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Evaluation of Triticale Grain Yield and Quality under the Influence of Genotype and Fertilization on Acid Soil

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ABSTRACT

Triticale, a hybrid of wheat and rye, is valued for its high yield potential, adaptability to marginal soils, and nutritional quality. Grain yield and quality are influenced by genotype, fertilization, and environmental conditions. Understanding the interactions among these factors is essential for optimizing productivity, especially on acidic soils where nutrient availability can be limited. In a two-year study, variations in grain yield, hectoliter weight and 1000 grain weight of triticale were investigated, depending on the genotype, fertilization and the year of the study. Genotype Triamo (G2) achieved the highest grain yield (6.50 t ha^{-1}) in the T5 treatment in the second year, compared to the control treatment (3.66 t ha^{-1}), with a significant factor interaction ($p<0.05$). The hectoliter weight was the highest in the Triamo genotype (65.80 kg hL^{-1}) in all treatments, while the Odisej genotype in the first year in the T5 treatment had the highest of 1000 grain weight (48.20 g). The correlation between grain yield and hectoliter mass was positive ($r=0.44^{**}$), while between grain yield and 1000 grain weight, a weak negative relationship was established ($r=-0.03$). The results indicate the importance of an optimal combination of genotype and agrotechnical measures in order to achieve optimal yields and quality of triticale grains on acidic soils.

Keywords: triticale, acidic soil, tallow, grain quality, lime fertilizer, microbiological fertilizer.

INTRODUCTION

In the context of modern challenges in agriculture, such as climate change, soil degradation and the need for sustainable production, triticale represents an important type of alternative grain. This culture, created by crossing two different types of grain, wheat (*Triticum sp.*) and rye (*Secale cereale*), it shows exceptional adaptability to marginal and acidic soils, which makes it suitable for cultivation in variable agroecological conditions (Rajičić et al., 2023). In recent times, next to corn, triticale grain is one of the most important nutrients and sources of energy in the diet of domestic and farmed animals in Serbia (Glamočlija et al., 2018). The nutritional value of the grain is at the level of wheat, with the observation that it has slightly more amino acid lysine (Fraś et al., 2016). Climate change, characterized by high interannual variability and extreme weather events such as droughts and heat waves, significantly affects grain yields and quality (Addy et al., 2020). Alluvial soils, which are widespread in Serbia, further complicate production due to their unfavorable chemical and physical properties (Gudzic et al., 2019; Stojiljković et al., 2021), including acidity and low content of organic matter (Jelic et al., 2015; Rajičić et al., 2023; Dugalić et al. 2025). The traditional application of mineral fertilizers often does not give satisfactory results on acidic soils, while at the same time it contributes to further soil degradation (Terzic et al., 2018; Zhu et al., 2023; Jimma et al., 2024). Calcification is carried out only moderately in Serbia, despite its known advantages, while manure is not used to a sufficient extent. In this sense, innovative agronomic practices, including the application of environmentally acceptable fertilizers such

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as microbiological preparations (Zin and Badaluddin, 2020; Alaylar, 2022; Bajagić et al., 2025; Šević et al., 2025) manure and lime fertilizer (Babić et al., 2023; Rajičić et al., 2025a), become crucial for improving soil fertility and stability yield. This approach can not only mitigate the negative effects of soil acidity and climate fluctuations, but also contribute to preserving the fertility of soils with poor production characteristics and increasing the economic profitability of production. The aim of the research is to evaluate the importance of the selection of triticale genotypes in combination with integrated agronomic practices on acidic soils, taking into account changing climatic and agroecological conditions. Special focus is on the interaction of climatic factors and the application of environmentally friendly fertilizers (microbiological preparations, cow manure and lime fertilizer) in order to ensure stable production of triticale and improve grain quality. The novelty of the work is reflected in the comprehensive examination of the effects of the combined application of ecologically acceptable fertilizers and the selection of triticale genotypes on acidic soils under conditions of climatic fluctuations. The research studies the use of microbiological preparations, cow manure and lime fertilizer with the aim of improving soil fertility and achieving satisfactory yields and grain quality. The work contributes to the understanding of the interaction of genotypic variability and agronomic measures, providing new knowledge for sustainable agriculture on marginal lands. The working hypothesis is based on the fact that the combined application of environmentally acceptable fertilizers (microbiological preparations, cow manure and lime fertilizer) and the selection of triticale genotypes tolerant to soil acidity will significantly increase the yield and grain quality, while mitigating the negative effects of climate change and improving soil fertility.

MATERIAL AND METHODS

Experimental location

The two-year experiment was conducted on a family farm in the village of Orašje, municipality of Vlasotince, Serbia (geographic coordinates: 42°93´48´´ N, 22°09´55´´ E; altitude: 345 m), cadastral plot number 2732 (Figure 1). The soil at the experimental site was classified as loam with an acidic reaction (pH 4.74 in KCl), low organic matter content (2.79%), medium nitrogen availability (0.13%), low phosphorus availability (11.40 mg 100 g^{-1} P_2O_5) and high potassium content (32.10 mg 100 g^{-1} K_2O). Soil analysis was performed before starting the experiment in the Laboratory of the Agricultural Advisory and Expert Service in Leskovac, using standard methods: pH (Kappen method), humus (Kotzmann method), total nitrogen (by calculation), available phosphorus and potassium (Engner-Riehm Al method). According to the content of mechanical fractions (sand, dust, clay), these soils belong to medium and heavy clay soils (Jakovljević et al., 2002).

Figure 1. Location of the experiment. Orašje, village of Vlasotince, Serbia on cadastral plot number 2732.

Experimental design

The experiment was conducted over two growing seasons (2021-2022 and 2022-2023) using a randomized block design with three replications. The area of the basic plot was 500 m². Two genotypes (G) of winter triticale were tested: Odisej (G1) developed at the Institute for Crop and Vegetable Production in Novi Sad, Republic of Serbia, and Triamo 2S (G2) developed by Biogranum, Novi Sad, Serbia, chosen based on their production characteristics. Sowing was done with a manual mechanical seeder on October 5, 2021 and October 1, 2022, under favorable weather conditions.

Fertilization treatments

The experiment included a control plot (T1: without fertilization) and four fertilization treatments: T2: 300 kg ha^{-1} NPK fertilizer (16:16:16; Elixir Zorka, Serbia); T3: 150 kg ha^{-1} NPK + 150 kg ha^{-1} Unimax (microbiological fertilizer, Agrounik d.o.o., Šimanovci, Serbia); T4: 150 kg ha^{-1} Unimax; T5: 150 kg ha^{-1} NPK + 150 kg ha^{-1} Unimax + 4 t ha^{-1} lime fertilizer (CaO, purity 99%) + 20 t ha^{-1} cow manure. Unhydrated lime and cow manure were applied in early October 2021, after the corn harvest, and were plowed into the soil to improve fertility in the T5 treatment. Other fertilization treatments were applied during plowing in the recommended amounts. Unimax is a granular microbiological preparation (4-8 mm) that contains *Bacillus megaterium* (3×10^7 cfu cm^{-3}) and *Azotobacter chroococcum* (1×10^7 cfu cm^{-3}) on a zeolite support, which improves enzyme activity and availability of nutrients.

Agrotechnical measures

Standard agricultural practices were applied during the growing season. Top dressing with calcium-ammonium nitrate (KAN, 27% N) was carried out in the amount of 150 kg ha^{-1} at the 2-3 leaf stage (February 27, 2022 and March 1, 2023), and the second top dressing (70 kg ha^{-1}) was carried out during intensive growth (March 20, 2022 and March 25, 2023). Suppression of weeds, pests and diseases was carried out on the basis of monitoring the state of health by visual inspection of plants for the presence of weeds, diseases and pests. Harvesting was done at full maturity (July 6, 2022 and July 15, 2023), with moisture content checked using a hand-held moisture meter (Dickey-John, Auburn, Illinois, USA).

Yield and quality analysis

Samples for determining grain yield, hectoliter weight, and 1000-grain weight were harvested by hand from a 25 m² area in each plot, with three replicates per treatment. The harvest was carried out at the stage of full maturity, after checking the water content in the grain with a manual moisture meter (Dickey-John). Grain yield was corrected to 14% moisture. The hectoliter weight and the 1000 grains weight were determined in the Laboratory of the Agricultural Advisory and Expert Service in Leskovac. 1000 grain weight is determined using an automatic seed counter and is expressed in grams, with two decimal places (Rajičić et al., 2025b). Hectoliter mass was determined by measurement on an Inframatic 9500 NIR grain analyzer. Analysis of all samples was performed in three replicates.

Meteorological conditions

In Figure 2, it can be seen that there were variations between the research years (2020-2023) in relation to the multi-year period (1991-2020) in terms of average values of monthly air temperatures (Figure 2a), as well as in the amount and distribution of precipitation (Figure 2b). The average temperature for the period October-July during the thirty-year average was 10°C, while the average measured temperature during the first year of the test was 10.8°C, and in the second 11.9°C. The average temperature exceeded the multi-year average by 0.8°C in 2021 and 1.9°C in 2022, especially during the key stages of growth. These deviations confirm the sensitivity of agricultural production to climate variations.

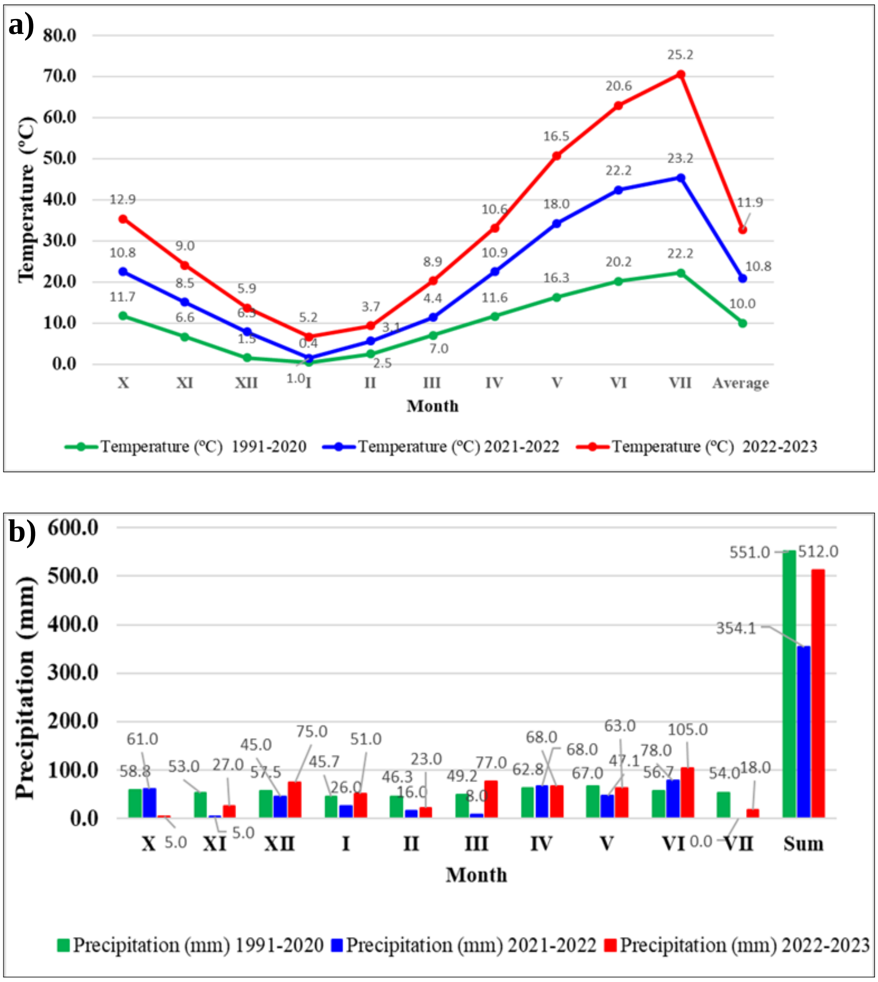

Figure 2. Average monthly air temperatures, ºC (a) and the distribution precipitation, mm (b) during the experimental periods (2021-2023) and multi-year averages (1991-2020) in Orašje, Leskovac (Serbia) location

The total amount of precipitation in the growing season (October-July) was 551.0 mm in the thirty-year average, 354.1 mm in the 2021-2022 season, and 512.0 mm in the 2022-2023 season. The 2021-2022 season was unfavorable due to lower amounts of precipitation (100 mm in the October-March period), which reduced the yield of both genotypes, while in June 2023, the precipitation of 105.0 mm delayed the harvest and affected the poor quality of the grain. Compared to the multi-year average (1991-2020), total precipitation in the 2021-2022 season was 354.1 mm (average 529.4 mm), while in the 2022-2023 season it was 512.0 mm, but the uneven distribution of precipitation affected the yield and quality of triticale grains.

Statistical data processing

All data collected during the experiment were subjected to statistical analysis to determine differences between genotypes and fertilization treatments in the years of the study in terms of grain yield and quality. The results of the investigated variables are expressed as average values followed by standard deviations. Statistical data analysis was done with the help of IBM SPSS Statistics software, version 26.0. The first factor was the year of production (Y), the second factor was genotip of triticale (G), while the third factor was fertilization treatments (T). To compare mean values between treatments, the LSD test (Least 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 visualising the relative importance of different factors affecting the variables and their interactions. The results are presented tabularly and graphically.

RESULTS AND DISCUSSION

On acidic soils, triticale exhibits specific responses to mineral nutrition. New varieties of triticale have significantly higher fertility potential, however, their requirements in terms of mineral nutrition are significantly higher (Derejko et al., 2020). Inadequate or improper application of mineral fertilizers negatively affects the chemical properties of the soil.

Grain yield

Variations in the yield of triticale grains are shown in Figure 3a, where it can be seen that the second year of research, due to more favorable meteorological conditions that prevailed during the growing season, significantly influenced the formation of the grain yield. That grain yield is influenced by meteorological conditions was determined in the research of Đekić et al. (2014), Kirčev and Georgieva (2017), Bielski et al. (2020), while the influence of the year on the yield of triticale was not significant in the research of Lalević et al. (2022).

Adverse weather conditions (high and low temperatures, large amounts of precipitation with stormy and strong winds, drought, acidic and salty soils) have a strong negative impact on the production of triticale and represent a great risk, as they limit the expression of the maximum genetic potential of the cultivated crop (Dubis et al., 2017; Kizilgeci and Yildirim, 2017; Kosev et al., 2022; Babić et al., 2023; Camerlengo and Kiszonas, 2023).

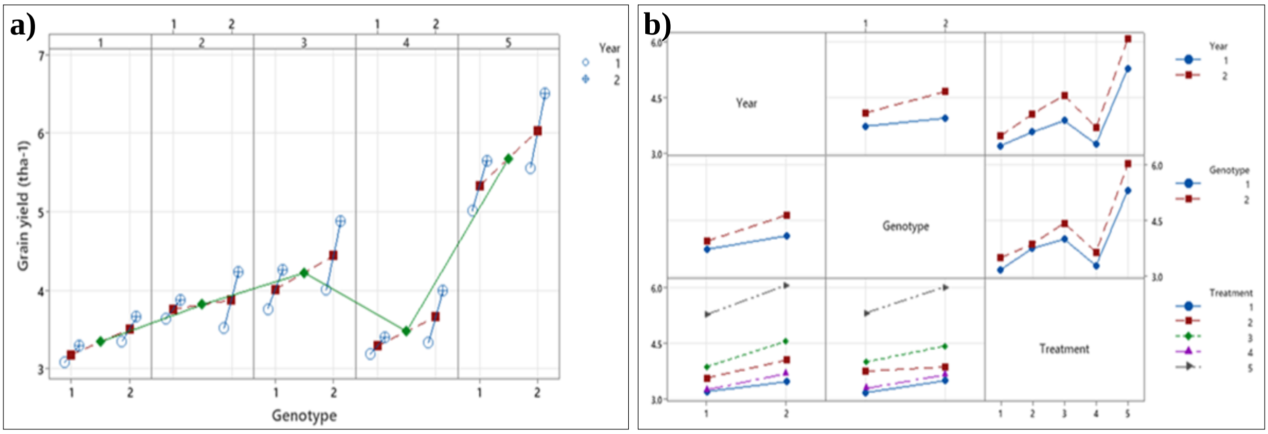

Figure 3. Multi-Vari Chart (a) for Grain Yield (t ha^{-1}) and Interaction Plot (b) under the influence of factors. Average values of grain yield (t ha^{-1}) of tested triticale genotypes: 1 - Odisej; 2 - Triamo in different treatments of the combination of fertilizers. T1: control; T2: 300 kg ha^{-1} NPK fertilizer (16:16:16); T3: 150 kg ha^{-1} NPK + 150 kg ha^{-1} Unimax; T4: 150 kg ha^{-1} Unimax; T5: 150 kg ha^{-1} NPK + 150 kg ha^{-1} Unimax + 4 t ha^{-1} lime fertilizer + 20 t ha^{-1} cow manure - treatments with different combinations of fertilizers applied in a 2 yr period (Year: 1 - 2021-2022; 2 - 2022-2023).

In particular, genotype Triamo (2) in the T5 treatment achieved the highest yield (6.50 tha^{-1}) compared to the control treatment (3.66 t ha^{-1}). Terzic et al. (2018) and Lalević et al. (2019) found a very significant effect of fertilization on grain yield of winter triticale, while a significant impact of combined nutrition of NPK, lime and manure on grain yield on acidic soils was determined in the research results of Rajičić et al. (2020, 2023), which is in accordance with the results of our research. The interaction of the observed factors is present when the effect of one factor on the examined trait depends on the level of another factor, which is obvious and statistically significant in the influence of all three factors observed individually (Figure 3b), while their interaction on the obtained average grain yield values was absent. The results emphasize that in order to achieve the maximum yield, it is necessary not only to choose the genotype or treatment, but also to find an optimal combination of all factors (Table 1). The results of this research confirm the significant role of genotype and ameliorative treatments in shaping triticale grain yield.

Table 1. Analysis of Variance of the Grain yield triticale (ANOVA) for 2 yr period (2021-2023)

Effect	SS	df	MS	F test	Sign.	LSD (p<0.05)	LSD (p<0.01)
Year (Y)	4.234726667	1	4.234726667	107.7721412	**	0.10344186	0.138418536
Genotype (G)	2.25816	1	2.25816	57.4692908	**	0.10344186	0.138418536
Treatment (T)	42.59815667	4	10.64953917	271.0266161	**	0.163555941	0.218858922
Y x G	0.44376	1	0.44376	11.29351883	**	0.146288881	0.195753371
Y x T	0.524423333	4	0.131105833	3.336592297	*	0.23130303	0.309513256
G x T	0.54329	4	0.1358225	3.456629623	*	0.23130303	0.309513256
Y x G x T	0.077423333	4	0.019355833	0.492598405	ns	0.327111883	0.437717844
Total	52.25167333	59	0.885621582				
St.Dev.	0.941						
Coef.Var.	4.825						

** Highly significant at p<0.01 probability level; * Significant at p<0.05; ns Nonsignificantat p>0.05 level; SS-Sum of squares; df - Degree of freedom; MS - Mean Squares; F test - F value calculated; Sign. - significant; LSD - Least Significant Difference; St.Dev - Standard Deviation; Coef.Var. - Coeficient Variance.

Hectoliter weight

Hectoliter weight is a general indicator of grain quality that determines the physical characteristics of the grain. The highest average values were measured in genotype Triamo (G2) in both years and in all treatments (ranging from 63.27-65.80 kg hL^{-1}), which is significantly higher than genotype G1 (Figure 4a). It is a very interesting result that points out that the choice of genotype has a strong influence, which is shown through the achieved average values for Triamo in the control treatment (65.53 kg hL^{-1}) in contrast to the values that Odisej had in the T5 treatment, where the application of a combination of all types of fertilizers (63.17 kg hL^{-1}) in the second year of the study. Lines that do not intersect or are not parallel (Figure 4b) indicate that the interaction of the factors is statistically significant, which is in accordance with the results of Lalević et al. (2022) and Rajičić et al. (2023).

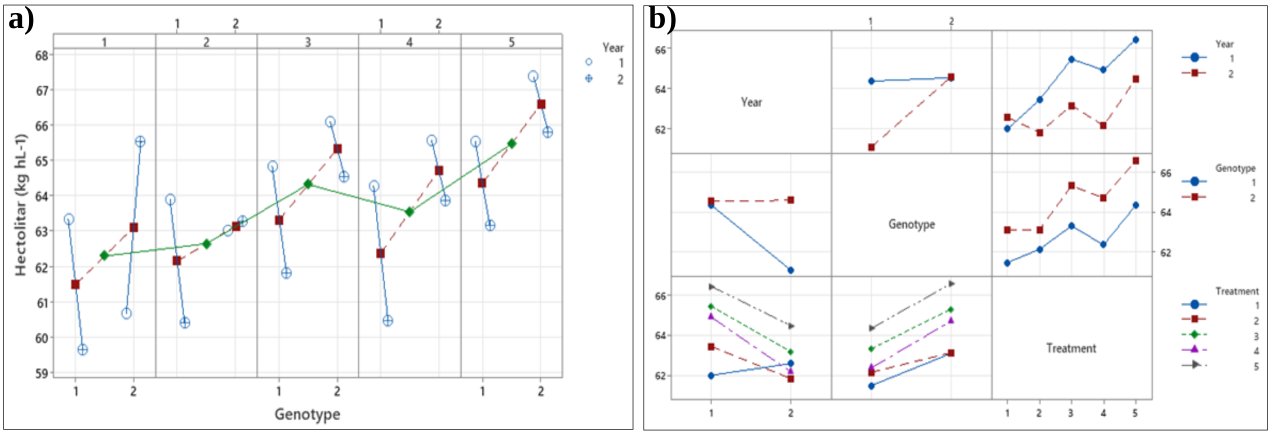

Figure 4. Multi-Vari Chart (a) for Hectoliter weight (kg hL^{-1}) and Interaction Plot (b) under the influence of factors. Average values of hectoliter weight (kg hL^{-1}) of tested triticale genotypes: 1 - Odisej; 2 - Triamo in different treatments of the combination of fertilizers. T1: control; T2: 300 kg ha^{-1} NPK fertilizer (16:16:16); T3: 150 kg ha^{-1} NPK + 150 kg ha^{-1} Unimax; T4: 150 kg ha^{-1} Unimax; T5: 150 kg ha^{-1} NPK + 150 kg ha^{-1} Unimax + 4 t ha^{-1} lime fertilizer + 20 t ha^{-1} cow manure - treatments with different combinations of fertilizers applied in a 2 yr period (Year: 1 - 2021-2022; 2 - 2022-2023).

The combinations of observed factors had a highly significant effect on the measured traits (Table 2). The effect of one factor on the achieved outcome of another is not constant, but varied depending on the level of the other factor. The effect of the environment on hectoliter weight in the triticale was significant at the 0.01 level, which is in accordance with the results of Đekić et al. (2014), Terzic et al. (2018) and Rajičić et al. (2020). Also, Sirat et al. (2022), state that the hectoliter weight of triticale varies significantly depending on the growing season.

Table 2. Analysis of Variance of the Hectoliter weight (ANOVA) for 2 yr period (2021-2023)

Effect	SS	df	MS	F test	Sign.	LSD (p<0.05)	LSD (p<0.01)
Year (Y)	38.8815	1	38.8815	644.4447514	**	0.128178606	0.171519489
Genotype (G)	50.60016667	1	50.60016667	838.6767956	**	0.128178606	0.171519489
Treatment (T)	79.419	4	19.85475	329.0842542	**	0.202668171	0.271196125
Y x G	41.8335	1	41.8335	693.3729282	**	0.181271923	0.242565188
Y x T	20.141	4	5.03525	83.45718232	**	0.286616076	0.383529238
G x T	3.672333333	4	0.918083333	15.21685083	**	0.286616076	0.383529238
Y x G x T	29.249	4	7.31225	121.1975138	**	0.405336343	0.54239225
Total	266.2098333	59	4.512031073				
St.Dev.	2.124						
Coef.Var.	0.385						

** Highly significant at p<0.01 probability level; SS - Sum of squares; df - Degree of freedom; MS - Mean Squares; F test - F value calculated; Sign. - significant; LSD - Least Significant Difference; St.Dev - Standard Deviation; Coef.Var. - Coeficient Variance.

1000 grain weight

The difference in average values for this individual varies in both years, depending on the genotype and treatment, and they range from 35.17 - 48.20 years. The advantage was shown by the genotype Odisej in the first year in T5 (48.20 g) compared to the genotype Triamo (43.40 g), and the differences are very significant compared to the control (Figure 5a), which is in accordance with the results of Ivanova and Tsenova (2014), Lalević et al. (2022), Rajičić et al. (2023). In the second year, lower values were measured for both genotypes (G1 - 40.10 g, G2 - 39.47 g), while in the control treatment, 1000 grain weight was for genotype G1 - 36.47 g and G2 - 35.17 g.

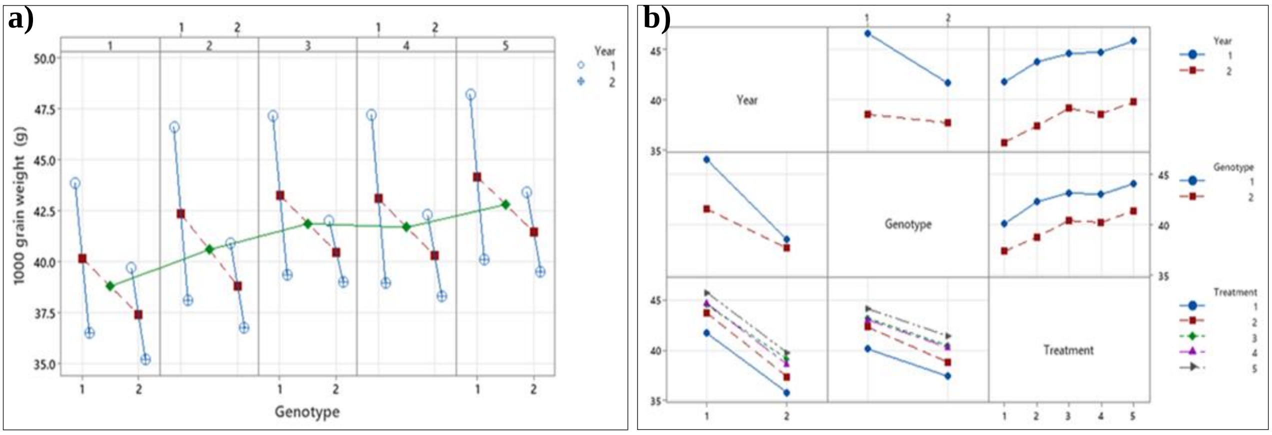

Figure 5. Multi-Vari Chart (a) for 1000 grain weight (g) and Interaction Plot (b) under the influence of factors. Average values of 1000 grain weight (g) of tested triticale genotypes: 1 - Odisej; 2 - Triamo in different treatments of the combination of fertilizers. T1: control; T2: 300 kg ha^{-1} NPK fertilizer (16:16:16); T3: 150 kg ha^{-1} NPK + 150 kg ha^{-1} Unimax; T4: 150 kg ha^{-1} Unimax; T5: 150 kg ha^{-1} NPK + 150 kg ha^{-1} Unimax + 4 t ha^{-1} lime fertilizer + 20 t ha^{-1} cow manure - treatments with different combinations of fertilizers applied in a 2 yr period (Year: 1 - 2021-2022; 2 - 2022-2023).

The year of the research shows a significant influence of 1000 grain weight in winter triticale, which was previously determined in the results of research by Terzić et al. (2018), Sirat et al. (2022), Rajičić et al. (2023). The interaction of the factors is statistically significant, especially year, as suggested by the above result (Figure 5b, Table 3). All factors and their interaction had a strong influence on the obtained values.

Table 3. Analysis of Variance of the 1000 grain weight (ANOVA) for 2 yr period (2021-2023)

Effect	SS	df	MS	F test	Sign.	LSD (p<0.05)	LSD (p<0.01)
Year (Y)	533.4201667	1	533.4201667	9330.965014	**	0.124769467	0.166957622
Genotype (G)	126.4401667	1	126.4401667	2211.781341	**	0.124769467	0.166957622
Treatment (T)	112.6956667	4	28.17391667	492.8381924	**	0.197277849	0.263983179
Y x G	63.0375	1	63.0375	1102.696793	**	0.176450672	0.236113733
Y x T	1.482333333	4	0.370583333	6.482507289	**	0.278993009	0.373328592
G x T	1.419	4	0.35475	6.205539359	**	0.278993009	0.373328592
Y x G x T	1.595	4	0.39875	6.975218658	**	0.394555698	0.527966358
Total	842.3765	59	14.2775678				
St.Dev.	3.779						
Coef.Var.	0.581						

** Highly significant at p<0.01 probability level; SS - Sum of squares; df - Degree of freedom; MS - Mean Squares; F test - F value calculated; Sign. - significant; LSD - Least Significant Difference; St.Dev - Standard Deviation; Coef.Var. - Coeficient Variance.

The interaction of factors, especially pronounced in the second year, indicates the complexity of the relationship between genotype, treatment and climatic conditions. These results indicate that in order to achieve optimal yields, precise adjustment of these factors is necessary, taking into account the specificities of acidic soils and climatic variability. Future research should focus on further understanding factor interactions and developing new genotypes adapted to changing conditions.

The correlation coefficient expresses the degree of connection between the examined traits (Figure 6). A positive correlation of medium strength was established between the traits grain yield and hectoliter weight (r=0.44**) and hectoliter weight (r=0.42**), while a negative very weak relationship was found between grain yield and 1000 grain weight (r=-0.03), which is very surprising and suggests that a higher grain weight does not necessarily lead to a higher yield. According to the results of Stupar et al. (2021), grain yield showed a positive correlation with 1000 grain weight, which is contrary to these results. In the research by Rajičić et al. (2023) found significant positive relationships between grain yield and 1000 grain weight, yield and hectoliter weight, as well as between 1000 grain weight and hectoliter weight. Research by Ayranci et al. (2014) also indicated the existence of significant correlations between grain yield and individual yield components, while the research of Bielski et al. (2020) found a negative and significant correlation with grain yield and 1000 grain weight of different genotypes of winter triticale, which is in accordance with the results of our research.

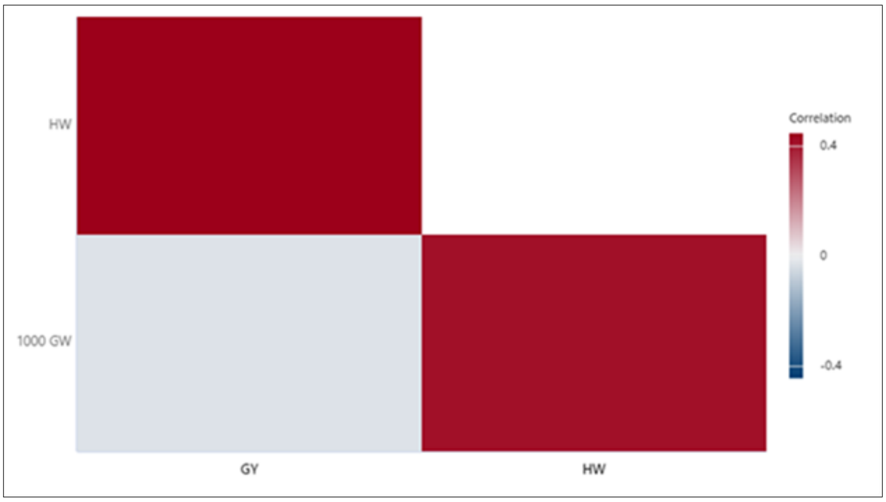

Figure 6. Coefficients of correlation between grain yield (GY), hectoliter weight (HW) and 1000 grain weight (1000 GW). **Correlation is significant at the 0.01 level.

CONCLUSIONS

Based on the results of the two-year research, it can be concluded that the Triamo genotype achieved significantly higher results than the Odisej genotype in terms of grain yield (up to 6.50 t ha^{-1} in the T5 treatment) and hectoliter mass (up to 65.80 kg hL^{-1}), while Odisej achieved higher average values for 1000 grain weight in the first year (48.20 g). Statistically significant interaction of factors (year, genotype, treatment) indicates the necessity of an integrated approach in the selection of genotype and treatment to achieve high and stable yields. A positive correlation between grain yield and hectoliter mass (r=0.44**) emphasizes the importance of grain quality, while the weak negative correlation with 1000 grain weight (r=-0.03) indicates that a higher grain weight does not guarantee a higher yield. These results support the application of combined agrotechnical measures and genotype selection to improve triticale productivity on acid soils, providing a sustainable strategy to maintain stable yields under climate change conditions.

ACKNOWLEDGEMENTS

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