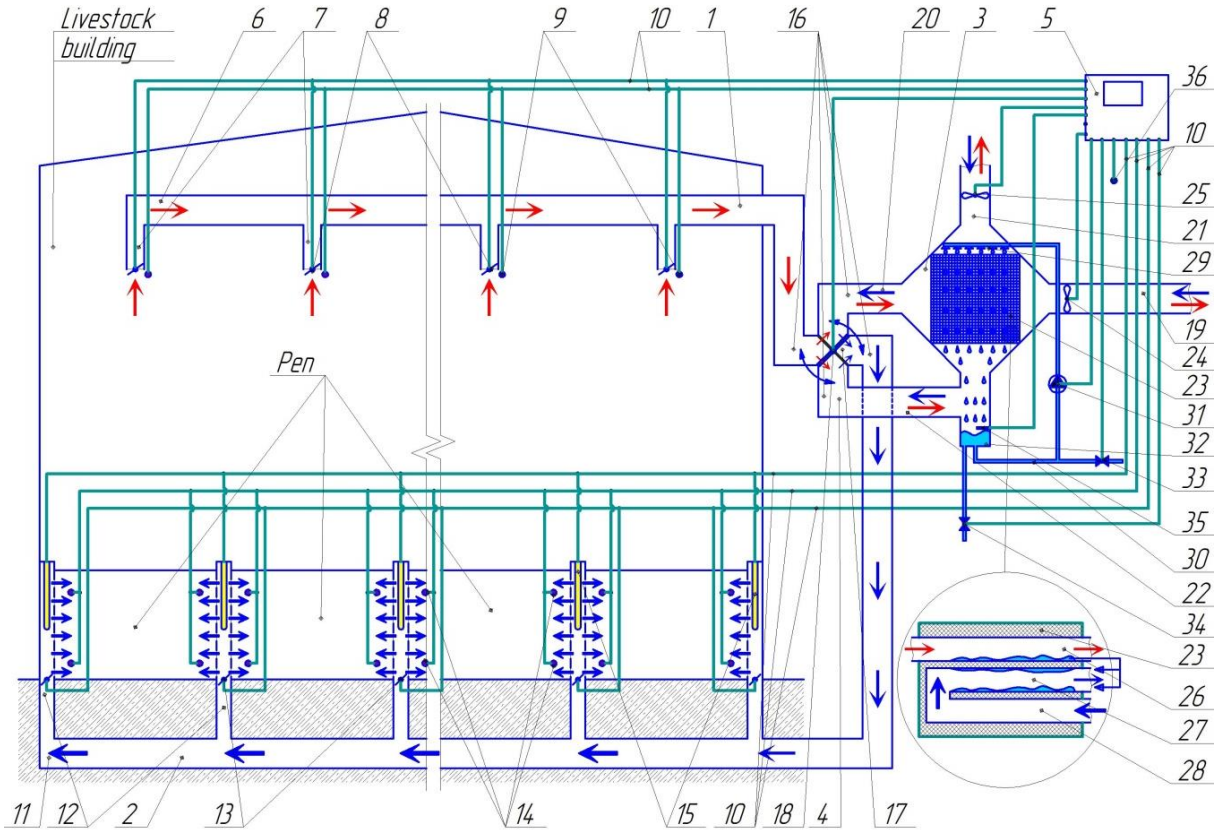

Figure 1. Structural and process flow diagram of the mechatronic system for pigsty microclimate maintenance: 1 – contaminated air intake ventilation system; 2 – clean air charging ventilation system; 3 – indirect evaporative heat exchanger; 4 – four-way valve; 5 – control unit; 6 – central air intake duct; 7 – air intake nozzles; 8 – servo-operated intake valves; 9 – temperature, humidity and air quality sensors; 10 – electrical wires; 11 – central air injection duct; 12 – branch air injection pipes; 13 – servo-operated discharge valves; 14 – temperature and humidity sensors; 15 – heating elements; 16 – nozzles; 17 – central cavity; 18 – servo-operated rotating valve; 19 – outer working air pipe; 20 – inner working air pipe; 21 – outer recycled air pipe; 22 – inner recycled air pipe; 23 – cross-channel set; 24 – blower fan; 25 – exhaust fan; 26 – working channels; 27 – wet channels; 28 – dry channels; 29 – water injection nozzles; 30 – pipeline system; 31 – water pump; 32 – water intake tank; 33 – electromagnetic water top-up valve; 34 – electromagnetic water draining valve; 35 – level sensor; 36 – external temperature and humidity sensors

Simultaneously with the foregoing, cold and dry airflow from the pigsties outside enters the outer recycled air pipe (21). Next, cold and dry air flow moves to cross-channel set (23) of the indirect evaporative heat exchanger (3), where it continues moving first along dry channel (28) and then along wet channel (27). In dry channel (28), cold and dry airflow is heated due to heat exchange through the walls connecting wet channels (27) and dry channels (28), and in wet channel (27) already warm and dry airflow is enriched with moisture, continuing to be heated.

Under the action of gravity, excess moisture flows to the bottom of water intake tank (32). Initially, control unit (5) via electrical wires closes electromagnetic water draining valve (34). In addition, the control unit (5) turns on water pump (31), which supplies collected water from water intake tank (32) and directs the same through pipeline system (30) to water injection nozzles (29). Water from water injection nozzles (29) washes wet channels (27). The water level in water intake tank (32) is determined using level sensor (35), which via electrical wires (10) transmits this information to control unit (5). The water level should be lower than the intended one, the control unit (5) opens electromagnetic water top-up valve (33), and water from the pigsty's water consumption system enters pipeline system (30). Otherwise, the control unit (5) closes electromagnetic water top-up valve (33) and opens electromagnetic water draining valve (34), and the water from water intake tank (32) enters the manure removal system.

After wet channels (27), warm and wet airflow enters inner recycled air pipe (22), which is connected to nozzles (16) and central cavity (17) of four-way valve (4). Next, warm and wet airflow enters central air injection duct (11) where through branch air injection pipes (12) enters the pigsty's middle part directly into the stalls, where livestock is kept. Since central air injection duct (11) is located under the floor below the soil freezing level, the process of geothermal heating of warm and wet airflow additionally occurs.

Information from temperature and humidity sensors (14) via electrical wires (10) is supplied to control unit (5), where it is compared with local microclimate parameters set by the operator for each stall. Where additional airflow heating is required in some particular stall, control unit (5) switches on respective heating element (15) and opens servo-operated discharge valve (13) entirely. Air temperature should be above or equal to the one required, control unit (5) switches off

respective heating element (15) and closes servo-operated discharge valve (13) partially. The servo-operated discharge valve (13) closure degree is directly proportional to the difference between the pre-set and the measured temperature.

Let us consider the case when the temperature pre-set by the operator is lower than the temperature on the pigsty's outside (summer period). The control unit transmits the signal to servo-operated rotating valve (18), which is set to the position that allows connecting contaminated air intake ventilation system (1) with inner recycled air pipe (22) of the indirect evaporative heat exchanger (3). In its turn, clean air charging ventilation system (2) is connected to inner working air pipe (20) of the indirect evaporative heat exchanger (3). Control unit (5) starts blower fan (24) in the direction of air supply from the pigsty's outside to the pigsty's middle part, while exhaust fan (25) does the same in the opposite direction of air supply from the pigsty to its outer side.

Depending on air quality above the stalls, as determined using temperature, humidity and air quality sensors (9) and limit values set by the operator, control unit (5) via electrical wires transmits the signal to servo-operated intake valves (8). Measured air quality parameters should be lower than limit values set by the operator, servo-operated intake valve (8) is closed. Otherwise, the servo-operated intake valve (8) opens at an angle that is directly proportional to the respective difference between air quality values and limit values. Air is sucked into air intake nozzles (7), being formed into the stream that moves along central air intake duct (6) of contaminated air intake system (1). Further, airflow enters nozzles (16) and central cavity (17) of four-way valve (4). After that, airflow enters inner recycled air pipe (22) and then cross-channel set (23) of the indirect evaporative heat exchanger (3). This airflow passes through dry channel (28) and wet channel (27), where it is heated using heat exchange through the walls adjacent to working channel (26). Further, airflow is supplied to the pigsties outside through outer recycled air pipe (21).

Simultaneously with the foregoing, warm and dry airflow from the pigsties outside enters the outer working air pipe (19). Next, warm and dry air flow moves to cross-channel set (23) of indirect evaporative heat exchanger (3), where it continues to flow through working channels (26), where it is cooled and its humidity is reduced along with condensate generation. This process occurs due to heat exchange through the walls that connect working channels (26) and wet channels (27).

Under the action of gravity, excess moisture flows to the bottom of water intake tank (32). Initially, control unit (5) via electrical wires closes electromagnetic water draining valve (34). In addition, control unit (5) turns on water pump (31), which supplies collected water from water intake tank (32) and directs the same through pipeline system (30) to water injection nozzles (29). Water from water injection nozzles (29) washes wet channels (27). The water level in water intake tank (32) is determined using level sensor (35), which via electrical wires (10) transmits this information to control unit (5). The water level should be lower than the intended one, the control unit (5) opens electromagnetic water top-up valve (33), and water from the pigsty's water consumption system enters pipeline system (30). Otherwise, control unit (5) closes electromagnetic water top-up valve (33) and opens electromagnetic water draining valve (34), and the water from water intake tank (32) enters the manure removal system.

After wet channels (27), warm and wet airflow enters inner working air pipe (20), which is connected to nozzles (16) and central cavity (17) of four-way valve (4). Next, warm and wet airflow enters central air injection duct (11) where through branch air injection pipes (12) enters the pigsty's middle part directly into the stalls, where livestock are kept. Since central air injection duct (11) is located under the floor below the soil freezing level, the process of geothermal heating of warm and wet airflow additionally occurs.

Information from temperature and humidity sensors (14) via electrical wires (10) is supplied to control unit (5), where it is compared with local microclimate parameters set by the operator for each stall. Where additional airflow heating is required in some particular stall, control unit (5) switches on respective heating element (15) and opens servo-operated discharge valve (13) entirely. Air temperature should be above or equal to the one required, control unit 5 switches off respective heating element (15) and closes servo-operated discharge valve (13) partially. The servo-operated discharge valve (13) closure degree is directly proportional to the difference between the pre-set and the measured temperature.

Investigation of parameters of the developed mechatronic system for pigsty microclimate maintenance was carried out in three stages:

- investigation of the indirect evaporative heat exchanger;
- substantiation of the contaminated air intake ventilation system;
- substantiation of clean air charging ventilation system taking into account its geothermal heating/cooling.

The first investigation stage was intended for determining the feasibility of using an indirect evaporative heat exchanger based on the Maisotsenko cycle (M-cycle) in the proposed mechatronic system. Heat and mass transfer processes taking place in such heat exchangers are close to thermodynamically inverse processes, thus allowing obtaining maximum air cooling effect with minimum energy consumption. The dew point temperature is the theoretical limit of wet air-cooling in such a device. The invariability of airflow concentration also is a positive effect of cooling in the working channel. Studies of this heat exchanger were conducted based on numerical simulations in the Star

CCM+ software package (Aliev *et al.*, 2018; Honcharuk *et al.*, 2021). The diagram for simulating the channels of the indirect evaporative heat exchanger is shown in Fig. 2.

The second investigation stage, and namely the substantiation of the contaminated air intake ventilation system, was carried out based on analytical calculations. The model for determining the geometrical arrangement of holes in the contaminated air intake ventilation system is shown in Fig. 3.

As the abscissa axis, the air duct axis with coordinate origin in the centre of its end section was selected. Air duct length is L, along which there are n holes of the same plane σ. The airflow rate at the duct's beginning is v_n. It is necessary to establish how the distance between the holes varies along the air duct length to ensure air's uniform distribution between the holes.

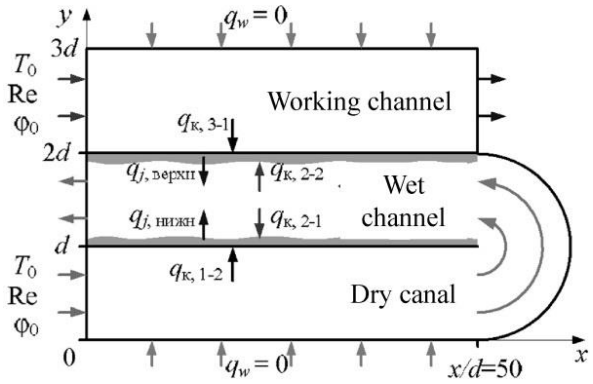

Figure 2. Diagram for simulating the channels of the indirect evaporative heat exchanger

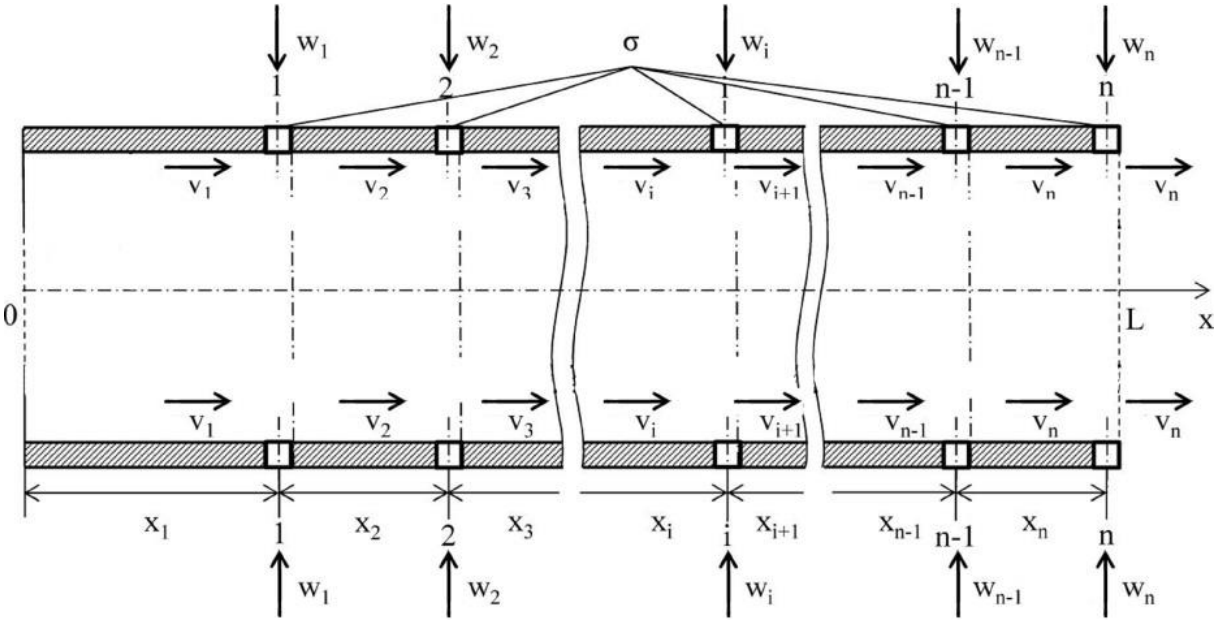

Figure 3. A computational model for determining the geometrical arrangement of holes in the contaminated air intake ventilation system

To determine distance x_i, velocity w_i, hole area σ and the number of holes n, let us make the method (Fig. 4) consisting of the following steps (Yaropud, Aliyev, 2015, Solona, Kupchuk, 2020).

1. The setting of parameters: air duct length L, hole discharge ratio φ, shock smoothing ratio α, friction resistance ratio κ, air duct effective diameter d_e, airflow rate at air duct beginning v_n, air duct's cross-sectional area A, the rate of the airflow passing through hole w_1, the airflow rate at air duct's cross-section v_1.
2. Setting the hole area variation increment σ = 0.001·j, where j is the hole number.
3. Calculation of distance x_i using the formula where i is the hole number.

$$x_i = \frac{L\varphi^2\sigma^2 v_i(\kappa x_{i-1} + d_e)}{v_n(\varphi^2\sigma^2(\kappa x_{i-1} + d_e + 2\alpha\alpha_e) - A^2 d_e)} - \frac{\sqrt{L^2\varphi^4\sigma^4 v_i^2(\kappa x_{i-1} + d_e)^2 - (L^2\kappa\varphi^2\sigma^2 v_i^2 x_{i-1} + A^2 v_n^2 d_e x_{i-1}^2)(\varphi^2\sigma^2(\kappa x_{i-1} + d_e + 2\alpha\alpha_e) - A^2 d_e)}}{v_n(\varphi^2\sigma^2(\kappa x_{i-1} + d_e + 2\alpha\alpha_e) - A^2 d_e)} \quad (1)$$

4. Calculation of distance w_i using the formula

$$w_i = \frac{x_i \cdot A \cdot v_n}{\sigma \cdot L} \quad (2)$$

5. Calculation of the sum of distances

$$L_{calc} = \sum_{i=1}^{n} x_i \quad (3)$$

6. Meeting the condition: if the sum of distances $L_{calc} > L$, then clause 7 actions of is performed, otherwise clause 3 is fulfilled.
7. Determining the number of holes n = i.
8. To ensure required convergence of the air duct's total length, we fulfil the condition: if the modulus is the difference between the sum of distances and accepted air duct length $| L_{calc} - L | < 0.01$, clause 9 action is performed, otherwise clause 2 is fulfilled.
9. Determination of hole area $\sigma_{calc} = \sigma$.
10. Determination of n, σ_{calc}, x_i, w_i parameters.

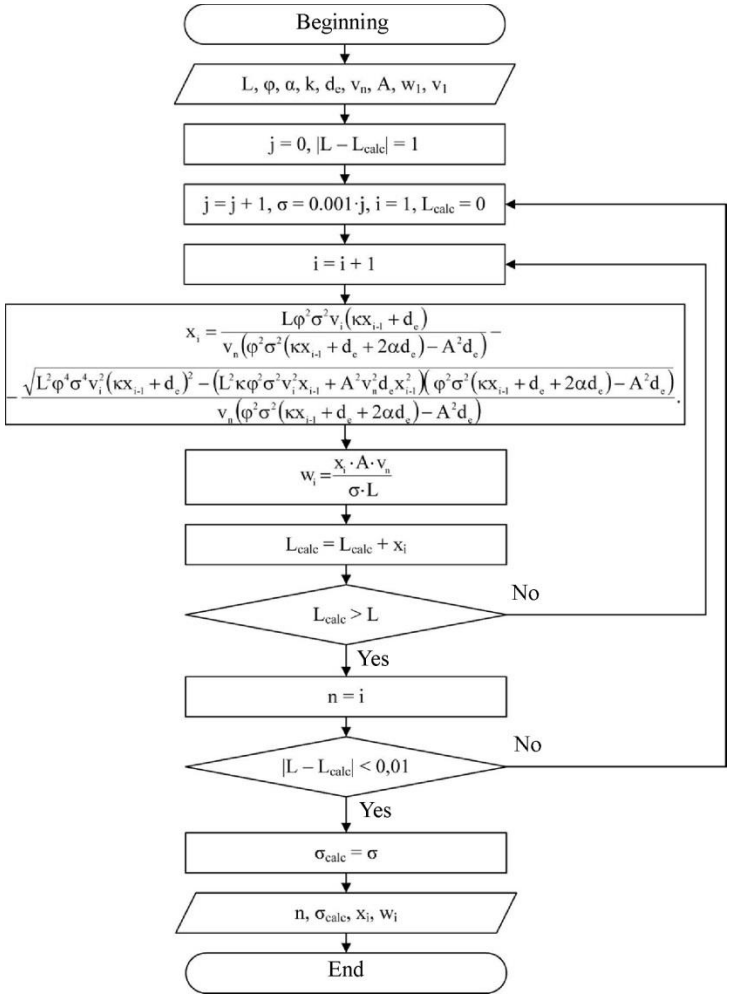

Figure 4. Algorithm for calculating the geometrical arrangement of holes in the microclimate system's air duct

The method so developed and the algorithm implemented on its basis (Fig. 4) are implemented in the Mathematica software package.

The third stage of investigations, and namely the substantiation of clean air charging ventilation system taking into account its geothermal heating/cooling, was conducted based on analytical studies in the Mathematica software package (Aliev *et al.*, 2018). To develop the mathematical model for heat elimination process in clean air charging ventilation system taking into account it's geothermal heating/cooling, we make the following assumptions: heat elimination process through air duct walls takes place in their thickness only; the process of heat elimination through air duct walls is instantaneous; due to a slight change in airflow pressure (Δp = 10–200 Pa) during its movement along the air duct, the system's thermodynamic process is considered isobaric; airflow in air ducts is homogeneous and isotropic; the air duct is at the depth of 3–5 m from the surface (soil temperature ranging from 7 °C to 13 °C depending on the season). To investigate the heat elimination process, the computational model was generated, which is shown in Fig. 5.

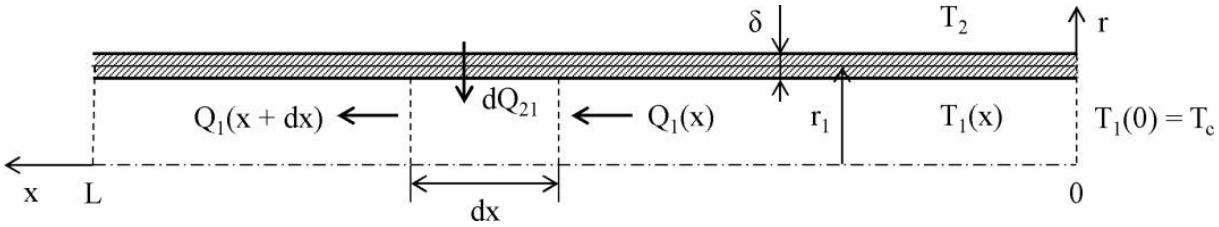

Figure 5. A computational model for heat elimination process in clean air charging ventilation system taking into account it's geothermal heating/cooling

According to Newton-Richman's law (Schmidt, 2019) and the equation for heat elimination through a cylindrical wall (Kreith *et al.*, 2010) we obtain a differential equation for heat elimination process within clean air charging ventilation system taking into account its geothermal heating/cooling:

$$\dot{m}_1 C_p dT_1(x) - \pi K_1 (T_2 - T_1(x)) dx = 0, \quad (4)$$

where x is the coordinate, m; $\dot{m}_1 = V_1 \cdot \rho(T_1)$ – mass air consumption in the air duct, kg s 3^s^{-1}; $V_1 = v_1 A_1$ – volumetric air consumption in the i-th air duct, m^3 s^{-1}; v_i – air velocity in the air duct, m s^{-1}; $A_1 = \pi \cdot r_1^2$ – air duct's cross-sectional area, m^2; r_1 – air duct radius, m; C_p – specific air heat; T_1 – air flow temperature in the air duct, K; T_2 – soil temperature, K; $K_1 = ((\alpha_1(2r_1 - \delta))^{-1} + (\alpha_1(2r_1 + \delta))^{-1} + \lg((2r_1 + \delta)/(2r_1 - \delta))/(2\lambda))^{-1}$ – linear heat elimination ratio for a cylindrical air duct can be calculated using the formula; $\alpha_1 = \lambda \cdot Nu_1/d_1$ – heat elimination ratio in the air duct, W (m^2·K)$^{-1}$; δ is the air duct wall thickness, m; λ is the air duct wall specific thermal conductivity, for polyethene; $Nu_1 = 0.018\ Re_1^{0.8}$ – Nusselt number for air flow in the i-th air duct; $d_1 = 2r_1$ – air duct diameter, m; $Re_1 = d_1 v_1 \rho(T_1)/\mu$ – Reynolds number for air flow in the air duct; μ – dynamic air viscosity; v_i – air velocity in the i-th air duct, m s^{-1}; $\rho(T_1) = 273\rho_0/T_1$ – air density in the i-th air duct at constant pressure, which is associated with its temperature, kg m$^{3\,-1}$; ρ_0. – air density under normal conditions ($T_{n.c.}$ = 273 K, P_0 = 101325 Pa), ρ_0 = 1.293 kg m$^{3\,-1}$; L is the air duct length, m. According to Fig. 5, boundary conditions are $T_1(0) = T_c$, where T_c – the temperature at air duct inlet, K.

Results

As a result of the first stage of investigations, and namely, the numerical simulation, obtained was the field of temperatures and mass concentrations in the channels of the indirect evaporative heat exchanger (with Reynolds number Re = 100, the temperature at the working channel inlet t_0 = 30 °C, initial humidity φ_0 = 30% shown in Fig. 6. It follows from the figure that the average air temperature in the working channel (under these conditions) is lower than the wet channel temperature (P-value for numerical simulation was 0.05). At the same time, the mass concentration of air in the wet channel increases. The data also indicate that a fairly large part of the heat exchange area in the wet channel is in the saturation state. Moreover, temperature change along the wet channel length is not monotonous, and at a certain distance from the inlet, its minimum is observed. Reduction of relative humidity value at the inlet to the heat exchanger will increase the intensity of water film evaporation in the wet channel, and therefore, will reduce temperatures parameters in the dry and the working channels.

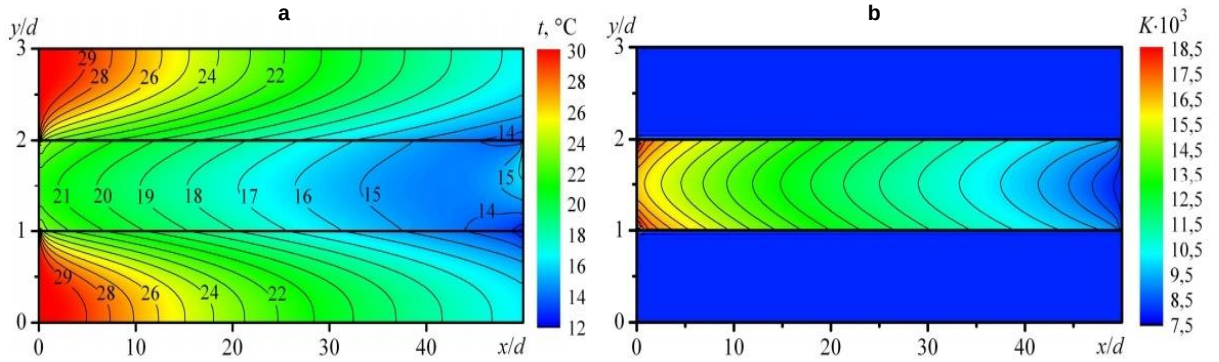

Figure 6. Fields of temperatures (a) and mass concentrations (b) in channels of the indirect evaporative heat exchanger (Re = 100, t_0 = 30 °C, ϕ_0 = 30%)

As a result of the second stage of investigations, and namely the substantiation of the contaminated air intake ventilation system, taking into account its structural and process parameters (L = 5.8 m; φ = 0.65; α= 0.4; κ= 0.01717 m; r_2 = 0.14 m; r_3 = 0.2 m; V_0 = 0.14 m^3 s^{-1}; x_1 = 0.9 m; v_1 = 0 m s^{-1}), determined was the number of holes n = 7 and their area σ = 0.011 m$_2$, as well as the distribution of distance between the holes according to Figure 7 and air velocities through the holes.

Analyzing Figure 7, one can state that the distance between the holes gradually decreases from 0.94 to 0.6 m in the direction opposite to the airflow. However, at the end of the duct, observed is a slight decrease in the

distance by 0.04 m, which is caused by back airflow, which collides with the muffled end. A similar phenomenon is also observed with the distribution of air velocities through holes.

As a result of the third stage, and namely the solution of the differential equation (4) together with boundary conditions in Mathematica software package and assuming the structural and process parameters (L = 20 m; r_1 = 0.25 m; V_1 = 0.14 $m^3 s^{-1}$; δ = 0.0002 m) of the clean air charging ventilation system air, we obtain the temperature distribution of air flows along the air duct length for different periods of the year (Fig. 8).

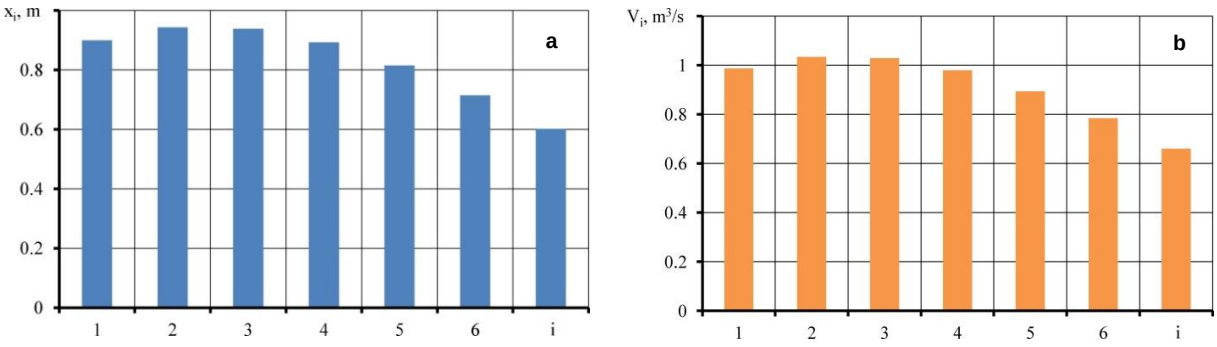

Figure 7. Distribution of distance between the holes (a) and air velocities through them (b) along the length of the air duct of the contaminated air intake ventilation system

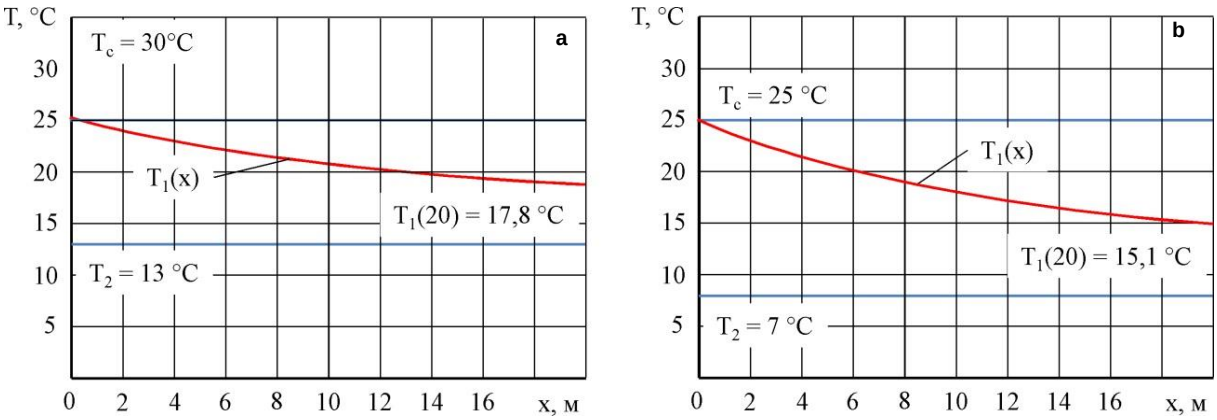

Figure 8. Distribution of air flow temperature in the air duct of the ventilation system for injecting clean air along its length in summer (a) and winter (b) periods of the year

As can be seen from Figure 8 (a), in the summer period (soil temperature – 13 °C) the airflow from the indirect evaporative heat exchanger (temperature – 25 °C), moving inside the air duct (length 20 m) of the clean air charging ventilation system, reduce its temperature down to 17.8 °C. In its turn, in the winter period (soil temperature – 8 °C) the airflow from the indirect evaporative heat exchanger (temperature – 25 °C), moving inside the air duct, reduces its temperature down to 15.1 °C.

Discussion

The presented results of numerical simulation of the indirect evaporative heat exchanger allow us to state that the cooling effect obtained in indirect evaporative channels can be quite high in comparison with traditional air conditioning patterns. The presented heat exchanger based on the Maisotsenko cycle (M-cycle) of considered heat carrier flow scheme is characterized by its high cost-effectiveness, low specific cost, small operational costs and structural simplicity, which is confirmed in the works (Mahmood *et al.*, 2016). The models obtained in the Star CCM +software package can be used for optimization analysis of air-cooling with variations in the Reynolds number, humidity, channel length and geometric dimensions of channels. One can assume that similar trends will be observed at other temperature and air humidity parameters at the heat exchanger inlet, but this conclusion requires additional calculations. These calculations will allow you to build an automated control system of the heat exchanger side-evaporator type to control the humidity in the room depending on the temperature. Indoor humidity is very significant and must be constantly adjusted depending on the temperature. At low humidity, livestock tolerates high temperatures more easily. Pigs are most resistant to high humidity. At the temperature of 32 °C, pigs weighing 100 kg respond equally both to the humidity of 30% and to that of 90% (Zhizhka, Povod, 2019).

Because of analytical investigations of the contaminated air intake ventilation system, the method was developed and on its basis – the algorithm was implemented for the determination of geometrical arrangement of holes in the air duct of the mechatronic system

for pigsty microclimate maintenance. It was established that the distance between the holes gradually decreases to a certain value in the direction opposite to airflow movement. However, a slight reduction in the distance at the air duct end is observed due to the backflow of air colliding with the muffled end. Previous experimental studies allowed concluding that generated algorithm for the calculation of geometrical arrangement of holes in the air duct of the mechatronic system for pigsty microclimate maintenance is adequate and may be used in engineering calculations, as evidenced by a high correlation between theoretical and experimental data R = 0.92–0.98.

Because of theoretical investigations of the clean air charging ventilation system taking into account its geothermal heating/cooling, developed was the mathematical model of the heat transfer process in the pipe heat exchanger, which allows determining the distribution of airflow temperature along its length. Further investigations will be aimed at optimizing the results of theoretical studies to determine the dependence between structural parameters of the clean air charging ventilation system (length, radius and air duct material) and volumetric consumption of the air passing through the same under the condition of maximum useful heat output.

Presented results of numerical simulation, analytical and theoretical investigations allow asserting the feasibility of using the indirect evaporative heat exchanger based on the Maisotsenko cycle, the contaminated air intake ventilation system and the clean air charging ventilation system taking into account its geothermal heating/cooling.

In addition, it is expedient to use the indirect evaporative heat exchanger based on the Maisotsenko cycle not only as a cooler but at the same time as a humidifier of airflows. It should also be noted that in the management of the above processes, only mechanical energy is consumed to drive fans to blow air through respective channels.

Conclusion

The advantage of the proposed mechatronic system for pigsty microclimate maintenance is that it allows increasing the efficiency of microclimate maintenance thanks to expedient use of recycled air energy (due to the use of indirect evaporative heat exchanger based on Maisotsenko cycle) and thermal potential of soil (geothermal energy) with the ventilation system's reduced energy costs thanks to the additional provision of mechatronic elements.

It was established as a result of analytical investigations of the expedient geometrical arrangement of holes in the contaminated air intake ventilation system that the option of hole arrangement (as obtained according to the calculation algorithm so developed) is the most efficient one, as it ensures a uniform airflow distribution along the air duct length.

Analysis of results of theoretical investigations of heat elimination process in the clean air charging ventilation system taking into account its geothermal heating/cooling has proved its feasibility and efficiency, which allows reducing the specific energy consumption for maintenance of the entire microclimate system.

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Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions

VY – study conception and design, drafting of the manuscript;
IG – critical revision and approval of the final manuscript;
EA – analysis and interpretation of data;
IK – acquisition of data, drafting of the 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 – CUPRINS, 54(1):95–104. http://aliev.in.ua/doc/stat/2018/stat_2.pdf

Braun, M.B., Dunmire, K.M., Evans, C.E., Stark, C.R., Woodworth, J.C, Paulk, C.B. 2020. Evaluation of Conditioning Temperature and Die Specifications on Nursery Pig Performance. – Kansas Agricultural Experiment Station Research Reports, 6(10):1–10. https://doi.org/10.4148/2378-5977.8009

Forcada, F., Abecia, J.A. 2019. How pigs influence indoor air properties in intensive farming: practical implications – a review. – Ann. Anim. Sci., 19(1):31–47. DOI: 10.2478/aoas-2018-0030

Gunko, I., Hraniak, V., Yaropud, V., Kupchuk, I., Rutkevych, V. 2021. Optical sensor of harmful air impurity concentration. – Przegląd Elektrotechniczny, 7:76–79. DOI: 10.15199/48.2021.07.15

Godyn, D., Herbut, P., Angrecka, S., Vieira, F.M.C. 2020. Use of different cooling methods in pig facilities to alleviate the effects of heat stress – a review. – Animals this link is disabled, 10(9):1–14, 1459. DOI: 10.3390/ani10091459

Honcharuk, I., Kupchuk, I., Solona, O., Tokarchuk, O., Telekalo, N. 2021. Experimental research of oscillation parameters of vibrating-rotor crusher. – Przegląd Elektrotechniczny, 3:97–100. DOI: 10.15199/48. 2021.03.19

Huynh, T.T.T., Aarnink, A.J.A., Verstegen, M.W.A., Gerrits, W.J.J., Heetkamp, M.J.W., Kemp, B., Canh, T.T. 2005. Effects of increasing temperatures on physiological changes in pigs at different relative humidities. – Jornal of Animal Science, 83:1385–1396. DOI: 10.2527/2005.8361385x

Il'in, I.V., Kuryachiy, M.G., Ignatkin, I.Yu. 2011. Vliyaniye parametrov mikroklimata na produktivnost' sviney [Influence of microclimate parameters on pig productivity]. – Perspektivnoye svinovodstvo: teoriya i praktika [Promising pig breeding: theory and practice], 3:21–25. https://cyberleninka.ru/article/n/vliyanie-parametrov-mikroklimata-na-produktivnost-sviney/viewer [In Russian]

Ivanov, Yu., Novikov, N. 2020. Digital intelligent microclimate control of livestock farms. – E3S Web of Conferences, 175(5):11012. DOI: 10.1051/ e3sconf/202017511012

Johnston, L.J., Brumm, M.C., Moeller, S.J., Pohl, S., Shannon, M.C., Thaler, R.C. 2013. Effects of reduced nocturnal temperature on pig performance and energy consumption in swine nursery rooms. – Journal of Animal Science, 91(7):3429–3435. DOI: 10.2527/jas.2012-5824

Kaletnik, G., Honcharuk, I., Okhota, Y. 2020. The The Waste-Free Production Development for the Energy Autonomy Formation of Ukrainian Agricultural Enterprises. – Journal of Environmental Management and Tourismthis, 11(3): 513–522.

Kozlovski, V.G. 1984. Tekhnologiya promyshlennogo svinovodstva [Technology of industrial pig breeding]. – M.: Rossel'khozizdat: 348 p. [In Russian]

Kreith, F., Manglik, R.M., Bohn, M.S. 2010. Principles of Heat Transfer. 7 edition. – Cengage Leaing. 784 p. ISBN: 049566770.

Mahmood, M.H., Sultan, M., Miyazaki, T., Koyama, S., Maisotsenko, V.S. 2016. Overview of the Maisotsenko cycle – A way towards dew point evaporative cooling. Renewable and Sustainable Energy Reviewsthis link is disabled, 66:537–555. DOI: 10.1016/j.rser.2016.08.022.

Renaudeau, D., Anais, C., Tel, L., Gourdine, J.L. 2010. Effect of temperature on thermal acclimation in growing pigs estimated using a nonlinear function. – Journal of Animal Science, 88, 3715–3724.

Solona, O., Kupchuk, I. 2020. Dynamic synchronization of vibration exciters of the three-mass vibration mill.– Przegląd Elektrotechniczny, 1(3):163–167. DOI: 10.15199/48.2020.03.35

Song, J.I., Park, K.-H., Jeon, J.H., Choi, H.L., Barroga, A.J. 2013. Dynamics of Air Temperature, Velocity and Ammonia Emissions in Enclosed and Conventional Pig Housing Systems. – Asian-Australas J. Anim. Sci., 26(3):433–442. DOI: 10.5713/ajas.2011. 11515

Schmidt, A. 2019. Technical thermodynamics for engineers. – Springer Nature: Cham, Suisse. 813 p. DOI: 10.1007/978-3-030-20397-9

Van Wagenberg, A.V. 2005. Measurement, evaluation and control of the microclimate in rooms for weaned piglets. – Ph.D. Thesis, Wageningen University and Applied Research Division of Animal Sciences Group, Lelystad, The Netherlands. With summaries in English and Dutch.

Yaropud, V.M., Aliev, E.B. 2015. Metodyka inzhenernoho rozrakhunku parametriv teploutylizatora dlya tvarynnyts′kykh prymishchen′ [Methods of engineering calculation of heat utilizer parameters for livestock premises]. – Naukovyy visnyk Natsional′noho universytetu bioresursiv i pryrodovykorystannya Ukrayiny. Seriya: Tekhnika ta enerhetyka APK [Scientific Bulletin of the National University of Life and Environmental Sciences of Ukraine. Series: Engineering and energy of agro-industrial complex], 212(2):214–221. http://aliev.in.ua/doc/stat/2015/stat_8.pdf [In Ukraine]

Zhizhka, S.V., Povod, M.G. 2019. Vidtvoryuval′ni yakosti svynomatok zalezhno vid system mikroklimatu vprodovzh roku [Reproductive qualities of sows depending on microclimate systems during the year]. – Visnyk Sums′koho natsional′noho ahrarnoho universytetu. Seriya: Tvarynnytstvo [Bulletin of Sumy National Agrarian University. Series: Livestock], 4(39):85–91. http://repo.snau.edu.ua/bitstream/123456789/8512/1/5.pdf [In Ukraine]

70 AASTAT EESTI PÕLLUMAJANDUSE AKADEEMIA MOODUSTAMISEST. ARENGUD ÕPPETEGEVUSES

Nõukogude korra taaskehtestamise järel toimus põllumajandusliku kõrgharidusega spetsialistide ettevalmistamne Tartu Riikliku Ülikooli (TRÜ) juures asuvas Põllumajandus-, Metsandus- ja Loomaarsti-teaduskonnas. Ent uues olukorras ei suutnud see enam katta vajadust põllumajanduse eriteadlaste järele.

1951 – Eesti Põllumajanduse Akadeemia

NSV Liidu Ministrite Nõukogu 1950. aasta 4. novembri määruse nr 4516 "Eesti NSV põllumajanduse edasiarendamise abinõudest" põhjal antud NSV Liidu kõrgema hariduse ministri käskkirjaga loodi 1. jaanuarist 1951 Tartusse Eesti Põllumajanduse Akadeemia.

Rektoriks määrati dots Richard Antons, kes täitis ka õppeprorektori ülesandeid. Haldusprorektoriks sai Eduard Hunt.

Akadeemia asutati TRÜ Põllumajandus-, Metsandus- ja Loomaarstiteaduskonna ja kahe õppe-katsemajandi baasil. Ülikoolist tuli akadeemiasse üle 95 õppejõudu ja 850 üliõpilast. Samal aastal toodi üle ka Tallinna Polütehnilise Instituudi (TPI) Põllumajanduse Mehhaniseerimise Teaduskonna üliõpilased. Akadeemia pidulik avamine toimus õppeaasta algusele pühendatud akadeemia kollektiivi koosolekul 31. augustil 1951 (tabel 1).

Eesti Põllumajanduse Akadeemia loomisega pandi alus kõrgema põllumajandusliku haridusega spetsialistide ja teaduslik-pedagoogilise kaadri ettevalmistamisele, teaduslikule uurimistööle ning selle materiaal-tehnilise baasi rajamisele.

Tabel 1. Üliõpilaste arv Eesti Põllumajanduse Akadeemias 1951 a

Teaduskond	Erialad	Üliõpilaste arv
Agronoomiateaduskond	Agronoomia sh kõ	234
Dekaan prof August Marland	Aiandus	97
Zootehnikateaduskond	Zootehnika sh kõ	159
Dekaan dots Evald Peebsen	Piimasaaduste tehnoloogia	25
Veterinaariateaduskond Dekaan dots Evald Peebsen	Veterinaaria	225
Hüdromelioratsiooni ja maakorralduse teaduskond	Maaparandus	25
Dekaan dots Herbert Muischneek	Maakorraldus	50
	Metsamelioratsioon	86
Metsamajanduse teaduskond	Metsamajandus	165
Dekaan dots Teodor Krigul	Metsatööstus	110
Põllumajanduse mehhaniseerimise teaduskond Dekaan v.-õp. Hermann Tamm	Põllumajanduse mehhaniseerimine	75
Kokku üliõpilasi		1251

Eesti Põllumajanduse Akadeemia oli NSVL Põllumajandusministeeriumi otsealluvuses ja õppetöö toimus NSV Liidu Kõrgema- ja Keskerihariduse Ministeeriumi poolt kinnitatud õppeplaanide alusel. Õppeaeg oli 5 aastat, sellest 3,5–4 kuud praktikat.

Tööd alustas Üliõpilaste Teaduslik Ühing (ÜTÜ), mille eesmärk oli üliõpilaste kaasamine teadustöösse. ÜTÜ tegevus oli suunatud lisaks kateedrites tehtavale uurimistööle ka kolhooside ja sovhooside tootmisega seotud küsimuste teaduslikule lahendamisele ning oli põhiliselt eksperimentaalse iseloomuga. Korraldati igaaastaseid konverentse, anti välja teaduslike tööde kogumikke.

1952. aastal lõpetas EPA esimene lend; 157 üliõpilast sh 43 õpetatud agronoomi, 22 õpetatud zootehnikut, 34 veterinaararsti, 21 metsamajanduse inseneri, 24 metsatööstuse inseneri, 13 metsamelioratsiooni inseneri.

1953. aastal avati aspirantuur (3 aastat) sh sihtaspirantuur teiste kõrgemate õppeasutuste, eeskätt Leningradi ja Moskva õppeasutuste juures. 1962. aastal avati ühiskondlik aspirantuur, kuhu võeti õppima tootmises töötavaid spetsialiste. Aspirantuuri lõpetajatele anti kandidaadikraad (nt põllumajandusteaduste kandidaat), mis oli teaduskraad. Doktori teadusliku kraadi/teaduskraadi saamiseks tuli kaitsta doktoriväitekiri. Kõik kandidaadi- ja doktoriväitekirjad vaadati läbi ja kinnitati Moskvas asuva Kõrgema Atestatsioonikomisjoni poolt.

1954. aastal avati EPAs esimene venekeelne osakond põllumajanduse mehhaniseerimise teaduskonnas.

Kaugõppeteaduskond loodi 1955. aastal. Teaduskonnas oli neli osakonda: agronoomia-, zootehnika-, hüdromelioratsiooni- ja põllumajanduse mehhaniseerimise osakond.

1955. aastal õppis kaugõppes kokku 445 üliõpilast. Kaugõppes oli õppeaeg ühe aasta võrra pikem kui statsionaarses õppes. Suureks soodustuseks kaugõppeteaduskonnas õppivatele meestöötajatele oli see, et neile anti pikendust Nõukogude armeesse kutsumisel kuni õppeasutuse lõpetamiseni. Alates 1959.-ndast aastast said kaugõppes õppivad üliõpilased palgalist puhkust õppe- ja eksamisessioonidest osavõtuks. 1965. aastal töötas enamik (86%) kaugõppeteaduskonna üliõpilas-

test põllumajanduses. Seega täitis teaduskond oma peamise ülesande – tõsta erialal töötavate keskharidusega spetsialistide kvalifikatsiooni.

Üliõpilased, kes astusid statsionaarsesse õppesse, saadeti esimesel õppeaastal septembri algul kolhoosidesse/sovhoosidesse terveks kuuks sügis-/põllutöödele. Selline kord kehtis 1980-ndate aastate lõpuni.

1961. aastal õppis EPA-s 2348 üliõpilast sh 847 kaugõppeteaduskonnas ja 61 õhtuses osakonnas põllumajanduse mehhaniseerimise teaduskonna juures.

Kolmes teaduskonnas (zootehnika-, veterinaaria-, põllumajanduse mehhaniseerimise) oli avatud ka vene osakond.

1961 – Eesti Põllumajanduse Akadeemia

Rektor Minna Klement. Õppeprorektor dots August Eenlaid. Teadusprorektor dots Valentin Matin. Haldusprorektor Eduard Hunt.

Tabel 2. Üliõpilaste arv Eesti Põllumajanduse Akadeemias 1961 a

Teaduskond	Erialad	Üliõpilaste arv	Lõpetajate arv
Agronoomiateaduskond. Mitšurini tn 30	Agronoomia	345	71
Dekaan dots Arnold Sau	Põllumajanduslik raamatupidamine	50	–
	Põllumajandusliku tootmise õpetaja (tootmisõpetaja)	25	–
Zootehnikateaduskond. Mitšurini tn 30	Zootehnika	240	32
Dekaan dots Karl Kurm			
Veterinaariateaduskond. Leningradi mnt 84	Veterinaaria	176	39
Dekaan dots Paul Saks	Liha- ja piimasaaduste tehnoloogia	40	–
Metsamajanduse ja hüdromelioratsiooni teaduskond. Vanemuise tn 46	Metsamajandus	134	26
	Hüdromelioratsioon	106	19
Dekaan dots Endel Laas	Maakorraldus	16	1
Põllumajanduse mehhaniseerimise teaduskond. Riia mnt 12	Põllumajanduse mehhaniseerimine	308 + 61 õhtune osakond	56
Dekaan dots Gleb Bichele			
Kaugõppeteaduskond. Riia mnt 12	Agronoomia	374	32
Dekaan dots Helmut Raig	Zootehnika	121	13
	Liha- ja piimasaaduste tehnoloogia	48	–
	Hüdromelioratsioon	60	7
	Põllumajanduslik raamatupidamine	26	–
	Pm mehhaniseerimine	218	13
Kokku üliõpilasi/lõpetajaid		2348 sh 847 kaugõppes	309 sh 65 kaugõppes

Alates 1964. aastast oli õppeaeg 4 aastat ja 4–10 kuud. Kõikides teaduskondades õpetati esimesel kursusel peamiselt üldhariduslikke õppeaineid (NLKP ajalugu, markistlik-leninlik filosoofia, vene keel ja võõrkeel, keemia, füüsika, kõrgem matemaatika). Teisel kursusel alustati erialaste õppeainete õpetamist.

Agronoomia eriala üliõpilased õppisid järgmisi õppeaineid: botaanika, mikrobioloogia, taimefüsioloogia, põllumajanduse mehhaniseerimine, geodeesia ja mullateadus, maaviljelus, agrokeemia, maaparandus, entomoloogia, fütopatoloogia, keemiline taimekaitse, aiandus, loomakasvatus, taimekasvatus, sordiaretus ja seemnekasvatus, rohumaaviljelus, sookultuurid, põllumajanduse ökonoomika, põllumajanduse teaduslik organiseerimine ja planeerimine, põllumajandussaaduste tehnoloogia jne. Õpetati ka agronoomile vajalikke naaberteadusi (metsandus, põllumajanduslikud ehitised, statistika, raamatupidamine). Teoreetiliste teadmiste kinnitamiseks ja praktiliste kogemuste omandamiseks toimusid erinevad suvepraktikad. Agronoomia eriala üliõpilased omandasid ka III liigi traktoristi-masinisti ning IV liigi autojuhi kvalifikatsiooni. Sellele järgnes II kursuse suvel mehhaniseerimisalane tööpraktika vabariigi majandites, kus üliõpilased töötasid traktoritel, kombainidel, veoautodel ja teistel põllutöömasinatel, et omandada vajalikke võtteid mehhanismidega töötamisel. Kolmandal kursusel oli tähtsamaks õppepraktikaks sordikülvide tunnustamise kursus, mille lõpetamisel ja eksami sooritamisel said üliõpilased põllukultuuride sordikülvide tunnustaja kvalifikatsiooni. Suvel toimunud katsetehnilise praktika ajal rajasid üliõpilased individuaalkatse (taimekasvatuse, maaviljeluse, aianduse vm alal), mida nad hooldasid kogu vegetatsiooniperioodi jooksul. Sel viisil omandasid tulevased agronoomid vajalikud kogemused põllumajanduslikuks katsetööks ning teaduse saavutuste juurutamiseks põllumajandusse. Neljanda kursuse suvel töötasid üliõpilased tootmise juhtimise ja planeerimise praktikal

(menetluspraktika) vabariigi paremates sovhoosides ja kolhoosides.

Agronoomiateaduskonna lõpetamine toimus diplomitööga või kompleksete riigieksamitega agronoomias (haaras mullateadust, agrokeemiat, maaviljelust, taimekasvatust jne) ning ökonoomilistes ainetes (poliitiline ökonoomia, põllumajandusökonoomika, tootmise organiseerimine, statistika ja raamatupidamine jne).

Praktika zootehnika, veterinaaria, metsanduse ja maaparanduse erialadel: I ja II kursusel – 4–10 nädalat tööpraktikat, 20–22 nädalat õppepraktikat, III ja IV kursusel 19–20 nädalat menetluspraktikat EPA õppemajandites, vabariigi uurimisinstituutide majandites, vabariigi sovhoosides ja kolhoosides/veterinaariaosakondades/loomade haiguste tõrje jaamades/liha ja piimatööstuse ettevõtetes/metsamajandites jm. Üliõpilased omandasid II kursusel III liigi traktoristi-masinisti ning III liigi autojuhi kvalifikatsiooni.

Praktika põllumajanduse mehhaniseerimise erialal: I kursusel 4 nädalat õppetöökojas (omandasid lukksepa kvalifikatsiooni ja traktoristi oskused). II kursusel 4 nädalat tööd NSV Liidu suuremates auto- või traktoritehastes (omandasid eriala metallilõikepinkidel töötamiseks), 5 nädalat tööd kombainide ja traktoritega (omandasid laiaprofiiliga traktoristi-masinisti kutse). III kursusel – autojuhipraktika (omandasid III liigi autojuhi kutse), 18 nädalat tööd majandis autojuhina, traktoristina ja kombainerina. IV kursusel – 9 nädalat tööd masina-traktoripargi tööjuhina, peainseneri abina. V kursusel – 6 nädalat masinate remondi praktikat suuremates töökodades ja tehastes.

1964. aastal moodustati Ühiskondlike Erialade Teaduskond (ÜET). ÜET eesmärgiks oli süvendada üliõpilaste teadmisi ning avardada nende silmaringi väljaspool kohustuslikku erialast õppetööd eesmärgiga rakendada omandatud teadmisi ja oskusi pärast kõrgkooli lõpetamist oma töökohal. Üliõpilastel oli võimalik omandada lektori, kodukultuuri, looduskaitse, ehisaianduse või spordiinstruktori tunnistus, tavandijuhi, liiklus- või matkaringi jt ringide (20) juhendaja tunnistus.

Paralleelselt spetsialistide ettevalmistamisega statsionaarses õppes ja kaugõppes organiseeriti tootmises töötavatele spetsialistidele kvalifikatsiooni tõstmise kursuseid. 1966. aastal loodi kvalifikatsiooni tõstmise teaduskond. 6-kuulistel täienduskursustel käisid põhiliselt kolhooside ja sovhooside juhtivad töötajad. 1970. aastal loodi ettevalmistusosakond, mille ülesandeks oli abistada töölisnoori ja armeest demobiliseerituid EPAsse sisseastumisel.

1971. aastal õpetati põllumajandusspetsialiste seitsmes teaduskonnas (agronoomia-, zootehnika-, veterinaaria-, majandusteaduskond, metsanduse- ja maaparanduse teaduskond, põllumajanduse mehhaniseerimise teaduskond ja kaugõppeteaduskond) kokku 12 erialal (agronoomia, rohumaaviljelus ja seemnekasvatus, zootehnika (eesti ja vene osakond), veterinaaria (eesti ja vene osakond), piima- ja piimasaaduste tehnoloogia, liha- ja lihasaaduste tehnoloogia, põllumajanduslik raamatupidamine, põllumajanduse ökonoomika ja organiseerimine, metsamajandus, maaparandus, maakorraldus, põllumajanduse mehhaniseerimine). Üliõpilasi oli kokku 3641 sh kaugõppeteaduskonnas (9 erialal) 1550.

1971. aastal oli lõpetajaid 501 sh 103 õpetatud agronoomi, 53 õpetatud zootehnikut, 35 veterinaararsti, 7 liha- ja lihasaaduste tehnoloogiainseneri, 19 piima- ja piimasaaduste tehnoloogiainseneri, 47 metsamajandusinseneri, 35 hüdrotehnikainseneri, 26 maakorraldusinseneri, 106 mehaanikainseneri, 37 õpetatud agronoomökonomisti, 33 põllumajanduse ökonomist-raamatupidajat.

1981. aastal õppis Eesti Põllumajanduse Akadeemias juba 4035 üliõpilast sh kaugõppes 1635. Võrreldes 1971. aastaga suurenes veterinaariat õppivate üliõpilaste arv ning üliõpilaste arv põllumajanduse mehhaniseerimise teaduskonnas, kus 1972. aastal avati põllumajanduse elektrifitseerimise eriala.

Joonis 1. Zooinseneriteaduskonna venekeelse rühma ehk rahvusvahelised üliõpilased. Keskel kursuse juhendaja Anne Lüpsik

1981 – Eesti Põllumajanduse Akadeemia

Rektor dots Nikolai Kozlov. Õppeprorektor dots Enn Altosaar. Teadusprorektor dots Armand Sukamägi. Kvalifikatsiooniprorektor v.-õp. Kaljo Tein. Haldusprorektor Raivo Sein.

Tabel 3. Üliõpilaste ja lõpetajate arv Eesti Põllumajanduse Akadeemia 1981. aastal

Teaduskond	Erialad,	Üliõpilaste arv	Lõpetajate arv
Agronoomiateaduskond. Mitšurini 34 Dekaan dots Arnold Sau	Agronoomia	341	55
Zooinseneriteaduskond. Mitšurini tn 30 Dekaan prof Ülo Oll	Zootehnika	249	37
Veterinaariateaduskond. Leningradi mnt 84	Veterinaaria	360	59
Dekaan dots Aadu Kolk	Liha- ja piimasaaduste tehnoloogia	123	23
Majandusteaduskond. Riia mnt 12	Põllumajanduslik raamatupidamine	97	25

Teaduskond	Erialad,	Üliõpilaste arv	Lõpetajate arv
Dekaan dots Harri Piho	Pm ökonoomika ja organiseerimine	125	30
Metsanduse ja maaparanduse teaduskond.	Metsandus	239	48
Riia mnt 12	Maakorraldus	119	25
Dekaan prof Endel Laas	Maaparandus	215	38
Põllumajanduse mehhaniseerimise teaduskond. Kreutzwaldi tn 56	Põllumajanduse elektrifitseerimine	197	26
Dekaan prof Heino Möller	Põllumajanduse mehhaniseerimine	334	53
Kaugõppeteaduskond. Riia mnt 12	Agronoomia	372	45
Dekaan dots Enn Jaama	Zootehnika	299	20
	Metsamajandus	196	19
	Põllumajanduslik raamatupidamine	152	22
	Pm ökonoomika ja organiseerimine	283	38
	Pm mehhaniseerimine	333	–
Ühiskondlike erialade teaduskond (ÜET) Riia mnt 12 Dekaan dots Sinaiida Riives			
Kvalifikatsioonitõstmise teaduskond Riia mnt 12. Prorektor v-õp Kaljo Tein			
Kokku üliõpilasi/lõpetajaid		4035 sh 1635 kaugõppes	563 sh 144 kaugõppes

1990/1991 õppeaastal rakendus uus õppekorraldus. Õppetöö hakkas toimuma neljas tsüklis ja igale tsüklile järgnes eksamite sooritamise nädal. Õppetöö mahtu hakati arvestama ainepunkti-süsteemis; üks nädal õppetööd (35 tundi auditoorset tööd) andis 1 ainepunkti (AP).

Üliõpilased, kes immatrikuleeriti 1990. aastal, saadeti II poolaastaks (st III ja IV tsüklis) praktilisi teadmisi omandama sovhoostehnikumidesse (Türi, Vana-Võidu, Kehtna jt). 1991/1992 ja 1992/1993 õppeaastal õppisid esmakursuslased (v.a need, kes olid lõpetanud tehnikumi) kõrgemates põllumajanduskoolides (Türi, Olustvere, Vana-Võidu, Kehtna, Räpina) ja tehnikumides (Luua, Väimela) terve aasta, seejärel jätkasid õpinguid Tartus.

1993/1994 õppeaastal_immatrikuleeritud üliõpilased olid sügissemestril põllumajanduskoolides ja kevadsemestril Tartus.

1991. aasta 1. septembrist reorganiseeriti teaduskonnad. Moodustati 5 teaduskonda: põllumajandusteaduskond, mille koosseisus oli 4 instituuti (agronoomia-, loomakasvatus-, majandus- ja liha-piimainstituut), veterinaariateaduskond, Inseneriteaduskond, mille koosseisus oli 2 instituuti (tehnika- ja maainseneriinstituut), metsandusteaduskond, humanitaarteaduskond. Erialasid oli kokku 17, üliõpilasi 3957 sh kaugõppes 1302 (tabel 4).

Tabel 4. Üliõpilaste ja lõpetajate arv Eesti Põllumajanduse Akadeemia 1991. aastal

Teaduskond/Instituut	Erialad	Üliõpilaste arv	Lõpetajate arv
Põllumajandusteaduskond Dekaan dots Armand Sukamägi) sh		1062	160
1. Agronoomiainstituut. Viljandi mnt Eerika	Agronoomia	352	51
Direktor dots Juhan Jõudu	Aiandus	45	
2. Loomakasvatusinstituut. Lai tn 30 Direktor dots Anne Lüpsik	Loomakasvatus	297	37
3. Majandusinstituut. Riia mnt 12 Direktor dots Harri Piho	Põllumajanduse ökonoomika ja organiseerimine	64	29
	Põllumajandusraamatupidamine ja -analüüs	24	21
4. Liha-piimainstituut. Narva mnt 84 Direktor dots Meili Rei	Liha- ja piimatehnoloogia	137	22
Veterinaariateaduskond. Narva mnt 84 Dekaan dots Aadu Kolk	Veterinaaria	368	48
Inseneriteaduskond (dekaan prof kt Kuno Jürjenson) sh		947	119
1. Tehnikainstituut. Kreutzwaldi tn 56	Põllumajanduse mehhaniseerimine	461	58
Direktor dots Tõnis Peets	Põllumajanduse elektrifitseerimine	110	31
2. Maainseneriinstituut. Kreutzwaldi tn 5	Maamõõtmine	101	13

Teaduskond/Instituut	Erialad	Üliõpilaste arv	Lõpetajate arv
Direktor dots Väino Tamm	Maaparandus	69	17
	Maaehitus	56	–
	Maainseneri	118	–
	Keskkonnakaitse	32	–
Metsandusteaduskond. Kreutzwaldi tn 5	Metsamajandus	253	38
Dekaan prof Ivar Etverk	Metsatööstus	25	–
Kaugõppeteaduskond. Riia mnt 12	Agronoomia	273	9
Dekaan dots Matti Liiske	Loomakasvatus	230	14
	Metsamajandus	157	6
	Pm ökonoomika ja organiseerimine	234	24
	Põllumajanduslik raamatupidamine	154	19
	Pm mehhaniseerimine	254	3
Humanitaarteaduskond. Riia mnt 12			
Dekaan dots Albert Saunanen			
Täiendusõppeteaduskond. Riia mnt 12			
Prorektor prof kt Kuno Jürjenson			
Kokku üliõpilasi/lõpetajaid		3957 sh 1302 kaug-õppes	440 sh 75 kaugõppes

Humanitaarteaduskond ühendas filosoofia ja sotsiaalteaduste, võõrkeelte ning kehakultuuri kateedrid. Teaduskonna eesmärgiks oli anda üliõpilastele humanitaarteadmisi inimesest ja ühiskonnast, rahvuskultuurist ja ajaloost; et meie kõrgkoolis õppijatest ei saaks mitte lihtsalt kõrgharidusega oskustöölised, vaid isiksused, kes aitaksid kaasa Eesti küla taasärkamisele.

Doktoriõppesse vastuvõttu alustati 1991/1992 õppeaastal, kui rektori 19. juuni 1991 käskkirjaga avati individuaalplaani alusel toimuv doktoriõpe kestusega 4 aastat. Doktoriõpe avati kaheksal erialal: taimekasvatus, mullateadus, rohumaaviljelus ja söödatootmine, loomakasvatus, veterinaarmeditsiin, metsamajandus, põllumajanduse mehhaniseerimine, põllumajanduse ökonoomika.

Ülikooli rektori 14.01.1991 käskkirjaga moodustati neli doktorinõukogu: põllumajandusteaduste ja majandusteaduse nõukogu (esimees prof Olev Saveli), loodusteaduste nõukogu (esimees prof Loit Reintam), tehnikateaduste nõukogu (esimees prof Tõnu Keskküla), veterinaaria nõukogu (esimees prof Nikolai Kozlov).

Magistriõppe ja doktoriõppe lõpetajatele anti teaduskraad, nt põllumajandusmagister (*Master of Agriculture* (*M.Agr*) taimekasvatuse erialal, filosoofiadoktor (*PhD*) taimekasvatuse erialal, põllumajandusdoktor (*Doctor of Agiculture* (*D.Agr*)) taimekasvatuse erialal.

26. septembril 1991 nimetati Eesti Põllumajanduse Akadeemia Eesti Põllumajandusülikooliks (EPMÜ).

Eesti Põllumajandusülikoolist sai akadeemilist haridust ning selle taseme täiendusõpet ja nõuannet andev õppe- ja teadusasutus ning maamajanduse arenduskeskus. Õpetamise aluseks oli teadus ja tihe loominguline side maamajanduspraktikaga. Põllumajandusspetsialistide ettevalmistamise asemel sai ülikooli eesmärgiks loovharitlaste kujundamine, teadlaste ettevalmistamine, missioonitunde sisendamine maakultuuri, maamajanduse ja loodussõbraliku elukorralduse süsteemseks arendamiseks.

EPMÜ oli Eesti Vabariigi riiklik ülikool ja õppetöö toimus ülikoolis koostatud õppekavade alusel.

Ülikooli nõukogu 30.04.1992 otsusega likvideeriti põllumajandusteaduskond ja inseneriteaduskond ning kinnitati EPMÜ uus struktuur. Moodustati 10 instituuti ja üks teaduskond: agronoomiainstituut, loomakasvatusinstituut, majandusinstituut, liha- ja piimainstituut, tehnikainstituut, maainseneriinstituut, keskkonnainstituut, metsandusinstituut, humanitaarinstituut, taimekaitseinstituut ja veterinaariateaduskond.

Lõpetati vastuvõtt kaugõppeteaduskonda ja vähendati vastuvõttu statsionaarsesse õppesse seniselt 550-lt 275-le.

Aastatel 1992 ja 1993 anti lõpetajatele diplom eriala lõpetamise kohta (nt on lõpetanud tehnikainstituudi põllumajanduse mehhaniseerimise erialal).

Bakalaureuseõppesse võeti esimesed üliõpilased vastu 1994. aastal; õppeaja kestus 4 aastat.

1994. aasta 1. juunil ühendati EPMÜ Loomakasvatusinstituut (direktor dots Anne Lüpsik) ja Eesti Loomakasvatuse ja Veterinaaria Teadusliku Uurimise Instituut (ELVI) (direktori kt Toomas Vain). Moodustunud EPMÜ Loomakasvatusinstituudile anti teaduskonna õigused.

Ülikooliseadusest (jõustus 18.02.1995) tulenevalt rakendus ülikoolides alates 1995. aastast 4+2 õppesüsteem. 4-aastasele bakalaureuseõppele (õppekava maht 160 AP) järgnes 2-aastane magistriõpe (80 AP) ja 4-aastne doktoriõpe (160 AP). Loomaarstiõppe kestuseks sai 5 aastat (200 AP). Õppetöö toimus ülikoolis koostatud ja kõrgharidusstandardile vastavate õppekavade alusel.

Bakalaureuseõppe õppekava (160 AP) koosnes järgmistest moodulitest: üldõppemoodul (kuni 30 AP), suunaõppemoodul (20–25 AP), erialaõppemoodul (60–70 AP), lisaõppemoodul (19–25 AP), vabaained (14–20 AP), lõputöö või -eksam (kuni 10 AP). Üldõppemoo-

dulis olid järgmised õppeained: kohanemiskursus, kõrgem matemaatika, füüsika üldkursus, majandusõpetuse alused, ökoloogia ja keskkonnakaitse, kodanikukaitse, töökaitse üldkursus, õigusõpetus, võõrkeel, eesti keel, filosoofia üldkursus.

Agronoomia eriala üliõpilased õppisid järgmisi õppeaineid suunaõppemoodulis: üldkeemia, botaanika põhikursus, taimefüsioloogia biokeemia alustega, geneetika, mikrobioloogia üldkursus, informaatika, ja erialaõppemoodulis: mullateaduse põhikursus, Eesti mullastik, muldade väliuurimine, agrokeemia põhikursus, maaviljelusteadus, maaviljeluse põhikursus, seemneteadus, taimekasvatusteadus, eritaimekasvatus, sordiaretuse põhikursus, seemnekasvatuse põhikursus, taimekasvatussaaduste töötlemise, säilitamise ja hindamise põhikursus, fütopatoloogia põhikursus, põllumajandusentomoloogia, taimekaitse põhikursus, teadustöö metoodika, söötmisõpetus, eriloomakasvatus koos õppepraktikaga. Agronoomia eriala üliõpilased õppisid lisaõppemoodulis järgmisi õppeaineid: produktsioonibioloogia, sooteadus ja -kultuur, integreeritud ja alternatiivne maaviljelus, köögiviljandus, agrometeoroloogia, põllumajandusökonoomika üldkursus, ettevõtluse alused, informaatika II, metsanduse üldkursus, põllumajandusmasinad.

1995. aastal õppis EPMÜ viies teaduskonnas (agronoomia-, majandus- ja sotsiaal-, metsandus- ja maainseneri-, tehnika-, veterinaariateaduskond) ja ühes instituudis (loomakasvatusinstituut) kokku 2189 üliõpilast sh kaugõppes 483 (tabel 5).

1995 – Eesti Põllumajandusülikool

Rektor Mait Klaassen, õppeprorektor prof Kuno Järjenson, teadusprorektor prof Henn Elmet, halduseprorektor Rein Liblik.

Tabel 5. Üliõpilaste ja lõpetajate arv Eesti Põllumajandusülikoolis 1995. aastal

Teaduskond/instituut	Erialad	Üliõpilaste arv	Lõpetajate arv
Agronoomiateaduskond	Agronoomia	319 sh 88 kõ	28
Viljandi mnt Eerika	Aiandus	81	21
Dekaan dots Juhan Jõudu	Kodumajandus	35	4
Loomakasvatusinstituut Kreutzwaldi 1 Direktor prof Olav Kärt	Loomakasvatus	132 sh 55 kõ	31
Veterinaariateaduskond	Veterinaarmeditsiin	179	56
Kreutzwaldi 62	Lihatehnoloogia	48	8
Dekaan dots Madis Aidnik	Piimatehnoloogia	51	10
Majandus- ja sotsiaalteaduskond Riia mnt 12	Põllumajanduslik raamatupidamine ja rahandus	164 sh 59 kõ	13
Dekaan prof Viktor Jullinen	Põllumajanduse ökonoomika ja ettevõtlus	191 sh 79 kõ	17
Metsandus ja maainseneriteaduskond	Metsamajandus	197 sh 69 kõ	29
Kreutzwaldi 5	Metsatööstus	51	–
Dekaan dots Hardi Tullus	Maamõõtmine	111	14
	Maaehitus	69	22
	Veemajandus	53	7
	Maastikuarhitektuur	37	–
Tehnikateaduskond	Põllumajanduse mehhaniseerimine	197 sh 41 kõ	42
Kreutzwaldi 56	Põllumajandusenergeetika	64	13
Dekaan dots Matti Liiske	Konstruktor	17	2
Põhiõppes		1880 sh 391 kaugõppes	317
Magistriõppes		261 sh 92 kaugõppes	14
Doktoriõppes		48	6
Kokku üliõpilasi/lõpetajaid		2189 sh 483 kaugõppes	337

1996/1997 õppeaastal moodustati esimesed riigieelarvevälised (REV) ehk tasulised õppekohad statsionaarses õppes. REV õppekohtadele võeti lepingu alusel vastu 14 üliõpilast, 1997/1998 õppeaastal 61, 1998/1999 õppeaastal 101, 1999/2000 õppeaastal 325.

Kõige enam oli REV õppekohtadel õppivaid üliõpilasi põllumajandusraamatupidamise ja rahanduse erialal ning põllumajanduse ökonoomika ja ettevõtluse erialal. Teistel erialadel (aiandus, metsamajandus, metsatööstus, liha- ja piimatehnoloogia, maastikuarhitektuur, maastikukaitse ja -hooldus, maaehitus, maamõõtmine, põllumajanduse mehhaniseerimine) oli REV õppekohal õppijaid vähem.

Statsionaarses õppes riigieelarvevälistel (REV) õppekohtadel õppivad üliõpilased õppisid koos riigieelarvelistel (RE) õppekohtadel õppivate üliõpilastega ning

neile kehtisid kõik üliõpilaste õigused ja kohustused v.a. õigus saada riiklikku stipendiumi.

Kaugõpe avas uuesti uksed 1997. aastal, kui moodustati õppeprorektori vastutusalasse kuuluv iseseisev osakond – Avatud Ülikool, mille üheks tegevusvaldkonnaks sai riigieelarvevälise (REV) tasemekoolituse ehk tasulise diplomi- ja bakalaureuseõppe korraldamine kaugõppe teel. 1997/1998 õppeaastal võeti REV õppekohtadele kaugõppesse 60 üliõpilast, nendest 49 majandus- ja sotsiaalteaduskonda, 3 maainseneri-, 1 metsandus-, 1 agronoomia-, 4 loomaarsti- ja 2 tehnikateaduskonda.

Põllumajandusülikooli nõukogu 22. juuni 1998. a otsusega nr 5-98 viidi riigieelarveväline tasemekoolitus (täismahus diplomi-, bakalaureuse-, magistriõpe) Avatud Ülikooli vastutusalast üle õppe- ja teadusosakonna vastutusalasse. Avatud Ülikooli põhiülesandeks jäi täiendõppe korraldamine EPMÜ-s.

1998/1999 õppeaastal võeti kaugõppesse REV ehk tasulistele õppekohtadele vastu 147 üliõpilast; nendest 16 diplomiõppesse (12 liha- ja piimatehnoloogia, 4 ergonoomika ja väikeettevõtte tehnika). 1999/2000 õppeaastal võeti kaugõppe REV õppekohtadele vastu 180 üliõpilast.

Kaugõppe üliõpilased kuulusid vastava instituudi juurde. Üldõppe tunniplaan koostati õppeosakonnas, erialaainete tunniplaanid vastavas instituudis.

Bakalaureuseõppe lõpetajatele, kes astusid ülikooli alates 1994. aastast, anti bakalaureusekraad. Diplomile kirjutati, et on täitnud nt agronoomia bakalaureuseõppe õppekava täies mahus ja talle on antud bakalaureusekraad agronoomia erialal. Esimesed bakalaureusekraadiga diplomid väljastati 1998. aastal.

Enne 1994. aastat bakalaureuseõppesse astunud üliõpilased said diplomi ilma bakalaureusekraadita (ülikooli kraadita diplom). Diplomile kirjutati, et on täitnud nt veterinaaria eriala õppekava täies mahus, maaehituse eriala õppekava täies mahus.

Magistriõppe lõpetajatele anti magistri teadus- või kutsekraad (nt põllumajandusmagistri teaduskraad loomakasvatuse erialal, tehnikamagistri teaduskraad põllumajanduse mehhaniseerimise erialal), doktoriõppe lõpetajatele – doktorikraad (nt põllumajandusdoktor; Doctor of Agriculture (dr.Agr) taimekasvatuse erialal, filosoofiadoktor (PhD) taimekasvatuse erialal).

EPMÜ nõukogu 16.05.1997 otsusega kinnitati agronoomiateadukonna kodumajanduse eriala õpetajakoolituse õppekava ja kodumajanduse magistriõppe üliõpilastel oli võimalus omandada õpetaja kutsetunnistus. Õpetajakutset tõendav õpetaja kutsetunnistus kehtis koos bakalaureuse diplomiga.

1999/2000 õppeaastal oli ülikoolis 6 teaduskonda (agronoomia-, loomaarsti-, maainseneri-, majandus- ja sotsiaal-, metsandus- ja tehnikateaduskond) ja 7 teadus- ja arendusasutust (Eksperimentaalbioloogia Instituut, Keskkonnakaitse Instituut, Loomakasvatusinstituut, Metsanduslik uurimisinstituut, Polli aianduse instituut, Zooloogia ja Botaanika Instituut ning Taimebiotehnoloogia uurimiskeskus EVIKA).

2000. aastal õppis ülikoolis kokku 3625 üliõpilast (sh kaugõppes 634), nendest magistriõppes 291 ja doktoriõppes 114. 2001. aastal oli üliõpilasi 4019 (sh kaugõppes 782), nendest magistriõppes 352 ja doktoriõppes 129. Üliõpilased olid immatrikuleeritud vastavasse teaduskonda või loomakasvatusinstituuti.

Agronoomiateaduskonna dekaaniks oli dots Juhan Jõudu, prodekaaniks Hugo Roostalu, dekanaadi vanemmetoodikuks Koidu Veibri.

Loomaarstiteaduskonna dekaaniks oli dots Madis Aidnik, prodekaaniks prof Jaan Praks, dekanaadi vanemmetoodikuks Maie Vassiljeva.

Maainseneriteaduskonna dekaaniks oli dots Venno Paalmäe, prodekaanideks dots Siim Maasikamäe ja dots Feliks Virma, dekanaadi vanemmetoodikuks Ele Laas.

Majandus- ja sotsiaalteaduskonna dekaaniks oli prof Viktor Jullinen, prodekaaniks dots Jüri Krusealle, dekanaadi vanemmetoodikuks Jaana Orin.

Metsandusteaduskonna dekaaniks oli prof Hardi Tullus, prodekaaniks dots Kalev Jõgiste, dekanaadi vanemmetoodikuks Vaike Reisner.

Tehnikateaduskonna dekaaniks oli prof Matti Liiske, prodekaaniks prof Boris Reppo, dekanaadi metoodikuks Eve Möller.

Loomakasvatusinstituudi direktoriks prof Olav Kärt, asedirektoriks õppe alal dots Einar Orgmets, dekanaadi metoodikuks Piret Aus.

Eksperimentaalbioloogia Instituudi direktoriks oli prof Aavo Aaviksaar, Keskkonnakaitse Instituudi direktoriks prof Lembit Nei, Metsandusliku Uurimisinstituudi direktoriks oli Ülo Tamm, Polli Aianduse Instituudi direktoriks Toivo Univer, Zooloogia ja Botaanika Instituudi direktoriks Urmas Tartes. Taimebiotehnoloogia Uurimiskeskust (EVIKA) juhtis direktori kt Katrin Kotkas.

Ülikooli nõukogu 21.12.2000 otsusega rakendus õppetöö kvaliteedi hindamise süsteem; pidev õpetamise hindamine üliõpilaste küsitluse alusel ning kinnitati õpetamise hindamise juhend.

2000/2001 õppeaastast arvestati õppetöö mahtu ainepunktides (AP). Üks ainepunkt vastas 40 tunnile ehk ühele õppenädalale üliõpilase poolt õppeks kulutatud tööle, millesse arvestati auditoorne töö, praktiline töö, iseseisev töö ja teadmiste kontroll. 1 AP (40 tundi õppetööd) sisaldas kuni 20 t auditoorset õppetööd, veterinaarmeditsiini erialal 24 tundi. Alates 2002. a vastuvõtust kehtima hakkavates uutes õppekavades hakati õppe mahtu arvestama Euroopa ainepunktisüsteemis (ECTS) st 1 EAP vastab 26 tunnile tööle, mille üliõpilane on õppeks kulutanud. See moodustab 1560 tundi ja 60 ainepunkti õppeaastas.

Ülikooli nõukogu 28.06.2001 otsusega kinnitati **EPMÜ tegevuse põhivaldkonnas** (loodusressursside säästlik kasutamine) õppetöö ning teadus- ja arendustegevuse läbiviimiseks vajaliku õppetoolide (30) nimistu: taimekasvatus; rohumaaviljelus ja söödatootmine; aiandus; taimekaitse; mullateadus ja agrokeemia; loomageneetika ja tõuaretus; söötmisteadus; eriloomakas-

vatus; kalakasvatus ja kalandus; normaalne ja patoloogiline morfoloogia; füsioloogia, farmakoloogia ja loomatervishoid; sise- ja nakkushaigused; kirurgia ja sünnitusabi; toiduainete tehnoloogia; toiduhügieen ja kvaliteet; metsakasvatus ja metsaökoloogia; metsakorraldus; metsatööstus; keskkonnateadus; veemajandus; maastikuarhitektuur; biosüstemaatika; rakendushüdrobioloogia; põllumajandustehnika; põllumajandusenergeetika; geomaatika; maaehitus ja ehitustehnoloogia; agraarökonoomika ja turundus; maamajanduse arvestus; maamajanduse juhtimine ja maasotsioloogia.

Sätestati, et konkreetse õppetooli avamise otsuse teeb struktuuriüksuse nõukogus heakskiidetud õppetooli arendamise põhjendatud kava alusel ülikooli nõukogu. Esimesed viis õppetooli moodustati 2002. aastal loomaarstiteaduskonnas: morfoloogia õppetool, looma tervise õppetool, teraapia õppetool, nakkushaiguste õppetool ja toiduhügieeni õppetool.

Õppetool oli õpetamise ning teadusuuringutega tegelev akadeemiline struktuuriüksus, mis ühendas lähedase profiiliga õppeaineid. Õppetooli koosseisu võisid kuuluda ka muud õppe- ja teadustööga tegelevad üksused. Õppetooli juhtis professor või õppetooli hoidja, kes valiti teaduskonna nõukogus ja nimetati dekaani poolt ametisse kuni viieks aastaks, kuid mitte kauemaks kui 65. aastaseks saamiseni seisuga 31. august. Õppetooli juhiks oli õigus kandideerida õppetoolis töötavatel professoritel ja dotsentidel, nende puudumisel võis õppetoolile valida hoidja lektorite hulgast kuni viieks aastaks.

Ülikooli nõukogu 30.10.2003 määrusega Eesti Põllumajandusülikooli põhikiri sätestati, et õppetool kuulub instituudi koosseisu ja on korralise professori erialane ametikoht selle juurde kuuluvate töötajatega, kellele korraline professor on töökorraldaja.

Alates 2002/2003 õppeaastast rakendus Eesti ülikoolides sh Eesti Põllumajandusülikoolis **3+2 õppesüsteem**. Üliõpilaste vastuvõtt bakalaureuseõppesse, loomaarstiõppesse ja ehitusinseneriõppesse (st põhiõppesse) toimus uute (3+2 õppesüsteemi) õppekavade alusel, magistri- ja doktoriõppesse "vanade" ehk 4+2 õppesüsteemi õppekavade alusel.

3+2 õppesüsteemi magistri kvalifikatsioon on võrreldav spetsialisti kvalifikatsiooniga, mille said 4+2 õppesüsteemi bakalaureuseõppe lõpetajad ja kellele väljastati 4- või 5-aastase õppekava läbimisel bakalaureusekraad. 4+2 õppesüsteemi teadusmagistri kraadi andmine lõpetati alates 2012. aastast; ainsaks teaduskraadiks jäi doktorikraad.

Uued õppekavad kinnitati ülikooli nõukogus 14.02.2002 ja esitati registreerimiseks haridusministeeriumile. Loodi 10 bakalaureuseõppekava (õppe nominaalkestus 3 aastat, õppekava maht 120 AP), 1 loomaarstiõppekava (6 aastat, 240 AP), 2 ehitusinseneriõppekava (5 aastat, 200 AP), 24 magistriõppekava (2 aastat, 80 AP). Õppeaja lühenemise tõttu vähenes õppekavades praktika maht.

Kõrghariduse I astme (põhiõppe) õppekavad olid järgmised: põllu- ja aiasaaduste tootmine, loomakasvatussaaduste tootmine, metsandus, loodusvarade kasutamine ja kaitse, veterinaarmeditsiin, keskkonnakaitse, rakendushüdrobioloogia, keskkonnamajandus, maamajanduslik ettevõtlus ja finantsjuhtimine, geomaatika, maaehitus, veemajandus, tehnika ja tehnoloogia.

Bakalaureuseõppe õppekava (120 EAP, 3 aastat) koosnes järgmistest moodulitest/osadest: valdkonnaõpe, suunaõpe, erialaõpe, vabaained, bakalaureusetöö või -eksam.

Bakalaureuseõppekava **Põllu- ja aiasaaduste tootmine** üliõpilased õppisid 2005. aastal **järgmisi õppeaineid**: valdkonnaõppes (27 AP) – informaatika, põllumajanduse ajalugu, orgaaniline ja analüütiline keemia, üldloomakasvatus, erialane võõrkeel, ökoloogia ja keskkonnakaitse, majandusteaduse alused, õigusõpetus, riskianalüüs ja töökeskkonna ohutus, põllu- ja aiatöömasinad; suunaõppes (20,5 AP) – põllumajandustaimed, mullateaduse alused, agrokeemia, taimefüsioloogia biokeemia alustega, geneetika, teadustöö metoodika ja vormistamine, mikrobioloogia üldkursus, agrometeoroloogia; erialaõppes (27 AP) – rohumaaviljelus, murud, aianduse tehnoloogiad, maaviljeluse põhikursus, taimekasvatuse üldkursus, teadustöö praktika I, taimekahjustajad ja nende tõrje I, seemnekasvatus, põllumajandusökonoomika üldkursus; **spetsialiseerumisel agronoomia erialale** (20,5 AP) – Eesti mullastik, põllumajandustaimes II, muldade väliuurimine, sordiaretuse põhikursus, rohumaade tehnoloogiad, aia- ja põllusaaduste kvaliteet ja standardid, põllukultuuride tehnoloogiad, söötmisõpetus.

Magistriõppekava **Agronoomia** (80 AP, 2 aastat) üliõpilased õppisid 2005. aastal **järgmisi õppeaineid**: eksperimendi metoodika ja andmetöötlus, nõuandeteenistus ja -süsteemid, Euroopa Liidu üldkursus, taimesaaduste töötlemine, säilitamine ja kvaliteet, metsanduse üldkursus, maaviljelusteadus, taimede toitumine ja aineringed, rohumaateadus, seemneteadus ja -kasvatus, sooteadus ja -kultuur, taimekasvatusteadus, maakasutuse strateegiad ja ökonoomika, taimebiotehnoloogia, taimekahjustajad ja nende tõrje II, aiasaaduste turustamine, teadustöö praktika II, ettevõtte ja personali juhtimine, keskkonnasäästlik taimekasvatus ja mahetootmine. Magistriõpe lõppes magistritöö (20 AP) kaitsmisega.

Ülikooli nõukogu otsusega alustati vastuvõttu magistriõppesse majandusarvestuse ja finantsjuhtimise ning ökonoomika ja ettevõtluse uutele (3+2) õppekavadele. Üliõpilased immatrikuleeriti riikliku koolitustellimuse välistele (REV) st tasulistele õppekohtadele kaugõppesse. Kaugõppe üliõpilased kuulusid vastava instituudi juurde/alla.

2003. aastal õppis ülikoolis kokku 4621 üliõpilast (sh kaugõppes 1027), nendest magistriõppes 434 ja doktoriõppes 161. Üliõpilaste arvu suurenemise põhjuseks oli asjaolu, et 2002 ja 2003. aastal võeti üliõpilasi vastu nii uue (3+2) õppesüsteemi kui ka n.ö "vana" õppesüsteemi alusel (magistriõpe).

Ülikooliseadusest tulenevalt rakendus alates 2003. aastast täis- ja osakoormusega õpe. Täiskoormusega

õppes täidab üliõpilane iga õppeaasta lõpuks õppekava kohaselt täitmisele kuuluva õppe mahust vähemalt 75 protsenti, osakoormusega õppes 50 kuni 75 protsenti. Sätestati, et RKT alusel moodustatud õppekohtadele vastuvõetud üliõpilastele kehtivad täiskoormusega õppe nõuded. Täiskoormusega õppe nõudeid mittetäitva üliõpilase viib ülikool osakoormusega õppesse.

Alates 2003. aasta 1. septembrist rakendus õppetoetuste ja õppelaenu seadus. Üliõpilastel oli õigus taotleda põhitoetust, täiendavat toetust (n.ö sõidutoetust, kui elukoht asus kaugel) ning majanduslikku toetust. Doktorantidel oli õigus taotleda doktoranditoetust.

2003. aastal maksti õppetoetust kokku 564-le üliõpilasele; põhitoetuse saajaid oli 118, täiendava toetuse saajaid 216, mõlema so põhi- ja täiendava toetuse saajaid 192, doktoranditoetuse saajaid 38. Põhitoetuse ja majandusliku toetuse suurus oli 800 krooni kuus, täiendava toetus suurus 400 krooni kuus, doktoranditoetuse suurus 3000 krooni kuus.

1. jaanuaril 2005 rakendus ülikoolis uus akadeemiline struktuur. Senise 14 akadeemilise struktuuriüksuse asemele loodi 5 instituuti. Akadeemilise struktuurireformi eesmärgiks oli: õppe- ja teadustöö lähendamine, mille kaudu tõuseb õppetöö kvaliteet; professuuri tugevdamine; teadustöörühmade suurendamine; kaalukamate teadusprojektide saamine, teadus- ja arendustegevuse kvaliteedi parandamine; järelkasvu probleemi lahendamine.

Ülikooli nõukogu 17.02.2005 otsusega kinnitati akadeemilise tegevuse 32 vastutusvaldkonda: taimekasvatus; rohumaaviljelus ja söödatootmine; aiandus; taimekaitse; mullateadus ja agrokeemia; loomageneetika ja tõuaretus; söötmisteadus; eriloomakasvatus; kalakasvatus ja kalandus; normaalne- ja patoloogiline morfoloogia; looma tervis; nakkushaigused; teraapia; toiduainete tehnoloogia; toiduhügieen; metsakasvatus ja metsaökoloogia; metsakorraldus; metsatööstus; keskkonnateadus; veemajandus; maastikuarhitektuur; bioloogiline mitmekesisus; rakendushüdrobioloogia; põllumajandustehnika; energeetika; geomaatika; maaehitus; agroökonoomika ja turundus; majandusarvestus ja -analüüs; maamajanduse juhtimine ja maasotsioloogia; fütopatoloogia; maastikukorraldus ja loodushoid.

Vastutusvaldkond ühendas endas teadus- ja arendustegevust ja sellel tuginevat õppetööd, mille seisundi, konkurentsivõime ja arengu eest Eestis võttis Eesti Põllumajandusülikool endale vastutuse või kandis kaasvastutust teiste ülikoolidega kattuvates valdkondades.

Ülikooli nõukogu 04.05.2004 otsusega moodustati alates 01.01.2005 kolm teadus-ja arendusasutust, mille põhikirjajärgseks tegevuseks sai teadus- ja arendustegevus ning õppetöö läbiviimine ja korraldamine, ning kaks akadeemilist õppeasutust, mille põhikirjajärgseks tegevuseks sai õppetöö läbiviimine ja korraldamine ning osalemine teadus- ja arendustegevuses.

Teadus- ja arendusasutusteks kinnitati: agraar- ja keskkonnateaduste instituut, loomaarsti- ja loomateaduste instituut ning metsanduse ja inseneriteaduste instituut.

Akadeemilisteks õppeasutusteks kinnitati tehnika ja tehnoloogia instituut ning majandus- ja sotsiaalteaduste instituut.

Agraar- ja keskkonnateaduste instituut moodustati agronoomiateaduskonna (dekaan prof Juhan Jõudu), Eksperimentaalbioloogia Instituudi (dir Aavo Aaviksaar), Keskkonnakaitse Instituudi (dir Lembit Nei), Polli aianduse instituudi (dir Ave Kikas), Zooloogia ja Botaanika Instituudi (dir Urmas Tartes) ja Taimebiotehnoloogia Uurimiskeskus EVIKA (dir Katrin Kotkas) ühinemise teel.

Loomaarsti- ja loomateaduste instituut moodustati loomakasvatusinstituudi (dir prof Olav Kärt), loomaarstiteaduskonna (dekaan prof Toivo Suuroja) ja agrobiokeskuse (dir Jüri Kumar) ühinemise teel.

Metsanduse ja inseneriteaduste instituut moodustati metsandusliku uurimisinstituudi (dir Kalev Jõgiste), metsandusteaduskonna (dekaan dots Paavo Kaimre), maainseneriteaduskonna (dekaan dots Siim Maasikamäe) ning tehnikateaduskonna (dekaan prof Kuno Jürjenson) ühinemise ja/või jagunemise teel.

Tehnika- ja tehnoloogia instituut moodustati tehnikateaduskonna ja maainseneriteaduskonna jagunemise ja ühinemise teel.

Majandus- ja sotsiaalteaduste instituut moodustati majandus- ja sotsiaalteaduskonna (dekaan lektor Tiiu Ohvril) tegevuse ümberkorraldamise teel.

Ülikooli nõukogu võttis kuulda keeleekspertide arvamust struktuuriüksuste nimede asjus, muutis oma 25.11.2005 otsusega nr 43 ülikooli nõukogu 04.05.2004 otsusega nr 13 kinnitatud ülikooli struktuuriüksuste nimetusi ning kinnitas ülikooli akadeemiliste struktuuriüksuste uued nimetused: **põllumajandus- ja keskkonnainstituut** (PKI) (direktor Illar Lemetti, õppedirektor Are Selge), **veterinaarmeditsiini ja loomakasvatuse instituut** (VLI) (direktor Toomas Tiirats, õppedirektor Einar Orgmets), **metsandus- ja maaehitusinstituut** (MMI) (direktor Paavo Kaimre, õppedirektor Toomas Timmusk), **tehnikainstituut** (TI) (direktor Margus Arak, õppedirektor Arvo Leola), **majandus- ja sotsiaalinstituut** (MSI) (direktor Rando Värnik, õppedirektor Tiiu Ohvril).

Alustati õppekavade korrastamist. Moodustati 3+2 õppekavade hindamise ja analüüsi komisjon koosseisus prof Hugo Roostalu, van teadur Tiiu Kull ja dotsent Arvo Viltrop. Komisjon esitas aruande 2005. aasta juunikuus.

Õppekavade kvaliteedi tagamiseks moodustati õppekavakomisjon ning määrati õppekavade juhid. Lähedasi erialasid ühendavate õppekavade juhtideks määrati: prof Hugo Roostalu – põllumajandus (põllu- ja aiasaaduste tootmine, loomakasvatussaaduste tootmine, maamajanduslik ettevõtlus ja finantsjuhtimine); prof Andres Kiviste – metsandus (metsandus, loodusvarade kasutamine ja kaitse); prof Kalev Sepp – keskkonnateadus ja rakendusbioloogia (keskkonnakaitse, keskkonnamajandus, rakendushüdrobioloogia, BIOLandMan); dots Arvo Viltrop – veterinaarmeditsiin ja toiduteadus;

dots Jüri Olt – tehnika- ja inseneriteadus (tehnika ja tehnoloogia, maaehitus, veemajandus, geomaatika); dots Are Selge – õpetajakoolitus.

2005. aastal vähendati doktoriõppekavade arvu 22-lt 5-le. Ülikooli nõukogu otsusega kinnitati 5 doktoriõppekava: keskkonnateadus ja rakendusbioloogia; põllumajandus; veterinaarmeditsiin ja toiduteadus; metsandus; tehnikateadus.

Uuendati doktoriõppekava struktuuri ja õppeainete sisu. Senise 6 kaitsmiskomisjoni asemele moodustati 3 doktoritööde kaitsmiskomisjoni, käivitus doktorantide juhendajate tasustamise süsteem doktoritöö kaitsmise eest. Uuendati akadeemiliste kraadide kaitsmise tingimusi ning kinnitati doktorikooli statuut. Doktorikool on ülikooli doktoriõppekavade ühisosa koordineeriv ja arendav keskus, mille eesmärgiks on efektiivse ja kvaliteetse doktoriõppe korraldamine ja arendamine ning koostöö teiste ülikoolide doktorikoolidega. Doktorikool tegutseb õppeosakonna koosseisus ja seda juhib koordinaator; hilisema nimetusega doktoriõppe peaspetsialist. EPMÜ ühines ülikoolidevaheliste doktorikoolidega; biomeditsiini ja biotehnoloogia doktorikooli ja ökoloogia ja keskkonnateaduste doktorikooliga.

2005. aastal lõpetas ülikooli kaks lendu; lisaks 4+2 õppesüsteemi bakalaureuse- ja diplomiõppe lõpetajatele ka **esimene lend 3+2 õppesüsteemi bakalaureuseõppe lõpetajaid.**

3+2 õppesüsteemi lõpetajatele anti bakalaureusekraad, nt põllumajandusteaduse bakalaureus (*Bachelor of Science in Agriculture* (BSc)), loodusteaduse bakalaureus (*Bachelor of Science* (*BSc*)), tehnikateaduse bakalaureus (*Bachelor of Science in Engineering* (*BSc*)) või magistrikraad nt põllumajandusteaduse magister (*Master of Science in Agriculture* (*MSc*)), loodusteaduse magister (*Master of Science* (*MSc*)), tehnikateaduse magister (*MSc*). Ehitusinseneriõppe lõpetajatele anti tehnikateaduste magistrikraad (*Master of Science in Civil Engineering* (*MSc*)), loomarstiõppe lõpetajatele (õppeaeg 5 aastat) anti loomaarsti kvalifikatsioon, 6-aastase loomaarstiõppe lõpetajatele anti loomaarstikraad (*Degree in Veterinary Medicine* (*DVM*)).

3+2 õppesüsteemi bakalaureusekraad, magistrikraad ja loomaarstikraad ei ole teaduskraad. Teaduskraad on doktorikraad; filosoofiadoktor (*Doctor of Philosophy* (*PhD*). Diplomile kirjutati, et on täitnud nt metsanduse doktoriõppe õppekava (80131) täies mahus ja talle on antud filosoofiadoktori kraad (metsandus).

2005. aastal võeti põhiõppe 12-le õppekavale vastu kokku 1014 üliõpilast, nendest kaugõppesse 299.

3+2 magistriõppekavadele võeti vastu kokku 268 üliõpilast, nendest kaugõppesse 46.

Toimus **viimane vastuvõtt 4+2 õppesüsteemi magistriõppekavadele** (26) ja **õpetajakoolitusse** (põllumajanduslike erialade õpetaja õppekavale).

Kõrghariduse II astme (3+2 magistriõppe) õppekavad (22) olid järgmised: agronoomia, aiandus, põllumajandussaaduste tootmine ja turustamine, loomakasvatus, agroökoloogia, kalakasvatus, liha- ja piimatehnoloogia, metsamajandus, metsatööstus, loodusvarade kasutamine ja kaitse, maastikukaitse- ja hooldus, maastikuarhitektuur, keskkonnamajandus, ökonoomika ja ettevõtlus, majandusarvestus ja finantsjuhtimine, põllumajandustehnika, ettevõttetehnika, ergonoomika, energiakasutus, maakorraldus, geodeesia, kinnisvara planeerimine.

Haridus- ja teadusministeeriumi ning Eesti Põllumajandusülikooli vahel sõlmitud 2005. aasta riikliku koolitustellimuse (RKT) lepinguga määratud magistriõppe lõpetajate arv 2010. aastal oli 207. Ülikooli nõukogu otsusega võeti RKT täitmiseks bakalaureuseõppesse vastu 353 üliõpilast, seega moodustati iga magistriõppe lõpetaja kohta 1,7 bakalaureuseõppe õppekohta.

2005. aasta RKT lepinguga määratud loomaarstiõppe 25 lõpetaja kohta võeti vastu 40 ja ehitusinseneriõppe 31 lõpetaja kohta 40 üliõpilast. Kui doktoriõppe RKT oli 2003. aastal 23, siis 2004. ja 2005. aastal 18.

Konkurss põhiõppesse astumiseks 2005. aastal oli 6.18 kandidaati ühele õppekohale.

423-le riiklikule õppekohale esitati 2613 avaldust, 4+2 magistriõppe 49-le õppekohale esitati 180 avaldust, 3+2 magistriõppe 258-le õppekohale esitati 334 avaldust, doktoriõppe 18-le õppekohale esitati 41 avaldust. Konkurss õppekohtadele oli suhteliselt suur, kuid kuna kandideerijatel oli võimalus avaldus esitada mitmesse ülikooli ja mitmele erialale, jäi tegelik konkurss suhteliselt tagasihoidlikuks.

EPMÜ nõukogu tegi oma 25.11.2004 otsusega nr 42 haridus- ja teadusministrile ning Riigikogu kultuurikomisjonile ettepaneku muuta Eesti Põllumajandusülikooli nimi Eesti Maaülikooliks.

17. novembril 2005 ilmus Riigi Teatajas Riigikogus 20. oktoobril 2005 vastu võetud ning Vabariigi Presidendi poolt 7. novembril allkirjastatud Ülikooliseaduse § 3 muutmise seadus, mille kohaselt asendati Ülikooliseaduse § 3 lõikes 1 sõnad "Eesti Põllumajandusülikool" sõnadega "Eesti Maaülikool".

Alates 27. novembrist 2005 on ülikooli nimeks Eesti Maaülikool (EMÜ). Maaülikooli ülesandeks sai edendada teadust ja kultuuri, osutada ühiskonnale vajalikke õppe- ja teadus ning muul loometegevusel põhinevaid teenuseid, teha nüüdisaegsel tasemel teadus- ja arendustööd kõigis maaelu ja maamajanduse ning loodusressursside säästliku kasutamisega seotud valdkondades, korraldada teaduspõhist akadeemilist ja rakenduskõrghariduslikku ning täiendusõpet. EMÜ oli ja on Eesti Vabariigi avalik- õiguslik ülikool.

2005 – Eesti Maaülikool

Rektor prof Alar Karis, õppeprorektor prof Hardi Tullus, teadusprorektor Andres Koppel, haldusdirektor Jüri Kirss (tabel 6).

Tabel 6. Üliõpilaste ja lõpetajate arv Eesti Maaülikoolis 2005. aastal

Teaduskond	Õppekavad/spetsialiseerumised (erialad)	Üliõpilaste arv	Lõpetajate arv
Põllumajandus- ja keskkonnainstituut Viljandi mnt Eerika Direktor Illar Lemetti	Bakalaureuseõpe: Põllu- ja aiasaaduste tootmine (agronoomia, aiandus, põllumajandussaaduste tootmine ja turustamine) Keskkonnakaitse (maastikuarhitektuur, maastikukaitse ja -hooldus) Rakendushüdrobioloogia Õpetajakoolitus: Põllumajanduslike erialade õpetaja Magistriõpe: Aiandus Agronoomia Põllumajandussaaduste tootmine ja turustamine Maastikuarhitektuur Maastikukaitse ja -hooldus	Instituudis kokku 946 sh 24 kõ	Instituudis kokku 185 sh 17 teadusmagistrit ja 2 doktorit
Veterinaarmeditsiini ja loomakasvatuse instituut Kreutzwaldi 62 Direktor dots Toomas Tiirats	Bakalaureuseõpe: Loomakasvatussaaduste tootmine (loomakasvatus, kalakasvatus, liha- ja piimatehnoloogia) Magistriõpe: Loomakasvatus Agroökoloogia Kalakasvatus Liha- ja piimatehnoloogia Bakalaureuse- ja magistriõppe integreeritud õpe: Veterinaarmeditsiin	Instituudis kokku 706 sh 25 kõ	Instituudis kokku 96 sh 6 teadusmagistrit ja 4 doktorit
Majandus- ja sotsiaalinstituut Kreutzwaldi 64 Direktor dots Rando Värnik	Bakalaureuseõpe: Keskkonnamajandus Maamajanduslik ettevõtlus ja finantsjuhtimine (majandusarvestus ja finantsjuhtimine, ökonoomika ja ettevõtlus) Magistriõpe: Keskkonnamajandus Majandusarvestus ja finantsjuhtimine Ökonoomika ja ettevõtlus	Instituudis kokku 1084 sh 546 kõ	Instituudis kokku 210 sh 1 teadusmagister ja 3 doktorit
Metsandus- ja maaehitusinstituut Kreutzwaldi 5 Direktor dots Paavo Kaimre	Bakalaureuseõpe: Metsandus (metsamajandus, metsatööstus) Loodusvarade kasutamine ja kaitse Geomaatika (maakorraldus, geodeesia, kinnisvara planeerimine) Bakalaureuse- ja magistriõppe integreeritud õpe: Maaehitus Veemajandus Magistriõpe: Metsamajandus Metsatööstus Loodusvarade kasutamine ja kaitse Maakorraldus Geodeesia Kinnisvara planeerimine	Instituudis kokku 1518 sh 461 kõ	Instituudis kokku 246 sh 14 teadusmagistrit ja 5 doktorit
Tehnikainstituut Kreutzwaldi 56 Direktor Margus Arak	Bakalaureuseõpe: Tehnika ja tehnoloogia (ergonoomika, energiakasutus, ettevõttetehnika, põllumajandustehnika) Magistriõpe: Ergonoomika Energiakasutus Ettevõttetehnika Põllumajandustehnika	Instituudis kokku 530 sh 79 kõ	Instituudis kokku 99 sh 2 teadusmagistrit ja 2 doktorit
Põhiõppes Magistriõppes Doktoriõppes		3867 sh 1204 kõ 755 sh 460 4+2 õppesüsteemis, 287 3+2 õppesüsteemis (sh 45 kõ) 162	768 sh 175 kõ 43 sh 3+2 õppesüsteemis 3 16
Kokku üliõpilasi/lõpetajaid		4784 sh 1204 kaugõppes	836 sh 9 õpetajakoolituses

Eesti Maaülikool, Tartu Ülikool, Tallinna Tehnikakõrgkool ja Tartu Teaduspark sõlmisid 24.11.2006 ühiste kavatsuste protokolli eesmärgiga koordineerida nende asutuste vahelist tegevust tehnika- ja tehnoloogiaalase rakenduskõrghariduse arendamiseks Tartus. 3. jaanuaril 2007 liitus ühiste kavatsuste protokolliga Võrumaa Kutsehariduskeskus. Maaülikooli rektori 28.12.2006 korraldusega nr 187-RR moodustati tehnilise rakenduskõrghariduse andmise käivitamiseks ja sellega seotud tegevuste koordineerimiseks juhtkomitee. Eesti Maaülikooli nõukogu 25.01.2007 otsusega nr 3 moodustati Eesti Maaülikooli eesmärke ja ülesandeid aluseks võttes alates 1. veebruarist 2007 Eesti Maaülikooli põhikirja punktile 21 vastav akadeemilise struktuuriüksuse staatuses õppeasutus – **Eesti Maaülikooli Tartu tehnikakolledž.**

Vabariigi Valitsuse 18.12.2008 määruse nr 178 "Kõrgharidusstandard" kohaselt pidid kõrgkoolid tagama, et septembriks 2009 oleksid ülikooli õppekavade eesmärgid ja õpiväljundid sõnastatud nii, et nende alusel oleks võimalik hinnata õppekava lõpetaja teadmisi ja oskusi. Kõrgharidustaseme astmete õpiväljundid ehk mida üliõpilane peab bakalaureusekraadi, magistrikraadi, doktorikraadi või rakenduskõrgharidusõppe diplomi saamiseks teadma ja oskama/valdama**,** on kirjas kõrgharidusstandardi lisas 1.

Ülikooli nõukogu 28.05.2009 otsusega nr 20 kinnitati Eesti Maaülikooli õppekavade arendusena muudetud n.ö pädevuspõhised õppekavad; 13 bakalaureuseõppekava, 1 loomaarstiõppe õppekava, 2 ehitusinseneriõppekava, 24 magistriõppekava, 1 rakenduskõrgharidusõppekava ja 5 doktoriõppekava.

Pädevuspõhised õppekavad rakendusid alates 2009/2010 õppeaastast ülikooli immatrikuleeritud üliõpilastele ja enne 2009/2010 õppeaastat immatrikuleeritud nendele üliõpilastele, kes akadeemilisel puhkusel viibimise tõttu ei saanud alustada õpinguid immatrikuleerimise aastal.

Alates 2009/2010 õppeaastast on riiklikuks ainepunktisüsteemiks Euroopa ainepunktisüsteem (EAP). Selleks ajaks pidid varem kasutusel olevad ainepunktid (AP) olema ümber arvestatud ECTS süsteemi ainepunktideks (EAP) arvestusega, et 1 AP vastab 1,5 EAP-le. Õppeaasta mahuks arvestatakse 60 ainepunkti (EAP), mis on 1560 tundi tööd. 1 EAP vastab 26 tunnile tööle, mille üliõpilane on õppeks kulutanud.

Bakalaureuseõppe maht on 180 EAP, magistriõppe maht 120 EAP, loomaarstiõppe maht 360 EAP, ehitusinseneriõppe maht 300 EAP, rakenduskõrgharidusõppe maht 240 EAP ja doktoriõppe maht 240 EAP.

Ülikooli nõukogu 31.03.2009 otsusega kinnitati EMÜ akadeemilise tegevuse 26 vastutusvalda: taimekasvatus ja taimebioloogia; aiandus; taimetervis; mullateadus ja agrokeemia; maastiku- ja keskkonnakorraldus; maastikuarhitektuur; elurikkus; rakendushüdrobioloogia; loomageneetika ja tõuaretus; söötmisteadus; vesiviljelus; morfoloogia ja füsioloogia; pidamiskeskkond; veterinaarne mikrobioloogia ja parasitoloogia; kliiniline veterinaarmeditsiin; toiduteadus ja toiduhügieen; metsakasvatus ja metsaökoloogia; metsakorraldus; metsatööstus; geomaatika; maaehitus; veemajandus; biotehnilised süsteemid; tootmistehnika; energeetika; maamajanduse ökonoomika.

Sätestati, et **valdkonna tegevust juhib professor**, kes kannab vastutust valdkonna ja selle valdkonna raames töötava töörühma või -rühmade liikmete taseme ja arengu eest. Valdkonna juht nimetati instituudi nõukogu poolt instituudi direktori ettepanekul.

Seoses õppekavade läheneva üleminekuhindamise ja toiduainete tehnoloogia valdkonna õppekava reorganiseerimisega, esitas veterinaarmeditsiini ja loomakasvatuse instituut (VLI) taotluse bakakaureuseõppes uue õppekava Toiduainete tehnoloogia loomiseks/ avamiseks. Õppekava haakuks olemasoleva liha- ja piimatehnoloogia magistriõppekavaga, millele antakse riiklik koolitustellimus (RKT) "tehnika, tootmine ja ehitus" valdkonna "tehnika/tehnoloogia" õppesuuna alt. Senine liha- ja piimatehnoloogia alane bakalaureuseõpe on toimunud põllumajanduse valdkonna õppekava Loomakasvatussaaduste tootmine spetsialiseerumisena.

Praeguse bakalaureuseõppekava muutmise vajadust on korduvalt soovitanud ka rahvusvahelised akrediteerimiskomisjonid (nii loomakasvatuse kui tehnoloogia oma) ning liha- ja piimatööstuste spetsialistid, kes loomakasvatusliku suunaga bakalaureuseõppe asemel sooviksid laiemapõhjalist toiduainete tehnoloogia õpet, mis soodustakse tootearendust ja koostööd erinevate toiduainetööstuse valdkondades. Õppekava muutmist on soovinud ka üliõpilased.

Ülikooli nõukogus kinnitati bakalaureuseõppekava Toiduainete tehnoloogia ja ka rakenduskõrgharidusõppekava Biotehnilised süsteemid. Kehtestati doktorantide atesteerimise tingimused ja kord.

2009. aastal võeti esmakordselt vastu 13 üliõpilast magistriõppekavale Loodusturism kaugõppesse tasumääraga 22 000 eesti krooni aastas ja 9 üliõpilast RE õppekohtadele magistriõppekavale Ökonoomika ja ettevõtlus.

2010/2011. õppeaastal oli ülikoolis kokku 48 õppekava sh bakalaureuseõppes – 14, bakalaureuse- ja magistriõppe integreeritud õppes – 3, magistriõppes 24, rakenduskõrgharidusõppes – 2 ja doktoriõppes – 5. Üliõpilasi oli kokku 4847 (tabel 7).

Õppevaldkonnas Põllumajandus sh veterinaaria õppis 31,3% üliõpilastest, õppevaldkonnas Tehnika, tootmine ja ehitus – 31,3%, õppevaldkonnas Sotsiaalteadused, ärindus ja õigus – 18%, õppevaldkonnas Teenindus – 17% ning õppevaldkonnas Loodus- ja täppisteadused – 2,4% üliõpilastest.

Lõpetasid esimesed bakalaureuseõppekava Iluaiandus ja Põllumajandusettevõtte majandamine üliõpilased; vastavalt 10 ja 6, ning esimesed magistriõppekava Linna- ja tööstusmaastike korraldus üliõpilased (10). Ingliskeelse magistriõppekava Elustiku mitmekesisuse ja mitmefunktsiooniliste maastike korraldamine lõpetas 6 üliõpilast (kõik pärit Kosovost).

Avati vastuvõtt bakalaureuseõppekavale Toiduainete tehnoloogia; RKT 23-le õppekohale võeti vastu 35 üliõpilast. Avati vastuvõtt bakalaureuseõppekava Põllu- ja aiasaaduste tootmine aianduse erialale kaugõppesse;

õppima asus 10 üliõpilast. Alustati vastuvõttu Euroopa Liidu Sotsiaalfondist rahastatava projekti raames väljatöötatud rakenduskõrgharidusõppe õppekavale Biotehnilised süsteemid; projekti raames SA Archimedese poolt finantseeritavatele õppekohtadele (10) võeti vastu 25 üliõpilast. Rakendus programm "Kõrgharidus katkestanute haridustee jätkamine – TULE", mille raames võeti vastu 36 üliõpilast (tabel 8).

Tabel 7. Üliõpilaste ja lõpetajate arv Eesti Maaülikoolis 2010. aastal

Instituut	Üliõpilaste arv	Lõpetajate arv õppeastmeti				
		bak	mag	int	dokt	kokku
Põllumajandus- ja keskkonnainstituut	1303 sh 344 kõ	175	67		6	248
Veterinaarmeditsiini ja loomakasvatuse instituut	703	29	16	35	2	82
Metsandus- ja maaehitusinstituut	1321 sh 251 kõ	123	59	41	1	224
Majandus- ja sotsiaalinstituut	885 sh 554 kõ	106	44	–	–	150
Tehnikainstituut	510 sh 80 kõ	47	25	–	1	73
Tartu Tehnikakolledž	125					-
Kokku	4847 sh 1229 kõ	480	211	76	10	777

Tabel 8. Vastuvõtuks avatud õppekavad, erialad ja vastuvõetud üliõpilaste arv Eesti Maaülikoolis 2010. aastal

Õppesuund	Õppekava	Erialad/Spetsialiseerumine	Vastuvõetud üliõpilaste arv
Bakalaureuseõpe			
Põllumajandus, metsandus ja kalandus	Põllu- ja aiasaaduste tootmine	Aiandus Põllumajandussaaduste tootmine ja turustamine	92 sh 11 kõ
	Põllumajandusettevõtte majandamine		26 kõ
	Loomakasvatussaaduste tootmine	Loomakasvatus Kalakasvatus	39
	Metsandus	Metsamajandus Metsatööstus	83 sh 15 kõ
Keskkonnakaitse	Loodusvarade kasutamine ja kaitse	Loodusvarade kasutamine ja kaitse Taastuvenergia ressursid	36 sh 12 kõ
	Keskkonnakaitse	Maastikukaitse ja -hooldus Maastikuarhitektuur	68
	Linna- ja tööstusmaastike korraldus		25 kõ
	Loodusturism		46 sh 28 kõ
Bioteadused	Rakendushüdrobioloogia		11
Ärindus ja haldus	Maamajanduslik ettevõtlus ja finantsjuhtimine	Ökonoomika ja ettevõtlus Majandusarvestus ja finantsjuhtimine	120 sh 48 kõ
Arhitektuur ja ehitus	Geomaatika	Maakorraldus Geodeesia Kinnisvara planeerimine	50
Tehnikaalad	Tehnika ja tehnoloogia	Ergonoomika Energiakasutus Tootmistehnika	99 sh 14 kõ
Tootmine ja töötlemine	Toiduainete tehnoloogia		44
Bakalaureuse- ja magistriõppe integreeritud õppekavadel põhinev õpe			
Veterinaaria	Veterinaarmeditsiin		59
Arhitektuur ja ehitus	Maaehitus		23
	Veemajandus		26
Rakenduskõrgharidusõpe			
Tehnikaalad	Tehnotroonika		34
	Biotehnilised süsteemid		23
Kokku üliõpilasi vastu võetud kõrghariduse I astmesse			904 sh 179 kõ
Magistriõpe			
Põllumajandus, metsandus ja kalandus	Aiandus		16
	Põllumajandussaaduste tootmine ja turustamine		25
	Loomakasvatus		6

Õppesuund	Õppekava	Erialad/Spetsialiseerumine	Vastuvõetud üliõpilaste arv
	Kalakasvatus		9
	Metsamajandus		14
	Metsatööstus		15
Keskkonnakaitse	Linna- ja tööstusmaastike korraldus		12 kõ
	Loodusturism		7 kõ
	Loodusvarade kasutamine ja kaitse		16
	Taastuvenergia ressursid		3
	Maastikukaitse ja -hooldus		16
Bioteadused	Rakendushüdrobioloogia		10
Ärindus ja haldus	Ökonoomika ja ettevõtlus		30 sh 14 kõ
	Majandusarvestus ja finantsjuhtimine		37 kõ
Arhitektuur ja ehitus	Maastikuarhitektuur		21
	Maakorraldus		12
	Geodeesia		10
	Kinnisvara planeerimine		14
Tehnikaalad	Ergonoomika		14
	Energiakasutus		20 sh 8 kõ
	Tootmistehnika		14
Tootmine ja töötlemine	Liha- ja piimatehnoloogia		13
Kokku üliõpilasi vastu võetud magistriõppesse			334 sh 78 kõ
Doktoriõpe			
Põllumajandus, metsandus ja kalandus	Põllumajandus		8
	Metsandus		5
Veterinaaria	Veterinaarmeditsiin ja toiduteadus		3
Keskkonnakaitse Bioteadused	Keskkonnateadus ja rakendusbioloogia		8
Arhitektuur ja ehitus Tehnikaalad	Tehnikateadus		5
Kokku üliõpilasi vastu võetud doktoriõppesse			29

2013. aastal õppis Maaülikoolis kokku 4294 üliõpilast, nendest REV ehk tasulistel õppekohtadel 922 ehk 21,5%. Statsionaarses õppes õppis kokku 3372 üliõpilast, nendest bakalaureuseõppes 1698, ehitusinseneriõppes 281, loomaarstiõppes 315, rakenduskõrgharidusõppes 175, magistriõppes 630, doktoriõppes 225. Kaugõppes õppis 922 üliõpilast (2012. aastal 1022; 2011. aastal 1109; 2010. aastal 1229), nendest bakalaureuseõppes 547, ehitusinseneriõppes 94 ja magistriõppes 281.

Välisüliõpilasi õppis 2013. aastal kõikides õppeastmetes kokku 166. Kõige enam (141) oli välisüliõpilasi loomaarstiõppes.

Õppevaldkonnas *Põllumajandus* (sh veterinaaria) õppis 31,22% üliõpilastest, õppevaldkonnas *Tehnika, tootmine ja ehitus* 34,14%, õppevaldkonnas *Sotsiaalteadused, ärindus ja õigus* 17,38%, õppevaldkonnas *Teenindus* 14,15% ning õppevaldkonnas Loodus- ja täppisteadused 3,11% üliõpilastest.

2013. aastal lõpetas ülikooli 712 üliõpilast, nendest 394 bakalaureuseõppe, 48 loomaarstiõppe (sh 23 välisüliõpilast/soomlast), 39 ehitusinseneriõppe, 205 magistriõppe ja 12 rakenduskõrgharidusõppe. Lõpetas I lend bakalaureuseõppekava *Toiduainete tehnoloogia* lõpetajaid (23 üliõpilast). Kaitsti 14 doktoritööd.

2013. aastal Haridus- ja Teadusministeeriumi ning Eesti Maaülikooli vahel sõlmitud halduslepingu kohaselt vastutas ülikool kõrgel tasemel ja ühiskonna vajadustele vastava õppe läbiviimise, kvaliteedi ja arendamise eest põllumajanduse, metsanduse ja kalanduse ning veterinaaria õppekavagruppides. Ülikool jagas kaasvastutust õppetegevuse osas keskkonnahoiu õppekavagrupis TÜga, tehnika, tootmise ja tehnoloogia ning arhitektuuri ja ehituse õppekavagruppides TTÜga. Ülikool pidi tagama teiste asjaomaste ülikoolide ning tööandjatega maamajanduse ökonoomika spetsialistide ettevalmistuse.

SA Kutsekoda Inseneride kutsenõukogu 5.06.2013 otsusega anti Maaülikoolile esmase kutse andja õigus. Maaülikool omistas 2013. aastal Maaehituse õppekava lõpetajatele (22) diplomeeritud ehitusinseneri esmakutse, Veemajanduse õppekava lõpetajatele (17) diplomeeritud hüdrotehnikainseneri ning veevarustuse- ja kanalisatsiooniinseneri esmakutsed.

2013. aastal toimus õppekavade hulgas mitmeid muudatusi. Vastuvõtuks ei avatud Põllu- ja aiasaaduste tootmise bakalaureuseõppekava, selle asemel toimus vastuvõtt kahele erinevale bakalaureuseõppekavale: Aiandus ning Põllumajandussaaduste tootmine ja turustamine. Avati vastuvõtt uuele bakalaureuseõppekavale Vee ja maismaa ökosüsteemide rakendusbioloogia (endise nimetusega Rakendushüdrobioloogia). Vastuvõtuks jäid avamata ka bakalaureuseõppe õppekavad Linna- ja tööstusmaastike korraldus ning Põllumajandusettevõtte

majandamine. Soovijate vähesuse tõttu jäi avamata kaks magistriõppekava (Taimesaaduste tootmistehnoloogiad ja tootearendus ning Kalakasvatus).

Vastuvõtuks avati uued inglise õppekeelega õppekavad: Veterinaarmeditsiin (loomaarstiõpe) ja Maastikuarhitektuur (magistriõppe õppekava). Ingliskeelsele veterinaarmeditsiini õppekavale võeti vastu 31 üliõpilast, ingliskeelsele maastikuarhitektuuri magistriõppekavale 1 üliõpilane.

2013/2014 õppeaastal rakendus õppekava statuudi uus redaktsioon, millega kehtestati, et õppekavade arendustegevuses lähtutakse järgmistest valdkondadest: põllumajandus ja maamajanduse ökonoomika; metsandus; keskkonnateadus ja rakendusbioloogia; veterinaarmeditsiin ja toiduteadus; tehnika- ja inseneriteadus. Kinnitati õppekavade uus struktuur. Bakalaureuseõppekava moodulid olid: alammoodul (22–35 EAP); suunamoodul 22–35 EAP); erialamoodul(id) (45–100 EAP); eriala valikmoodul(id) ja/või eriala valikained (vähemalt 12 EAP); vabaained (8 EAP); bakalaureusetöö või -eksam (8–15 EAP). Bakalaureuse-, ehitusinseneri- ja loomaarstiõppe õppekavade alusmoodulisse viidi sisse kohustuslikud üleülikoolilised õppeained: ökoloogia ja keskkonnakaitse (4 EAP), riskianalüüs ja töökeskkonna ohutus (3 EAP), majandusteaduse alused (4 EAP), õigusõpetuse alused (3 EAP), inglise või saksa erialakeel (4 EAP), filosoofia ja/või suhtlemispsühholoogia (3 EAP).

Bakalaureuseõppekava Põllumajandussaaduste tootmine ja turustamine õppekava sisaldas järgmisi mooduleid ja õppeaineid: alusmoodul (28 EAP), suunamoodul (30 EAP), erialamoodul (92 EAP), eriala valikmoodul (24 EAP; valida 14 EAP), vabaained (8 EAP), bakalaureusetöö või -eksam (8 EAP).

Alusmooduli (eesmärk – laiapõhjaliste baasteadmiste omandamine, mis aitavad kaasa avatud silmaringiga spetsialisti kujunemisele ning erialaainete paremale mõistmisele) õppeained olid: informaatika ja biomeetria, põllumajanduse ajalugu, inglise või saksa erialakeel, ökoloogia ja keskkonnakaitse, majandusteaduse alused, õigusõpetus, riskianalüüs ja töökeskkonna ohutus, filosoofia. Suunamooduli (eesmärk – omandada teoreetilised ja praktilised alusteadmised ja oskused mullast, taimedest ning ainete liikumisest põllumajanduslikuks tootmiseks) õppeained olid: põllumajandustaimed, mullateaduse alused, agrokeemia, taimefüsioloogia biokeemia alustega, geneetika, agrometeoroloogia. Erialamooduli (eesmärk – omandada teoreetiline ja praktiline baas põllumajanduslikuks tootmiseks ning turustamiseks) õppeained olid: mikrobioloogia üldkursus, eritaimekasvatus, Eesti mullastik, maaviljeluse põhikursus, muldade väliuurimine, nüüdisaegsed masintehnoloogiad, rohumaaviljelus, taimekasvatuse üldkursus, aianduse tehnoloogiad, sordiaretus ja seemnekasvatus, taimekahjustajad ja nende tõrje, raamatupidamine mittemajanduse erialadele, põllumajandusökonoomika, ühistegevuse alused, eriloomakasvatus, praktika ettevõttes (9 EAP). Eriala valikmooduli (eesmärk – omandada süvendatud teadmisi kas loomade aretuse ja söötmise alustest, ettevõtte majandusanalüüsist või taimefüsioloogiast) õppeained olid: aretusõpetus, söötmisõpetus toitumise alustega, majandusanalüüs, taimede stressibioloogia, biogeensed lenduvad ühendid).

Ülikooliseaduse kohaselt rakendus alates 2013/2014 õppeaastast ülikooli astujatele õppekulude hüvitamise uus süsteem. Kõik eesti õppekeelega õppekavale täiskoormusega õppesse sh kaugõppesse astunud üliõpilased said esimesel semestril õppida tasuta. Esimese semestri lõpuks pidid nad täitma 75% ettenähtud 30 EAP-st. Järgmistel semestritel said nad tasuta õppida juhul kui nad olid algavaks semestriks täitnud kumulatiivselt eelmistel semestritel õppekava kohaselt täitmisele kuuluva õppe mahu (Ül seadus § 13^3 lg 1). Kui semestri alguseks oli täitmata rohkem kui 8 EAP-d, pidid nad maksma üle 8 EAP puudu jäänud ainepunktide eest.

Osakoormusega õppesse astujad ja osakoormusega õppes õppivad üliõpilased tasuta õppida ei saanud. Nemad pidid maksma õppeteenustasu ainepunkti hinna alusel vastavalt semestri alguses registreeritud õppeainete mahule; 1 EAP eest 35 eurot, alates 2017/2018 õppeaastast 40 eurot. Õppeteenustasu pidid maksma ka inglise õppekeelega õppekava üliõpilased v.a doktoriõppe üliõpilased.

Üliõpilastel, kes õppisid täiskoormusega õppes, oli võimalus taotleda rahalist toetust hariduse omandamiseks kaasnevate kulutuste katmiseks.

Alates 2013/2014 õppeaasta kevadsemestrist oli üliõpilastel õigus taotleda tulemusstipendiumi (100 eurot kuus). Tulemusstipendiumi maksti väga heade õpitulemuste eest alates 2013/2014 õppeaastast täiskoormusega õppesse immatrikuleeritud üliõpilastele. Alates 2016/2017 õppeaastast oli õigus tulemusstipendiumi taotleda ja saada ka neil, kes astusid ülikooli enne 2013. aastat.

2003. aastal rakendunud õppetoetuste ja õppelaenu seaduse alusel saime 2014/2015 õppeaasta sügissemestril maksta õppetoetusi järgmiselt: põhitoetust 49-le üliõpilasele, täiendavat toetust 39-le, põhi- ja täiendavat toetust 162-le ning majanduslikku toetust 35-le üliõpilasele. Doktoranditoetust maksti kõikidele doktorantidele.

Üliõpilaste õppetoetuste määrad olid väikesed: põhitoetus ja majanduslik toetus – 55,93 eurot, täiendav toetus – 28,13 ja doktoranditoetus 383,47 eurot kuus. Põhitoetuse, täiendava toetuse ning majandusliku toetuse maksmine lõpetati 2015/2016 õppeaasta lõpul.

Alates 2014/2015 õppeaastast oli üliõpilastel õigus taotleda ka erialastipendiumi, erivajadustega üliõpilaste stipendiumi ja vajaduspõhist õppetoetust. Erialastipendiumi maksti riigile prioriteetsetes valdkondades täiskoormusega õppivatele üliõpilastele (160 eurot kuus). Maaülikoolis oli selliseid n.ö nutika spetsialiseerumise erialasid/õppekavasid 8; loomakasvatus (bak), toiduainete tehnoloogia (bak), liha- ja piimatehnoloogia (mag), metsamajandus (mag), metsatööstus (mag), põllumajandussaaduste tootmine ja turustamine (mag), tootmistehnika (mag) ning tehnotroonika (rak). Erialastipendiumi maksmisel arvestati õpitulemusi. 2015/2016 õppeaastal maksti erialastipendiumi 108-le üliõpilasele, 2016/2017 õppeaastal 134-le üliõpilasele.

Vajaduspõhist õppetoetust on õigus saada täiskoormusega õppes õppival üliõpilasel (v.a doktorandil), kelle pereliikme sissetulek ei ületa igaks aastaks riigieelarvega kehtestatud vajaduspõhise õppetoetuse saamiseks arvestatava keskmise sissetuleku ülemmäära. Sissetuleku ülemmäär oli 2015. aastal 329 eurot kuus, 2016. aastal 358, 2017. aastal 394, 2018. aastal 429, 2019, aastal 468, 2020. aastal 523 ja 2021. aastal 569 eurot kuus. Toetust makstakse sõltuvalt pere sissetulekust 75 või 135 või 220 eurot kuus. Toetust taotletakse www.eesti.ee kaudu. Need, kelle vajaduspõhine taotlus jäeti rahuldamata ja kui pere sissetulek vähenes viimasel kolme kuul, võivad taotleda vajaduspõhist eritoetust (135 eurot kuus) ülikooli kaudu.

2014. aastal õppis ülikoolis 3927 üliõpilast. Üliõpilaste arv vähenes võrreldes 2010. aastaga 19%. 2014. aastal ei avatud vastuvõtuks rakenduskõrgharidusõppe õppekava Biotehnilised süsteemid. Samuti jäi avamata magistriõppe õppekava Maakorraldus; see liideti õppekavaga Kinnisvara planeerimine. Toimus esimene vastuvõtt TTÜ ja EMÜ ühisõppekavale Hajaenergeetika. Magistriõppekava Hajaenergeetika haldajaks sai TTÜ, kes korraldas ka üliõpilaste vastuvõtu (tabel 9).

Tabel 9. Üliõpilaste arvud Eesti Maaülikooli instituutides/kolledžis 10.2011)

Instituut	Üliõpilaste arv sh kaugõppes	
	2014	2015
Metsandus- ja maaehitusinstituut (MI)	1003 sh 134 kõ	939 sh 102 kõ
Majandus- ja sotsiaalinstituut (MS)	701 sh 456 kõ	647 sh 443 kõ
Põllumajandus- ja keskkonnainstituut (PK)	1008 sh 185 kõ	929 sh 155 kõ
Tehnikainstituut (TI)	459 sh 82 kõ	424 sh 101 kõ
Veterinaarmeditsiini ja loomakasvatuse instituut (VL)	618	569
Tartu Tehnikakolledž (TS)	138	119
Kokku	3927	3627

Alates 2015. aastast on Maaülikoolil õigus väljastada energiakasutuse magistriõppekava lõpetajatele diplomeeritud elektriinseneri esmane kutse (tase 7), alates 2016. aastast tootmistehnika magistriõppekava lõpetajatele diplomeeritud mehaanikainseneri esmane kutse (tase 7) ning rakenduskõrgharidusõppekava tehnotroonika lõpetajatele mehhatroonikainseneri esmane kutse (tase 6). 2015. aastal omistati diplomeeritud elektriinseneri kutse 8-le energiakasutuse magistriõppe lõpetajale, 2016. aastal 14-le lõpetajale (tabel 10). Diplomeeritud mehaanikainseneri esmased kutsed väljastatakse alates 2017. aastast.

2015. aastal avati vastuvõtt kahele uuele õppekavale; rakenduskõrgharidusõppekavale Puidutöötlemise tehnoloogia ning magistriõppekavale Maaettevõtete strateegiline arendamine. Puidutöötlemise tehnoloogia õppekavale võeti vastu 21 üliõpilast.

Maaettevõtete strateegilise juhtimise õppekava oli mõeldud osakoormusega õppena kaugõppes. Õppekava loomise algatus tuli EMÜ vilistlaskogu liikmetelt – tegevettevõtjatelt ja maapoliitika kujundajatelt. Õppekava on suunatud maaettevõtete, põllumajandusettevõtete, kohalike omavalitsuste, tulundusühistute ja mittetulundusühingute juhtidele, spetsialistidele ja ettevõtete omanikele, kes omavad vähemalt bakalaureusekraadi (ei pea olema majanduserialal), kaheaastast valdkondlikku töökogemust ja valmisolekut jagada parimaid praktilisi kogemusi kaasõppuritega.

Lisaks Eesti Maaülikooli ja Tartu Ülikooli õppejõududele oli plaanis kaasata õppeprotsessi ka mitmete välisülikoolide (Rootsi, Norra, jne) professoreid, EMÜ teiste instituutide õppejõude, kõrgeid riigiametnikke ja mitmeid majanduspraktikuid.

Vastuvõttu õppekavadele Maaettevõtete strateegiline arendamine ja Biotehnilised süsteemid ei toimunud vähese arvu soovijate tõttu.

Tabel 10. Õppekavade ja lõpetajate arv 2016. aastal ehk 65 aasta möödumisel EPA asutamisest

Õppekavasid haldav instituut	Õppekavade arv	Üliõpilaste arv seisuga 10.11.2016	Lõpetajate arv 2016. aastal
Põllumajandus- ja keskkonnainstituut (dir Aret Vooremäe)	10 bakalaureuseõppekava	472 sh 15 kõ	111 sh 6 kõ
	8 magistriõppekava sh 1 inglise õppekeelega magistriõppekava (maastikuarhitektuur)	309 sh 150 kõ	61 sh 16 kõ
Veterinaarmeditsiini ja loomakasvatuse instituut (dir Toomas Tiirats)	2 bakalaureuseõppekava	114	24
	2 loomaarstiõppekava sh 1 inglise õppekeelega	338	40
	3 magistriõppekava	42	12
Majandus- ja sotsiaalinstituut (dir Ants-Hannes Viira)	1 bakalaureuseõppekava	351 sh 185 kõ	73 sh 23 kõ
	3 magistriõppekava	250 sh 248 kõ	34 sh 32 kõ
Metsandus- ja maaehitusinstituut (dir Toomas Timmusk)	3 bakalaureuseõppekava	298 sh 22 kõ	76 sh 4 kõ
	1 rakendus. õppekava (puidutöötlemise tehnoloogia)	34	-

Õppekavasid haldav instituut	Õppekavade arv	Üliõpilaste arv seisuga 10.11.2016	Lõpetajate arv 2016. aastal
	2 ehitusinseneriõppekava (maaehitus, vesiehitus ja veekaitse)	263 sh 54 kõ	28 sh 1 kõ
	8 magistriõppekava sh 1 ühisõppekava TTÜga (hajaenergeetika)	153 (sh 29 hajaenergeetika õppekaval)	48 sh 6 hajaenergeetika
Tehnikainstituut	1 bakalaureuseõppekava	221 sh 102 kõ	48 sh 13 kõ
(dir Margus Arak)	3 magistriõppekava	96 sh 17 kõ	28
Tartu tehnikakolledž (dir kt Margus Arak)	2 rakendus. õppekava	98	10
Kokku	17 bakalaureuseõppekava		332 sh 44 kõ
	4 integreeritud õppekava		68 sh 1 kõ
	24 magistriõppekava	3259 sh 793 kõ	183 sh 52 kõ
	3 rakenduskõrg. õppekava		10
	5 doktoriõppekava		20

Üliõpilasi võeti vastu 14-le bakalaureuseõppekavale, 3-le bakalaureuse- ja magistriõppe integreeritud õppekavale (1 eesti õppekeelega ja 1 inglise õppekeelega veterinaarmeditsiini õppekava, maaehituse õppekava), 2-le rakenduskõrgharidusõppekavale, 20-le magistriõppekavale sh TTÜga ühisõppekavale, 5-le doktoriõppekavale.

Kui 2012. aastal õppis ülikoolis 4514 üliõpilast ja vastuvõtt avati 47-le õppekavale, siis 2017. aastatel õppis ülikoolis vastavalt 3006 üliõpilast. Õppekavasid on EHISe andmetel 2017. aastal kokku 50, vastuvõtuks avati 43 õppekava (tabel 11, 12).

Tabel 11. Õppekavade arv ja üliõpilaste arv õppekavasid haldavates Eesti Maaülikooli instituutides/kolledžis

Instituut	Õppekavade arv seisuga 17.11.2017	Üliõpilaste arv seisuga 10.11.2012	Üliõpilaste arv seisuga 10.11.2017	Lõpetajate arv 2016/2017. õa
PK	9 bakalaureuseõppekava	750 sh 213 kõ	450 sh 3 kõ	83
	8 magistriõppekava sh 1 inglise õppekeelega magistriõppekava (maastikuarhitektuur)	296 sh 40 kõ	297 sh 152 kõ	83
	Kokku üliõpilasi:	1153 sh 107 doktoranti	849 sh 102 doktoranti	176 sh 10 doktoranti
VL	2 bakalaureuseõppekava	229	100	26
	2 loomaarstiõppekava sh 1 inglise õppekeelega	327	328 sh 143 ingl.	56
	3 magistriõppekava	88	24	12
	Kokku üliõpilasi:	686 sh 42 doktoranti	497 sh 45 doktoranti	96 sh 2 doktoranti
MS	1 bakalaureuseõppekava	551 sh 460 kõ	316 sh 168 kõ	64
	2 magistriõppekava	217 sh 183 kõ	244 kõ	29
	Kokku üliõpilasi:	775 sh 7 doktoranti	568 sh 8 doktoranti	93
MI	3 bakalaureuseõppekava	550 sh 119 kõ	238 sh 51 kõ	56
	1 rakendus. õppekava	–	47	-
	2 ehitusinseneriõppekava	416 sh 116 kõ	228 sh 37 kõ	31
	6 magistriõppekava sh 1 ühisõppekava TTÜga (hajaenergeetika)	202	113 sh 13 hajaen	47 sh 10 hajaen
	Kokku üliõpilasi:	1224 sh 56 doktoranti	670 sh 44 doktoranti	140 sh 6 doktoranti
TI	1 bakalaureuseõppekava	376 sh 70 kõ	213 sh 105 kõ	37
	3 magistriõppekava	116 sh 4 kõ	108 sh 33 kõ	22
	Kokku üliõpilasi:	507 sh 15 doktoranti	343 sh 22 doktoranti	59
TS	2 rakendus. õppekava	169	79	21
Kokku	16 bakalaureuseõppekava	2456	1317	266
	4 integreeritud õppekava	743	556	87
	22 magistriõppekava sh 1 TTÜga	919	786	193
	3 rak. õppekava	169	126	21
	5 doktoriõppekava	227	221	18
Kokku üliõpilasi:		4514 sh 1022 kõ	3006 sh 756 kõ	585 sh 101 kõ

Tabel 12. Üliõpilaste arvud ja osakaal õppevaldkonniti Eesti Maaülikoolis

Õppevaldkond	2012. aastal üliõpilaste		2017. aastal üliõpilaste	
	arv	osakaal %	arv	osakaal %
Põllumajandus, metsandus, kalandus ja veterinaaria	1452	32,17	971	32,3
Loodusteadused, matemaatika statistika	772	17,10	563	18,73
Tehnika, tootmine ja ehitus	1522	33,72	912	30,34
Ärindus ja haldus	768	17,01	560	18,63
Kokku	4514	100,00	3006	100,00

2019. aastal ei toimunud enam vastuvõttu magistriõppe õppekavale Maastikukaitse ja -hoolduse (490) ning Linna- ja tööstusmaastike korraldus (80407). Õppekava Linna- ja tööstusmaastike korraldus baasil arendati välja õppekava Keskkonnakaitse ja -korraldus (80407). Vee ja maismaa ökosüsteemide rakendusbioloogia (423) õppekava asemel ootas ülikool sisseastujaid Kalanduse ja rakendusökoloogia (423) õppekavale. Esmakordselt avati vastuvõtt uuele pikalt ette valmistatud inglise õppekeelega õppekavale Põllumajanduse ja toiduainete tootmise ärijuhtimine (163697), mis töötati välja kolme Balti riigi koostöös: Eesti Maaülikool, Läti Põllumajandusülikooli ning Vytautas Magnuse Ülikooli Põllumajandusakadeemiaga.

2019. aastal lõpetas esimene lend (20 välisüliõpilast) inglise õppekeelega õppekaval Veterinaarmeditsiin.

2019. aastal Haridus- ja Teadusministeeriumi ning Eesti Maaülikooli vahel sõlmitud halduslepingu kohaselt vastutab ülikool kõrgetasemelise ja ühiskonna vajadustele vastava õppe läbiviimise, kvaliteedi, arendamise ja populariseerimise eest järgmistes õppekavagruppides: põllumajandus, metsandus ja kalandus, veterinaaria, samuti bio- ja keskkonnateaduste õppekavagrupi keskkonna õppesuuna õppekavarühmades, tugevdab ettevõtluse ja majandusainete õpetamist nende õppekavagruppide õppekavades, et valmistada ette maamajandusliku ettevõtluse oskustega spetsialiste.

2019. aastal algas õppekava statuudis 2018. aastal tehtud muudatuste elluviimine. Õppekavade eesmärgid ja õpiväljundid kaasajastati ning õppekava õppeainete õpiväljundid seostati tugevamalt õppekava eesmärkide ja õpiväljunditega. Seoste paremaks ja selgemaks esile toomiseks muudeti õppekavade ülesehitus alammoodulite põhiseks koondades õppeained mooduli õpiväljunditest lähtuvateks eesmärgistatud kogumiteks. Õppekavade õpiväljundid ajakohastati ka vastavalt tööturu ja OSKA raportis esile toodud vajadustele sh tulevikuoskusi ning säästva arengu eesmärke arvestades.

Õppekava spetsialiseerumistele kehtestati miinimummaht ja kõikidesse kõrghariduse esimese astme õppekavadesse lisati ülikooli visioonist ja eesmärgist lähtuvalt interdistsiplinaarne biomajanduse ja keskkonna moodul (8 EAP) ning ettevõtlusmoodul (8 EAP). Suurendati praktika mahtusid: bakalaureuseõppekavades suurenes ettevõttepraktika min. maht 6 EAP-ni (varasema 5 EAP asemel), loomakasvatuse õppekavas on ettevõttepraktikat 8 EAP-d, aianduse ja põllumajandussaaduste tootmise õppekavades 10 EAP-d, toiduainete tehnoloogia õppekavas 12 EAP-d. Õppepraktikat on kõige rohkem metsanduse ja loodusturismi bakalaureuseõppekavades.

Kõige enam on praktikat sh ettevõttepraktikat loomaarstiõppe ja rakenduskõrgharidusõppe õppekavades.

Efektiivsema ja tulemuslikuma ettevõttepraktika korralduse tagamiseks sõlmitakse enne praktikale minemist üliõpilase, praktikaettevõtte ja ülikooli vahel kohustuslik praktikaleping. Praktikalepingu lisana on kohustus praktikakohapoolsel juhendajal täita tagasiside küsimustik ja hinnata muu hulgas üliõpilase eelnevate teadmiste ja oskuste taset, suhtumist töösse ning kohanemisvõimet.

Bakalaureuseõppekavade, ehitusinseneri- ja loomaarstiõppe ning rakenduskõrgharidusõppe õppekavade uued/täiustatud versioonid rakendusid alates 2020/2021 õppeaastast.

Magistri- ja doktoriõppe õppekavade uued versioonid rakendusid alates 2021/2022 õppeaastast. Doktoriõppes ajakohastati õppekavade eesmärke ja õpiväljundeid, erialaõppe õppeaineid, üldõpet, vähendati spetsialiseerumiste arvu. Muudatuste vajaduse üheks ajendiks oli Eesti ülikoolide kokkulepped ja erinevate osapoolte (doktorantide, juhendajate, tööandjate, välishindajate) tagasisidena esile kerkinud probleemid ja kitsaskohad ning vajadus ettevõtlusesse suunatud doktoriõppe järele.

Bakalaureuseõppekavad (180 EAP, nominaalkestus 3 aastat) koosnevad järgmistest moodulitest: üldmoodul, erialamoodul, eriala valikmoodul, vabaained, lõputöö või -eksam. Üldmoodul sisaldab alammoodulit Keskkonnakorraldus ja biomajandus (8 EAP) ning alammoodulit Ettevõtlus (8 EAP).

Bakalaureuseõppekava Põllumajandussaaduste tootmine ja turustamine uue versiooni moodulid/ õppeained on järgmised: Üldmoodul (30 EAP; eesmärk – valdkonna alusteadmiste omandamine erialaainete omandamiseks): sissejuhatus erialasse ja teadustöö alused, informaatika ja biomeetria, inglise erialakeel, riskianalüüs ja töökeskkonna ohutus, alammmooduli Keskkonnakorraldus ja biomajandus õppeained: keskkonnakaitse ja korraldus, biomajanduse alused; Ettevõtlusmooduli õppeained: maaettevõtluse alused, ideest äriplaanini.

Erialamoodul (117 EAP*;* eesmärk – omandada teadmised ja oskused maaviljelusest, taime- ja loomakasvatusest ning põllumajandussaaduste tootmisest ja turustamisest): alammoodul Muld ja väetamine (17 EAP): Eesti mullastik, muldade väliuurimine, mullateaduse alused, agrokeemia; alammoodul Maaviljelus ja masintehnoloogiad (15 EAP): maaviljelus, taimekasvatuse masintehnoloogiad, aianduse tehnoloogiad; alammoodul Taimekasvatus (42 EAP): põllumajandustaimed, geneetika, taimefüsioloogia, rohumaaviljelus, taime-

kasvatus I, II, III, kvaliteetne saak ja põllumajandustaimede areng, sordiaretus ja seemnekasvatus; alammoodul Taimetervis (13 EAP): taimekahjustajad ja nende tõrje; alammoodul Majandus ja turundus (8 EAP): põllumajandusökonoomika, turundus põllumajandusturunduse alustega; alammoodul Praktika (3+7 EAP): praktika ettevõttes.

Eriala valikmoodul (28 EAP, valida tuleb vähemalt 15 EAP): aretusõpetus, raamatupidamine mittemajanduse erialadele, taimede stressibioloogia, agrometeoroloogia, ühistegevuse alused, mikrobioloogia üldkursus, kuivenduse ja niisutuse alused, õigusõpetus.

Magistriõpekavad (120 EAP, nominaalkestus 2 aastat) koosnevad järgmistest moodulitest: erialamoodul, valikmoodul, vabaained, magistritöö.

Magistriõppekava Põllumajandussaaduste tootmine ja turustamine erialamooduli (72 EAP) alammoodulid ja õppeained: alammoodul Taimekasvatus (31 EAP): keskkonnasäästlik taimekasvatus ja mahetootmine, saagi formeerumise alused, integreeritud taimekaitse, täppispõllumajandus, muldade kaitse ja jätkusuutlik kasutamine, põllumajanduslik mikrobioloogia, kliima muutused ja põllumajandus; alammoodul Taimse tooraine väärindamine ja turustamine (12 EAP): taimse tooraine väärindamine, rohumaade tehnoloogiad ja söödatootmine, söötmisprogrammid; alammoodul Tootmise planeerimine ja juhtimine taimekasvatuses (17 EAP): ratsionaalse maakasutuse ja põllumajandustootmise analüüs ja planeerimine, nõuandeteenistus ja -süsteemid, maamajanduse ökonoomika, äristrateegiad; alammoodul Taimekasvatusteadus (12 AP): eksperimendi metoodika ja andmetöötlus, praktika ettevõttes (6 EAP). Valikmoodul (30 EAP, valida tuleb vähemalt 13 EAP): rakendusentomoloogia, fütopatoloogia, biogeensed lenduvad ühendid, toidupoliitika ja strateegiad, biogaasi tootmine põllumajanduses, ettevõtte ja personali juhtimine, kompostide tootmine ja kasutamine, taimede toitumine ja aineringed, projektijuhtimine.

2020. aastal lõpetati vastuvõtt bakalaureuseõppe õppekavadele Vee ja maismaa ökosüsteemide rakendusbioloogia (377) ning Kalandus ja vesiviljelus (143997). Nende asemel avati 2020. aastal vastuvõtt uuele bakalaureuseõppe õppekavale Kalandus ja rakendusökoloogia (214638). 2021. aastal toimus kolmas vastuvõtt 2019. aastal avatud inglise õppekeelega magistriõppekavale Põllumajanduse ja toiduainete tootmise ärijuhtimine (163697).

Ülikooli ning haridus- ja teadusministeeriumi vahel sõlmitud halduslepingu kohaselt vähendas ülikool üliõpilaste vastuvõttu bakalaureuseõppe õppekavale Maamajanduslik ettevõtlus ja finantsjuhtimine (371) alates 2019/2020. õppeaastast kahe aasta jooksul 50% võrreldes 2017/2018. õa tegeliku vastuvõtuga. Halduslepingu kohaselt vähendasime vastuvõttu 2019. aastal ka keskkonna õppesuunas 10% võrreldes 2017/2018. õa tegeliku vastuvõtuga. 2019. aastal avati vastuvõtuks keskkonna õppesuunas 86 õppekohta, 2020. aastal 74 õppekohta, 2021. aastal 81 õppekohta.

Kõige populaarsemad st suurima konkursiga magistriõppekavad on Majandusarvestus ja finantsjuhtimine, Ökonoomika ja ettevõtlus, Põllumajandussaaduste tootmine ja turustamine, Loodusturism, Keskkonnakorraldus ja -poliitika.

Tabel 13. Väiksema konkursiga õppekavad

Õppekava	Vastu võetud/õppima asunud (seisuga 10.11)			
	2018	2019	2020	2021
Loomakasvatus (mag)	13	9	6	4
Toiduainete tehnoloogia (mag)	9	12	15	5
Kalandus ja rakendusökoloogia (mag)	8	20	7	7
Metsatööstus (mag)	3	15	7	5
Ergonoomika (mag)	5	7	9	9

2020. aastal loodi koostöös Tartu Ülikooliga uus inglise õppekeelega magistriõppekava Keskkonnajuhtimine kliimamuutuste tingimustes. 2021. aasta vastuvõtuks loodi 20 õppekohta, õppima asus 15 välisüliõpilast.

2021. aastal avatud magistriõppe õppekohtadest 73,3% olid sessioonõppes, 26,7 päevaõppes (2020. aastal vastavalt 65 ja 35%, 2019. aastal 59 ja 41%). Kõrghariduse esimese astme õppekohtadest 9,3% olid sessioonõppe õppekohad (2020. aastal 9,4%, 2019. aastal 11,4%).

2021. aastal õppis 27,3% üliõpilastest Põllumajandus- ja keskkonnainstituudi hallatavatel õppekavadel, 23,3% Metsandus- ja maaehitusinstituudi, 19,3% Veterinaarmeditsiini ja loomakasvatuse instituudi, 15,6% Majandus- ja sotsiaalinstituudi, 10,9% Tehnikainstituudi hallatavatel õppekavadel. Tartu Tehnikakolledži hallataval õppekaval õppis 3,6% üliõpilaste arvust.

Üliõpilastest 35,8% õppis õppevaldkonnas põllumajandus, metsandus, kalandus ja veterinaaria, 34,0% õppevaldkonnas tehnika, tootmine ja ehitus, 14,9% õppevaldkonnas loodusteadused, matemaatika ja statistika ning 15,3% õppevaldkonnas sotsiaalteadused, ärindus ja õigus.

2020/2021 õppeaastal lõpetas ülikooli kokku 457 kõrghariduse I ja II astme üliõpilast (2019/2020 õppeaastal 410, 2018/2019 õppeaastal 470, 2017/2018 õppeaastal 506, 2016/2017 õppeaastal 567 üliõpilast), nendest 219 bakalaureuseõppe, 45 loomaarstiõppe (sh 31 välisüliõpilast) 13 ehitusinseneriõppe, 169 magistriõppe (sh 20 välisüliõpilast) ja 11 rakenduskõrgharidusõppe. 2021. aastal lõpetas esimene lend (12 üliõpilast) inglise õppekeelega magistriõppekava Põllumajanduse ja toiduainete tootmise ärijuhtimine (tabel 14).

Tabel 14. Haridus- ja teadusministri 11.06.2020 käskkirja kohaselt Eesti Maaülikoolile antud õppeõigused

	Õppekavagrupp	Õpe	Antav kraad	Tähtaeg
1.	Ärindus ja haldus	Bakalaureuseõpe	Sotsiaalteaduse bakalaureus	Tähtajatu
2.	Ärindus ja haldus	Magistriõpe	Sotsiaalteaduse magister	Tähtajatu
3.	Bio- ja keskkonnateadused	Bakalaureuseõpe	Loodusteaduse bakalaureus	Tähtajatu
4.	Bio- ja keskkonnateadused	Magistriõpe	Loodusteaduse magister	Tähtajatu
5.	Bio- ja keskkonnateadused	Doktoriõpe	Filosoofiadoktor	Tähtajatu
6.	Tehnika, tootmine ja tehnoloogia	Rakenduskõrgharidusõpe	Tehnikateaduse bakalaureus	Tähtajatu
7.	Tehnika, tootmine ja tehnoloogia	Bakalaureuseõpe	Tehnikateaduse bakalaureus	Tähtajatu
8.	Tehnika, tootmine ja tehnoloogia	Magistriõpe	Tehnikateaduse magister	Tähtajatu
9.	Tehnika, tootmine ja tehnoloogia	Doktoriõpe	Filosoofiadoktor	Tähtajatu
10.	Arhitektuur ja ehitus	Bakalaureuseõpe	Tehnikateaduse bakalaureus	Tähtajatu
11.	Arhitektuur ja ehitus	Magistriõpe	Tehnikateaduse magister	Tähtajatu
12.	Arhitektuur ja ehitus	Integreeritud bakalaureuse- ja magistriõpe	Ehitusteaduste magister	Tähtajatu
13.	Põllumajandus, metsandus ja kalandus	Bakalaureuseõpe	Põllumajandusteaduse bakalaureus	Tähtajatu
14.	Põllumajandus, metsandus ja kalandus	Magistriõpe	Põllumajandusteaduse magister	Tähtajatu
15.	Põllumajandus, metsandus ja kalandus	Doktoriõpe	Filosoofiadoktor	Tähtajatu
16.	Veterinaaria	Integreeritud bakalaureuse- ja magistriõpe	Loomaarstikraad	Tähtajatu
17.	Veterinaaria	Doktoriõpe	Filosoofiadoktor	Tähtajatu

Tabel 15. Üliõpilaste ja lõpetajate arv Eesti Maaülikoolis 2020. ja 2021. aastal

Õppekava haldav struktuuriüksus	Õppekavad	Üliõpilaste arv 10.11.2021 seisuga	Lõpetajate arv (1.10.2019 – 30.09.2020)
Põllumajandus- ja keskkonnainstituut Kreutzwaldi 5 Direktor Aret Vooremäe	Instituudis kokku	811	168
	Bakalaureuseõpe:	427 sh	78 sh
	Aiandus	48	8
	Põllumajandussaaduste tootmine ja turustamine	100	18
	Loodusturism	55	11
	Keskkonnakaitse	93	23
	Keskkonnaplaneerimine ja maastikukujundus	82	12
	Vee ja maismaa ökosüsteemide rakendusbioloogia	15	5
	Kalandus ja vesiviljelus	2	1
	Kalandus ja rakendusökoloogia	32	
	Magistriõpe:	293 sh	80 sh
	Aiandus	36 sh 34 kõ	12
	Põllumajandussaaduste tootmine ja turustamine	45 sh 40 kõ	4
	Keskkonnakorraldus ja -poliitika	90 sh 76 kõ	19
	Loodusturism	37 kõ	12
	Maastikuarhitektuur (eesti õppekeel)	29	13
	Maastikuarhitektuur (inglise õppekeel)	17	8
	Maastikukaitse ja -hooldus	4	2
	Kalandus ja rakendusökoloogia	20 kõ	10
	Keskkonnajuhtimine kliimamuutuse tingimustes	15	
	Doktoriõpe	91 sh	10 sh
	Põllumajandus	41	4
	Keskkonnateadus ja rakendusbioloogia	50	6

Õppekava haldav struktuuriüksus	Õppekavad	Üliõpilaste arv 10.11.2021 seisuga	Lõpetajate arv (1.10.2019 – 30.09.2020)
Veterinaarmeditsiini ja loomakasvatuse instituut	Instituudis kokku	574	80
	Bakalaureuseõpe:	121 sh	19 sh
Kreutzwaldi 62	Loomakasvatus	58	7
Direktor Toomas Tiirats	Toiduainete tehnoloogia	63	12
	Bakalaureuse- ja magistriõppe integreeritud õpe:	365 sh	45 sh
	Veterinaarmeditsiin (eesti õppekeel)	161	14
	Veterinaarmeditsiin (inglise õppekeel)	204	31
	Magistriõpe:	38 sh	11 sh
	Loomakasvatus	13 kõ	6
	Toiduainete tehnoloogia	25 kõ	5
	Doktoriõpe:	50 sh	5 sh
	Põllumajandus	13	2
	Veterinaarmeditsiin ja toiduteadus	37	3
Majandus- ja sotsiaalinstituut	Instituudis kokku	466	108
Kreutzwaldi 1a	Bakalaureuseõpe:	221 sh	
Direktor Ants-Hannes Viira	Maamajanduslik ettevõtlus ja finantsjuhtimine	221 sh 124 kõ	58
	Magistriõpe:	236 sh	48 sh
	Ökonoomi ka ja ettevõtlus	81 kõ	15
	Majandusarvestus ja finantsjuhtimine	139 kõ	21
	Põllumajanduse ja toiduainete tootmise ärijuhtimine (inglise õppekeel)	16	12
	Doktoriõpe	9 sh	
	Põllumajandus	9	2
Metsandus- ja maaehitusinstituut	Instituudis kokku	692	65
	Rakenduskõrgharidusõpe	71 sh	
Kreutzwaldi 5	Puidutöötlemise tehnoloogia	71	8
Direktor Marek Metslaid	Bakalaureuseõpe:	265 sh	27 sh
	Metsandus	163	18
	Loodusvarade kasutamine ja kaitse	2	2
	Geodeesia, kinnisvara- ja maakorraldus	100	7
	Bakalaureuse- ja magistriõppe integreeritud õpe:	224 sh	13 sh
	Maaehitus	159 sh 4 kõ	13
	Vesiehitus ja veekaitse	65	
	Magistriõpe:	95 sh	14 sh
	Metsamajandus ja metsaökoloogia	32	5
	Metsatööstus	22 sh 12 kõ	1
	Geodeesia, kinnisvara- ja maakorraldus	41 sh 37 kõ	8
	Doktoriõpe	37 sh	3 sh
	Metsandus	29	2
	Tehnikateadus	8	1
Tehnikainstituut	Instituudis kokku	325	54
Kreutzwaldi 56	Bakalaureuseõpe:	201 sh	
Direktor Margus Arak	Tehnika ja tehnoloogia	201 sh 106 kõ	37
	Magistriõpe:	96 sh	16 sh
	Ergonoomika	20 kõ	7
	Energiakasutus	46 sh 42 kõ	5
	Tootmistehnika	30 sh 26 kõ	4
	Doktoriõpe:	28 sh	
	Tehnikateadus	28	1
Tartu Tehnikakolledž	Kolledžis kokku	106	7
Kreutzwaldi 56	Rakenduskõrgharidusõpe:	106 sh	
Direktori kt Margus Arak	Tehnotroonika.	106	3
Bakalaureuseõppes		1235	219
Rakenduskõrgharidusõppes		177	11

Õppekava haldav struktuuriüksus	Õppekavad	Üliõpilaste arv 10.11.2021 seisuga	Lõpetajate arv (1.10.2019 – 30.09.2020)
Integreeritud õppes		589	58
Magistriõppes		7658	169
Doktoriõppes		215	21
Kokku:		2974	478

2021 – Eesti Maaülikool

aastal moodustati Eesti Maaülikooli struktuuri analüüsi ja reformi ettevalmistamise komisjon, mille ülesandeks sai: 1. Analüüsida ülikooli struktuuri vastavust ja võimekust oma ülesannete täitmise sh uute õppekavade loomise suhtes; 2. Teha õppekavade nimistu kohta ettepanekuid, et tagada õppekavade kaudu ülikooli tegevuse vastavus ühiskonna ootustele; 3. Teha ettepanekuid õppetöö korralduse kohta sh sisemise dubleerimise vältimiseks; 4. Teha ettepanekuid ülikooli võimaliku uue struktuuri kohta.

Komisjoni esimees prof Kalev Sepp esitas aruande analüüsi tulemuste kohta ülikooli senatile 27.05.2021. Komisjon tegi muuhulgas ettepaneku hinnata õppekavade jätkusuutlikkust regulaarselt õppekavade sisehindamisega. Ettevalmistus õppekavade sisehindamiseks oli selleks ajaks juba tehtud. Õppekavade sisehindamise pilootprojekt rakendus 2021. aastal.

Võttes aluseks Eesti Maaülikooli struktuuri analüüsi ja reformi ettevalmistamise komisjoni aruande ja ettepanekud, otsustas ülikooli senat 17. juunil 2021 moodustada alates 1.01.2022 senise viie instituudi ümberkorraldamise teel kolm instituuti (tabel 16, 17):

1. **Eesti Maaülikooli põllumajandus- ja keskkonnainstituut**, inglise keeles *Institute of Agricultural and Environmental Sciences of Estonian University of Life Sciences*. Instituut moodustatakse senise põllumajandus- ja keskkonnainstituudi ning majandus- ja sotsiaalinstituudi ühinemise teel;
2. **Eesti Maaülikooli metsanduse ja inseneeria instituut**, inglise keeles *Institute of Forestry and Engineering of Estonian University of Life Sciences*. Instituut moodustatakse senise metsandus- ja maaehitusinstituudi ning tehnikainstituudi ühinemise teel;
3. **Eesti Maaülikooli veterinaarmeditsiini ja loomakasvatuse instituut**, inglise keeles *Institute of Veterinary Medicine and Animal Sciences of Estonian University of Life Sciences*.

Direktorite valimiseks korraldatud konkursi tulemuste alusel nimetati rektori käskkirjaga põllumajandus- ja keskkonnainstituudi direktoriks Aret Vooremäe, metsanduse ja inseneeria instituudi direktoriks Marek Metslaid, veterinaarmeditsiini ja loomakasvatuse instituudi direktoriks Toomas Tiirats alates 01.01.2022 kuni 31.12.2026

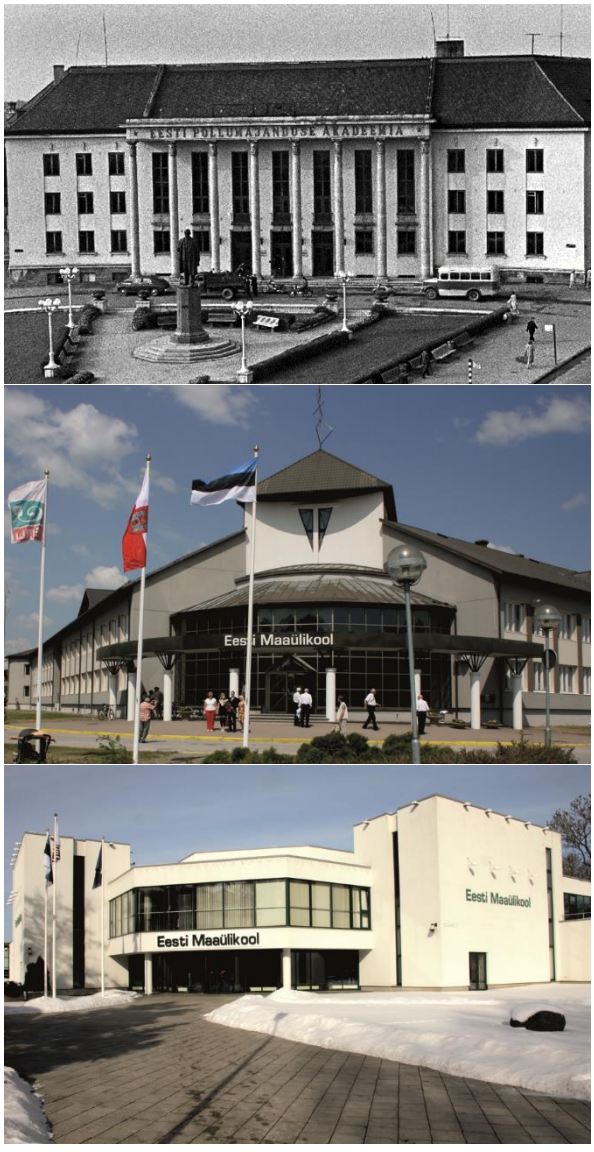
Tabel 16. Eesti Maaülikooli õppetoolid ja nende juhid alates 1.01.2022

Õppetool	Õppetooli juht
Põllumajandus- ja keskkonnainstituut	
Aiandus	Prof Ulvi Moor
Elurikkus ja loodusturism	Prof Tiiu Kull
Hüdrobioloogia ja kalandus	Prof Kalle Olli
Keskkonnakaitse ja maastikukorraldus	Prof kalev Sepp
Maamajanduse ökonoomika	Prof Rando Värnik
Maastikuarhitektuur	Prof Simon Bell
Mullateadus	Prof Alar Astover
Taimekasvatus ja taimebioloogia	Prof Ülo Niinemets
Taimetervis	Prof Marika Mänd
Metsanduse ja inseneeria instituut	
Geomaatika	Dots Evelin Jürgenson
Maaehitus ja veemajandus	Prof Toomas Tamm
Metsakasvatus ja metsaökoloogia	Prof Hardi Tullus
Metsa- ja maakorraldus ning metsatööstus	Prof Ahto Kangur
Biomajandustehnoloogia (BT)	Prof Timo Kikas
Energiakasutus (EQ)	Prof Protima Rauwel
Veterinaarmeditsiini ja loomakasvatuse instituut	
Kliiniline veterinaarmeditsiin	Prof. Toomas Orro
Söötmisteadus	Prof Meelis Ots
Toiduhügieen ja rahvatervis	Prof Mati Roasto
Toiduteadus ja toiduainete tehnoloogia	Dots. Ivi Jõudu
Tõuaretus ja biotehnoloogia	Prof Haldja Viinalass
Vesiviljelus	Prof Riho Gross
Veterinaarne bio- ja populatsioonimeditsiin	Prof Arvo Viltrop

Tabel 17. Õppekavad ja üliõpilaste arvud alates 1.01.2022

Instituut/õppeaste/õppekava	Üliõpilaste arv seisuga 01.01.2022
Metsanduse ja inseneeria instituut	1096 sh
Bakalaureuseõpe	458 sh
Geodeesia, kinnisvara- ja maakorraldus (379)	99
Loodusvarade kasutamine ja kaitse (407)	2
Metsandus (401)	158
Tehnika ja tehnoloogia (384)	199
Magistriõpe	183 sh
Energiakasutus (432)	45
Ergonoomika (436)	20

Instituut/õppeaste/õppekava	Üliõpilaste arv seisuga 01.01.2022
Geodeesia, kinnisvara- ja maakorraldus (426)	38
Metsamajandus ja metsaökoloogia (460)	31
Metsatööstus (461)	21
Tootmistehnika (437)	28
Ehitusinseneriõpe	222 sh
Maaehitus (382)	158
Vesiehitus ja veekaitse (383)	64
Rakenduskõrgharidusõpe	170 sh
Puidutöötlemise tehnoloogia (136557)	66
Tehnotroonika (81050)	104
Doktoriõpe	63 sh
Metsandus (80131)	28
Tehnikateadus (80133)	35
Põllumajandus- ja keskkonnainstituut	1244 sh
Bakalaureuseõpe	630 sh
Aiandus (119257)	48
Kalandus ja rakendusökoloogia (214638)	31
Kalandus ja vesiviljelus (143997)	2
Keskkonnakaitse (406)	89
Keskkonnaplaneerimine ja maastikukujundus (119358)	82
Loodusturism (80520)	55
Maamajanduslik ettevõtlus ja finantsjuhtimine (371)	212
Põllumajandussaaduste tootmine ja turustamine (119337)	96
Vee ja maismaa ökosüsteemide rakendusbioloogia (377)	15
Magistriõpe	518 sh
Aiandus (451)	34
Kalandus ja rakendusökoloogia (423)	19
Keskkonnajuhtimine kliimamuutuse tingimustes (218263) (ingl)	15
Keskkonnakorraldus ja -poliitika (80407)	89
Loodusturism (80519)	37
Maastikuarhitektuur (439)	29
Maastikuarhitektuur (119359) (ingl)	17
Maastikukaitse ja -hooldus (490)	4
Majandusarvestus ja finantsjuhtimine (412)	136
Põllumajanduse ja toiduainete tootmise ärijuhtimine (163697**) (ingl)**	15
Põllumajandussaaduste tootmine ja turustamine (463)	44
Ökonoomika ja ettevõtlus (414)	79
Doktoriõpe	96 sh
Põllumajandus (80132)	49
Keskkonnateadus ja rakendusbioloogia (80130)	47
Veterinaarmeditsiini ja loomakasvatuse instituut	569 sh
Bakalaureuseõpe	117 sh
Loomakasvatus (396)	55
Toiduainete tehnoloogia (100984)	62
Magistriõpe	37
Loomakasvatus (449)	13
Toiduainete tehnoloogia (455)	24
Loomaarstiõpe	365 sh
Veterinaarmeditsiin (398)	161
Veterinaarmeditsiin (118977) (ingl)	204
Doktoriõpe	50 sh
Põllumajandus (80132)	13
Veterinaarmeditsiin ja toiduteadus (80134)	37
Kokku üliõpilasi sh	2909 sh
bakalaureuseõppes	1205
magistriõppes	738
Integreeritud õppes (ehitusinseneriõpe ja loomaarstiõpe)	587
rakenduskõrgharidusõppes	170
doktoriõppes	209



Joonis 2. Peahooned – endised ja praegune (1x E. Norman EFA.204.0.43682a ja 2x A. Tänavots)

Rektorid 1951–2021

1951–1954	Dots Richard Antons
1954–1969	Dots Minna Klement
1969–1977	Dots Arnold Rüütel
1977–1988	Prof Nikolai Kozlov
1988–1993	Prof Olev Saveli
1993–1998	Mait Klaassen
1995–1998 rektori kt	Prof Hardi Tullus (M. Klaasseni haridusministrina töötamise ajal)
1998–2002	Prof Henn Elmet
2002–2003	Prof Hardi Tullus (rektori ülesannetes)
2002. sept–dets	Prof Hugo Roostalu (rektori kt)
2003–2007	Prof Alar Karis
2007–2008 (1.07.2007–01.2008)	Prof Hardi Tullus (rektori kt)
2008–2012, 2012–2017 2018...	Mait Klaassen

Teadusprorektorid 1951–2021

1952–1955	Prof Nikolai Vassiljev
1955–1958	Prof Osvald Hallik
1958–1965	Dots Valentin Matin
1965–1978	Dots Nikolai Kozlov
1978–1992	Dots Armand Sukamägi
1992–1993	Prof Ivar Etverk
1993–1998	Dots Henn Elmet
1998–2001	Andres Koppel
2002–2003	Prof Lembit Nei
2003–2008	Andres Koppel
2008–2012	Prof Anne Luik
2012–2017, 2018...	Prof Ülle Jaakma

Õppeprorektorid 1951–2021

1951–1952	Dots Richard Antons
1952–1954	Prof Nikolai Vassiljev
1954–1972	Dots August Eenlaid
1972–1977	Dots Jaan Kivistik
1977–1986	Dots Enn Altosaar
1986–1993	Dots Koit Alekand
1993–1996	Prof Kuno Jürjenson
1996–1998	Prof Hugo Roostalu
1998–2001	Prof Enn Plaan
2001–2002	Prof Lembit Nei
2002–2003	Prof Hugo Roostalu
2003–2008	Prof Hardi Tullus
2008–2012	Dots Jüri Lehtsaar
2012–2017	Dots Paavo Kaimre
2018...	Prof Endla Reintam

Õppeosakonna juhatajad 1951–2021

1952–1.09.1957	Pr Marland (õppeosakonna ülem)
1957–1966	Kaljo Tein (ülem)
1966–31.08.1968	Udo Veibri (ülem)
1.09.1968–1972	Aino Sütt (ülem)
1972–1974	Tiiu Alep (ülem)
1974–1976	Endla Reinvee (ülem)
1976–1977	Toomas Tael (ülema kt)
1977–1979	Tiiu Alep (ülem)
1979–1984	Enn Martma (ülem)
1984–1992	Koidu Veibri (ülem/juhataja)
1992–1993 (õppe- ja teadusosakond)	Prof kt Kuno Jürjenson
1993–1994 (õppe- ja-teadusosakond)	Mart Hovi
1995–1997 (õppe- ja teadusosakond)	Raivo Sein
1.09.1997–31.03.1999 (õppe- ja teadusosakond)	Anne Lüpsik
1.04.1999–31.12.2004 (õppeosakond)	
1.01.2005–31.01.2008 (õppekorraldusosakond)	
1.01.2005–31.01.2008 (õppearendusosakond)	Aret Vooremäe
1.02.2008–31.12.2011 (õppeosakond)	Priit Pajuste
2.01.2012–19.02.2012	Anne Lüpsik (juhataja kt)
20.02.2012–2.10.2015	Anneli Lorenz
5.10.2015–31.12.2015	Anne Lüpsik (juhataja kt)
1.01.2016...	Ina Järve

Eesti Põllumajanduse Akadeemia (EPA), Eesti Põllumajandusülikooli (EPMÜ) ja Eesti Maaülikooli (EMÜ) õppetegevuse arendamisse on oma panuse andnud väga paljud õppejõud/teadlased.

Mina olen osalenud õppetegevuses/õppekorralduses alates 1977. aastast, kui alustasin tööd õppejõuna EPA põllumajandusloomade aretuse kateedris akadeemik prof Aarne Punga käe all. Enne seda, 1974. aastal saatis EPA mind sihtaspirantuuri Moskva Veterinaaria Akadeemiasse, kus kaitsesin ka kandidaadikraadi (1978). Oma panuse õppetegevuse arendusse olen saanud anda lisaks õppejõu ametitele ka EPA ÜET dekaanina (1987–1990), EPA Zooinseneriteaduskonna dekaanina (1990–1992), EPMÜ Loomakasvatusinstituudi direktorina/dekaanina ja asedirektorina õppe alal (1992–1997), EPMÜ õppeosakonna juhatajana (1997–2008), juhataja asetäitjana (2008–2014).

Mul on olnud võimalus töötada väga paljude toredate kolleegidega, nendelt õppida ja nendega koos õppetegevust arendada.

Anne Lüpsik
emeriitdotsent

20 AASTAT EESTI MAAÜLIKOOLI VILISTLASKOGU

2001. aasta 21. septembril asutati Eesti Maaülikooli vilistlaskogu (VK). Asutamist oli kavandatud vahelduva innuga juba aastaid, asutamisaeg ja -päev ise osutusid pooljuhuslikult mitmeti tähendusrikkaks.

Nimelt on Elu Parimate Aastate kool EPA asutatud 50 aastat varem põllumajandus-, veterinaaria- ja metsanduserialade eraldamise kaudu Tartu Ülikoolist. Samal päeval valiti Estonia kontserdisaalis valimiskogus Eesti Vabariigi kolmandaks presidendiks EPA rektor aastatel 1969–1977 Arnold Rüütel. Selleks ajaks oli tollase nimega Eesti Põllumajandusülikoolil (EPMÜ) ligikaudu 20 000 vilistlast – tõeline maa sool aastakümnete vältel kõigis valdades ja väikelinnades, põldudel ja metsades, insenerkond aga domineerimas isegi Tartu linnas.

Tollasest taustast

Aastatuhande vahetusel toimusid Eesti kõrghariduses, esialgu ministeeriumide kabinettide vaikuses, seejärel ülikoolides, Riigikogus ja avalikkuses, tormilised diskussioonid. Oli ju avalik-õiguslikke kõrgkoole küll 6 nagu praegu, erineva tasemega erakõrgkoole aga mitukümmend ja tudengeid rohkem kui kunagi varem ja hiljem. Kõrgkoolide süvenev rahapuudus rõhus, õppe- ja teadustase vajasid kõikjal tõstmist.

Tartu Ülikooli rektor Jaak Aaviksoo algatas arutelu, kus põhiväideteks, et väiksesse Eestisse mahub vaid üks tõeline ülikool, isegi Tallinna Tehnikaülikool ei peaks tingimata ülikooli nime kandma, maailma 500 parema ülikooli hulka väikesed ei jõua ja alustada tuleks EPMÜ liitmisest TÜ-ga. Teisalt kutsus ekspankur ja episoodiline poliitik Jüri Mõis kõiki pealinna, kuna maaelu vabas turumajanduses ei võimaldavat normaalset toimetulekut, edukusest rääkimata. Henn Elmet (EPMÜ rektor aastatel 1998–2002) koos ülikooli nõukogu ja tudengkonnaga, mõistagi ei arvanud TÜ-ga liitumisest head, küll aga soovisid nad hea naabriga mitmekülgset koostööd ja põhjendamatu dubleerimise vältimist nii õppe- kui teadustegevuses.

2000. aasta novembris moodustati ülikooliseaduse alusel Vabariigi Valitsuse korraldusega kuuele ülikoolile kuratooriumid. EPMÜ kuratoorium pidi paraku esimesest istungist vahetult jõulude eel asuma oma ülikooli eksistentsi kaitsma. 2001. a 11. jaanuaril võttis Riigikogu Maaelukomisjon, esimeheks Ants Käärma, vastu otsuse, mille põhipunktiks põllumajandusliku kõrgharimise jätkumise vältimatu vajadus EPMÜ-s. Järgmisel päeval kinnitas sedasama oma teisel istungil EPMÜ kuratoorium.

EMÜ-l on TÜ-ga ühised mitmesaja aastased "juurikad" alates loomaarstiteadusest-õppest, agronoomiast, metsandusest jne, samas nende valdkondade praegune õpe ja teaduski on valdavalt meie ülikoolis praeguseks 70 aastat. Ja edukalt, nagu teame.

Vilistlaskogu saamisest

Liikumine-tegutsemine oma ülikooli tuleviku eest elavnes ka vilistlaskonnas, alates Aret Vooremäest, Külli Annamaast, Maire Nurmetist, Nelly Oinusest, Jaan Õunapuust ja Argo Normakust kuni tollaste Toompea vilistlasteni välja. 2001. aasta 17. augustil ülikooli 50. aastapäeva pidustuste käigus pidasime ühe viimaseid arutelusid rektori ja teadusprorektor Andres Koppeli osalusel. Peaettekande "EPMÜ VK loomisest", kus kirjas VK tegevuse eesmärgid, struktuur ja tööpõhimõtted (liikmeskond, juhtimine, varad ja vajalikud sammud MTÜ asutamiseks), koostas vilistlane ja tollane EPMÜ rahvusvaheliste ja avalike suhete osakonna juhataja Aret Vooremäe.

21. septembril 2001 tehti kavandatu teoks – peeti EPMÜ vilistlaskogu asutamiskoosolek, kus sõlmiti MTÜ asutamisleping, kinnitati põhikiri ning valiti 7-liikmeline juhatus ja revisjonikomisjon.

Vilistlaskogu tegevusest

Juhatuse esimesel koosolekul 2002. a 31. jaanuaril valis juhatus esimeheks allakirjutanu ja aseesimeesteks Aret Vooremäe ja Jaan Õunapuu ning registreeris esimesed 29 vilistlaskogu liiget. Esimeste registreeritud liikmete hulgas on ka agronoomiavilistlane president Arnold Rüütel.

VK liikmeskonna suuruse suhtes olime alguses optimistlikumad, lootes ajapikku kuni neljakohalist arvukust. Esimesed sada tulid kiiresti, ligi kolmsada (täpsemalt 290) liiget aga esimeseks üle 2500 osalejaga EMÜ aastapäevapeoks 2011. aastal.

Vilistlaskond on alati toetamas oma ülikooli ja selle VK olemasolu ja tegemisi, kuid küllap olemasoleva seltside, klubide jms rohkuse olukorras VK-ga ise liituma ei kiirustata.

Olulisemateks ettevõtmisteks algaastatel olid lisaks korralistele aastakoosolekutele konverentside korraldamine ühistöös rektorite ja rektoraatidega. Neid sai kokku viis. Näiteks üks VK juhatuse eestvõttel korraldatud kaalukamaid konverentse toimus 2006. a 27. jaanuaril teemal "Kõrgharidus Maaülikoolist – tööjõuturg, õpe ja praktika". Sisuka ettekande tegid seal muuhulgas tudengiesinduse juhid Piret Hartman ja Roomet Sõrmus.

2008. a 4. aprillil korraldasime koostöös rektoraadi ja APS-iga konverentsi "Põllumajandusteaduse võimalused ja rakendused tootmises", kus peaettekandjateks EMÜ tulevikuvisioonist olid rektor Mait Klaassen ja prorektor Anne Luik. Ühtlasi toimus sel päeval VK aastakoosolek, kus valiti uus juhatus, esimeheks Jaan Õunapuu ja aseesimeheks Külli Annamaa.

Aastakoosolekutel on olnud traditsiooniline rektori ülevaade ülikooli seisust ja arengutest ning mõne kaaluka teadlase või praktiku (selle Aasta Vilistlase) esinemine. Lisaks mõne ülikooli instituudi külastus-tutvustus, mõne Tartu teatrietenduse külastus jms. Algaastatel sai osaletud ülikooli kahes meeleolukas suvelaagris – Kauksis ja Käsmus. Alates 2006. aasta aprillist on VK esindus osalenud ja tutvustanud ennast Maamessil. 2006. aasta novembris oli VK kutsutud ja soovijad osalesid EMÜ 55. aastapäeva üritustel, sh Maaülikooli tu-

levikukonverentsil "Eesti maa – elamisväärne ja igikestev". Vahepealsetel aastatel saadeti VK liikmetele maaülikooli ajalehte.

2009. aastast alates selgitatakse välja EMÜ Aasta Vilistlane. Praeguseks on selle austava tiitli pälvinud 15 Eestimaa teenekat naist ja meest maaülikooli vilistlaskonnast.

Vilistlaskogu juhatuse ja rektoraadi ühistöö keerukamateks ja mastaapsemateks näideteks on seni kahtlemata kahe ülikooli juubelipeo korraldamine – 2011. a 2500, 2016. aastal aga rohkem kui 3000 õppejõule, vilistlasele ja külalisele.

Vilistlased on olnud alati oodatud EMÜ olulistele üritustele. VK juhatuse liikmed on olnud kutsutud septembri avaaktustele, ülikooli aastapäeva tähistustele, konverentsidele, lõpuaktustele.

Alates moodustamisest kuni tänaseni on kestnud väga hea koostöö kõigi rektoritega, kes põhikirja järgi on juhatuse liikmed *ex officio*, samas kõik on (olnud) ka EPA/EMÜ vilistlased. Niisiis, suur tänu lahkunud rektor Henn Elmetile aastate 2001–2002 eest, rektor Alar Karisele aastate 2003–2007 eest ja rektor Mait Klaassenile 2008. aastal alanud laitmatu koostöö eest! Mis salata, maaülikooli ja meie vilistlaskonna uhkuseks on juba meie teise rektori valimine Eesti Vabariigi presidendiks!

Vivat Academia, vivant professores!

Jaanus Männik
EMÜ vilistlaskogu juhatuse esimees aastatel 2002–2008

ANDRES VALDMANN – 60

5. detsembril 2021 tähistas 60 sünnipäeva EMÜ veterinaarmeditsiini ja loomakasvatuse instituudi professor Andres Valdmann.

Andres Valdmann lõpetas 1985. aastal *cum laude* diplomiga Eesti Põllumajanduse Akadeemia veterinaarmeditsiini erialal. Juba üliõpilasena tundis ta sügavat huvi uurimistöö vastu ja seetõttu oli järgmiseks loogiliseks sammuks astumine aspirantuuri Eesti Loomakasvatuse ja Veterinaaria Teadusliku Uurimise Instituudis (ELVI) ning tööle asumine nooremteadurina sigimisbioloogia osakonnas. Andres Valdmann alustas juba tudengina uuringuid loomade sigimishormoonide määramise immunoloogiliste meetodite väljatöötamiseks koostöös Tartu Ülikooli üld- ja molekulaarpatoloogia instituudi professor Aavo-Valdur Mikelsaare töörühmaga. Saadi üle 30 progesteroonivastaseid monokloonseid antikehi produtseeriva hübridoomiliini. Saadud antikehadest valiti sobivaim, mille baasil töötati välja piima progesteroonisisalduse määramise immuunensümaatiline meetod. Andres Valdmanni väljatöötatud ELISA-meetod on kõrge tundlikkusega ja täpne ning leidis rahvusvahelist tunnustust ja kasutamist välisülikoolides Norras ja USA-s. Andres Valdmanni doktoriväitekiri "*Studies on progesterone in bovine milk. Immunoanalysis, distribution in the mammary gland, and influence at first insemination on fertility of dairy cows*" (1999) valmis prof Aavo-Valdur Mikelsaare, prof Ilmar Müürsepa ja Norra kolleegi prof Erik Ropstadi juhendamisel.

Tööka ja sihikindla teadlasena on Andres Valdmann arendanud edasi sigimise endokrinoloogia uurimissuunda. Ta on Eesti piimakarja sigivuse uuringutes saavutanud mitmeid olulisi teadustulemusi. Nii on ta esmakordselt näidanud, et lisaks piima rasvasisaldusele sõltub piima progesteroonisisaldus piima päritolust piimanäärmes, siit ka uued teadmised progesterooni imendumisest piima, selle jaotumisest piimanäärmes ja väljutamisest. Munasarjade endokrinoloogiaalastes uuringutes on tal õnnestunud välja selgitada mitmeid lehmade innatsükli sünkroniseerumist mõjutavaid tegureid ja näidata innatsükli sünkroniseerimise efektiivsuse sõltuvust looma ainevahetuslikust seisundist inna sünkroniseerimise ajal. Andres Valdmann on olnud teerajajaks piimakomponentide sisalduse abil munasarjahäirete esinemissageduse ja tüüpide prognoosimisel karja tasandil ja näidanud suprabasaalse progesterooni mõju lehmade tiinestumisele. Aastate jooksul saadud uurimistulemused paljud faktorite nagu näiteks keskkond, tõug, toodang, negatiivne energiabilanss ja looma tervislik seisund mõjust lehmade munasarjafunktsioonile, tiinestumisele ja emakakeskkonnale on suunanud teda otsima tegurite vahelisi seoseid. Nende teadmine ja arvestamine on piimalehmade sigivuse parandamise oluliseks eelduseks. Innovaatiliste lahendusteni on ta jõudnud ka emakapõletike diagnoosimisel, võttes uurimistöös kasutusele tsütoloogilise meetodi. Uudsele seadmele emakast proovide võtmiseks anti välja EL-i patent. Andres Valdmann teeb uurimistööd ja kraadiõppurite juhendamist suure põhjalikkusega, tegemata kompromisse töö kvaliteedi osas. See on toonud talle rahvusvahelise tuntuse ja mitmeid tunnustusi.

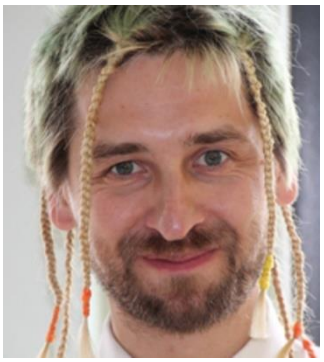
Andres Valdmann on avaldanud üle 100 teadusartikli, neist üle 50 on ilmunud rahvusvahelistes teadusväljaannetes. Ta teeb tihedat rahvusvahelist koostööd, olles muuhulgas Euroopa Koduloomade Reproduktsiooniühingu (*European Society for Domestic Animal Reproduction*) juhatuse liige, osaleb mitmetes teadus- ja kõrgharidusalastes otsustuskogudes, on veterinaarmeditsiini ja toiduteaduse doktoriõppekava juht ja juhib veterinaarmeditsiini ja toiduteaduse doktoritööde kaitsmiskomisjoni tööd. Alates 2019. aastast jagab ta oma kompetentsi regulaarselt ka naaberriigis Lätis, olles Läti Põllumajandusülikooli külalisprofessor ja veterinaarmeditsiini suuna professorite nõukogu liige ning andes eksperdina nõu veterinaarmeditsiini doktoriõppe programmi arendamiseks.

Andres Valdmann teeb suure pühendumisega oma tööd, kuid tema elus on väga tähtsal kohal pere, loodus, Lätimaa suvekodu ja sõbrad. Kolleegid hindavad Andrese sihikindlust, teadmisi, laia silmaringi, raudset loogikat, abivalmidust ja sõbralikkust.

Soovime heale kolleegile jätkuvat edu teadustöös, palju uusi ideid ja tugevat tervist!

Ülle Jaakma

TANEL KAART – 50



17. detsembril tähistas oma sünnipäeva Eesti Maaülikooli andmeteaduse professor Tanel Kaart.

Tanel Kaart on väljapaistev isiksus, viljaks õppejõud ja teadlane. Tema sihikindla töö tulemusena on suurenenud kogu maaülikoolis tervikuna matemaatilise statistika ja modelleerimise alased teadmised ja oskused, mis on oluliselt aidanud kaasa publitseeritavuse ja ülikooli nähtavuse suurendamisele. Tema osalusel on senini publitseeritud 120 *Web of Sciences* esindatud teadusartiklit. Ta on nelja patentse leiutise kaasomanik.

Tanel Kaart alustas oma karjääri Eesti Maaülikoolis (toonases Eesti Põllumajandusülikoolis) 1. jaanuaril 1995. aastal, õppides samal ajal Tartu Ülikooli magistriõppes matemaatilise statistika erialal. Sellest ajast sai alguse tema kokkupuude loomakasvatuse, tõuaretuse ja geneetikaga, mis vormus 1997. a Tartu Ülikoolis kaitstud magistritööks teemal „Dispersioonikomponentide ja päritavuskoefitsiendi hindamine loomapopulatsioonides“. Magistrantuurile järgnes loogilise jätkuna samas doktorantuur. Doktoritöö teemaks kujunes „Lineaarsete segamudelite usaldusväärsus geneetilistes uuringutes“, mille Tanel kaitses edukalt 2006. aastal ja talle omistati filosoofiadoktori kraad matemaatilise statistika alal. Oma doktoritöös juhindus ta eelkõige põllumajandusloomade aretuses kasutatavatest mudelitest, kuid paljud käsitletud probleemid on üldised ja võimaldavad seetõttu teha katsete planeerimise ja andmeanalüüsialaseid otsuseid ka teistes valdkondades, kus kasutatakse lineaarseid segamudeleid.

Taneli kompetentsi hulka kuulub andmeanalüüs eluteadustes, täpsemalt (populatsiooni)geneetikas, loomaja taimekasvatuses, (veterinaar)meditsiinis, toiduteaduses ja ökoloogias. Oma kompetentsist lähtuvalt on ta ühenduslüliks ja koostöö edendajaks paljude uurimisgruppide inimeste, oma koduinstituudi erinevate õppetoolide ja ülikooli teiste instituutide ja õppetoolide vahel, olles oma töös erakordselt loov ja innovaatiline sünergia looja ning ka ülikooli väärtuste hoidja ja kandja. Ta kuulub ka teadusajakirja "Agraarteadus" toimetuskolleegiumi koosseisu.

Kaasaegse teadustöö aluseks on hästi kavandatud katsed, kvaliteetne andmete kogumine, andmete mõtestatud analüüsimine, esitamine, interpreteerimine ja järelduste tegemine ning tulemuste publitseerimine nii kõrgetasemelistes teadusajakirjades kui ka saadud tulemuste populaarteaduslik tutvustamine. Kõrge teadustöö tase nõuab lisaks väga headele spetsiifilistele erialateadmistele ka väga oskuslikku sobivate tarkvaraprogrammide kasutamist ja head andmeanalüüsi oskust. Suured andmehulgad on erinevate eluvaldkondade lahutamatus osaks – olgu nendeks näiteks piimafarmis lüpsi ajal automaatselt registreeritavad või suure tihedusega geenikiibi kasutamisest saadavad andmed. Seda kõike Tanel valdab.

Lisaks maaülikoolile viib ta läbi õppetööd ja juhendab üliõpilasi ka Tartu Ülikoolis. Tema lai silmaring ja arenenud empaatiavõime on aidanud panustada paljude erinevate valdkondade teadusuuringuisse. Tema rahvusvahelist tuntust kinnitab ka statistikalaste loengute pidamine külalisõppejõuna Kuopio Ülikoolis.

Tanel osaleb ta aktiivselt erinevate Eesti ja rahvusvaheliste organisatsioonide töös ning nõustab erinevaid Tartu T&A asutusi ja ettevõtteid ning aretusorganisatsioone ja ka riigiameteid. Lisaks on ta leidnud aega, et hinnata arvukaid doktori-, magistri- ja bakalaureusetöid SA Eesti Teadusagentuuri poolt korraldatud Eesti üliõpilaste teadustööde riiklikel konkurssidel.

Aktiivse ja sportliku inimesena tuiskab Tanel Tartus ringi jalgrattaga, olgu siis eesmärgiks ühest õppehoonest teise jõudmine või ühelt ürituselt teisele, olgu ilm või aastaaeg milline tahes. Aktiivse sportliku eluviisi viljelejana on ta eeskujuks nii kolleegidele kui üliõpilastele. Tanel on suurepärane kaaslane kõikvõimalikel üritustel ja ühisettevõtmistel. Lisaks on ta innukas muusika ja teatri austaja, keda kohtab väga sageli erinevatel kultuuriüritustel.

Tanel on ise öelnud, et andmeteadlaseks ei sünnita, vaid selleks kasvatakse. Ja see kasv on olnud muljetavaldav. Tema oskuste pagasisse on koondunud aastate pikkused kogemused alates katsete planeerimisest, kirjeldavast statistikast ja visualiseerimisest ning lõpetades keerukate mudelite, mitmemõõtmelise statistika meetodite ja masinõppe algoritmidega, ja seda nii rakendamise, õpetamise kui ka arendamise osas.

Soovin kõigi kolleegide nimel palju huvipakkuvaid teemasid ja projekte, mis ärgitavad uusi lahendusi otsima ja seoseid leidma ning palju üliõpilasi, kes innustuvad huvist andmemaailma süüvida!

Haldja Viinalass

LAINE ILUS – 100

Laine Ilus sündis Viljandimaal Uue-Kariste vallas Torimu talus Marie ja Heino perre teise lapsena 3. mail 1921. aastal, noorem õde sündis kolm aastat hiljem. Laine Ilus õppis 1928–1934. a Araku algkoolis ja aastatel 1934–1940 Viljandi Eesti Haridusseltsi tütarlaste gümnaasiumis.

Torimu oli hea põllumaaga ja eeskujulikult majandatud talu. Pereisa Heino Ilus oli agar kohaliku kogukonna tegevuses: tuletõrje ühingu, turbaühingu, Kaarli Tarvitajate Ühisuse esimees, karja kontrollühingu juhatuse liige, valla volinik. 14. juunil 1941. a küüditati pere Siberisse. Laine oli asumisel 16 aastat. Ta töötas loomakasvatuses lüpsjana. Laine Ilus sai Eestisse tagasi tulla alles 1957. aastal (E. Piir, 1991). Siin sai ta tööd Väikemõisa lastekodus sanitarina. Samal ajal asus Laine Ilus õppima Eesti Põllumajanduse Akadeemiasse kaugõppe teaduskonda. Tol ajal kehtis nõue, et kaugõppe üliõpilane peab töötama põllumajanduses. Laine Ilus vahetaski töö- ja elukohta. Ta tuli tööle EMMTUI Polli katsebaasi katsetöölisena 1961. a EPA õpetatud agronoomi diplomi omistamisel (1965) edutati ta puuviljanduse osakonna nooremteaduriks marjakultuuride agrotehnika alal. Laine Ilus jätkas E. Haagi ja A. Jaama katseid selles valdkonnas. Marjaistandike istutuseelse mulla harimisviisi ja väetussüsteemi välja töötamiseks korraldati EMMTUI Polli katsebaasis aastatel 1959–1970 katse sõstra ja karusmarjaga 0,64 ha suurusel pinnal. Alates 1968. a spetsialiseerus Laine Ilus maasikakasvatuse tehnoloogia uurimisele katsetades maasika istutuseelse ja kandeeas istandiku mulla harimist ning väetamist, taimede istutustihedust jm. Ta soovitab õhema kui 25 cm künnikihiga mulla puhul maasika eelkultuurile sügiskündi koos põhja kobestamisega. Suurte saakide eelduseks on maa korralik väetamine enne istandiku rajamist. Häid saake võib loota istandikust, kus mullas esineva P_2O_5 ja K_2O sisaldus on 15 mg või enam 100 g mullas. Orgaanilise väetise efektiivsus kasvab annuse suurenemisega 40–100 t ha^{-1}. Keskmise viljakusega ja raskematel muldadel võib maasika varuväetisena antava sõnniku kas osaliselt või täielikult asendada haljasväetisega. Katsetest selgus, et sõnnik (85 t ha^{-1}) antuna varuväetisena eelkultuuri alla katab maasika väetise tarbe kolme aasta vältel peaaegu täielikult. Hilisemates katsetes osutus tõhusamaks võtteks anda maasikale kogu rotatsiooniks ette nähtud PK väetised varuväetisena koos orgaanilise väetisega kas maasika viimase eelvilja alla või mustkesale enne istandiku rajamist. Taimede väetistarbe kindlaks määramisel tuleb lähtuda mulla- ja leheanalüüsidest. Maasikataimed on toitainetega hästi varustatud kui nende lehtedes sisaldub õitsemise ajal 2,7–3,2% N, 0,50–0,60% P_2O_5 ja 1,7–2,0% K_2O. Toitainete vajaku korral on abiks lehtede kaudu väetamine. Taimed omastavad toitaineid lehtede kaudu kiiremini kui juurte kaudu. Optimaalne maasikataimede istutustihedus oli tol ajal enamlevinud sortide puhul 80–90 × 20–25 cm ehk 44–65 tuhat tk ha^{-1}.

Laine Ilus propageeris marjakultuuride teaduspõhist viljelust ajakirjas "Sotsialistlik Põllumajandus" jm. Samal ajal näitas ta head praktilist eeskuju. 1976. a oli Eesti aianduse ajaloos suurim (arvestuslik) puuvilja- ja marjasaak – kokku 98 196 t (E. Mägi, 1977). Polli katsebaasis 91 ha suuruses kandeealises istanduses toodeti 1162 t puuvilja ja marju, sh 1043 t õunu ja pirne ning 90 t ploome ja kirsse. Laine Ilusa 1,4 ha suuruselt katsepõllult koguti 20,3 t maasikaid, mis oli Eesti aiandusmajandite hulgas suurim maasikasaak tol aastal.

Laine Ilus töötas Polli katsebaasis teaduri ja katsetöölisena 27 aastat, kaitses põllumajandusteaduste kandidaadi väitekirja "Väetamise efektiivsus maasikakasvatuses" (1975). Ta on avaldanud ajakirjades ja teaduskogumikes ligikaudu 50 artiklit ja trükised: "Sõstrad" (1971, kaasautor), "Aiapidaja käsiraamat" (1974, kaasautor), "Maasikas" (1981, 1988).

Elu lõpuni jäi Laine Ilus üksikuks, Siberi-aastad jätsid oma jälje. Seltskondlikus elus võttis ta aktiivselt osa Eesti Looduskaitse Seltsi tööst, Põllumeeste Klubi "Iva" tööst. Oli suur kultuuri- ja kunstihuviline. Teadlasena väga täpne ja visa, samas sõbralik ja alati naeratav. Peaoperatsiooni tüsistuste tagajärjel Laine Ilus suri 30.aprillil 1989. a ja maeti saadetuna oma töökoha saalist Halliste kalmistule Torimu talupere platsile.

Allikad.

Piir, E. 1991. Sakalamaa ei unusta. Halliste kihelkond. – Memento: Viljandi, 136 lk.

Mägi, E. 1977. 1976. a tulemusi puuviljakasvatuses. – Sotsialistlik Põllumajandus, 12:561–562.

Toivo Univer

EDGAR HAAK – 90

Edgar Haak sündis 27. novembril 1931. a Sõmerpalu vallas Võrumaal talupidajate peres. Tema koolitee algas Vastse-Otepää algkoolis 1939. a, mille lõpetas 1945. a ja jätkus Valgjärve 7-klassilises koolis ja Otepää keskkoolis. 1950. a astus ta Tartu Riiklikku Ülikooli põllumajandusteaduskonna aianduse osakonna üliõpilaseks. Eesti Põllumajanduse Akadeemia loomise tulemusena 1951. a koondusid põllumajanduslikud erialad uude kõrgkooli ja õpetatud agronoomi diplomi aianduse erialal omandas Edgar Haak 1955. a. Tudengina oli ta aktiivne üliõpilasringides. Tootmispraktika kohaks valis Edgar Haak Polli katsebaasi, kus ta vaimustus dr. Aleksander Siimoni agrotehnikaalastest katsetest. Kõrgkooli lõpetamise järel suunati E. Haak tolleaegse Keila rajooni Kalevi kolhoosi agronoomiks (1955–1956). Võimalus asuda tööle õpitud erialal avanes detsembris 1956. a. Ta kutsuti tööle nooremteaduriks Eesti Maaviljeluse ja Maaparanduse Teadusliku Uurimise Instituudi (EMMTUI) puuviljanduse osakonnas. Tema töö valdkonnaks olid marjakultuurid. Aastail 1958–1959 töötas ta sama osakonna Saaremaal asuvas Karja katsepunktis uurides erinevate viljapuude, sh aprikoosi ja viinamarja sorte ning haljasväetiste kasutamist viljapuude reavahedes. Õpingutel aspirantuuris (1960–1962) oli juhendajaks dr. Aleksander Siimon. Uurimisvaldkonnaks valiti puuviljaaedade agrotehnika. 1965. a E. Haak kaitses väitekirja "Erinevate vahekultuuride mõju noortele viljapuudele Eesti NSV tingimustes" ning sai põllumajandusteaduste kandidaadi kraadi. 1968. a haigestus A. Siimon sedavõrd raskesti, et tuli leida järglane Polli katsebaasi juhataja kohale. EMMTUI direktor I. Jürisson tegi ettepaneku võtta vastu see vastutusrikas ametikoht E. Haagil. Alates 1. juunist 1969. a oli E. Haak Polli katsebaasi direktor ja samaaegselt ka EMMTUI puuviljanduse osakonna juhataja, samas jätkas ta teaduskatseid ning koordineeris puuviljandusalaseid uurimusi kogu Eestis. Polli katsebaasi direktori ametist loobus E. Haak 1992. aastal, olles juhtinud asutust 23 aastat ja puuviljandusosakonna juhataja tööst 1995. a. Sellest peale jätkas ta tööd vanemteadurina. Vanemteaduri kutse omistati 1982. a.

Alustanud puuvilja- ja marjasortide uurijana sai mõne aasta pärast Edgar Haagist agrotehnik, kes uuris õunapuude viljelemisega seotud probleemistikku. E. Haagi peamised uurimisteemad olid õunaaedade rajamiseelne väetamine, erinevate vahekultuuride mõju noortele viljapuudele, istutustihedus, kandeealise istanduse väetamine, viljapuude võra kujundamine, pookealuse mõju uurimine õunasaagi suurusele ja kvaliteedile. Viimastel aastatel olid E. Haagi ülesandeks astelpaju väetamiskatsed ja astelpaju saagi koristustehnoloogia uurimine. Valdav osa viljapuude kasvatamise tehnoloogia uurimisel saadud katsetulemustest on leidnud rakendust suurtootmise suunaga istandustes. Pikaajalised aedkatsete tulemused on publitseeritud ajakirjas "Agraarteadus": "Õunapuu lehtede põhitoitainete sisalduse sõltuvus väetamisest ja muudest teguritest" (1999, 1, lk-d 38–45), "Õunapuu kloonaluste aedkatsete tulemustest Eestis" (2001, 1, lk-d 8–13), "Kloonaluste ja vahepoogendite mõjust õunapuude kasvule ja saagikusele“ (2003, 5, lk-d 251–259).

Edgar Haak täitis teadus-administratiivseid ülesandeid EMMTUI esindajana Üleliidulise Leenini- nimelise Põllumajandusteaduste Akadeemia Lääne osakonnas, kus koordineeriti Eesti, Läti, Leedu ja Valgevene teadurite aiandusalaseid uurimistöid. Koostöö naabritega oli otstarbekas ja tulemuslik. Ühiskatsed õuna-, pirni- ja ploomipuu pookealustega andsid materjali tuumakateks ühisteks artikliteks ja olid aluseks paarile doktoritööle.

E. Haak on avaldanud üle 90 teadus- ja populaarteadusliku artikli. On ENE, EE, EPE erialaste artiklite autor. Kirjutanud raamatud "Noore viljapuu võra kujundamine" (1969, koos J. Palgiga), "Aiapidaja käsiraamat" (1974, kaasautor), "Polli" (1983), "Õun aias ja köögis" (1999, kaasautor), "Eesti põllumajandus XX sajandil III" (2009, kaasautor). Ta on koostanud istanduste rajamise projekte mitmele majandile.

1982. a sai Edgar Haak Eesti NSV teenelise aiandustöötaja austava nimetuse ja 1986. a Eesti Aianduse ja Mesinduse Seltsi teeneliseks liikmeks.

E. Haagi paljutahulises elutöös on oluline Polli asula väljakujundamine ja haljastuse loomine. Tema juhtimisel ehitati Polli laborihoone, õunahoidla, 4 kolmekorruselist elamut, 11 ühepereelamut, 3 kaarhalli, rekonstrueeriti seemneviljakuivati ja karjalaudad Pollis ja Allastel. Polli asula viidi tsentraalküttele, ehitati puurkaev ja biopuhastiga kanalisatsioon. Polli katsebaas tegeles puuviljade ja marjade uurimise ning tootmisega. Rekordsaak koguti 1976. aastal. Peale aianduse tegeleti ka loomakasvatuse ja põllukultuuride seemneviljatootmisega. Mõlemal viimasel alal oli Polli järjekindlalt Viljandimaal esikohal, millest annavad tunnistust kümned autasud. E. Haak oli aktiivne ühiskondlikus elus nii ametiühingu esimehena, pilli- ja spordimehena kui ka Polli esindajana Abja Tarbijate Kooperatiivis.

Edgar ja Evi Haagi peres kasvasid tütar ja kaks poega. Vanem poeg Aivar tegutseb aianduses ja on spetsialiseerunud viljapuuistikute kasvatajaks Põhja-Eestis Arli puukoolis ja sellega jätkab ta oma perega isa tegevust aianduse alal.

E. Haak suri 79-aastasena 22. juulil 2011. aastal olles tööl vanemteadurina osalise töökoormusega. Ta põrm puhkab Kanepi kalmistul.

Toivo Univer

MART KUIV – 90

Mart Kuiv sündis 7. novembril 1931 Võrumaal Antsla lähedal Vaabina külas. Tema vanemad Jakob ja Marie pidasid asunikutalu, olid edumeelsed talupidajad. Isa oli kihelkonnakooli haridusega. Oli aega teeninud Peterburis kaardiväe polgus, osalenud esimeses ilmasõjas, seejärel Vabadussõjas. Sõjas osalemise eest saadigi Põldmäe asunikutalu. Mardi ema onu oli Tartu Ülikoolis meditsiiniprofessor, ülikooli lastekliiniku rajaja dr Aadu Lüüs. Perekonnas hoolitseti lastele (kolm poega) hea hariduse andmise eest.

Mart alustas 1939. aastal, aastajagu varem kui nõutud, kooliteed kohalikus Vaabina algkoolis, pärast Vaabina 7-klassilise kooli lõpetamist 1946 jätkas Antsla keskkoolis, kus sai lõputunnistuse juunis 1950. Kuigi lõputunnistus oli hea, ei riskinud ta kõrgkooli astumist üritada. Mitte sissesaamise korral oleks tulnud kohe minna sõjaväkke. Riskide maandamiseks otsustas Mart koos mitme keskkooli klassikaaslasega astuda Tallinna Mäetehnikumi. Sealt õpiajal sõjaväkke ei võetud, maksti ka stipendiumi, mis noorele iseseisvat elu alustavale inimesele oli tähtis. Kooli valikul oli üheks kallutavaks jõuks spordi ja sportlaste soosimine. Mardil olid head eeldused (ja paljulubavad tulemused) nii kergejõustiku aladel kui talvel suuskadega murdmaal. Kool sai edukalt läbi 1953, saades mäetehniku kutse. Suunamise järel töötas Kohtla-Järvel kaevanduses nr 8 pool aastat mäemeistrina. Novembris 1953 järgnes lühiajaline sõjaväeteenistus suurtükiväes Tallinnas, kust vabanes novembris 1955 ja seejärel töö Antsla rajooni kohalikus ajalehes Kolhoosi Elu korrektorina.

1956. aasta suvel õnnestus täide viia ammune unistus ja astuda Eesti Põllumajanduse Akadeemia mehhaniseerimise teaduskonda. Nagu tol ajal kombeks, tähendas see teoreetilise õppe kõrval kõigepealt terve septembrikuu vältel kolhoositööd, hiljem üht suve uudismaal (Kasahstanis), üht praktikasuve Valgevene traktoritehases, üht välispraktikat kusagil majandis ja lõpuks diplomitööd. Varasemat elukäiku ja elukooliõpet Kohtla-Järvel arvestades pole imestada, et Mart Kuiv valiti kursusevanemaks (tookordse tava järgi kinnitati kursusevanemaks rektori käskkirjaga). Korraks kerkis esile ka võimalus õppida üks aasta ja teha diplomitöö Praha Põllumajanduse Akadeemia juures, kuid poliitilised tuulepuhangud on sama suunamuutlikud kui ilmaennustusteski. Kõrgharitud inseneri diplom ulatati Mart Kuivale siiski Tartus suvel 1961, hinnetelehel üks neli rohkem kui kiitusega diplomil lubatud.

Tööle suunati Mart Kuiv Valgamaale Hummuli näidissovhoosi vanem-insener-tehnoloogiks. Jäi ta sinna paariks aastaks, mille järel naasis Tartusse. Naasmiseks oli kaks põhjust. Esimene – üks sportlikku iluvõimlemist harrastav, 1963 ülikooli rahanduse ja krediidi eriala lõpetanud tudengineiu nimega Kaja Sandberg (abielluti 1961) ja teiseks soov õppida edasi aspirantuuris. Tartus algas 1963 töö Eesti Loomakasvatuse ja Veterinaaria Teadusliku Uurimise Instituudi erikonstrueerimisbüroos Märjal vaneminsener-konstruktorina, mõne aja pärast juhtkonstruktorina ja veidi enne kandidaadikraadi kaitsmist erikonstrueerimisbüroo juhataja asetäitjana teaduslikul alal.

Kandidaaditöö kirjutas Mart Kuiv teemal "Vedelsõnniku pumba lõikeorgani konstruktsiooni parameetrite uurimine". Kaitsmine leidis aset 22. veebruaril 1970 Leedu Põllumajanduse Akadeemias, 10. veebruaril 1971 väljastas Kõrgem Atestatsioonikomisjon (VAK) teaduste kandidaadi diplomi.

Edukas töö erikonstrueerimisbüroos kestis veerandsada aastat – kuni 1987. aastani. Selle aja jooksul uuris ta tööde mehhaniseerimise võimalusi loomakasvatusfarmides, juhtides ja suunates ELVI EKB-s veiste ja sigade pidamise tehnoloogiat, sööda valmistamise ja jaotamise, sõnniku eemaldamise, lauda mikrokliima, farmisisustuse jm alast uurimistööd. Kokku on Mart Kuiv avaldanud üle 60 publikatsiooni. Esines sageli ettekannetega paljudel konverentsidel, nõupidamistel ja näitustel, olles töökohast tingituna ise ka nende aktiivne organiseerija ning konverentsikogumike koostaja. Panuse eest erikonstrueerimisbüroo väljaarendamise ja loomakasvatusvaldkonna tööde mehhaniseerimisel omistati Mart Kuivale Eesti NSV teenelise inseneri aunimetus (1984). Aastatel 1987–1994 töötas Mart Kuiv Tartus ELVI-s teadusliku informatsiooni ja propaganda sektori juhataja ning vanemteaduri ametikohal kuni ELVI liitmiseni Eesti Põllumajandusülikooliga. Koostas ja toimetas ELVI väljaannet "Loomakasvatus" ning ajakirja "Lammas ja Kits".

Oli inimesena väga aus, kaastöötajatega suheldes viisakas ja alati korrektne.

Mart Kuiv oli perele pühendunud. Koos abikaasa Kajaga kasvatati üles ja koolitati kaks last. Poeg Paavo valis ajaloo eriala, lõpetas Tartu Ülikooli 1992, töötab riigiametnikuna Tallinnas. Tütar Reet, erialalt filoloog, filosoofiadoktor aastast 2009, töötab kaasprofessorina Tartu Ülikoolis.

Pensionärina tegeles Mart Kuiv aiatööga, pidas mesilasi, hobideks olid mälumäng ja lugemine. Leidis rakendust abistava jõuna Vambola Veinla teadusprojektides ja Maaülikoolis mehhaniseerimisteaduskonna lõputööde kaitsmiskomisjoni esimehena – viimast korda aastal 2000.

Mart Kuiv lahkus meie seast kuuekümne kaheksa aastasena 27. oktoobril 2000 ja sängitati mulda 2. novembril Raadi kalmistule.

Ants Bender

DOKTORIKRAADI KAITSJAD EESTI MAAÜLIKOOLIS 2021. AASTAL
THESIS DEFENDERS ESTONIAN UNIVERSITY OF LIFE SCIENCES IN 2021

KAIRI MAILEHT
FÜTOPLANKTON JÄRVEDE SEISUNDI INDIKAATORINA
PHYTOPLANKTON AS ECOLOGICAL QUALITY INDICATOR OF LAKES
Juhendajad: emeriitprofessor Ingmar Ott, juhtivteadur Peeter Nõges
19. veebruar 2021

PAUL FRIDTJOF MÕTSKÜLA
ELEKTRO- JA PILTDIAGNOSTIKA TÄIENDAVAD RAKENDUSED KOERTE SÜDAMEHAIGUSTE DIAGNOOSIMISEL NING PROGNOOSIMISEL
CONTRIBUTION TO THE DIAGNOSIS AND PROGNOSIS OF CANINE CARDIAC DISEASE THROUGH ELECTRODIAGNOSTICS AND DIAGNOSTIC IMAGING
Juhendajad: professor Toomas Orro, Professor Virginia Luis Fuentes (The Royal Veterinary College, UK), Professor David Connolly (The Royal Veterinary College, UK) ja doktor Ranno Viitmaa
8. märts 2021

JONATHAN MARTIN WILLOW
TIAKLOPRIIDI, TAIMSETE EETERLIKE ÕLIDE JA KAHE-AHELALISE RNA RAKENDAMISE VÕIMALUSED HIILAMARDIKATE KESKKONNASÄÄSTLIKUS TÕRJES
EXAMINING THIACLOPRID, ESSENTIAL OILS AND DOUBLE-STRANDED RNA FOR POTENTIAL USE IN BIOSAFE MANAGEMENT OF POLLEN BEETLE
Juhendajad: professor Eve Veromann, professor Guy Smagghe
12. aprill 2021

MARIA SOONBERG
GRUPEERIMISE MÕJU PIIMALEHMADE KÄITUMISELE JA HEAOLULE
REGROUPING EFFECTS ON BEHAVIOUR AND WELFARE OF DAIRY COWS
Juhendajad: professor David Arney, doktor Marko Kass ja professor Tanel Kaart
26. aprill 2021

MARIANA MAANTE-KULJUS
VIINAPUU (*VITIS* SP) SAAGI KÜPSUSNÄITJAD
MATURITY PARAMETERS OF GRAPEVINE (*VITIS* SP) YIELD
Juhendajad: professor Kadri Karp, dotsent Leila Mainla, dotsent Ele Vool
24. mai 2021

BURAK ÖĞLÜ
KLIIMAMUUTUSTE JA TEISTE ÖKOLOOGILISTE TEGURITE MÕJU VALITUD KALALIIKIDE POPULATSIOONIDELE JA KALAPÜÜGILE EESTI SUURJÄRVEDES
IMPACT OF CLIMATE CHANGE AND OTHER ECOLOGICAL FACTORS ON SELECTED FISH POPULATIONS AND FISHERY IN ESTONIAN LARGE LAKES
Juhendajad: professor Tanel Kaart, vanemteadur Külli Kangur, vanemteadur Fabien André Daniel Cremona
28. mai 2021

TARMO PILVING
TOURISM KOOSTÖÖ EESTI MAATURISMIS
COLLABORATION IN ESTONIAN RURAL
Juhendajad: vanemteadur Ants-Hannes Viira, professor Tiiu Kull, nooremprofessor Monika Suškevičs
11. juuni 2021

MARIKA KOSE
RANNANIIDUD: SÄILIMINE, TAASTAMINE JA TAASTUMINE
COASTAL MEADOWS: MAINTENANCE, RESTORATION AND RECOVERY
Juhendajad: vanemteadur Karin Kauer, vanemteadur Kadri Tali
11. juuni 2021

ELINA KARRON
ERINEVATE KASVATUSTEHNOLOOGIATE MÕJU *FUSARIUM* SPP. ESINEMISELE JA MÜKOTOKSIINIDE TEKKIMISELE TERAVILJADEL
INFLUENCE OF CULTIVATION TECHNOLOGIES ON PATHOGENIC *FUSARIUM* SPP. OCCURRENCE AND PRODUCTION OF MYCOTOXINS IN CEREALS
Juhendajad: dotsent Eve Runno-Paurson, professor Ülo Niinemets, emeriitdotsent Enn Lauringson
15. juuni 2021

IMBI NURMOJA
SIGADE AAFRIKA KATKU EPIDEMIOLOOGIA EESTIS JA ÜHE VIIRUSTÜVE ISELOOMUSTUS
EPIDEMIOLOGY OF AFRICAN SWINE FEVER IN ESTONIA AND CHARACTERIZATION OF ONE VIRUS STRAIN
Juhendajad: doktor Arvo Viltrop, doktor Sandra Blome, doktor Klaus Robert Depner
15. juuni 2021

MERILI TOOM

ERINEVATE VAHEKULTUURIDE BIOMASSI MOODUSTAMISE JA LÄMMASTIKU SIDUMISE VÕIME SÕLTUVALT KÜLVIAJAST NING VAHEKULTUURIDE MÕJU SUVIODRA SAAGILE
BIOMASS AND NITROGEN ACCUMULATION BY COVER CROPS DEPENDING ON SPECIES AND SOWING DATE AND THE EFFECT OF COVER CROPS ON SPRING BARLEY YIELD
Juhendajad: dotsent Enn Lauringson, dotsent Liina Talgre, doktor Andres Mäe
16.juuni 2021

KAIRE LOIT

PATOGEENSED JA ARBUSKULAARMÜKORIISSED SEENED EESTI KARTULIPÕLDUDEL
PATHOGENIC AND ARBUSCULAR MYCORRHIZAL FUNGI IN POTATO FIELDS IN ESTONIA
Juhendajad: professor Alar Astover, dokor Maarja Öpik ja doktor Leho Tedersoo
22. juuni 2021

NASIME JANATIAN GHADIKOLAEI

HÜDROMETEOROLOOGILISTE JA KLIIMATEGURITE MÕJU JÄRVEDE FÜTOPLANKTONILE: AJASKAALADE OLULISUS
HYDROMETEOROLOGICAL AND CLIMATIC CONTROL OVER LAKE PHYTOPLANKTON: THE IMPORTANCE OF TIME SCALES
Juhendajad: juhtivteadur Peeter Nõges, Biel Obrador, vanemteadur Fabien Cremona, vanemteadur Alo Laas
27. august 2021

KRISTIINA AUN

RAIETE LÜHIAJALINE MÕJU SÜSINIKU VOOGUDELE JA VARUDELE ERINEVATES EESTI METSAÖKOSÜSTEEMIDES
SHORT-TERM EFFECT OF FELLING ON CARBON FLUXES AND STORAGES IN DIFFERENT ESTONIAN FOREST ECOSYSTEMS
Juhendaja: professor Veiko Uri
27. august 2021

KRISTIINA AUNRAIETE

LÜHIAJALINE MÕJU SÜSINIKU VOOGUDELE JA VARUDELE ERINEVATES EESTI METSAÖKOSÜSTEEMIDES
SHORT-TERM EFFECT OF FELLING ON CARBON FLUXES AND STORAGES IN DIFFERENT ESTONIAN FOREST ECOSYSTEMS
Juhendaja: professor Veiko Uri
27. august 2021

PRIIT KARIS

TOITUMUSE, LIPOMOBILISATISOONI JA INSULIINIRESISTENTSUSE SEOSED PIIMALEHMADEL
RELATIONSHIPS BETWEEN BODY CONDITION, LIPOMOBILIZATION AND INSULIN RESISTANCE IN DAIRY COWS
Juhendajad: vanemteadur Hanno Jaakson, vanemteadur Katri Ling, kaasprofessor Meelis Ots
31. august 2021

HARES KHAN

KALTSIIDI AVAVEELINE SADENEMINE: PÕHJUSED JA TAGAJÄRJED GLOBAALSES JA KOHALIKUS VAATES
PELAGIC CALCITE PRECIPITATION IN LAKES: FROM A GLOBAL TO A LOCAL PERSPECTIVE ON ITS DRIVERS AND IMPLICATIONS
Juhendajad: doktor Biel Obrador (University of Barcelona, Hispaania), vanemteadur Alo Laas
16. september 2021

HEIKI LILL

ERINEVATE ENERGIA SALVESTUSTEHNOLOOGIATE UUDSED RAKENDUSPÕHIMÕTTED LIGINULLENERGIAHOONETES
NOVEL APPLICATION PRINCIPLES FOR ENERGY STORAGE TECHNOLOGIES IN NEARLY ZERO ENERGY BUILDINGS
Juhendajad: Teadur Alo Allik, professor Andres Annuk
29. oktoober 2021

MARGUS ARAK

AMMENDATUD FREESTURBAVÄLJADEL KASVATATAVA AHTALEHISE MUSTIKA MASINVILJELUSTEHNOLOOGIA
CULTIVATION TECHNOLOGY FOR LOW-BUSH BLUEBERRY CULTIVATION IN MILLED PEAT FIELD PLANTATIONS
Juhendaja: professor Jüri Olt
1. november 2021

LIINA JÜRISOO

JALAKASURMA TEKITAJATE LEVIK JA KAHJUSTUSED KIRDEEUROOPAS
DISTRIBUTION OF AND DAMAGES BY DUTCH ELM DISEASE AGENTS IN NORTHEASTERN EUROPE
Juhendaja: professor Rein Drenkhan
11. november 2021

PIRET RAUDSEPP

HARILIKU RABARBERI (*RHEUM RHAPONTICUM* L.) JA MUSTA SÕSTRA (*RIBES NIGRUM* L.) POLÜFENOOLNE KOOSTIS, NENDE TAIMEDE ANTIBAKTERIAALSE TOIME JA VABADE RADIKAALIDE SIDUMISE VÕIME VÕRDLUS MÕNEDE TEISTE TOIDUTAIMEDEGA
POLYPHENOLIC COMPOSITION OF RHUBARB (*RHEUM RHAPONTICUM* L.) AND BLACKCURRANT (*RIBES NIGRUM* L.), ANTIBACTERIAL AND FREE RADICAL SCAVENGING PROPERTIES OF THESE PLANTS IN COMPARISON WITH SOME OTHER FOOD PLANTS
Juhendajad: professor Tõnu Püssa, dr Ave Kikas
10. detsember 2021

INGRID BENDER

MEETODITE MÕJU PORGANDI SAAGILE JA KVALITEEDILE NING UMBROHTUDELE
EFFECT OF ORGANIC MANAGEMENT METHODS ON YIELD AND QUALITY OF CARROT AND ON WEEDS MAHEVILJELUSE
Juhendajad: emeriitprofessor Anne Luik, dotsent Evelin Loit, vanemteadur Ilmar Tamm
17. detsember 2021