Agraarteadus
1 • XXXII • 2021 111–116

Journal of Agricultural Science
1 • XXXII • 2021 111–116

THE IMPACT OF NUTRITION OPTIMIZATION ON CROP YIELD AND GRAIN QUALITY OF SPRING BARLEY VARIETIES (*Hordeum vulgare* L.)

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Saabunud: Received: 31.03.2021
Aktsepteeritud: Accepted: 21.06.2021

Avaldatud veebis: Published online: 22.06.2021

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Keywords: spring barley, variety, plant nutrition, yield, grain quality.

DOI: 10.15159/jas.21.18

ABSTRACT. The research is aimed to determine the yield and quality of spring barley grain depending on the varietal characteristics and optimization of nutrition. Methods. The experimental studies were conducted during 2013–2018. on the research field of Mykolayiv National Agrarian University (Ukraine). Results. The highest grain yield of spring barley varieties in all years of research is determined to be formed by growing the crop on the background of applying $N_{30}P_{30}$ and carrying out two foliar top dressing of crops with Escort-Bio or Organic D2 preparations. So, on average, over the years of research on the variety factor, the grain yield was 3.41 and 3.37 t ha^{-1}, which exceeded its level in the non – fertilized control by 26.7–28.2%. The optimization of nutrition affected the grain quality indicators of the studied varieties of spring barley significantly as the maximum values of grain nature (606.2 up to 611.2 g l^{-1}, depending on the variety) were reached by applying $N_{30}P_{30}$ before sowing and double applying of Escort-bio to the crops. The protein content in the grain and digested protein in this nutrition option was also determined to be the maximum as 12.5 up to 13.1% and 61.0 up to 63.8 g kg^{-1}, respectively, depending on the variety. Slightly higher grain quality indicators among the spring barley varieties taken for the study were formed by the 'Aeneas' variety. The highest protein content in the spring barley grain of 'Stalker' and 'Vakula' varieties was accumulated in 2018, and the last one was in 2016. The amount of protein in both varieties increased under the influence of nutrition optimization and, on average, it increased from 10.8% in the control up to 11.3–11.6% in the variants with fertilizing in ‘Stalker’ variety and from 10.7 up to 11.3–11.6% in 'Vakula' variety during three years.

Introduction

Barley (*Hordeum vulgare* L.) is the fourth cereal crop in the world and it is a secondary small grain crop cultivated in Europe. The most adaptable: there are barley varieties suited to temperate climatic conditions, subarctic climatic conditions as well as subtropical climatic conditions. For achieving good yields of spring barley, the best environment is a temperate moist climate with a growing period of at least 90 days (Daničić *et al*., 2019). Barley is one of the major crops, its grain is widely used for food and feed purposes (Lapa *et al*., 2016).

Increasing the yield and quality of grain crops, including spring barley, is the basis for the economic stability of agricultural enterprises. The steady growth of grain production today is associated with the intensification of the technological process of cultivation, aimed at creating highly productive sowings, improving the quality of grain while maintaining environmental safety, reducing resource and energy costs (Kalenskaya *et al*., 2015; Novotna *et al*., 2015; Povilaitis *et al*., 2018). It is known that for growing stable yields of spring barley with high grain quality indicators, it is important for the plants to be provided with nutrients from the very beginning of the growing season by means of mineral fertilizers. It is possible to compensate the lack of nutrition in subsequent phases of growth and development of spring barley by carrying out foliar top dressing of plants with growth-stimulating preparations (Panfilova *et al*., 2019). Due to synthetic preparations the resistance of plants to adverse weather conditions and to crop infestation increases, thus, the yield and quality of grain, etc. increases (Kolesnikov *et al*., 2016; Panfilova *et al.*, 2020). Nowadays, there are a large number of preparations affecting the growth and development of plants but their impact on the yield and quality of spring barley grain has not been sufficiently studied and covered in the world scientific literature.

Material and methods

Experimental researches were carried out during 2013–2018. on the research field of Mykolayiv National Agrarian University, Ukraine.

We studied the following varieties of spring barley. The technology of growing spring barley in the experiment, except for the studied factors, was generally accepted to the existing zonal recommendations for the southern steppe of Ukraine, which has a temperate continental climate and chernozem soils (black soil of the South, light clay-loam soil on loess). Spring barley was sown in the third decade of March and harvested in the first decade of July. During spring barley vegetation, the temperature of the air exceeded the average annual parameters by 0.3–1.4 °C, depending on the year. The only exception was 2016, where the temperature of the air during the vegetation period was +14.9 °C, which was somewhat lower than the long-term figures. During the vegetation of spring barley, depending on the year of the study, the precipitation fell as 95.8–189.5 mm. At the same time, in 2015 and 2016, the largest precipitation was 189.5 and 179.0 mm respectively, which exceeded the average annual figures by 15.1–19.8%.

Two experiments were conducted:

Experiment 1

The experiment scheme included the following variants:

Factor A – variety: 1. 'Adapt'; 2. 'Stalker'; 3. 'Aeneas'.

Factor B – plant nutrition: 1. Control (water treatment); 2. $N_{30}P_{30}$ – under pre-sowing cultivation; 3. $N_{30}P_{30}$, Urea K1 (1 l ha^{-1}); 4. $N_{30}P_{30}$, Urea K2 (1 l ha^{-1}); 5. $N_{30}P_{30}$, Escort-bio (0.5 l ha^{-1}); 6. $N_{30}P_{30}$, Urea K1, Urea K2 (0.5 l ha^{-1}); 7. $N_{30}P_{30}$, Organic D2 (1 l ha^{-1}). The fertilization of crops by fertilizers was carried out at the beginning of the phases of the spring barley stooling and earing.

Experiment 2

The scheme of the experiment included the following variants:

Factor A ⁻ variety: 1. 'Stalker'; 2. 'Vakula'.

Factor B – plant nutrition: 1. Control (water treatment); 2. Fresh Florid (200 g ha); 3. Fresh Florid (300 g ha); 4. Fresh energy (200 g ha); 5. Organic D2–M (1 l ha); 6. Escort-bio (500 g ha). The standard working solution was 200 l ha. The crops were treated in three phases of vegetation: tillering, stooling and beginning of earing. In all three of these periods, one, two- or three-drug treatments were performed.

The yield was determined by the method of continuous harvesting of each registration area (Sampo - 130 combine harvester). Technological indicators of spring barley grain quality intended for food needs use were established by DSTU 3769-98 'Spring Barley'. Protein content and digestible protein content were determined by the Kjeldahl method (DSTU ISO 5983:2003).

The statistical analysis of the data experiment was performed using the Statistica 6.0 application package (Ermantraut *et al.*, 2007).

Results and discussion

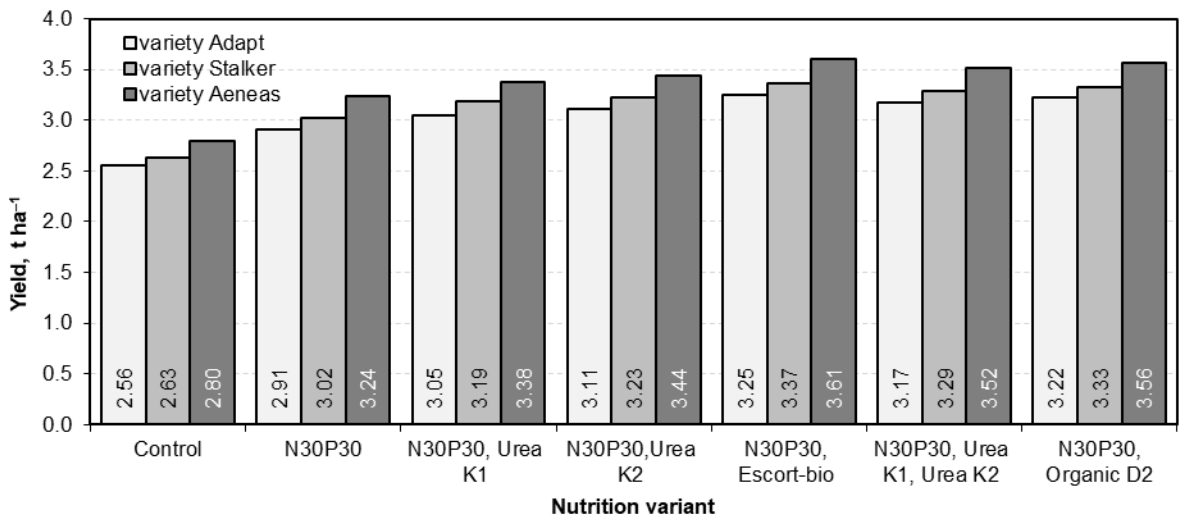
Our studies found the yield of spring barley grain changed under the influence of varietal characteristics, nutrition background and temperature regime during the vegetation season. Thus, the lowest yield of spring barley was formed in the dry year 2013. Favourable weather conditions in 2016 during the growing season of plants ensured the highest grain yield, regardless of the factors studied. It should be noted that on average, over the years of research, the nutrition factor had a greater impact on the formation of the yield of spring barley grain (Fig. 1).

Barley yield generally varies less under changing weather conditions relative to the other small grains (Newton *et al*., 2011). Concerning different cardinal temperature thresholds for different phenological processes, the crop’s response to a high temperature, in general, depended on the character of the temperature increase as well as the phonological stage of the crop (Porter *et al.*, 1999). However, its yield and biomass may be hindered by a high temperature and a severe water deficiency (Araya *et al*., 2010) if these occur during the flowering and grain-filling phase. The lowest yield of spring barley grain from all the years of the research was in the control version of the experiment as 2.56 up to 2.80 t ha^{-1}, depending on the variety. Carrying out foliar top dressing of plants with growth-stimulating preparations during the growing season contributed to an increase in grain yield, especially with the Escort-Bio application variant. Thus, the grain yield of the plants of 'Adapt' variety in this variant of the experiment increased by 21.2%, in the variant of 'Stalker' variety, it increased by 22.0%, and in the variant of 'Aeneas' variety, it increased by 22.4% compared to the control. The results were similar when using Organic D2.

According to the results of our research, it was established that, in addition to weather conditions and plant nutrition variants, the variety played an important role in the formation of spring barley yield and other cereals (Panfilova, Mohylnytska, 2019). So, on average, over the years of research, the highest yield was formed by the variety 'Aeneas' as 2.8 up to 3.61 t ha^{-1}. At the same time, it was the highest when using Organic D2 and Escort-Biogrowth-stimulating preparations. The same trend was observed when growing 'Adapt' and 'Stalker' varieties, but the yield was lower compared to 'Aeneas' variety by 6.5 up to 9.5 and 6.6 up to 10.0%, depending on the preparation.

Studies of many scientists (Laidig *et al*., 2017; Peltonen-Sainio *et al*., 2009; Rijk *et al*., 2013) also confirmed that in recent decades a significant impact on the increase of grain yields was made by the selection and genetic improvement of modern varieties.

Plant nutrition options had a positive effect on the quality indicators of spring barley grain (Table 1). In particular, on average during the years of research, the nature of grain of non-fertilized plants of 'Aeneas' and 'Stalker' varieties was from 6.1 to 6.4 g l^{-1}greater in comparison with the variant of fertilizing with the dose of $N_{30}P_{30}$. The foliar application in the phases of the spring barley stooling and earing contributed to the increase of this indicator by 1.4 up to 4.1 and 1.2 up to 2.3% depending on the studied varieties in comparison with the control, respectively. In the years of the research, a little more nature of grain is determined in the variety 'Adapt' as 601.3 up to 611.2 g l^{-1}.



$LSD_{0.5}$**:** Factor A (variety): 2–8. Factor B (plant nutrition): 1–4.

Figure 1. The yield of barley depending on the varietal characteristics and nutrition, t ha^{-1} (average for 2013–2017)

Table 1. Grain quality of spring barley varieties depending on nutrition optimization (average for 2013–2017)

Nutrition variant	Indicators		
	protein content, %	nature of the grain, g l^{-1}	digestible protein, g kg^{-1}
	'Adapt'		
Control	10.3	601.3	56.5
$N_{30}P_{30}$	11.2	605.5	58.9
$N_{30}P_{30}$, Urea K1	11.5	607.1	60.2
$N_{30}P_{30}$, Urea K2	11.7	608.3	60.9
$N_{30}P_{30}$, Escort-bio	12.6	611.2	63.1
$N_{30}P_{30}$, Urea K1, Urea K2	12.0	609.7	61.6
$N_{30}P_{30}$, Organic D2	12.2	610.5	62.4
	'Stalker'		
Control	10.4	593.4	54.5
$N_{30}P_{30}$	11.5	599.8	56.1
$N_{30}P_{30}$, Urea K1	11.9	600.5	57.6
$N_{30}P_{30}$, Urea K2	11.9	601.9	58.1
$N_{30}P_{30}$, Escort-bio	12.5	607.2	61.0
$N_{30}P_{30}$, Urea K1, Urea K2	12.1	604.9	58.7
$N_{30}P_{30}$, Organic D2	12.3	606.7	59.3
	'Aeneas'		
Control	10.9	581.4	57.8
$N_{30}P_{30}$	11.8	587.5	59.2
$N_{30}P_{30}$, Urea K1	12.4	589.6	60.9
$N_{30}P_{30}$, Urea K2	12.5	590.3	61.6
$N_{30}P_{30}$, Escort-bio	13.1	606.2	63.8
$N_{30}P_{30}$, Urea K1, Urea K2	12.7	603.6	62.7
$N_{30}P_{30}$, Organic D2	12.9	605.8	63.3
$LSD_{0.5}$: Factor A	0.2–0.3	11.2–13.5	10.2–12.5
Factor B	0.1–0.2	10.6–11.8	10.9–12.9

Carrying out of foliar fertilizing of plants during the vegetation season on the background of fertilizing with a dose of $N_{30}P_{30}$ also increased the content of digestible protein in the grain.

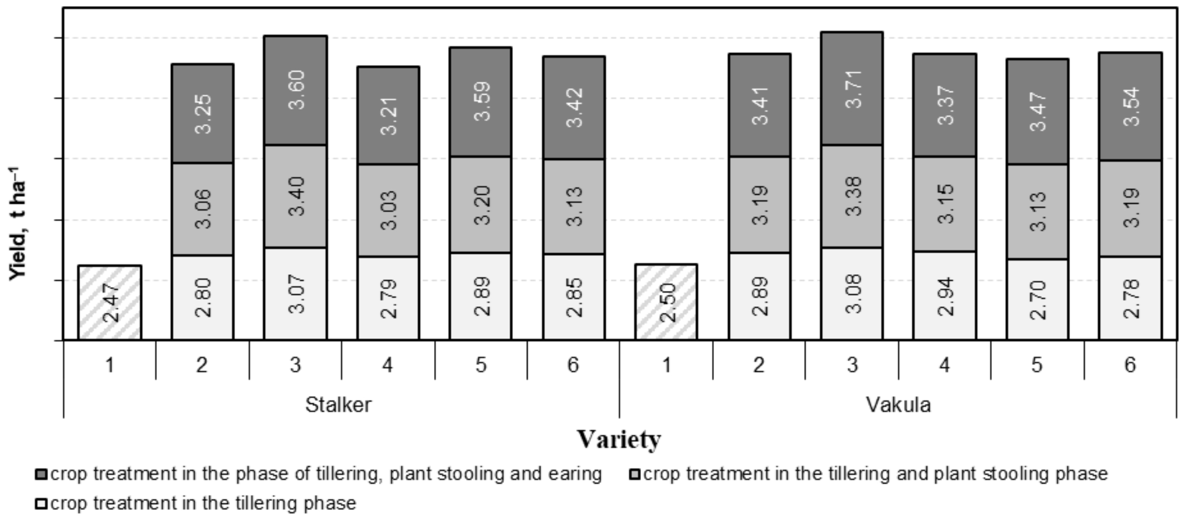
On average over the years of the research, where the Escort-bio preparation was used, this indicator increased by 9.4 up to 10.7% depending on the variety. On average by the nutrition factor, the digestible protein content in 'Aeneas' grain variety was slightly more: by 1.3 up to 5.5% than such content of 'Stalker' and 'Adapt' varieties.

To some extent, nutritional variants influenced the protein content in the grain of spring barley varieties. The application of $N_{30}P_{30}$ provided increasing of the protein content depending on the variety by 7.6–9.6 v. p., and carrying out on their background foliar feeding increased it by 10.4–18.3; 12.6–16.8 and 12.1–16.8 v. p. depending on the variety.

The barley protein content is highly dependent on the variety (Qi *et al*., 2006) and differs in growth conditions, particularly in the rate and timing of nitrogen fertilization (Duffus *et al*., 1993). The higher crude protein content in barley was usually accompanied by lower contents of starch and dietary fibre (Biel *et al*., 2013). Some investigations showed that an increase in protein content was accompanied by a decrease in essential amino acids, mainly lysine (Arendt *et al*., 2013).

Better grain was formed by spring barley plants when processing crops with Escort-Bio. The digestible protein content of the spring barley grain for this variant was 61.0 up to 63.8 g kg^{-1}, the protein content was 12.5 up to 13.1%, and the conditional protein yield from 1 hectare of sowing area was 0.41 up to 0.47 t depending on the varieties studied.

The high efficiency of modern growth-regulating substances application was also determined in another experiment with spring barley, in which 'Stalker' and 'Vakula' varieties were grown after peas. It was found that the grain productivity of both varieties under the influence of crop treatment with the studied preparations in the main periods of vegetation increased significantly in comparison with the control and depended on the number of top fertilizations, the preparation and its dose (Fig. 2).



1. Control (water treatment); 2. Fresh Florid (200 g ha^{-1}); 3. Fresh Florid (300 g ha^{-1}); 4. Fresh energy (200 g ha^{-1}); 5. Organic D2–M (1 l ha^{-1}); 6. Escort-bio (500 g ha^{-1})
$LSD_{0.5}$: Factor A (variety): 0.1–0.2. Factor B (plant nutrition): 0.2–0.3.

Figure 2. The yield of spring barley varieties depending on non-root fertilizing with bio preparations, t ha^{-1} (average for 2016–2018)

The research found that both varieties of spring barley formed the highest yield when three-fold processing of crops in the main phases of vegetation was carried out. On average, the maximum level of grain yield of 'Stalker' varieties, over the years of research, was provided by fertilizing plants with Organic D2–M as 3.59 t ha^{-1}, and the level of grain yield of 'Vakula' was provided by fertilizing plants with Escort-bio as 3.54 t ha^{-1}. This indicates almost identical grain productivity in the context of varieties.

The optimization of nutrition and the number of foliar fertilization carried out on crops also affected individual indicators of the quality of spring barley grain (Table 2).

Table 2. Grain quality of spring barley varieties depending on nutrition optimization (average for 2016–2018)

Nutrition variant (factor B)	Variety (factor A)			
	'Stalker'		'Vakula'	
	protein content, %	nature of the grain, g l^{-1}	protein content, %	nature of the grain, g l^{-1}
Control (water treatment)	10.8	588.1	10.7	543.0
Fresh Florid (200 g ha^{-1})	11.0	590.2	10.9	551.1
Fresh Florid (300 g ha^{-1})	11.3	591.4	11.3	553.7
Fresh energy (200 g ha^{-1})	11.0	593.0	11.0	551.1
Organic D2–M (1 l ha^{-1})	11.5	596.9	11.5	569.4
Escort-bio (500 g ha^{-1})	11.6	599.8	11.6	567.4
LSD0.5: Factor A	0.1–0.2	11.9–14.7		
Factor B	0.1–0.3	11.9–12.2		

The varieties of spring barley taken for research did not differ in the protein content of the grain. Both of them responded equally to nutrition optimization by increasing its content. Thus, the maximum protein content was accumulated during the three-time treatment of crops with the preparation Escort-bio, when this indicator for both varieties was 11.6%. The increase in the amount of protein compared to the control for 'Stalker' variety was 0.8%, and the increase in the amount of protein in 'Vakula' variety was by 0.9%, or by 7.4 and 8.4 relative points, respectively. Organic D2–M also had a positive effect on the grain protein content.

The nature of the grain was also greater in 'Stalker' variety. Maximum values of nature were reached on the background treatment of crops with Escort-bio in the amount of 500 g ha^{-1} to 599.8 g l^{-1} for the 'Stalker' variety, and 567.4 g l^{-1} for the 'Vakula' variety with indicators without fertilizing (with water treatment of plants) of 588.1 and 543.0 g l^{-1}, or increased by 2.0 and 4.5%, respectively, compared to the control variant.

Conclusions

In the South of Ukraine, optimizing spring barley plants nutrition based on the principles of resource conservation provides an increase in grain yield and its quality. It was determined that the double application of top fertilization with modern complex organic-mineral fertilizers for foliar top dressing of plants in the main phases of vegetation on the background of $N_{30}P_{30}$ allows optimizing the nutrition regime of spring barley. Thus, the use of $N_{30}P_{30}$ and Escort-bio for the growth of spring barley 'Aeneas' provides an increase in grain yield by 22.4%, the content of protein in the grain increases by 2.2%, the nature of the grain increases by 4.1%, and the content of digestible protein increases by 9.4%.

The treatment of spring barley crops of 'Stalker' and 'Vakula' varieties in the earing phase with Organic D2–M and Escort-bio preparations provides an increase in the protein content in the grain by 6.1 up to 7.0 and 6.9 up to 7.8 percentage points, respectively. At the same time, the grain yield in these variants of the experiment was the highest one and it increased to 3.47 up to 3.59 and 3.42 up to 3.54 t ha^{-1}, respectively.

Conflict of interest

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

Author contributions

AP − study conception and design, acquisition of data, analysis and interpretation of data, drafting of the manuscript;
VG − drafting of the manuscript, critical revision and approval of the final manuscript;
NP − analysis and interpretation of data.

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