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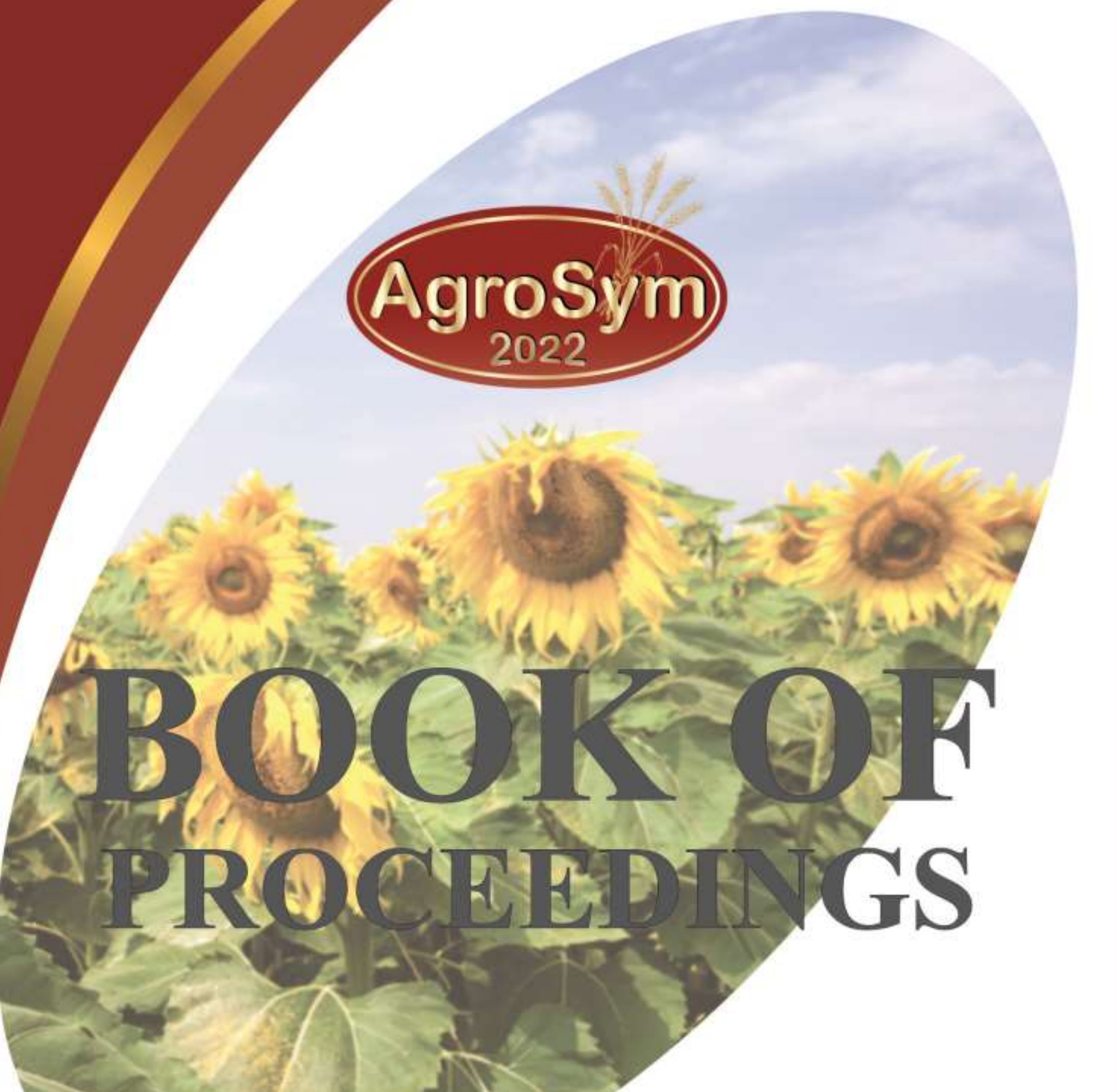

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STABILITY PERFORMANCES OF DIFFERENT WHEAT GENOTYPES GROWN UNDER FAVORABLE AND SALINITY STRESS CONDITIONS

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Abstract

The present study was carried out to investigate the phenotypic variability and genotype × environment interaction (G×E) for spike weight of different wheat genotypes. The experiment included 27 wheat genotypes, grown under favorable conditions (Rimski Šančevi locality, Chernozem soil type) and salinity stress conditions (Kumane locality, Solonetz soil type), during two growing seasons. Using the AMMI analysis of variance we found a statistically significant ($p<0.01$) influence of additive and non-additive sources of variation on the phenotypic variation of spike weight. Additive sources of variation (genotype and environment) had a share of 62.29% in the total sum of square. The environmental factors (growing season and soil type) contributed to the variation of spike weight with a share of 53.75% in the total variation of the experiment, while the factor of genotype had a significantly smaller share (8.54%). The G×E participated to the total variation of spike weight with 20.84%, where the first two principal interaction components (PCA_1 and PCA_2) explained 91.74% of the interaction. The genotypes Harmonija, KG-58, Orašanka, Renesansa, Morava, Perfekta and Bankut 1205 were characterized by high values of spike weight and high stability. Genotypes Bankut 1205, Banatka, Grbljanka and Morava were in positive interaction with the vector of environment Rimski Šančevi 2015/2016 (favorable conditions), while the genotypes Harmonija, Gružanka, Oplenka, Šumadija and Premija reacted well to salinity stress conditions of environment Kumane.

Key words: *AMMI analysis, Chernozem, G×E, Solonetz, stability, wheat.*

Introduction

Wheat (*Triticum* spp.) accounts for 30% of world grain production and for 45% of cereal nutrition, thus representing a major food crop species (Charmet, 2011). Due to its primary presence in human nutrition, wheat is ranked first, as the most important among cereals (Iqbal *et al.*, 2021). In 2020, the total global production of wheat was 760 million tons, with global trade greater than all other crops combined (http://www.faostat.fao.org). Due to the ever-growing human population, the need to increase the area under wheat is growing, both in favorable and unfavorable environmental conditions (Shewry and Hey, 2015). The Global Map of Salt-Affected Soils (GSASmap) shows that more than 424 million hectares of topsoil (0-30 cm) and 833 million hectares of subsoil (30-100 cm) in the world are salt-affected, where 85% of salt-affected topsoils are saline, 10% are sodic and 5% are saline-sodic (https://www.fao.org/soils-portal/en/). In addition to drought, increased sodium content in the soil is one of the most common causes of abiotic stress which greatly reduces crop growth and productivity (Wang and Huang, 2019). Soil salinity causes stress in plants in two ways -

high concentrations of salt in the soil reduce the uptake of water and essential minerals; and high concentrations of salt in the plant lead to ionic toxicity (Hassanuzzaman *et al.*, 2021). Khokhar *et al.* (2017) and Mansour *et al.* (2020) found a significant decrease in the value of the grain yield and grain yield components of wheat under conditions of increased soil salinity. In order to select useful genetic variability for successful wheat production under stress conditions, it is important to study genotypes under real environmental conditions (Moustafa *et al*., 2021). However, grain yield and its components are not only under the influnce of genotype and environmental factors, but also of their interaction (Mohammadi *et al.*, 2018; Verma and Singh, 2021; Sime and Tesafaye, 2021). A widely used multivariate method for studying genotype and environment interactions (G×E) is AMMI (Additive Main Effects and Multiplicative Interaction). This method is effective because it considers a large part of the G×E sum of the squares, clearly separates the interaction effects and provides a good interpretation of the genotypes stability. The AMMI method uses analysis of variance to separate additive from multiplicative variance (G×E) and then uses a multiplicative procedure - PCA analysis, to explain G×E in detail (Zobel *et al*., 1988). This study aimed to: (i) establish the influence of additive and non-additive effects of variation on the phenotypic expression of spike weight; (ii) determine the stability performances of genotypes in different agro-ecological conditions; as well as (iii) single out highly stable genotypes with high values of spike weight.

Material and Methods

The experiment included 27 wheat genotypes, such as: two local landraces (Banatka, and Grbljanka); old Hungarian variety (Bankut 1205); twenty genotypes (Gružanka, Zastava, Aleksandra, Srbijanka, Kosmajka, Orašanka, Rujna, Šumadija, Harmonija, Ljubičevka, Perfekta, Premija, KG-56, KG-75, KG-58, KG-78, Morava, Lepenica, Šumadinka, and Oplenka) created at the Centre for Small Grains in Kragujevac; and four genotypes (Renesansa, NSR-5, Jugoslavija, and Pesma) released by the Institute of Field and Vegetable Crops in Novi Sad.

A field trial was conducted at two localities (Kumane, Vojvodina Province, 45.522°N 20.195°E, on Solonetz soil type; and Rimski Šančevi, Vojvodina Province, 45.322° N 19.836° E, on Chernozem soil type), according to a randomized complete block design with three replications. Solonetz is considered a soil of unfavorable physical and chemical properties, due to the high content of clay and Na ions in argiluvian (Bt) horizon. Also, with the increase in the sum of exchangeable cations in the Bt horizon, the content of exchangeable Na increases, as well as the alkalinity (pH > 9) (Belić *et al*., 2012). Chernozem soil type, chosen as a control treatment, is characterized by a good crumbly structure, stable aggregates, and good water permeability. Also, this soil is well provided with humus (3-4%) and plant nutrients (Hadžić *et al*., 2002).

During the study, the usual agro-technical practices for wheat production were applied. The size of the basic plot was 2 m^2. In both soil types, the examined genotypes were sown by continuous sowing, where the row spacing was 10 cm, and the distance between plots was 25 cm. In both growing seasons, the harvest was performed at the optimal time (last week of June), when the grain moisture was below 14%. The spike weight was measured in 30 plants for each analyzed genotype. The weather conditions of the 2015/2016 growing season were more favorable for wheat production compared with the weather conditions of the 2017/2018 season, in both localities. The amount of precipitation was higher in Rimski Šančevi locality compared to the amount of precipitation recorded in Kumane locality, while the mean monthly temperatures did not differ significantly in the analyzed localities, in both seasons. The warmer weather and lack of precipitation affected the earlier maturation of plants in 2017/2018 season (Figure 1).

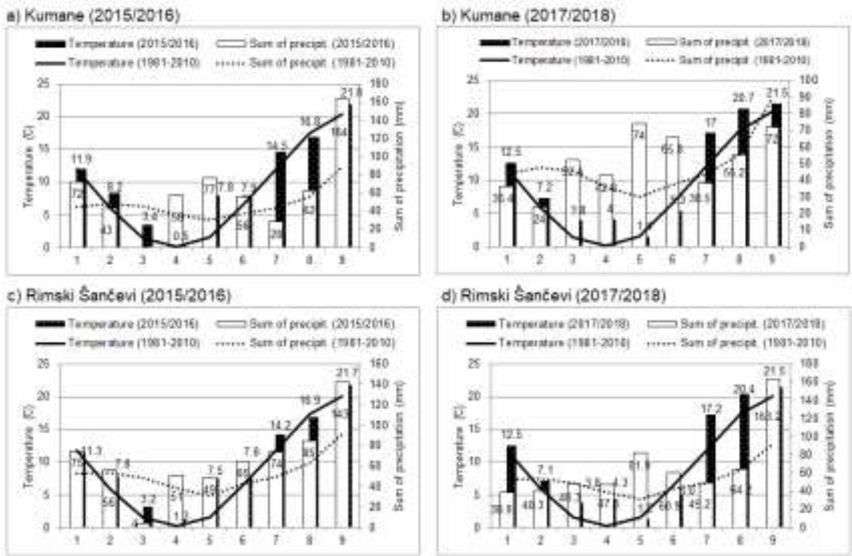

Figure 1. Mean monthly temperatures and sum of precipitation in Kumane locality (a, b) and Rimski Šančevi (c, d), during examined growing seasons

Additive main effects and multiplicative interaction (AMMI) analysis was applied in order to determine the stability of genotypes in different ecological environments. This analysis was performed using the program GenStat, Trial Version 18.1.0.17005 (https://www.vsni.co.uk/).

Results and Discussion

Using AMMI analysis of variance, a statistically highly significant ($p<0.01$) influence of additive and non-additive sources of variation on the variation of spike weight was found (Table 1).

Table 1. AMMI analysis of variance for spike weight in 27 wheat genotypes grown in different agro-ecological conditions

Source of variation	Df	Sum of squares (SS)	Mean of squares (MS)	F-value	Probability (p)	Share in variation (%)[1]
Total	323	108.13	0.335	-	-	100
Treatmants	107	89.89	0.840	11.90^{**}	0.000	83.13
Genotype (G)	26	9.24	0.355	5.03^{**}	0.000	8.54
Environment (E)	3	58.13	19.376	43.59^{**}	0.000	53.75
Block	8	3.56	0.445	6.30^{**}	0.000	3.29
G×E interaction	78	22.53	0.289	4.09^{**}	0.000	20.84
$IPCA_1$	28	13.35	6.76	6.76^{**}	0.000	59.25
$IPCA_2$	26	7.32	3.99	3.99^{**}	0.000	32.49
$IPCA_3$	24	1.86	1.10	1.10	0.349	8.25
Residue	0	0.00	-	-	-	-
Error	208	14.68	0.071	-	-	-

[1] The share of the sum of the squares of the main factors (genotype and environment), as well as the G×E interaction is expressed in relation to the sum of the squares of the total, while the share of the sum of the squares of the principal interaction components is expressed in relation to the sum of the squares of the G×E interaction (100%).

The environmental factor (growing season and locality) mostly contributed to the variation of spike weight, with a share of 53.75%, while the factor of genotype had a significantly smaller share (8.54%) in the total variation of the abovementioned trait. Similar results were established by Banjac (2015), in the study of wheat variability on ameliorated Solonetz. The share of G×E interaction in the total phenotypic variation of spike weight was 20.84%, where the first two main interaction components had a share of 91.74% in the G×E interaction ($IPCA_1$=59.25% and $IPCA_2$=32.49%), as shown in Table 1.

Assessment of genotype tolerance to salinity in real environmental conditions is of great importance in breeding wheat for increased tolerance to salinity (Moustafa *et al.*, 2021). In contrast to controlled laboratory conditions, in real environmental conditions the plants are exposed to all other abiotic factors, together with the factor of increased soil salinity. Therefore, an $AMMI_1$ biplot was created to assess the stability of wheat genotypes, in terms of spike weight, grown in favorable and unfavorable environmental conditions – in situ (Figure 2a). The genotypes Harmonija, KG-58, Orašanka, Renesansa, Morava, Perfekta, and Bankut 1205 showed high stability and high values of spike weight. Based on the expressed values of spike weight and stability, these genotypes are desirable for cultivation in the studied agro-ecological environments and for use in breeding programs. Also, these results confirmed that old genotypes, such as: Bankut, KG-58, Orašanka, and Morava, could be appropriate parental material in wheat breeding programs. Also, Gharib *et al.* (2020) emphasized that wheat landraces and old varieties can be considered valuable genetic resources for diversity and adaptation to salinity stress.

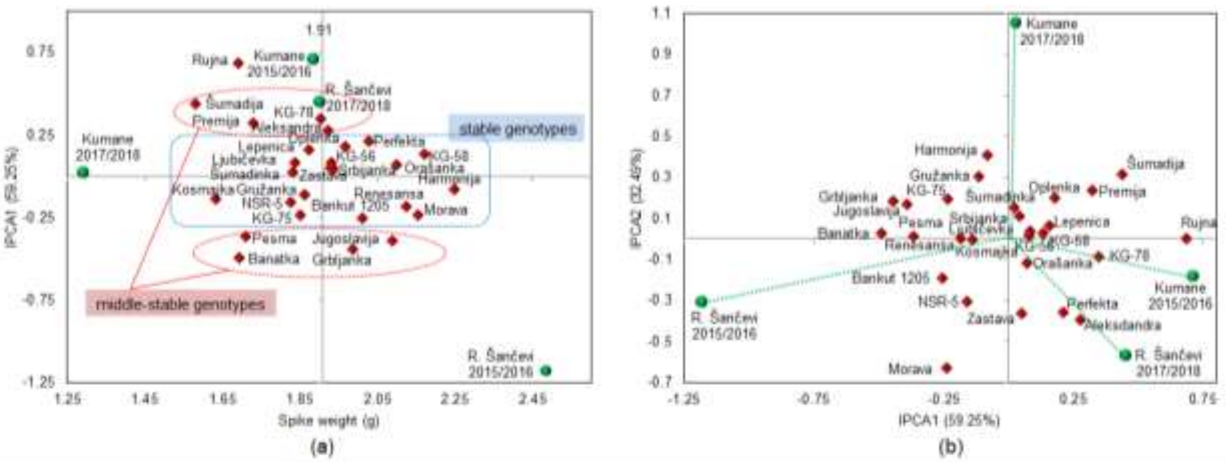

Figure 2. $AMMI_1$ (mean value of spike weight vs. $IPCA_1$) (a) and $AMMI_2$ ($IPCA_1$ vs. $IPCA_2$) (b) biplot for assessing the stability of 27 wheat genotypes grown on different environments

The genotypes Šumadinka, Ljubičevka, NSR-5, and Kosmajka had high stability, as well as values of spike weight that were lower than the average value for the trial. The genotypes Gružanka, KG-75, Lepenica, Oplenka, KG-56, Srbijanka, and Zastava were characterized by high stability and values of the spike weight close to the average for the experiment. Due to moderate stability and below-average values of analysed trait, the genotypes Šumadija, Premija, Pesma, and Banatka are considered undesirable for cultivation in different environmental conditions. The arrangement of the points of agro-ecological environments on the $AMMI_1$ biplot shows that genotypes reacted differently in various environmental conditions in terms of phenotypic expression of spike weight. The agro-ecological environment of Kumane 2017/2018 was characterized by the highest stability and the lowest average value of the abovementioned trait. On the other hand, the agro-ecological environment Rimski Šančevi 2015/2016 showed the highest instability and the highest average value of spike weight. Agro-ecological environments Kumane 2015/2016 and

Rimski Šančevi 2017/2018, with almost equal values of the spike weight, differed in the multivariate part of the variation, where environment Rimski Šančevi 2017/2018 had higher stability. Conditions of the increased soil salinity affected the decrease in the spike weight by 27% in relation to the value achieved in favorable soil conditions, on Chernozem soil type. Petrovic *et al*. (2016) found that spike weight on Solonetz was twice as small as spike weight achieved on Chernozem. Therefore, spike weight could be considered valuable phenotypic marker for selecting wheat genotypes with high salinity tolerance. Also, Khokhar *et al*. (2017) and Mansour *et al*. (2020) found a decrease in the value of wheat yield components under conditions of increased salinity.
By creating the $AMMI_2$ biplot, an additional 32.49% of the G×E interaction was explained (Figure 2b). The genotypes Ljubičevka, KG-56, KG-58, Lepenica, Srbijanka, Orašanka, Kosmajka, and Šumadinka showed low values of interaction with all agro-ecological environments. The genotypes Rujna, Šumadija, Morava, Aleksandra, Perfekta, Zastava, Harmonija, Grbljanka and Banatka showed the highest values of interaction components. However, the mentioned genotypes achieved positive correlations with the vectors of certain environments. The genotype Rujna achieved a positive correlation with the vector of environment Kumane 2015/2016. Unstable genotypes, such as: Aleksandra, Perfekta, and Zastava, with their interaction vectors, were close to the vector of agro-ecological environment Rimski Šančevi 2017/2018. Therefore, these genotypes reacted well to the favorable conditions of Chernozem soil in 2017/2018 growing season, which was characterized by a lack of precipitation. Genotypes Bankut 1205, Banatka, Grbljanka, and Morava, with moderately high and high values of $IPCA_1$ and $IPCA_2$, were positively correlated with the vector of agro-ecological environment Rimski Šančevi 2015/2016. The genotypes Harmonija, Gružanka, Oplenka, Šumadija, and Premija, were well adapted to the unfavorable conditions of environment Kumane 2017/2018.

Conclusion

A significant influence of additive and non-additive effects on the variation of spike weight has been established, where environmental factors had the largest share. Conditions of increased soil salinity reduced the value of spike weight by 27%, due to this trait can be an appropriate phenotypic marker in the selection of salt-tolerant wheat genotypes. The genotypes Harmonija, Orašanka, KG-58, Renesansa, and Morava were characterized by high stability and high values of spike weight. The highest stability and the lowest value of the analyzed trait was manifested in the agro-ecological environment Kumane 2017/2018, while the highest value of spike weight and highest instability were established in the environment Rimski Šančevi 2015/2016. The genotypes Harmonija, Gružanka, Oplenka, Šumadija, and Premija were well adapted to unfavorable conditions of Solonetz spil in conditions of reduced rainfall, while the genotypes Bankut 1205, Banatka, Grbljanka, and Morava reacted well on favorable environmental conditions of Rimski Šančevi locality in 2015/2016 growing season.

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