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UTILIZING THE STABILITY OF YIELD PARAMETERS AS A TECHNIQUE TO SELECT SALINITY-TOLERANT WHEAT GENOTYPES

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SUMMARY

Considering that agricultural production needs to be adjusted to global climate changes, it is of particular importance to develop bread wheat germplasm with improved tolerance to abiotic stress conditions. Therefore, the aim of this research was to identify stable wheat genotypes with increased salinity stress tolerance. The experiment was conducted with 27 wheat genotypes, at two localities: Kumane (solonetz soil type) and Rimski Šančevi (chernozem soil type) during two growing seasons. A significant influence of genotype and environment, as well as G × E interaction, on the phenotypic expression of yield components was found. The factor of genotype had the largest effect on the variation in plant height (38.7%) and the smallest effect on the variation in the number of grains per spike (8.24%). The greatest influence of the environment (64.7%) and G × E interaction (17.44%) was found in the variation in the number of grains per spike. Salinity conditions contributed the most to the decrease in the number of grains per spike (30%), which is considered the best indicator of the impact of stress on the plant. The smallest decrease in the number of grains per spike was recorded in the genotypes Šumadija (16.0%) and Harmonija (18.8%). However, AMMI and PCA analyses showed that the genotype Harmonija is characterized by a higher value of the number of grains per spike and greater stability. The genotypes Renesansa, Jugoslavija, Bankut 1205, and Harmonija were characterized by the smallest reduction in plant height under salinity conditions, among which Jugoslavija and Renesansa exhibited high stability and lower trait values. The smallest reduction in spike length was found in the genotypes Jugoslavija and Šumadija, which exhibited the specific adaptability to salinity stress. In terms of salinity tolerance, the genotypes Šumadija, Harmonija, and Renesansa are considered valuable genetic resources in breeding programs.

Key words:
AMMI, G × E interaction, PCA analysis, stability, salinity stress

Abbreviations:
AMMI – Additive Main Effects and Multiplicative Interaction; PCA – Principal Component Analysis; G × E – genotype and environment interaction

INTRODUCTION

Global food security is currently negatively affected by a wide range of unexpected and drastic changes in climate. This is due to the fact that climate change is correlated to other abiotic factors that negatively affect agricultural productivity and drastically reduce the yields of many plant species (Chaudhry & Sidhu, 2021). Salinity is a major abiotic stress that affects plant growth and productivity worldwide (Munns & Tester, 2008). Climate change is expected to exacerbate the problem of soil salinity, particularly in arid and semi-arid regions (Corwin et al., 2021; Mukhopadhyay et al., 2021). Previous research indicates that 954 million hectares, or nearly 20% of the total arable land, are affected by some form of salinity (Arora, 2019; Liu et al., 2020). The demand for food will increase by 60% by 2050 due to the rapid expansion of the global population and the constant reduction of arable land (Ray et al., 2013). Wheat (*Triticum aestivum* sp.) is one of the most widely cultivated and consumed staple crops in the world, providing a significant source of calories and nutrition for billions of people. However, the increasing global demand for wheat leads to the expansion of wheat cultivation into new areas – unfavorable for plant production (Shewry & Hey, 2015; Giraldo et al., 2019; Iqbal et al., 2021). Numerous studies show that salt stress has negative impact on wheat yield and yield-related traits (Petrović et al., 2016; Khokhar et al. 2017; Mansour et al., 2020; Nadeem et al., 2020; Alzahrani et al., 2021; Banjac et al., 2022; Sen et al., 2022). Therefore, creating salinity-tolerant wheat genotypes is a good approach to overcome the negative impact of salinity (El-Hendawy et al., 2017; Al-Ashkar et al., 2019). However, salinity tolerance in wheat, as in many other plant species, is a complex and polygenic trait that is influenced by both genetic and environmental factors (Arzani & Ashraf, 2016). By growing divergent genotypes of wheat in different environmental conditions, it is possible to evaluate their adaptive value. El-Hendawy et al. (2017) and Allel et al. (2019) stated that the assessment of wheat tolerance to salinity in real environmental conditions – in situ, in which plants are exposed to abiotic stress – is of particular importance when it comes to breeding for increased tolerance to salinity. However, the response of genotypes is usually not the same in different agro-ecological environments, as a result of which there is a qualitative crossover interaction, i.e. a change in the ranking of genotypes by environment (Dimitrijević & Petrović, 2005). Understanding the complex interplay between genetics and environment in determining salt tolerance in wheat is important for developing effective strategies to improve wheat production in saline soils. Multivariate statistical analysis, which includes Additive Main Effects and Multiplicative Interaction (AMMI) analysis and principal component analysis (PCA), is considered a successful approach in studying the interaction of genotype and environment. AMMI analysis is a statistical method used to assess the stability of crop yield and quality across different environments. It is a widely used statistical method for analyzing the performance of different genotypes across multiple environments in crop breeding programs. By analyzing the performance of different genotypes across multiple environments, AMMI analysis can help plant breeders in identifying the genotypes that are best suited to specific environmental conditions, and also help in identifying stable genotypes that perform consistently well across different environments (Petrović et al., 2010; Mohammadi et al., 2018; Neisse et al., 2018; Luković et al., 2020; Banjac et al., 2022; Perišić et al., 2022). In order to identify additive and multiplicative variance, the AMMI method first performs an analysis of variance. Furthermore, it uses a multiplicative procedure (PCA analysis) to explain the G × E interaction (Gauch & Zobel, 1996).

The aim of this research was: (i) to investigate the influence of the genotype, environment, and their interaction on the phenotypic expression of yield components; (ii) to select genotypes that exhibit high stability and high values of yield components in different agro-ecological environments; (iii) to single out the most suitable phenotypic indicator of the impact of salinity on the plant.

MATERIAL AND METHODS

Plant material and experimental design

The experiment comprised 27 divergent wheat genotypes, which can provide valuable insights into the genetic basis of yield components and stress tolerance (Tab. 1). In the case of salinity stress, using multiple wheat germplasm sources can help in identifying genotypes that are more tolerant to high salt levels in the soil.

Table 1. Multiple sources of wheat germplasm used in the research

Genotype	Pedigree	Year of approval	Genotype	Pedigree	Year of approval
Banatka	Local landrace	-	Jugoslavija	NS 646/Bezostaya 1//Aurora	1980
Grbljanka	Local landrace	-	Oplenka	Kavkaz/KG-56	1982
Bankut 1205	Bankut 5/Marquis	1953	Ljubičevka	Orašanka/Zastava	1985
KG-75	Kruševačka 9083/Mara	1966	Srbijanka	Kavkaz/Argentina 29/60	1986

Šumadija	Mara/Funoto	1968	Šumadinka	KG-56/MVC-18	1988
Kosmajka	Fiorelo/Mara//Leonardo	1971	NSR-5	NSR-1/Tisa//Partizanka/3/Mačvanka 1	1991
Gružanka	Leonardo/Argento	1972	Renesansa	Jugoslavija/NS 55-25	1994
Morava	Mara/Fortunato	1972	Pesma	NS 51-37/Balkan	1995
Zastava	Besostaya 1/Abbondanza	1973	Aleksandra	Pobeda/SSK 19/94	2007
KG-56	Bezostaya 1/Halle Stamm//Bezostaya 1	1975	Perfekta	Pobeda/Studenica	2009
Orašanka	Bezostaya 1/Halle Stamm//Bezostaya 1	1976	Harmonija	Vraca/Renesansa	2012
KG-58	Bezostaya 1/Halle Stamm//Bezostaya 1	1977	Rujna	SK-54/K-45968//KG-56 S	2013
KG-78	Bezostaya 1/HalleStamm//Bezostaya 1	1978	Premija	PI-159102/Evropa//Studenica/3/KG-2086	2013
Lepenica	Bezostaya 1/IW 66	1980			

A field experiment was performed in Vojvodina Province (Serbia), at two localities (Kumane, Banat and Rimski Šančevi, Bačka), characterized by different soil types (solonetz and chernozem, respectively), Fig. 1. Conducting experiment on both solonetz and chernozem soils can help in identifying genotypes that are more tolerant to high levels of soil sodium, as well as in evaluating how different wheat varieties respond to the nutrient-rich conditions of chernozem soils. A randomized complete block design with three replications was used to perform the trial, and the basic plot size was 2 m^2. The examined genotypes were sown using continuous sowing at both localities. The distance between each row was 10 cm, while the plot distance was 25 cm. The standard agro-technical procedures for producing wheat, from pre-sowing to harvest, were used during the investigation, which is essential for achieving accurate results that reflect the situation in large-scale production. Wheat was harvested when the grain was ripe and turned golden brown and when the moisture content of the grain fell below 14%. The harvest was accomplished at the optimal time, which was the last week of June, in both vegetation seasons. The sample size was 30 plants per genotype, i.e. 10 plants per replication for each analyzed trait (plant height, spike length, number of grains per spike).

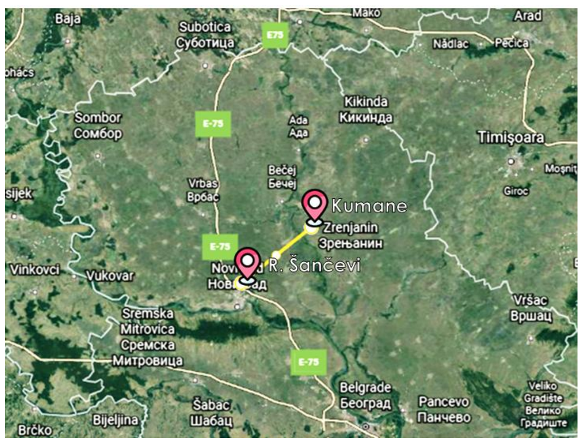

Figure 1. Localities where research was conducted (https://earth.google.com/web/)

Soil conditions

Solonetz soil is a type of soil that is characterized by a high salt content, a dense layer of horizon B (clay-rich layer) near the surface, and a subsurface layer of horizon C (sandy layer) with a high concentration of carbonates. Solonetz is characterized by high salinity and alkalinity (pH > 9), which can make it difficult for plants to grow. High Na content of solonetz can interfere with plant water uptake and limit the availability of essential nutrients. High clay content of the horizon B layer can also lead to poor water-holding capacity and high soil compaction, which can further limit plant growth (Belić et al., 2012).

Chernozem soil type was chosen as a control treatment. This soil is characterized by rich, dark-colored topsoil with appropriate humus content (3-4%), which provides a source of nutrients for plants and helps to improve soil structure and water-holding capacity. Chernozem soil is well-drained and has a neutral to slightly alkaline pH, which is favorable for plant growth (Hadžić et al., 2002).

Meteorological conditions

Meteorological data for the localities under examination was provided by the Republic Hydrometeorological Institute (http://www.hidmet.gov.rs/), Fig. 2. At the Rimski Šančevi locality a significantly higher amount of precipitation was recorded (603.0 mm during 2015/2016 and 594.2 mm during 2017/2018), compared to the Kumane locality, where the amount of precipitation in the first year of the research was 527.3 mm, and in the second 465.6 mm. The average monthly temperatures during the vegetation period of wheat were similar at both localities (10.2 °C). In the first year of the study, temperatures in February were around 6 °C higher in both locations than the long-term average, which resulted in the early beginning of vegetation. The continuing high temperatures and above-average precipitation in March allowed for an early shift into the phenophase of stem elongation. On the other hand, February in the second year of the study was marked by average monthly temperatures and precipitation that was 60% higher than the multi-year average. In the mentioned vegetation season, at both localities, March was characterized by low temperatures and a sum of precipitation higher than the multi-year average. In April and May, during the second year, higher temperatures were recorded compared to the multi-year average, at both localities. The mean temperatures in June, during the first growing season, were higher than the multi-year average, and both locations recorded abundant rainfall (143 mm in Rimski Šančevi and 164 mm in the Kumane location). In June of the second year of research, in the Rimski Šančevi location, the amount of precipitation was 163.2 mm, which was significantly higher than the amount of precipitation recorded in the Kumane location (72.0 mm). Such conditions led to a weaker grain filling and an earlier ripening of wheat at the Kumane locality (Fig. 2).

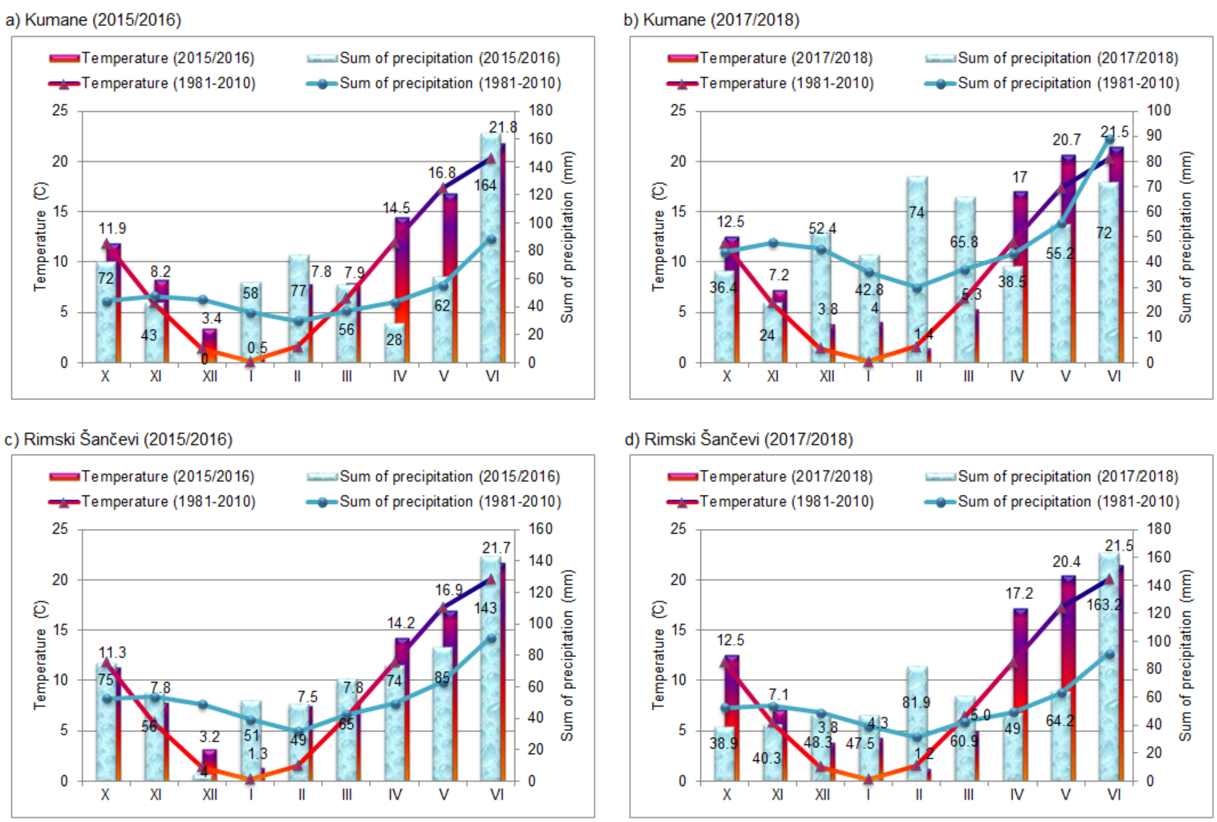

Figure 2. Meteorological conditions during the experiment

Statistical tools

The assessment of the stability of the genotypes across different environments was performed by employing the method of AMMI analysis, using the program GenStat, Trial Version 18.1.0.17005 (https://www.vsni.co.uk/).

RESULTS AND DISCUSSION

Salinity conditions affected the reduction of all analyzed wheat yield components (Fig. 3). The highest decrease was recorded in the number of grains per spike (around 30%), which is in accordance with the results obtained by

Dimitrijević et al. (2012). Also, Hasan et al. (2016) and Nadeem et al. (2020) found a decrease in the number of grains per spike in wheat grown on treatments with increased salt concentration compared to the control treatment. The highest decrease in the number of grains per spike was recorded in the genotype Perfekta (44.5%), while the smallest decrease was found in the genotypes Šumadija (16.8%) and Harmonija (18.8%).

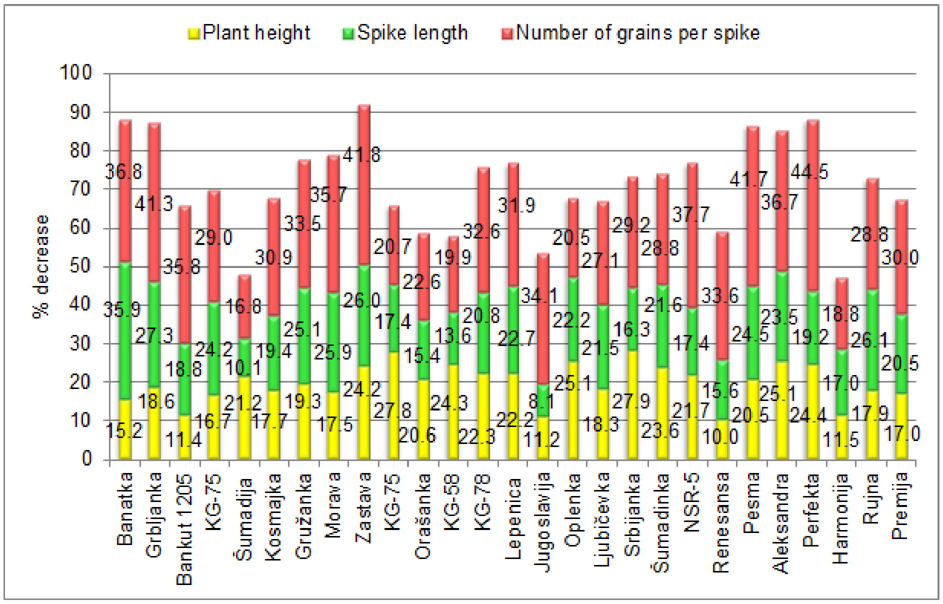

Figure 3. Decrease in yield components under salinity stress

The lowest reduction in plant height was found in the genotypes Renesansa (10.0%), Jugoslavija (11.2%), Bankut 1205 (11.4%), and Harmonija (11.5%), while the highest reduction was recorded in the genotypes Srbijanka (27.9%) and KG-75 (27.8%). Dimitrijević et al. (2012) and Petrović et al. (2016) found a reduction in plant height in saline conditions by 30 to 40% compared to plant height achieved on chernozem. Also, a significant decrease in plant height under the influence of salinity stress, compared to the control, was established by Kalhoro et al. (2016) and Nassar et al. (2020). The genotiypes Jugoslavija and Šumadija had the lowest reduction in spike length (8.1 and 10.1%, respectively), whereas local landrace Banatka had the highest reduction (35.9%), Fig. 3. This is in agreement with the results of Dimitrijević et al. (2009), who found that the conditions of the meliorated solonetz and chernozem influenced a significant decrease in the length of spikes in relation to the value of this trait achieved on chernozem. The reduction of spike length by increasing the concentration of salt in the soil was also established by Kalhoro et al. (2016) and Mansour et al. (2020).

Stability performances

AMMI analysis of variance was applied in order to establish in detail the effects of the main factors (genotype and environment), as well as their interactions, on the phenotypic variation in plant height. A significant influence ($p<0.01$) of additive (genotype and environment) and non-additive effects (G × E interaction) on plant height variation was found. The factor of the environment has the largest influence on the total variation of the trait (47.03%), followed by the factor of the genotype (38.68%), while the G × E interaction has the lowest influence (10.87%). A low share of the G × E interaction on the variation in plant height was established in the research by Zečević et al. (2008) and Banjac (2015). A detailed analysis of the G × E interaction revealed three significant ($p<0.01$) interaction components, where the first two components ($IPCA_1$ and $IPCA_2$) together explain 77.72% of the sum of squares of the interaction (Tab. 2).

Table 2. AMMI analysis for plant height of different wheat genotypes grown in multiple environments

Source of variation	Df	SS	MS	F – value	p – value	The share of total variation (%)[1]
Total	323	72295	224	-	-	100
Treatments	107	69825	653	66.95**	0.000	96.58
Genotypes	26	27961	1075	110.33**	0.000	38.68
Environments	3	34004	11335	205.04**	0.000	47.03
Blocks	8	442	55	5.67**	0.000	0.61
Interactions	78	7860	101	10.34**	0.000	10.87
$IPCA_1$	28	3956	141	14.49**	0.000	50.33
$IPCA_2$	26	2153	83	8.50**	0.000	27.39
$IPCA_3$	24	1750	73	7.48**	0.000	22.26
Residuals	-	-	-	-	-	-
Error	208	2027	10	-	-	-

Legend: df – Degree of freedom; SS – Sum of square; M – Mean of square; ** $p < 0.01$; IPCA – interaction component; [1] - The proportion of variation for each interaction component is expressed in relation to the interaction's sum of squares

The output of the AMMI analysis is presented in the form of $AMMI_1$ (mean value of the analyzed trait vs. $IPCA_1$) biplot, which displays the interaction between the genotypes and environments (Fig. 4). Local landraces Grbljanka and Banatka, and the genotype KG-75 had the highest values of plant height and contribute the most to the phenotypic variation of this trait. The mentioned genotypes are distinguished by a high value of $IPCA_1$, i.e. high instability, and are positioned in the same quadrant of biplot as the environment Rimski Šančevi 2015/2016. Other analyzed genotypes, with their trait values, are close to the average value for the trial, where the differences between them are mainly influenced by the multivariate effect. Dimitrijević et al. (2009) and Petrović et al. (2010) examined the stability of wheat genotypes in different agroecological environments and observed that the multivariate component of variation had more pronounced impact on plant height variation than the additive component. The genotypes Jugoslavija, Renesansa, Premija, Šumadinka, Bankut 1205, KG-56, Ljubičevka, and Pesma showed low values of $IPCA_1$, and therefore high stability. The genotypes Orašanka, NSR-5, Aleksandra, Srbijanka, and Perfekta showed extremely low values of the investigated trait, which is expected, considering that the breeding of the mentioned genotypes was carried out with the aim of reducing the stem height and increasing the harvest index. Also, the mentioned genotypes showed a moderately stable reaction in the expression of the phenotype, which favors them for cultivation in different agroecological environments. In all examined agro-ecological environments, significant instability in terms of plant height was established. Nevertheless, in the agro-ecological environment Kumane 2015/2016, the analyzed genotypes achieved higher stability than in other environments. The agro-meteorological conditions of the Rimski Šančevi locality in both growing seasons were favorable to the manifestation of higher average plant height values in the studied genotypes. Differences in plant height at one locality were more the result of multivariation than the additive effect of variation, while differences in plant height between localities in the same growing season were influenced by the additive effect. Therefore, plant height was more influenced by the locality factor than the factor of growing season. The agro-ecological environments of both localities in 2017/2018 growing season, with their positive interaction value, are distributed above the abscissa. Genotypes that had greater stability and lower mean trait values achieved positive interaction with the given environments. On the other hand, unstable genotypes, which achieved high trait values, showed positive interaction with agro-ecological environments in 2015/2016 growing season. High instability of these genotypes is the result of the fact that they had significantly higher trait values in the more favorable 2015/2016 growing season (Fig. 4).

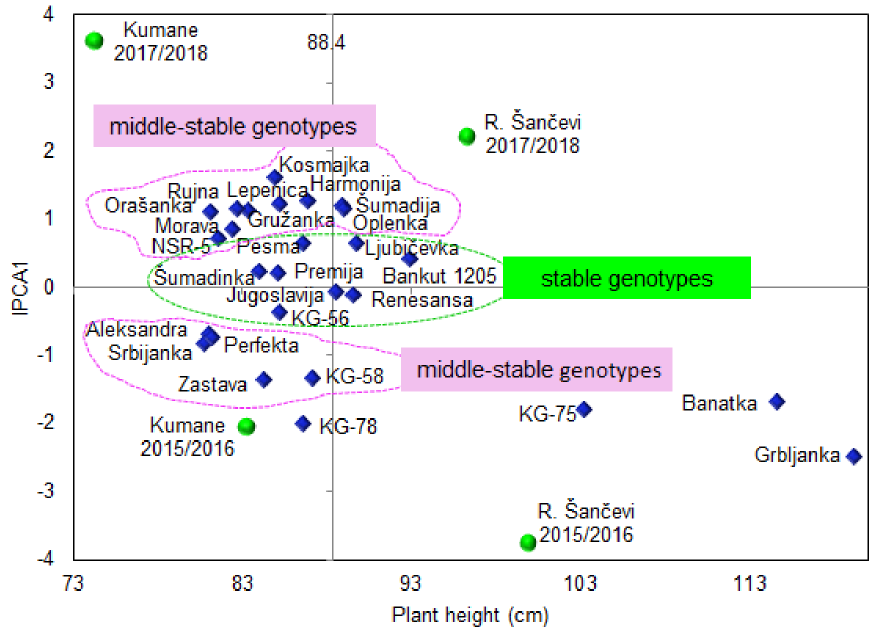

Figure 4. AMMI$_1$ (IPCA$_1$ vs mean value) biplot for assessing the stability of plant height in wheat genotypes grown in multiple environments

The factor of environment (localities and vegetation seasons) had the greatest impact on the variation in spike length, with a share in the total sum of squares of 61.33% (Tab. 3). Mladenov et al. (2019) and Popović et al. (2020) stated that the high proportion of environmental factors in the phenotypic variation in spike length is the result of significant differences between growing seasons and treatments.

Table 3. AMMI analysis for spike length of different wheat genotypes grown in multiple environments

Source of variation	Df	SS	MS	F – value	p – value	The share of total variation (%)[1]
Total	323	911.9	2.82	-	-	100
Treatments	107	843.0	7.88	25.07**	0.000	92.44
Genotypes	26	184.1	7.08	22.53**	0.000	20.18
Environments	3	559.3	186.42	413.53**	0.000	61.33
Blocks	8	3.6	0.45	1.43	0.184	0.39
Interactions	78	99.6	1.28	4.06**	0.000	10.92
IPCA$_1$	28	45.3	1.62	5.15**	0.000	45.48
IPCA$_2$	26	37.3	1.44	4.57**	0.000	37.45
IPCA$_3$	24	17.0	0.71	2.25**	0.001	17.07
Residuals	0	0.0	-	-	-	-
Error	208	65.4	0.31	-	-	-

Legend: df – Degree of freedom; SS – Sum of square; M – Mean of square; p < 0.01; IPCA – interaction component; [1] - The proportion of variation for each interaction component is expressed in relation to the interaction's sum of squares

The G × E interaction contributes to the variation in spike length by 10.92%. This is consistent with results revealed by Zečević et al. (2008) and Knežević et al. (2013). The results of the PCA analysis show that three main interaction components have a significant influence, where the first two components (IPCA$_1$ and IPCA$_2$) account for 82.93% of the interaction (Tab. 3).

Biplot analysis shows that the genotype Kosmajka is distinguished by the lowest value of IPCA$_1$, i.e. the highest stability. However, the mentioned genotype has the lowest value of spike length. On the other hand, the genotypes Harmonija, Bankut 1205, and Premija are characterized by extremely high stability and, at the same time, high average values of the analyzed trait, which makes these genotypes suitable for cultivation in diverse environments. The genotypes Aleksandra, Lepenica, Srbijanka, Zastava, and Orašanka are stable genotypes with spike length values within the average value at the trial level. Middle-stable genotype Rujna had the highest average value of spike length, while middle-stable genotypes Gružanka, Jugoslavija, and KG-56 had low average spike length. Nevertheless, the genotypes Jugoslavija and KG-56 are specially adapted to the stressful conditions of the environment Kumane 2017/2018. The local landraces Grbljanka and Banatka exhibit medium to high instability and high average values of spike length. However, these genotypes are suitable for cultivation in favorable conditions of the environment Rimski Šančevi 2015/2016. Greater spike length stability was expressed at both localities during 2017/2018 growing season. This is due to the fact that wheat genotypes in dry environmental conditions were unable to express their genetic potential. The differences between the environments Kumane 2017/2018 and Rimski Šančevi 2017/2018 in spike length were determined by the additive, but not the multiplicative effect of variation. Pronounced instability was present in 2015/2016 growing season at both localities, where the value of spike length was significantly higher at the Rimski Šančevi locality. The difference between the growing seasons in relation to the spike length was more pronounced under conditions of increased soil salinity. Therefore, at the Rimski Šančevi locality, the influence of the genotype factor in the variation in spike length was more dominant, while at the Kumane locality, the effect of the growing season was more pronounced (Fig. 5).

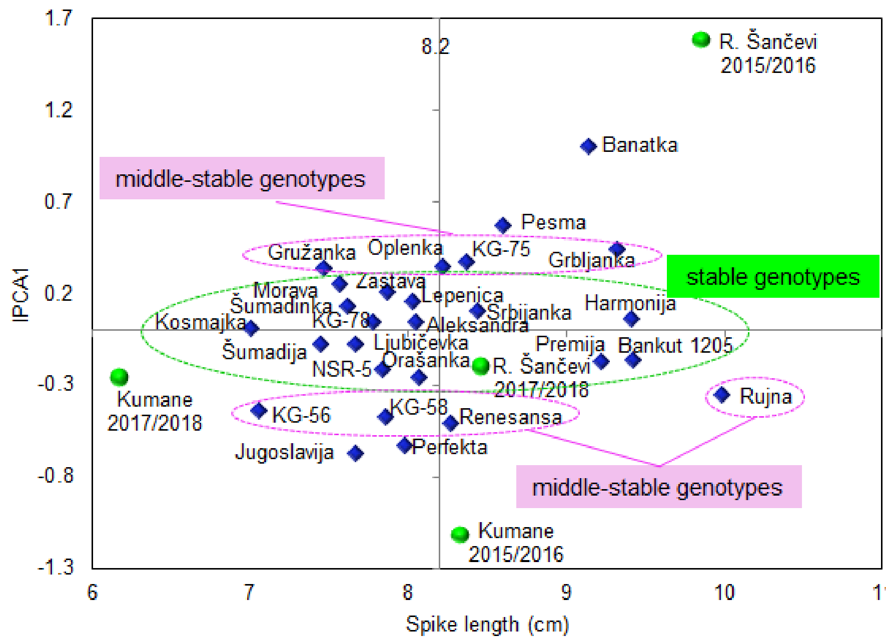

Figure 5. AMMI$_1$ (IPCA$_1$ vs mean value) biplot for assessing the stability of spike length in wheat genotypes grown in multiple environments

A significant influence of the additive and multivariate component in the variation in the number of grains per spike was established (Tab. 4). The environment factor (locality and growing season) had the highest contribution to the phenotypic variation of the trait (64.69%), while the factor of genotype had the lowest influence (8.24%). Also, in the research conducted on solonetz soil type, Petrović et al. (2009) found that the factor of environment contributed the most to the variation in the number of grains per spike. The G × E interaction explained 17.44% of the variation in the number of grains per spike. Similar results were reported by Zečević et al. (2010), who determined that the factor of growing season had the greatest influence on the number of grains per spike variation, followed by the G × E interaction, while the factor of genotype had the lowest influence on the phenotypic expression of the mentioned trait. Decomposing the G × E interaction reveals three significant interaction components, of which the first two (IPCA$_1$ and IPCA$_2$) account for 86.94% of the interaction. This is consistent with the results revealed by Banjac (2015).

Table 4. AMMI analysis for the number of grains per spike of different wheat genotypes grown in multiple environments

Source of variation	**Df**	**SS**	**MS**	**F – value**	**p – value**	**The share of total variation (%)[1]**
Total	323	24809	76.8	-	-	100
Treatments	107	22419	209.5	23.59**	0.000	90.37
Genotypes	26	2044	78.6	8.85**	0.000	8.24

Environments	3	16050	5350.0	78.94^{**}	0.000	64.69
Blocks	8	542	67.8	7.63^{**}	0.000	2.18
Interactions	78	4326	55.5	6.24^{**}	0.000	17.44
$IPCA_1$	28	2292	81.9	9.21^{**}	0.000	52.98
$IPCA_2$	26	1469	56.5	6.36^{**}	0.000	33.96
$IPCA_3$	24	565	23.5	2.65^{**}	0.000	13.06
Residuals	0	0	-	-	-	-
Error	208	1848	8.9	-	-	-

Legend: df – Degree of freedom; SS – Sum of square; M – Mean of square; ** $p < 0.01$; IPCA – interaction component; [1] - The proportion of variation for each interaction component is expressed in relation to the interaction's sum of squares.

Based on the distribution of genotypes on the biplot, high difference was established in the multivariate part of the variation (Fig. 6). The genotypes Aleksandra, Zastava, Lepenica, KG-56, NSR-5, KG-58, Kosmajka, KG-75, Srbijanka, Šumadinka, and Morava had the lowest value of $IPCA_1$, and therefore high stability. The mentioned genotypes differed in the additive part of the variation, where the highest average value was achieved by the genotype Šumadinka and the lowest one by the genotype Kosmajka. In the studied period, the highest average value of the number of grains per spike was found in the genotypes Bankut 1205 and Renesansa, which showed moderate stability. These genotypes were suited to the chernozems favorable conditions (Rimski Šančevi 2015/2016). The genotypes Perfekta, Harmonija, and Orašanka had high values of the tested trait and were well adapted to the unfavorable conditions of 2017/2018 growing season at the Rimski Šančevi locality, with pronounced temperature variations in the most important phenophases of plant development (stem elongation, heading and grain filling). The genotype Šumadija showed high instability and specific adaptability to stress conditions present at the locality Kumane. The environments Kumane 2017/2018 and Kumane 2015/2016 had low interaction axis values and differed only in the additive part of the variation. On the other hand, the environment Rimski Šančevi 2015/2016 and Rimski Šančevi 2017/2018 had high $IPCA_1$ value and high values of the number of grains per spike. It is observed that the conditions of the growing season have greater influence on the number of grains per spike under salinity stress conditions, while the favorable conditions of the chernozem mitigated the effect of the growing season.

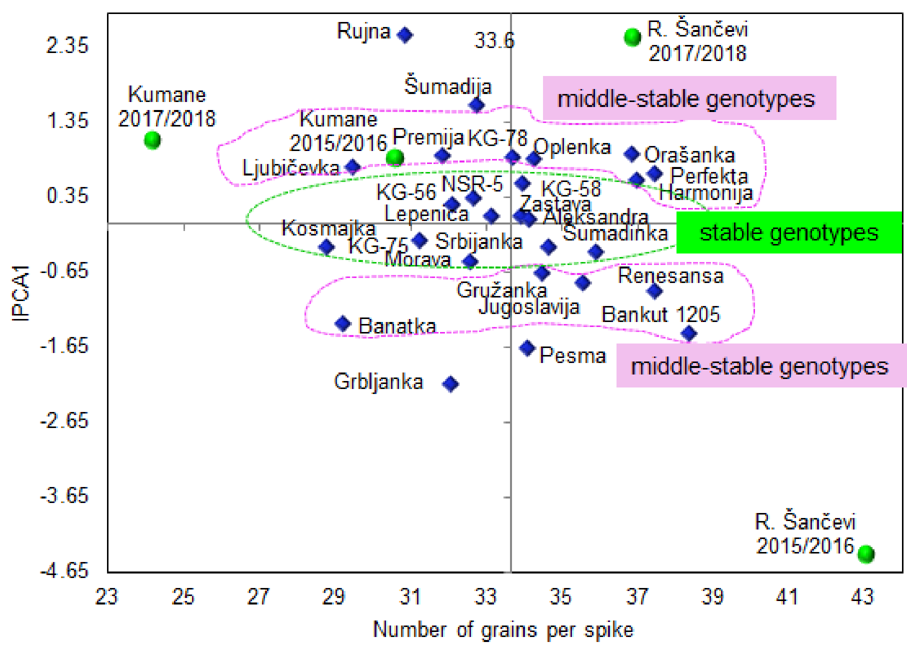

Figure 6. $AMMI_1$ ($IPCA_1$ vs mean value) biplot for assessing the stability of the number of grains per spike in wheat genotypes grown in multiple environments

CONCLUSION

The results show that there is a significant effect of the additive and multivariate component on the phenotypic variation of the analyzed traits. The plant height is a varietal characteristic that was most influenced by the genotype, followed by the factor of locality, while the factor of growing season had the smallest share in the variation. On the other hand, the locality and the growing season contribute equally to the variation in spike length, accounting for 61.3% of the variation. The variation in the number of grains per spike was mostly determined by the factor of the environment (64.7%), especially the factor of the locality, where the influence of the factor of the growing season was more pronounced under salinity conditions. The G × E interaction contributed the most to the variation in the number of grains per spike (17.44%). When compared to the values attained in the control (chernozem soil type), conditions of higher salinity (solonetz soil type) result in a decrease in the value of all yield components. Also, the studied genotypes at the Kumane locality in 2017/2018 achieved lower average values of the analyzed traits, compared to 2015/2016. It can be stated that the saline soil found at the Kumane locality can to a lesser extent mitigate the negative impact of high temperatures and lack of precipitation since they intensify detrimental effect of high concentration of salts in soil. The number of grains per spike was significantly reduced (30%) under the influence of salinity stress. From all the above, the number of grains per spike is considered the best phenotypic indicator of the effect of salinity stress on the plant. The genotypes Šumadija, Harmonija, Jugoslavija, and Renesansa showed the least reduction in the trait values when exposed to salinity. Among the aforementioned genotypes, the genotype Šumadija showed the lowest average values of the analyzed traits, but also the highest specific adaptability to the salinity stress conditions.

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