INFLUENCE OF INTEGRATED FERTILIZATION AND GENOTYPE ON BARLEY PRODUCTION IN CHANGING CLIMATE CONDITIONS

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Abstract. The research examined the influence of climatic conditions, genotypes and fertilization treatments on the yield and grain quality of winter barley during two production years (2021-2023) in sour soil (pH 4.74) in southern Serbia. The genotypes Bosut and Parip and five fertilization treatments (control and combinations of NPK, microbiological, lime fertilizer and cattle manure) were examined. Grain yield varied from 2.0 to 5.5 t/ha, hectoliter weight from 55.17 to 63.17 kg/hl, and weight of 1000 grains from 37.20 to 47.17 years. The highest yields were achieved in treatment 5 (150 kg/ha NPK + 150 kg/ha microbiological fertilizer + 4 t/ha lime fertilizer + 20 t/ha cattle manure), especially for genotype Parip (4.87 t/ha in 2022-2023). Analysis of variance showed that year ($F = 108.75$, $p < 0.01$), genotype ($F = 21.04$, $p < 0.01$) and treatments ($F = 327.37$, $p < 0.01$) significantly affect the yield, with climatic factors, especially precipitation (354.1 mm in 2021-2022, respectively 512 mm in 2022-2023) having a key role. Parip showed greater adaptability to variable conditions, while treatment 5 improved nutrient availability and yield on acidic soil. The results highlight the importance of integrated fertilization and genotype selection for the optimization of barley production in the conditions of climate change.
Keywords: *agrotechnical measures, acidic soil, grain quality, precipitation, interaction of factors*

Introduction

Climate change is a challenge for global economic sectors, especially in agricultural production, where productivity depends on stable agroecological conditions (Zandalinas et al., 2021). The increased frequency and intensity of abiotic stresses, such as extreme temperatures, drought and salinity, threaten stable production, causing significant yield losses at the worldwide (Stojiljković et al., 2021; Varshney and Bohra, 2023). These stress factors, accompanied by an increase in atmospheric concentrations of carbon dioxide, are mainly the result of human activities, including the burning of fossil fuels and inappropriate land management practices. Such changes disrupt the optimal temperature ranges necessary for plant phenological development, leading to reduced growth, yield and food availability (Saeed et al., 2023). Under field conditions, plants are exposed to temperature stresses, including heat stress, which seriously threaten stable

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food production globally (Zandalinas et al., 2021; Farooq et al., 2022; Raza et al., 2024). One of the most abundant types of grain is barley (*Hordeum vulgare* L.) in terms of arable land and volume of production; it is positioned behind wheat, but ahead of oats, triticale and rye both in the world and in Serbia (Rajičić et al., 2023; Bratković et al., 2024). In Serbia, barley is the second most important grain, with an annual production of 452.000 tons and an average yield of 4.818 t/ha in 2022 (FAO, 2022). According to FAO data in the World, in 2022, was 219.034 million ha were sown under wheat, 47.222 million ha under barley, and 9.488 million ha were sown under oats, in the Republic of Serbia, 631.086 ha were sown under wheat, 93.815 ha under barley, while 14.503 ha were sown under oats (FAO, 2022). The world's current average wheat, barley, and oats production in 2022 was 811.384,426 tons, 154.633,065 tons, and 26.331,760 tons, and in Republic of Serbia 3.109,827 tons, 452.001 tons, and 42.193 tons (FAO, 2022). However, unpredictable climatic oscillations, including variations in temperature, amount and distribution of precipitation, together with applied agrotechnical measures, limit the manifestation of the genetic potential of barley varieties (Senapati and Goyari, 2022; Nbiret et al., 2024; Balduci et al., 2024). Although barley shows greater drought tolerance than wheat or rye, abiotic stress is still the primary factor that reduces its productivity. The specificities of barley production in central Serbia are additionally conditioned by edaphic factors, because cultivation takes place predominantly on soils with an acidic to extremely acidic reaction, with poor organic matter and poor structure (Đekić et al., 2019). The physical and chemical properties of acidic soils do not allow a universal approach to fertilization (Rajičić et al., 2023). Mineral fertilizers have a positive effect on vegetative growth and yield, but their long-term use has negative effects in the form of: release of harmful gases (NH_4, CO_2, CH_4), eutrophication of irrigation water, soil degradation and loss of beneficial microorganisms (Sharma and Chetani, 2017; Pandiselvi et al., 2017). The negative effect of the application of mineral fertilizers requires greater use of organic, biological fertilizers and adequate melioration measures (Acir and Gunal, 2020; Abdelsalam and Ash-Shormillesy, 2022; Alves et al., 2023).

Appropriate application of calcareous materials in combination with organic and mineral fertilizers is the most effective way to eliminate the unfavorable production properties of those soils with poor physical and chemical properties (Stojiljković et al., 2021; Rajičić et al., 2023). The quality of barley grain depends on the interaction of genetic and external environment. Abiotic stress, including high and low temperatures, drought and soil acidity, limits the maximum yield in important phenological stages of growth and development (Madić et al., 2014; Đekić et al., 2019). The large arable areas under barley are the result of its various applications - from malt production, through animal feed (hay, silage, green mass), to the use of straw (Gill et al., 2013). In view of the aforementioned challenges, this research aims to examine the potential of organic and biological fertilizers in improving the yield and quality of barley on acidic soils in Serbia, and the need to preserve integrated principles of plant production.

Working hypothesis: It is expected that the combination of integrated agrotechnical measures, including the application of organic, microbiological and mineral fertilizers along with ameliorative measures (limestone), will affect the increase in the yield and grain quality of winter barley on acidic soils under conditions of climatic variations, whereby one genotype would show greater adaptability and productivity.

Novelty of the work: The work brings new insight into the effectiveness of an integrated fertilization approach (combination of NPK, microbiological fertilizers, limestone and manure) for optimizing the yield and grain quality of winter barley on

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acidic soils in southern Serbia, taking into account the influence of climatic factors, especially the amount of precipitation. A special contribution is the identification of a more adaptable genotype for changing climatic conditions and acidic soils, which provides practical recommendations for sustainable agricultural practices at sustainable production.

Materials and methods

Experimental design and location

The experiment was conducted in a two-year period (factor A) on an agricultural farm in the area of the village of Orašje of Vlasotince, on cadastral plot number 2732, located at geographic coordinates 42°93’48”N and 22°09’55”E, at an altitude of 345 m, as shown in *Picture 1*. The experiment was set up according to a completely randomized block system in three replications during the Year 1 - 2021-2022 first production season, and Year 2 - 2022-2023 (second production season), in order to study the yield and quality of winter barley grains, and the area of the basic plot was 500 m^2. The municipality of Vlasotince is located in south-eastern Serbia within the Jablanica district and extends over the area of the lower and middle basin of the Vlasina river.

Picture 1. *Location of the experiment. Village of Orašje of Vlasotince, Serbia on cadastral plot number 2732*

Plant material and sowing

Two genotypes of winter barley (factor B) were used in the experiment: 1 - Bosut, selected at the BC Institute for Plant Breeding and Production in Zagreb (Republic of

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Croatia) and 2 - Parip, developed at the Institute for Crop and Vegetable Production in Novi Sad (Republic of Serbia). Sowing was carried out with a mechanical seeder during the period of favorable weather conditions, 05.10.2021, for the first season and 01.10.2022, for the second season. The sowing rate was 500 germinating seeds per m² for the Bosut genotype and 350 germinating grains per m² for the Parip genotype, adapted to the specific characteristics of each genotype.

Fertilization treatments

The test included treatments (factor C) control (1) without fertilizer application and four fertilization treatments: (2) - NPK 16:16:16 in a dose of 300 kg/ha; (3) - a combination of NPK 16:16:16 in the amount of 150 kg/ha and Unimax in the amount of 150 kg/ha; (4) - Unimax in a dose of 150 kg/ha; (5) - a combination of NPK 16:16:16 in the amount of 150 kg/ha, Unimax in the amount of 150 kg/ha, lime fertilizer (non-hydrated CaO, 99% purity) in the amount of 4 t/ha and manure in the amount of 20 t/ha. In treatment 5, at the beginning of October 2021, after the harvest of maize, the soil was calcified using lime fertilizer and cow manure, with plowing to a depth of 25 cm together with the recommended amounts of mineral fertilizers, while in the other treatments (2, 3, 4) the recommended doses of fertilizers were introduced during plowing. NPK 16:16:16 (manufacturer: Elixir Zorka, Šabac, Republic of Serbia) is a highly water-soluble complex mineral fertilizer with a balanced availability of elements. Unimax (manufacturer: Agrounikd.o.o., Šimanovci, Republic of Serbia) is a granulated microbiological fertilizer with a granule size of 4-8 mm, containing the bacteria *Bacillus megaterium* (3×10^7cfu/cm^3) and *Azotobacter chroococcum* (1×10^7cfu/cm^3) on a zeolite carrier, which contributes to increased enzymatic activity and the breakdown of organic compounds N and P into accessible forms available to plants during the growing season.

Agrotechnical measures and topdressing

During the growing season, standard agrotechnical measures were applied, including crop protection from broadleaf and grass weeds, diseases and pests. Crop topdressing was carried out on two occasions: the first topdressing with lime ammonium nitrate (KAN, 27% N) in the amount of 110 kg/ha was applied at the beginning of intensive growth, in the phase of 2-3 leaves (23.02.2022 and 27.02.2023), while the second topdressing with the same fertilizer in a dose of 40 kg/ha was carried out in the phase of intensive growth (20.03.2022 and 25.03.2023).

Harvesting and yield analyses

The samples were harvested by hand from a plot of 25 m^2 (in three replicates) to determine the yield, hectoliter weight, and the weight of 1000 grains. The harvest was done at the stage of full, 30.06.2022, for the first season and 27.06.2023, for the second season, after checking the water content in the grain with a hand-held moisture meter (Dickey-John). The grain yield was corrected to 14% moisture, while the hectoliter weight and the weight of 1000 grains were determined in the laboratory of the Agricultural Advisory and Expert Service in Leskovac. The 1000 grains weight was determined using an automatic seed counter and expressed in grams, with two decimal places (Rajičić et al., 2025). Hectoliter weight was determined by measuring on the Inframatic 9500 NIR Grain Analyzer. Hectoliter weight is a general indicator of grain quality that determines the physical characteristics of the grain. Analysis of all samples was performed in triplicate.

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Soil characteristics

Soil analysis from the sample plot was carried out in the soil fertility testing laboratory of the Agricultural Advisory and Expert Service in Leskovac, Serbia. Soil acidity (pH in KCl) was determined by the Kapen method, humus content by the Kotzman method, total nitrogen by the Kjeldahl method, while readily available phosphorus and potassium were determined by the Engler-Riehm Al method.

The results of the analysis (*Table 1*) show that the soil has a pH value of 4.74, which places it in the group of acidic soils, the humus content of 2.79% indicates a weak humus soil, while the total nitrogen content is 0.13%, which makes it moderately supplied nitrogen. The content of readily available phosphorus is 11.4 mg P_2O_5/100 g (poorly provided), and potassium is 32.1 mg K_2O/100 g (highly provided).

Table 1. *Basic chemical properties of soil Smonica in the atar of the village of Orašje*

Depth (cm)	pH (KCl)	Humus (%)	Nitrogen (%)	Available (mg/100 g soil)		$CaCO_3$(%)
				P_2O_5	K_2O	
0-30	4.74	2.79	0.13	11.4	32.1	0.84

Meteorological conditions

Meteorological data on mean daily temperatures and precipitation were collected from the meteorological station in Leskovac.

During the two growing seasons (2021-2022 and 2022-2023), differences were observed compared to the fifty-year average in the total amount and distribution of precipitation, which is of key importance for barley production (*Fig. 1*).

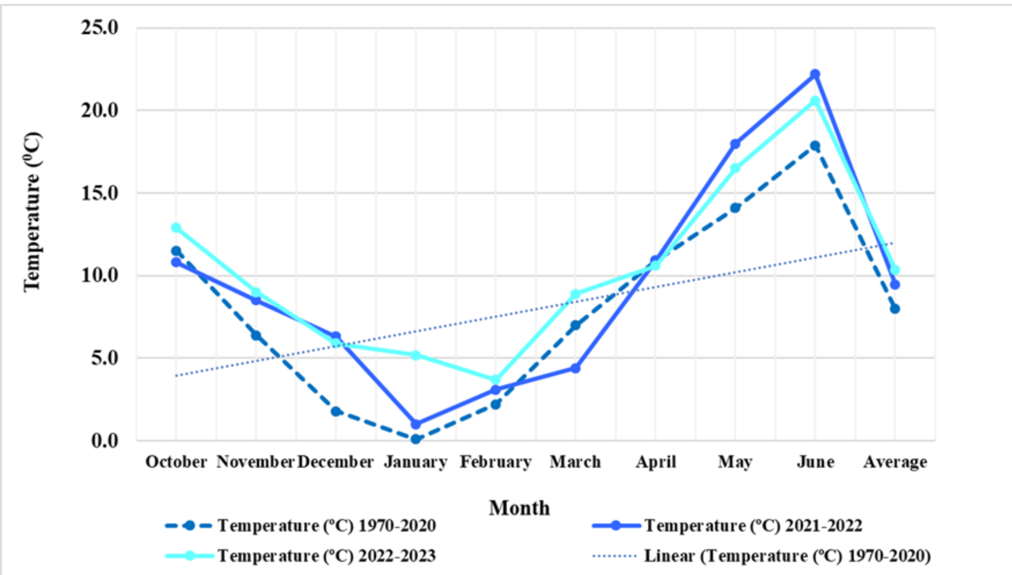

Figure 1. *Average monthly air temperatures (ºC) during the experimental periods (2021-2023) and multi-year averages (1970-2020) in the Vlasotince (Serbia) location*

The temperature during the examined period was higher by 1°C in 2021 and 2°C in 2022 compared to the fifty-year average, as shown in *Figure 1*. Average temperatures in

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the 2022-2023 season, we were higher by 1.1°C compared to the fifty-year average, while in 2021-2022 there were no differences. The average temperature exceeded the multi-year average by 1.5°C in 2021 and 2.6°C in 2022, especially during key growth stages. These deviations confirm the sensitivity of barley to climate variation, consistent with UK trials (Addy et al., 2020).

In October 2021, as shown in *Figure 2*, 61 mm of precipitation was recorded, which enabled high-quality soil preparation, but frequent precipitation delayed sowing, while only 5 mm of precipitation was measured in October 2022, which resulted in poorer soil preparation and sowing.

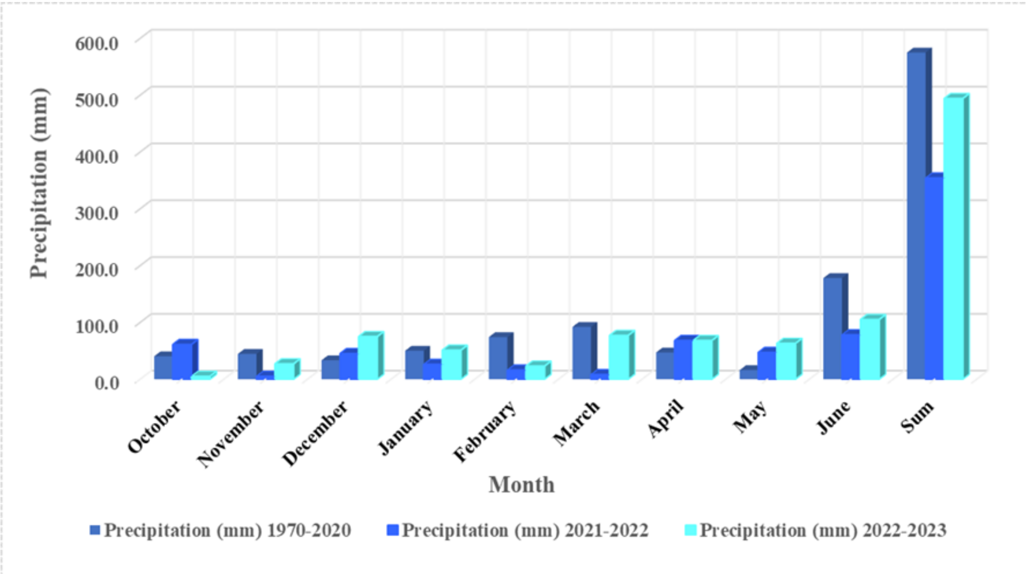

Figure 2. *The distribution of precipitation during the experimental periods (2021-2023) and multi-year averages (1970-2020) in the Vlasotince (Serbia) location*

Total precipitation in the growing season (October-July) amounted to 610.9 mm in the fifty-year average, 354.1 mm in the 2021-2022 season, and 512 mm in the 2022-2023 season (*Fig. 2*). Season 2021-2022 it was unfavorable due to lower amounts of precipitation (100 mm in the period October-March), which reduced the yield of both genotypes, while in June 2023, precipitation of 105 mm delayed the harvest and worsened the grain quality. Compared to the multi-year average (1970-2020), the total precipitation in the season 2021-2022, were 354.1 mm (average 529.4 mm), while in the 2022-2023 season it amounted to 512 mm, but the irregular distribution of precipitation affected the harvest.

Statistical data processing

Statistical data analysis was done with the help of IBM SPSS Statistics software, version 26.0. An analysis of variance (ANOVA, F test) was applied to assess the impact of the factors with significance levels set at $p < 0.05$ and $p < 0.01$. To compare mean values between treatments, the Tukey's test (HSD - Honestly Significant Difference) was performed. Minitab Statistical Software (Trial version) used for Pearson's correlation analysis was conducted to determine the relationship between the studied traits, as well as for visualizing the relative importance of different factors affecting the variables and their interactions. The results are presented tabularly and graphically.

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Results

Figure 3 shows how the average value of grain yield changes depending on the factors of year, genotypes and the applied different fertilization treatments.

Each point on the figure represents the average barley grain yield for a specific combination of year, genotype and treatment. Average grain yield values ranged from 2.0 t/ha to 5.5 t/ha, as shown in *Figure* 3. Lines extending above and below each point represent the 95% confidence interval for the mean. This indicates a certainty (95%) that the actual mean grain yield for that combination is within that interval. The wider the interval, the greater the variability of those combined factors. Confidence intervals were calculated based on the standard deviation of the data for each individual combination of factors, and the variability within each group was taken into account. Treatments in which higher barley grain yields were achieved and with a narrower confidence interval are more effective. The barley genotype with a higher average yield and narrower confidence interval is more productive (*Fig. 3*).

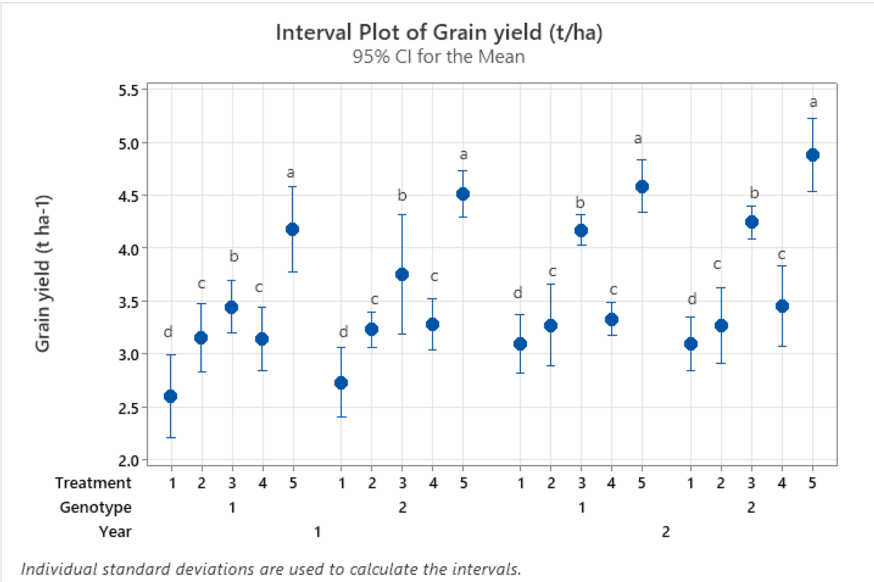

Figure 3. *Interval plot of grain yield (t/ha) with 95% confidence interval for the mean value. Different letters (a, b, c, d) indicate significant differences ($p < 0.05$)*

In the first year of research, genotype 2 achieved the highest average grain yield in treatment 5 with a narrower confidence interval (4.51 t/ha), while in the second year in the same treatment, treatment 5 also achieved the highest average yield of 4.87 t/ha, but the value shows a wider interval and therefore has lower efficiency, i.e. lower productivity of the genotype (*Fig. 3*). The first year of research was more favorable to this genotype in terms of climatic factors (average daily air temperatures and amount and distribution of precipitation) during the growing season.

Genotype 1 also achieved the highest average yields in treatment 5 in the first year (4.18 t/ha) with a narrower confidence interval, indicating higher productivity, while in the second year in treatment 5, it achieved 4.58 t/ha, when the confidence interval was wider, as shown in *Figure 3*. Significantly lower yields were achieved with both genotypes in both years of research in the control treatment and treatment 1. In these treatments, the average yields for genotype 1 in both years ranged from 2.60-3.27 t/ha,

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while for genotype 2, the average values were from 2.73-3.27 t/ha. The differences in the achieved yields of barley grains in the research years indicate the influence of climatic factors, which changed from year to year, thus highlighting the significant influence of the year factor. *Figure 3* clearly provides a visual representation of the complex analysis of grain yield, allowing for comparing the effect of different years on the height of grain yield, the productivity of genotypes and the efficiency of different treatments. Grain yield is influenced by complex relationships between all factors, and the optimal yield is achieved by combining individual genotypes and treatments in a given year.

The *Figure 3* clearly shows that there is a difference in yield between the examined years, genotype, treatment and the difference between the reaction of years and treatment, while there is no difference between the interaction of year x genotype, genotype x treatment and the interaction of year x genotype x treatment, which is confirmed by the data shown in *Table 2*.

Table 2. *Analysis of variance of the grain yield (ANOVA)*

Source	df	SS	MS	F-Value	P-Value
Year, A	1	1.6992	1.69916	108.75^{**}	0.000
Genotype, B	1	0.3287	0.32871	21.04^{**}	0.000
Treatment, C	4	20.4593	5.11483	327.37^{**}	0.000
Year x Genotype, AB	1	0.0413	0.04134	2.65^{ns}	0.112
Year x Treatment, AC	4	0.5292	0.13230	8.47^{**}	0.000
Genotype x Treatment, BC	4	0.1423	0.03557	2.28^{ns}	0.078
Year x Genotype x Treatment, ABC	4	0.0226	0.00564	0.36^{ns}	0.835
Error	40	0.6250	0.01562		
Total	59	23.8475			

**Highly significant at $p < 0.01$ probability level; ^{ns}Non significant at $p > 0.05$ level; df - Degree of freedom; SS - Sum of squares; MS - Mean Squares; F - Value-F value calculated; P-Value - P value calculated

Figures 4a show the main effects of the factors affecting the studied variable, barley grain yield, represented by lines connecting the points and visualizing the trend. The lines go up and show how an increase in factor level leads to an increase in yield. The horizontal dashed line represents the overall mean return for all data.

Figure 4b shows the influence of factors individually and in mutual interaction on barley grain yield. The standardized effect is shown on the X-axis, and the longer the column, the greater the influence of the observed factor on grain yield. The red line on the figure represents the critical value. Factors whose columns cross this line have a statistically significant influence on the studied trait, grain yield. The factor Year (A) has the greatest statistically significant influence on the realized grain yield values. The average grain yield values differ significantly between the years of the study. The factor Genotype (B) has a significant influence on the achieved value, and the genotypes achieved different heights of grain yields. The applied fertilization treatments (B) also have a significant effect on the achieved grain yield, but less than the year and genotype. With the application of different treatments, different grain yields are achieved. The interaction of the factors of age and treatments (AC) has an influence on this examined trait, while the other interactions AB, BC, and ABC have no significant influence, because their columns do not exceed the critical value, as shown in *Figure 4b*. It shows that the combined effect of these factors is not statistically significant compared to the individual effects.

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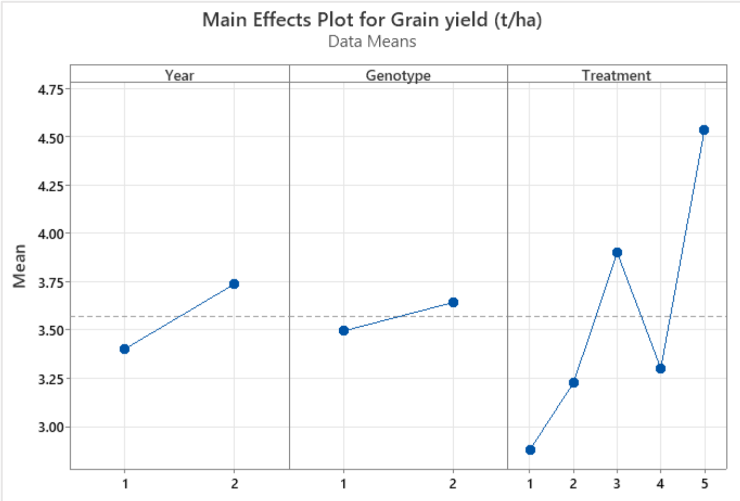
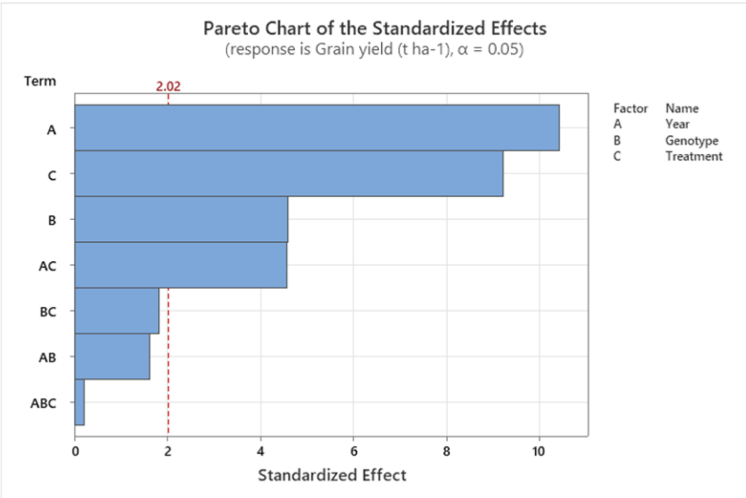
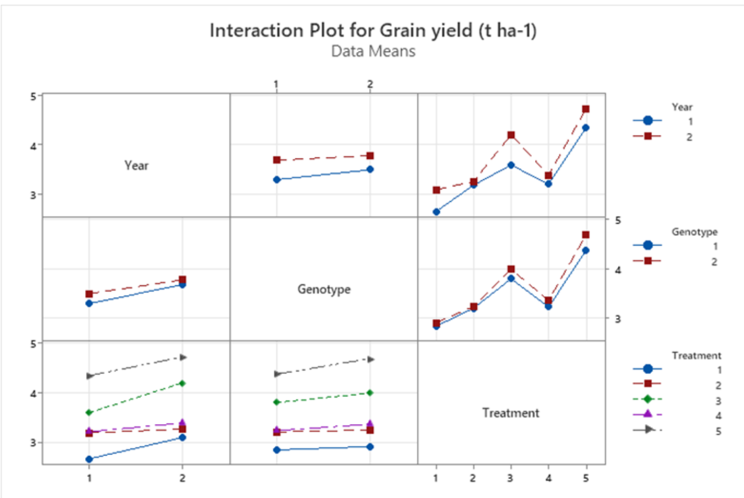


(a)



(b)



(c)

Figure 4. *Main effects plot (a), Pareto chart of the standardized effect on variable grain yield with a level of significance 0.05 (b) and interaction plot (c) for grain yield*

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The main factors affecting grain yield, as shown in *Figure 4c*, are individually observed year, genotype, treatments, and the interaction of AC. Factor treatments (different combinations of fertilization) also affect the achieved grain yields, but to a lesser extent than the year and genotype (*Table 2*).

Understanding yield variability can help plan strategies to optimize yields. When planning barley production, the year factor is extremely important and significantly affects the results. Climatic conditions should be taken into account, as well as the fact that different genotypes have different yield potentials and the appropriate genotype should be selected for the given conditions.

The effect of one factor on grain yield changes depending on the level of another factor. Mean values of hectoliter weight for each combination of year, genotype and treatment are shown in blue dots in *Figure 5*. Vertical lines indicate confidence interval (95%), which means that there is a 95% probability that the true mean lies within those limits. It is observed that hectoliter weight varies between treatments and genotypes, as well as between years. Wider intervals indicate greater data variability, while narrower intervals indicate less variability and greater precision in estimating the mean value.

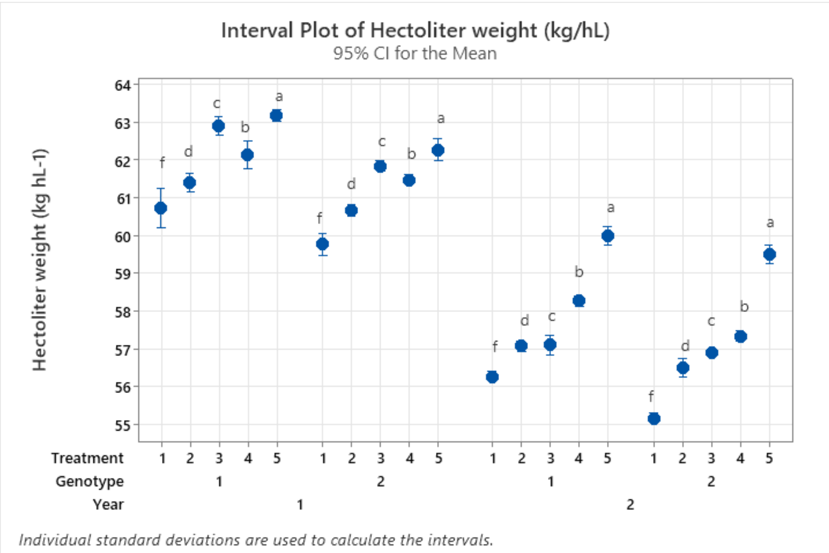

Figure 5. *Interval plot of hectoliter weight (kg/hl) with 95% confidence interval for the mean value. Different letters (a, b, c, d, f) indicate significant differences (p < 0.05)*

Genotype 1 in the first year has higher hectoliter weight values (63.17 kg/hl) compared to genotype 2 (62.27 kg/hl) in the first year (*Fig. 5*). In the second year, hectoliter weight values are lower compared to the first year for both genotypes (60.00 kg/hl and 59.50 kg/hl). There are significant differences between treatments within the same genotypes and years. The highest average values for both genotypes in both years were recorded in treatment 5. The differences between the treatments are visible, and the confidence intervals indicate the degree of certainty of these estimates. In the control treatment, both genotypes achieved the lowest values of this trait, especially in the second year of research (genotype 1, 56.27 kg/hl and genotype 2, 55.17 kg/hl). Climatic conditions in the first year of the research contributed to both genotypes having higher productivity, which was manifested through higher average values of hectoliter weight. Better grain quality is characterized by higher hectoliter weight values (*Fig. 5*).

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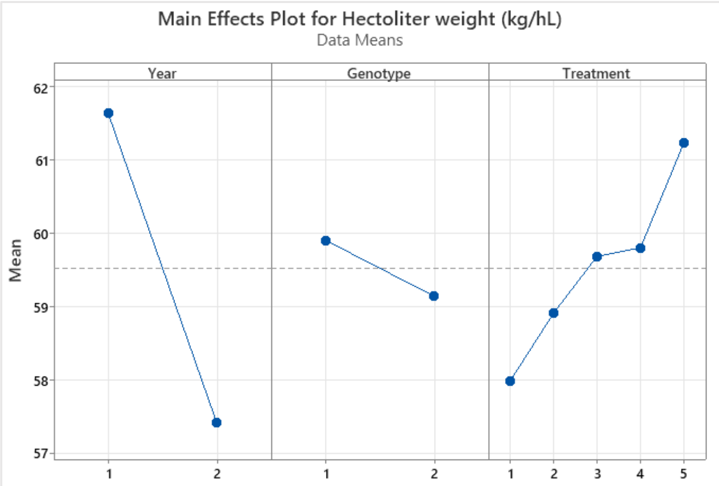
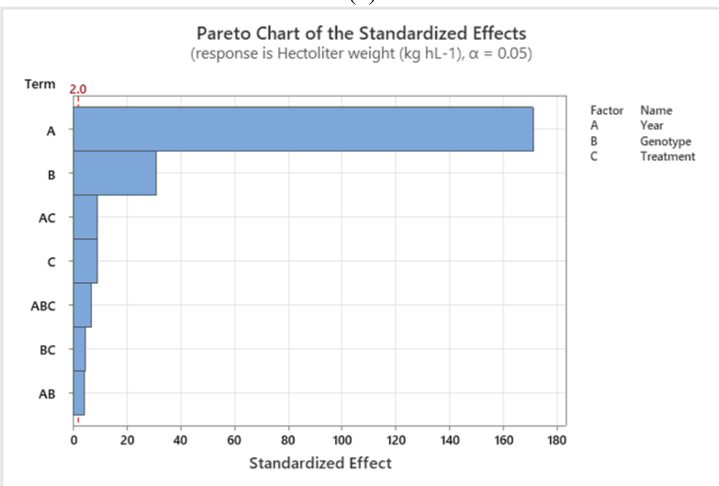
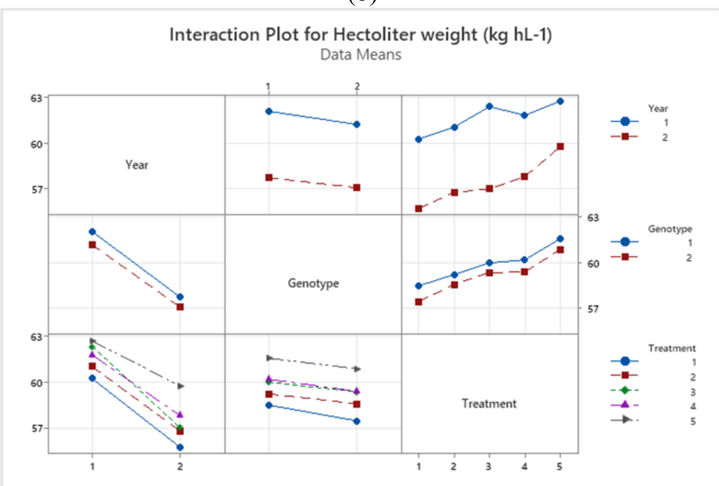
The main effects of the factors are shown in *Figure 6a*, where it is noted that the first year was significantly more suitable for achieving higher grain yields, with a difference in hectoliter weight values between genotypes, especially in treatment 5.



(a)



(b)



(c)

Figure 6. *Main effects plot (a), Pareto chart of the standardized effect on variable hectoliter weight with a level of significance 0.05 (b) and interaction plot (c) for hectoliter weight*

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Visualization of the relative importance of different factors influencing the hectoliter weight variable is shown in *Figure 6b*. The significance threshold is marked with a red line. If the effect of a factor is above this line, it indicates that it exerts a statistically significant influence. Factor A (year) has the largest standardized effect on hectoliter weight, which means that it has the greatest influence on the variability of the results and is dominant. Changes in climatic conditions during the years of the research had the most significant effect on the achieved values of this investigated property. Factor B (genotype) also has a significant but much smaller effect compared to factor A, but exerts a noticeable influence. Factors AC (interaction between A and C), C (treatment), ABC, BC, and AB have significantly smaller effects and are not statistically significant, shown in *Figure 6b*.

In *Figure 6c*, we observe the trends of the lines, which are parallel, indicating the absence of interactions between the factors. The effect of one factor is the same regardless of the level of the other factor. Lines that are not parallel indicate that there are interactions between factors and that the effect of one factor depends on the level of another factor. It is noted that in the first year, the control treatment (1) and treatment 2 have approximately hectoliter weight values, while in the second year, in treatment 2 that value is significantly higher.

Considering the influence of factors and their statistical significance (*Table 3*), the production process can be optimized with an adequate selection of genotype and the application of appropriate agrotechnical measures in a given year. There are $p < 0.01$ level differences in the average values for the variable hectoliter weight between different combinations of treatments, genotypes and years.

Table 3. *Analysis of variance of the hectoliter weight (ANOVA)*

Source	df	SS	MS	F-Value	P-Value
Year, A	1	267.548	267.548	29187.07**	0.000
Genotype, B	1	8.740	8.740	953.47**	0.000
Treatment, C	4	69.313	17.328	1890.35**	0.000
Year x Genotype, AB	1	0.160	0.160	17.47**	0.000
Year x Treatment, AC	4	9.099	2.275	248.16**	0.000
Genotype x Treatment, BC	4	0.324	0.081	8.84**	0.000
Year x Genotype x Treatment, ABC	4	0.611	0.153	16.65**	0.000
Error	40	0.367	0.009		
Total	59	356.162			

**Highly significant at $p < 0.01$ probability level; nsNon significant at $p > 0.05$ level; df - Degree of freedom; SS - Sum of squares; MS - Mean Squares; F-Value - F value calculated; P-Value - P value calculated

Each blue point in *Figure 7* represents the mean for a particular treatment, genotype, and year, and the lines extending from it represent 95% confidence intervals. Confidence intervals make it possible to assess the variability of the data, so smaller intervals mean greater measurement precision and certainty in the assessment. The year of the research plays an important role, because the achieved values differ statistically $p < 0.01$ level. Looking at the data shown in *Figure 7*, it is observed that in both years of the research, genotype 2 has significantly higher achieved values for the tested trait in all treatments, including in the control.

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Individually observed, in the first year, genotype 2 recorded the highest average values in treatment 5 (47.17 g), while genotype 1 achieved 41.60 g in the same treatment (*Fig. 7*). In the second year, significantly lower values were measured (genotype 2 - 43.23 g and genotype 1 - 38.60 g), due to bad climatic conditions that prevailed throughout the growing season. Approximate values were achieved in both years in treatment 3 (39.53 g, 37.20 g) and treatment 4 (40.03 g, 38.10 g) in genotype 1. Greater differences were measured in values in genotype 2 in both years in treatment 3 (45.73 g, 40.70 g) and treatment 4 (46.10 g, 41.20 g), shown in *Figure 7*.

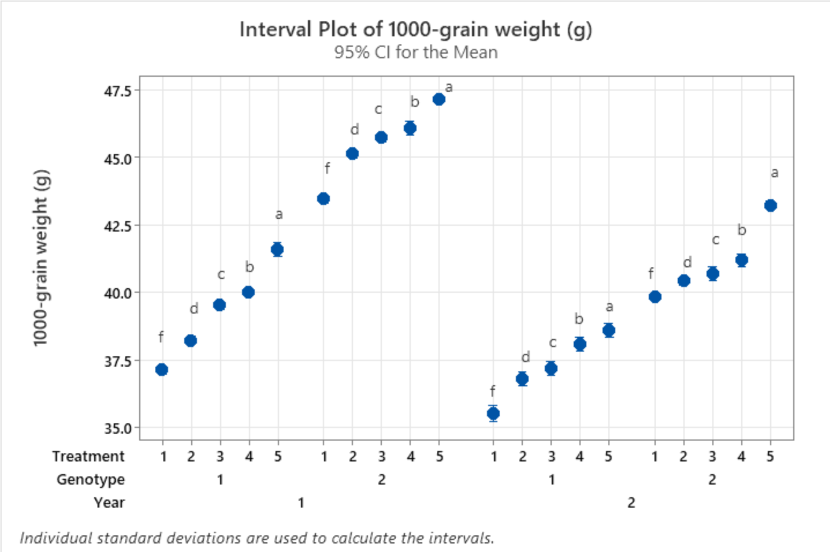

Figure 7. *Interval plot of 1000-grain weight (g) with 95% confidence interval for the mean value. Different letters (a, b, c, d, f) indicate significant differences ($p < 0.05$)*

Through the main effects of the factor, shown in *Figure 8a*, we observe a trend of change in the average values of 1000-grain weight as the level of the factor changes. A gradual increase in the average value of 1000-grain weight is present in different treatments from 1 to 5.

Figure 8b shows the influence of all factors on the examined property, 1000-grain weight, observed individually and in interaction, as shown in *Table 4*. Genotype as a factor (B) showed the greatest statistical significance on the achieved values of 1000-grain weight, followed by year (A). The interaction between year and genotype (AB) has a noticeable effect. *Figure 8b* and *Table 4* shows the influence of all factors on the examined property, 1000-grain weight, observed individually and in interaction. Genotype as a factor (B) showed the greatest statistical significance on the achieved values of 1000-grain weight, followed by year (A). The interaction between year and genotype (AB) has a noticeable effect.

Other observed factors treatment (C), interactions AC, BC and mutual interaction of all three factors ABC have a relatively small influence on this trait. The interaction between factors, shown in *Figure 8c*, is important because it shows that the effect of one factor depends on the level of another factor. The effect of treatment on this trait may be different depending on the genotype.

Based on the analysis of variance of two barley genotypes in different combinations of fertilization during two growing seasons (*Table 4*), a highly significant influence of

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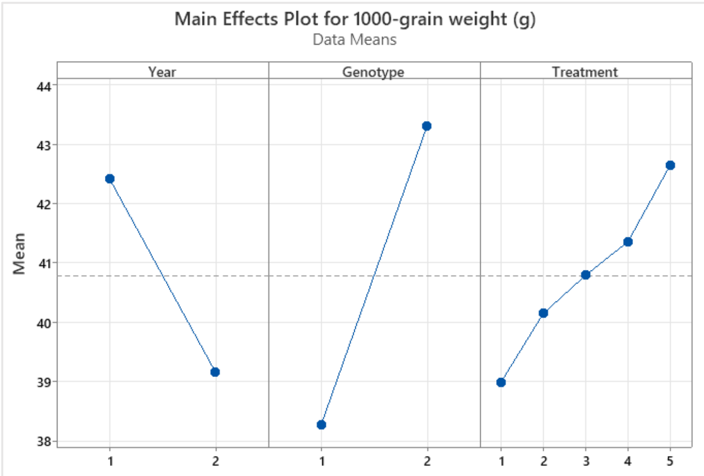
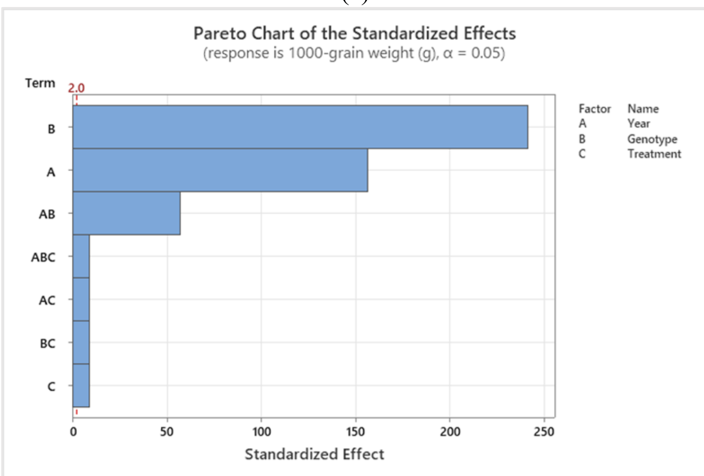
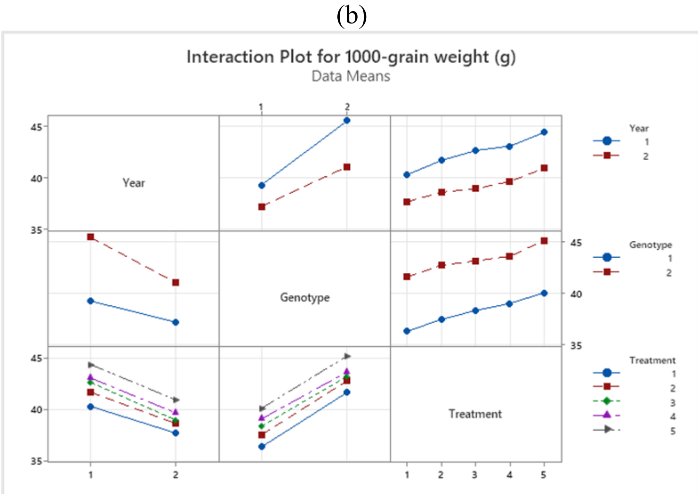
year, genotype, treatments, and the interaction of the factors of year, genotype and treatments on the 1000-grain weight was noted. Analysis showed a highly significant influence was found between the interaction of environmental factors with the genotype and treatment on the 1000-grain weight.



(a)



(b)



(c)

Figure 8. *Main effects plot (a), Pareto chart of the standardized effect on variable 1000-grain weight with a level of significance 0.05 (b) and interaction plot (c) for 1000-grain weight*

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Table 4. *Analysis of variance of the 1000-grain weight (ANOVA)*

Source	df	SS	MS	F-Value	P-Value
Year, A	1	158.437	158.437	24375.00**	0.000
Genotype, B	1	378.508	378.508	58232.03**	0.000
Treatment, C	4	89.114	22.279	3427.47**	0.000
Year x Genotype, AB	1	21.242	21.242	3267.92**	0.000
Year x Treatment, AC	4	2.092	0.523	80.45**	0.000
Genotype x Treatment, BC	4	1.124	0.281	43.24**	0.000
Year x Genotype x Treatment, ABC	4	2.584	0.646	99.40**	0.000
Error	40	0.260	0.006		
Total	59	653.362			

**Highly significant at $p < 0.01$ probability level; nsNon significant at $p > 0.05$ level; df - Degree of freedom; SS - Sum of squares; MS - Mean Squares; F-Value - F value calculated; P-Value - P value calculated

The correlation coefficient gives a clear insight into the degree of association between traits and indicates whether simultaneous improvement of correlated traits is possible or not (*Fig. 9*).

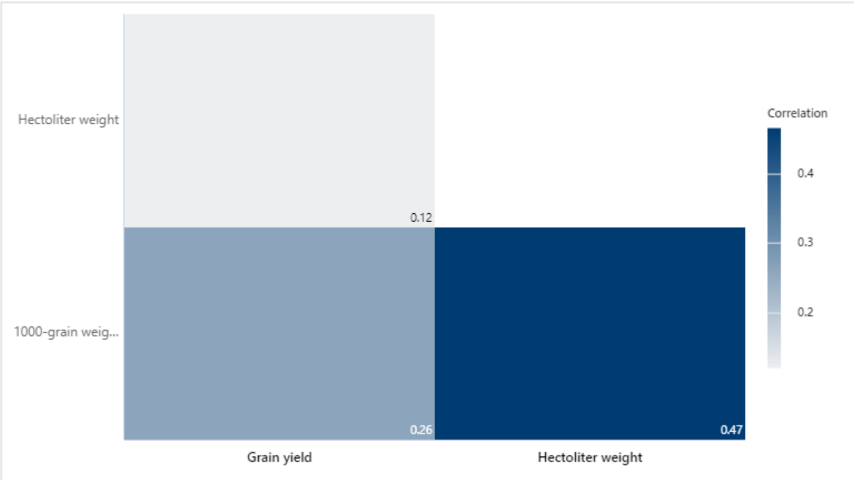

Figure 9. *Correlation coefficient between the studied traits*

A positive and very low correlation was found between grain yield and 1000-grain weight ($r = 0.26$), between grain yield and hectoliter weight ($r = 0.12$), shown in *Figure 9*. Positive correlation was found between the properties of hectoliter weight and 1000-grain weight ($r = 0.47$) in *Figure 9*.

Discussion

The yield and quality of small grains mostly depend on balanced mineral nutrition. The mineral nutrition of small grains depends on the climatic factors of the region and other agroecological factors, as well as the availability of nutrients in the soil (Laidig et al., 2022). However, some studies have shown that grain yield depends more on vegetation conditions

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than on the genetic traits of the genotype (Ayranci et al., 2014; Ahmadi et al., 2016). Modern barley production is largely directed towards the development of genotypes with high yield potential, with high adaptability to agro-climatic conditions and the level of applied agricultural techniques (Pržulj et al., 2014). The results of the research show that complex fertilization can significantly increase the productivity of barley on soils such as smonica in the area of the village of Orašje (pH 4.74). The effect of compound fertilization on barley yield indicates the importance of a balanced supply of nutrients under climate change conditions. The research of Çağlar et al. (2023) found that microbial fertilizers occupy an important place in sustainable agriculture systems due to their positive impact on environmental conservation. The year had the most significant influence on the achievement of a high grain yield ($F = 108.75$, $p < 0.01$), which is in accordance with the meteorological data that show large differences in the amount and distribution of precipitation between the studied growing seasons. In 2021-2022, total precipitation of 354.1 mm, with a deficit in the important period October-March (100 mm), negatively affected the yield, while the 2022-2023 season, with 512 mm of precipitation, was more favorable, although the irregular schedule (105 mm in June 2023) delayed the harvest and reduced the quality of grain. The sensitivity of barley to lack of moisture confirms that optimal yields are conditioned by the even distribution of precipitation during the growing season. Genotype Parip showed higher productivity compared to Bosut, especially in treatment 5, which may be due to better adaptation to stressful conditions, including lack of moisture and higher temperatures (average by 1.1°C-2.6°C above multi-year average). In the research of Abdelsalam and Ash-Shormillesy (2022), it was determined that the yield of barley is affected by the correct choice of genotype and fertilization regime. Also, the results indicate that the application of the fertilization regime (50% of the recommended dose with mineral fertilization + biofertilizer) gives the highest barley yield and yield components compared to 100% of the recommended dose with mineral fertilization or other biofertilizer regimes. This is in accordance with the results of this research, where the highest yields were achieved with a combination of mineral, organic and microbiological fertilizers. Research conducted by Rajičić et al. (2023) shows a significant influence of climatic factors on yield components and grain quality at the level of $p < 0.01$.

The joint application of pedo-ameliorative measures (calcification and humification) and mineral NPK fertilizers in combination with genotypes that are better adapted to low soil pH values is a good solution for increasing the stability and quality of grain yield produced on acidic soils. This is consistent with the results in this study. Hectoliter weight, as an indicator of grain quality, was significantly higher in the first year 63.17 kg/hl for Bosut and 62.27 kg/hl for Parip in treatment 5. Compared to the second year 60.00 kg/hl for Bosut and 59.50 kg/hl for Parip in treatment 5, which can be attributed to more favorable climatic conditions in 2021-2022. year. Analysis of variance (ANOVA) confirms that year has the greatest influence on this trait ($p < 0.01$), while genotype and treatments also contribute to variability, but to a lesser extent. Lower values in the control treatment, 56.27 kg/hl for Bosut and 55.17 kg/hl for Parip in 2022-2023, indicate the limitations of acidic soil without pH correction and additional nutrient input, which indicates the impact of acidity on nutrient absorption. The research results of Đekić et al. (2019) and Terzić et al. (2025) found statistically significant $p < 0.01$ level differences in hectoliter weight, weight of 1000 grains and grain yield between growing seasons. The weight of 1000 grains showed the greatest dependence on the genotype ($p < 0.01$), with Parip achieving higher values (47.17 g in 2021-2022 and 43.23 g in 2022-2023 in treatment 5) compared to Bosut (41.60 g in 2021-2022 and 38.60 g in 2022-2023

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in treatment 5). This difference can be attributed to the genetic characteristics of Parip, which apparently forms a larger grain, which is a desirable trait for barley. Treatment 5 again stood out as the most effective, probably due to the synergistic effect of microbiological fertilizer and organic matter, which increases the availability of phosphorus and nitrogen in acidic soil. The interaction of year and genotype ($p < 0.01$) further emphasizes the importance of adapting the genotype to specific seasonal conditions. The results of this research indicate a significant influence of the factors of year, genotype and fertilization treatment on grain yield, hectoliter weight and weight of 1000 grains of winter barley, which confirms the complex interaction between climatic conditions, genetic traits and agrotechnical measures. The results are in accordance with the research results of Rajičić et al. (2023) point out that the weight of 1000 grains is genetically determined, however, this trait is also influenced by climatic factors and methods of fertilization.

Correlation analysis between the tested traits showed a weak positive relationship between grain yield and weight of 1000 grains ($r = 0.26$), as well as between yield and hectoliter weight ($r = 0.12$), while a moderate positive correlation was observed between hectoliter weight and weight of 1000 grains ($r = 0.47$). These results suggest that the improvement of grain quality (hectoliter weight and 1000 grain weight) may not necessarily be directly related to yield increase, which requires careful selection of genotype and treatment depending on the production goal, quantity or quality. In a practical sense, these findings indicate the need to adapt agricultural techniques to specific climatic conditions and the genetic potential of crops. The combination of fertilization in treatment 5 proved to be the most effective strategy for increasing the yield and grain quality on acidic soils, while the superiority of the Parip genotype suggests its suitability for southeastern Serbia. Nevertheless, future research should focus on the long-term effects of such treatments and the stability of yields in conditions of increasingly pronounced climate change. The grain yield was positively correlated with the weight of 1000 grains (Stupar et al., 2021). In the research of Rajičić et al. (2023) found significant positive dependencies were found between grain yield and weight of 1000 grains, yield and hectoliter value, as well as weight of 1000 grains and hectoliter. In the research of Ayranci et al. (2014) found significant correlations between grain yield and yield components.

Conclusion

A statistically significant influence of year, genotype and fertilization treatment on the yield and grain quality of winter barley was established. Treatment 5 (combination of NPK, microbiological, lime fertilizer and cattle manure) ensured the highest yields of up to 5.5 t/ha and grain quality in the Parip genotype. Climatic conditions significantly influenced the results, while the Parip genotype showed greater adaptability. These results emphasize the importance of integrated agrotechnics and genotype selection for adapting production to acid soils.

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