Agronomy Research **22**(2), 898–912, 2024
https://doi.org/10.15159/AR.24.090

Effect of genotype x external environment interaction on the number of the kernel per ear of barley

V. Radic*, I. Komljenovic, S. Nastic and B. Petkovic

University of Banjaluka, Faculty of Agriculture, Bulevar Vojvode Petra Bojovica 1A, BA78000 Banjaluka, Bosnia and Herzegovina
*Correspondence: vojo.radic@agro.unibl.org

Received: May 24th, 2024; Accepted: September 3rd, 2024; Published: September 26th, 2024

Abstract. Genotype, external environment and their mutual interaction are determining or limiting a yield and barley tolerance to stressful conditions. This paper presents the results of a two-year study of nine selected genotypes at two localities. Aim of the investigation was determine which of the genotypes in the given production conditions gives the best results in the height and stability of yield. Based on the analysis of variance, *Duncan 's test* and interaction relations, a large variability between the examined genotypes was determined under the influence of different agroecological conditions of the locality, years of testing and their mutual interactions. All genotypes in this study achieved high yields. The highest total average yield from both localities and both years of testing was achieved by genotype 3 (8,767.99 kg ha^{-1}), and the lowest genotype 7 (6,075.85 kg ha^{-1}), which is significantly higher than the average yield in production in our country (3,150 kg ha^{-1}). This showed that, with the selection of quality genotypes, the application of quality agrotechnics in appropriate agroecological conditions, a higher yield can be achieved.

Key words: winter barley, selected genotype, interaction, cluster analysis.

INTRODUCTION

Due to its high polymorphism, barley belongs to the group of plants that are characterized by a high degree of plasticity, and because it can be grown in different climatic conditions, its distribution area is more significant than in other real cereals (Glamoclija, 2004). Widespread, despite different climatic conditions, indicates that the genetic pool of barley is rich in traits (genes) that allow wide adaptation to environmental conditions and good resistance to stress (Stanca et al., 2003). Drought is considered the main limiting environmental factor affecting crop productivity, including barley (Jana & Wilen, 2005). Therefore, drought due to low rainfall or high temperatures is one of the main problems underlying modern agriculture around the world, and is one of the most important environmental factors affecting plant growth, development and production. The most important environmental factors that affect the growth, development and production of plants (Hasanuzzaman et al., 2012; Hossain et al., 2012).

Genotypes tested in multiple environments often do not give the same rank in terms of yield, which is a consequence of the interaction of the genotype with the external environment. Interactions are the response of genotypes to changes in environmental conditions (Hühn, 1990; Kang, 1990). Without interaction, individual varieties would be grown in an extensive range, and yield trials to confirm the value of a particular genotype would be performed in only one location. Varieties with a smaller contribution to the interaction are less sensitive to changes in environmental conditions, so the values of the examined traits will not change much. Such varieties are stable. The ability of a variety to achieve high and stable yields is called adaptability (Ebdon & Gauch, 2002). Genetic variability plays a significant role in the adaptability of barley to the stress caused by the external environment and to the prevalence of barley in various climates (Cattivelli et al., 2002). At barley breeding and many aspects of barley research, the analysis of genotype-by-environment interactions (GEIs) is of primary importance, as it is also for other crops (Ceccarelli, 1996; Annicchiarico, 2002; Voltas et al., 2002). Crop improvement through breeding brings immense value relative to investment and offers a practical approach to improving food security (Tester & Langridge, 2010).

Kaydan & Yagmur, (2007) investigated yield and yield components in two years, (2004/05) and (2005/06), at one location in Van Province on 13 barley cultivars. The trials were set in a randomized block treatment in 4 replicates. The results showed significant differences at the tested traits among barley genotypes. The number of days to earing barley ranged from 179.3 to 189.7; the number of spikes per m^{-2} was 249.3–560.7; stem length 51.2–64.9 cm; ear length 5.83–7.26 cm; number of kernels per ear 16.32–20.24; kernel weight per ear 0.73–0.99 g; weight of 1,000 kernels 41.7–46.32 g; grain yield 197.3–319.7 kg ha^{-1} and harvest index ranged from 23.11% – 36.43%.

Pouraboughadareh et al. (2013) examined the tolerance of certain barley genotypes to water shortage in field conditions. The surveys were carried out at western Azerbaijan in two production years (2011 and 2012), on seven genotypes and five barley lines. The experiments were set in a randomized block treatment with four replicates, in conditions of lack of water and optimal conditions. Analysis of variance ($p \leq 0.01$) showed significant differences between genotypes and populations for all tested traits except for1,000 kernel weight. It showed significant effects of stress on water deficiency on all tested traits. The interaction of the stress effect from water deficiency x genotype was also significant ($p \leq 0.01$) for all examined traits (Kendal et al., 2019; Oral et al., 2019). Therefore, it is essential to develop high yield varieties which are physiologically and morphologically compatible with different environmental conditions (Kendal et al., 2019; Oral et al., 2019).

Karahan & Akgun (2020) of this study showed that the GYT approach puts too much weight on yield relative to other traits. However, this approach can be used in other crops studied based on multi-location, multi-years with multi-traits.

Arshadi et al. (2018) write that when it comes to the interaction between genotype and the environment, there are varieties with exceptional adaptability to smaller, homogeneous areas and varieties with a wide range of adaptation that can be grown in more expansive areas. Researchers often perform experiments in → an extensive range, and base their decision mainly on the average values of the genotype, neglecting the interaction (Babic, 2006). Ideal varieties are those with high grain yield and appropriate adaptability to various of environmental conditions (Dawson et al., 2007). Mirosavljevic et al. (2015) given the data, it can be concluded that in years with increased spring precipitation, sowing of medium early and late varieties of winter barley allows better accumulation of dry matter, and higher grain yields are achieved.

It has long been recognized that wheat productivity and quality of seed vary considerably as a result of genotype, environment and their interaction, which describe most agronomic traits, their affectedness by the growing environment, as well as by genetic factors (Ahmadi et al., 2012; Doehlert & McMullen, 2000; Doehlert et al., 2001).

Previous research has been empirical and has not dealt much with the nature of genotype responses to external stress conditions. Basford & Cooper (1998) and Voltas et al. (2002) highlight two groups of methods on G × E interaction depending on the level of understanding of genotypes and external environments. The first group consists of empirical models that do not provide a biological basis for interpreting the interaction. This group includes a large number of regression models. The second group consists of analytical models that provide a biological basis for explaining the interaction and explain the interaction as a complex problem that is a function of many climatic, genetic, morphological, phenological and physiological variables. This group includes multivariate models. Of the climate variables, precipitation and temperature have the most significant influence on barley yield, so they are also the most responsible for the interaction in barley (Voltas et al., 1999).

The aim of this study is to single out superior genotypes by yield and examined yield components that show minimal interaction, ie. high stability, and as such recommended for expansion in production or as parental components in future breeding programs.

MATERIALS AND METHODS

Study area

Field trials were conducted during two years (2016/2017 and 2017/2018) at two locations: Gradiska (N 45°01´48´´; E 17°32´52´´) and Bijeljina (N 44°4´25´´; E 19°14´14´´) in dry farming conditions. Nine winter barley genotypes were included in the study using the *Randomized Complete Block Design method (RCBD)*.

Chemical analysis of the soil was done before setting up the experiment when soil samples were taken at both sites (Table 1). It can be seen from the attached that both plots were suitable for growing small grains or barley. The amounts of nutrients were equal at both sites in both examined years (162 kg ha^{-1} of pure N; 60 kg ha^{-1} P_20_5 and 60 kg ha^{-1} K_2O). After chemical analysis of the soil, it was determined that the needs for phosphorus and potassium were not met at any locality, that the examined genotypes were in different production conditions when it comes to the amount of nutrients in the soil.

Table 1. Data of chemical analyses of soil

	Depth of sampling	pH		humus	P_20_5	K_2O
Locality		H_20	KCl	%	$mg/_{100g}$	$mg/_{100g}$
Gradiska	0–30 cm	6.00	5.00	2.90	15.9	14.9
Bijeljina	0–30 cm	6.49	5.39	2.53	5.0	19.1

Experimental design and data collection

Data of climatic characteristics for both localities were processed through climatic diagrams according to *Walter* (Fig. 1) and (Fig. 2) with the aim of better overview and comparison of these data. Fig. 1 shows the climate diagram for the Gradiska locality, which shows that the critical period for growing small grains in 2016/17 was during June.

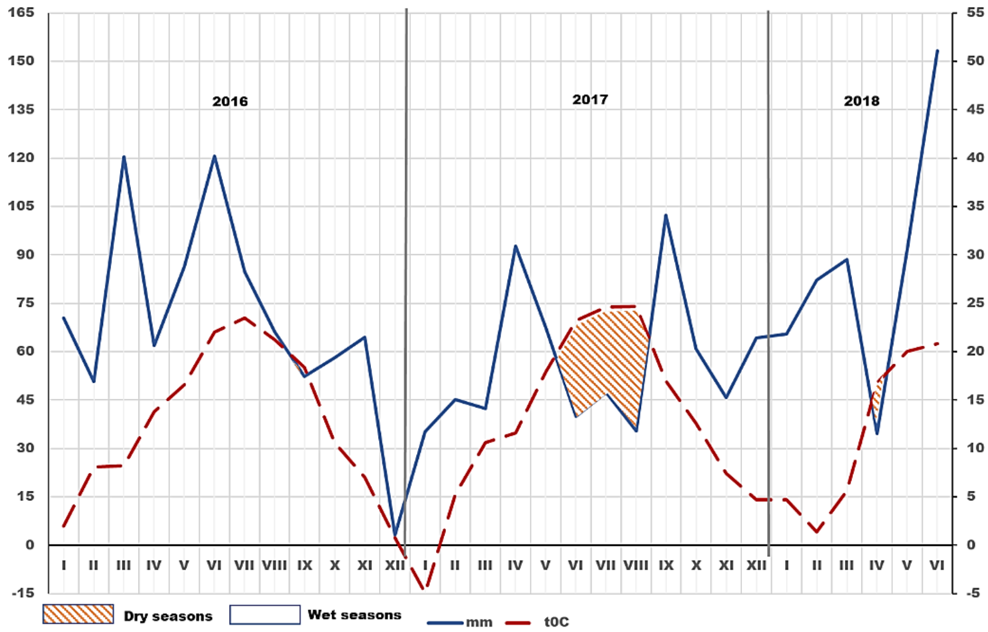

Figure 1. Climate diagram by *Walter* for Gradiska.

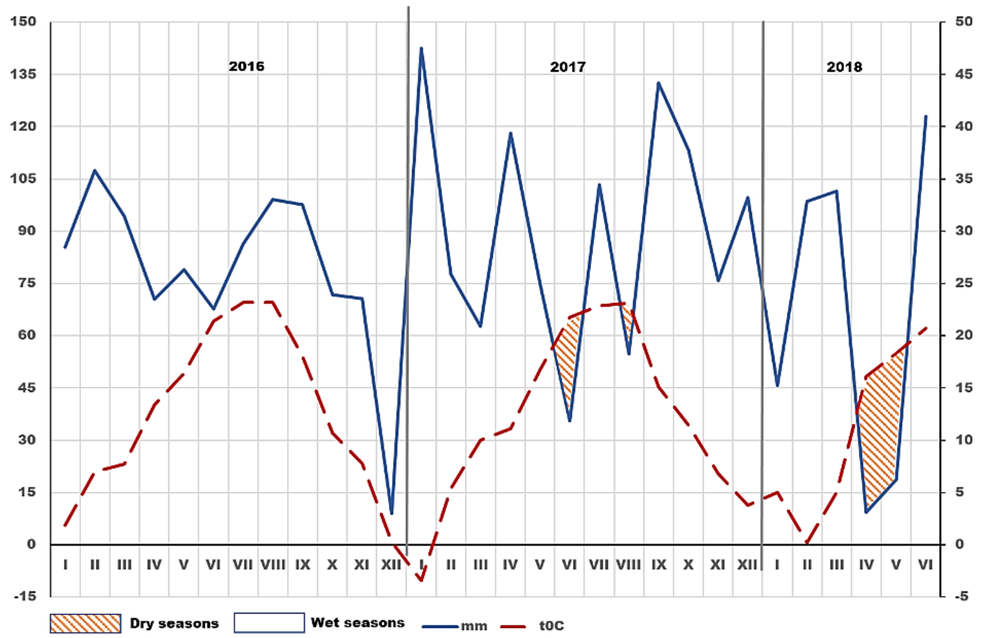

Figure 2. Climate diagram by *Walter* for Bijeljina.

When this is compared with the data from Fig. 2, which shows the climate diagram for the Bijeljina site, where it can be seen that in the same study year the drought period lasted during May, June and July, it can be concluded that for 2016/17 the Gradiska site had better, ie. more humid production conditions. When analyzing the year 2017/18, the climate diagrams from both locations show that during the spring there was a period of drought. The drought period at the Bijeljina site lasted during April and at the Gradiska site significantly longer, during April, May and June. In the soil of the Gradiska locality, gravel is present, and the water seeps faster, therefore this locality had more arid production conditions to the Bijeljina locality.

The trials were set in two vegetation seasons by a randomized block system in four replications. The size of the experimental unit was 2 m^2 (2×1 m).

Measured parameters for cluster analysis are: number of sprouted plants m^2, number of overwintered plants per m^2, height of whole plant, ear length, number of grains per ear, grain weight per ear, total mass, grain yield, straw yield, harvest index, hectoliter kernel mass, seed germination energy, total germination, 1,000 kernel weight and protein content.

Analytical methods

Measurement results were statistically processed. The results of biometric measurements were processed by PC applications for Windows: *Statistical Package for Social Sciences*, *StatSoft Statistica* and *Excel*. The results of the studied properties were processed by analysis of variance (*ANOVA*) by a computational program using the *GLM* procedure. The *Duncan's Multiple Range Test (DMRT)* was used to determine the significance of differences between genotypes and their ranking for significance levels $R = 0.01$. Grouping of data of examined traits by similarity was performed based on hierarchical cluster analysis. The evaluation of the divergence of the tested material was performed using the *UPGMA (unweighted pair-group method using arithmetic averages)*.

RESULTS AND DISCUSSION

The number of grains per ear is a trait formed during the vegetative phase and depends on the environmental conditions in which the morphogenesis of generative organs takes place during the process of ontogenesis. Arisnabarreta & Miralles (2008a) consider that the critical period for grain formation in six-row forms is 30 days before flowering, and the number of fertile ear is affected by the amount of assimilates available to the ear in the early stages of its development, Arisnabarreta & Miralles (2008b).

Grain yield of barley is strongly positively correlated with the number of kernels per ear than with kernel size (Gallagher et al., 1975). The number of kernels per ear is a very important component of the yield that is formed during the vegetative phase and depends on the environmental conditions in which the morphogenesis of generative organs takes place during ontogenesis. The increase yield of barley is conditioned by the increase the number of grains per ear (Barczak & Majcherczak, 2009), and the high number of grains per ear can compensate for the reduced number of ears and plants per unit area (Schillinger, 2005).

Between two-row and six-row forms, a statistically significant difference was obtained in the average number of kernels per ear 27.5 versus 53.4. Similar results are obtained the other authors (Przulj et al., 2001; Zare et al., 2011; Przulj & Momcilovic, 2012). The number of kernels per ear is the most important criterion in breeding barley to increase yield (Dofing & Knight, 1994).

Observing the average values of the number of grains per ear of nine examined barley genotypes from Table 2, it is evident that for the 2016/17 examined year, the average value of all genotypes from the Gradiska locality is lower compared to the Bijeljina locality. Genotype 9, had the highest value of the tested trait for 2016/17 at both localities, while genotype 1, had the lowest value of this trait for the first examined year at the Gradiska locality, and genotype 7 at the Bijeljina locality.

Table 2. Average values of the number grain per spike

Year	2016/17			2017/18		
Genotype	Gradiska	Bijeljina	$\bar{x}$	Gradiska	Bijeljina	$\bar{x}$
1	21.4	25.8	23.6	21.3	23.7	22.5
2	48.5	50.0	49.2	32.1	38.8	35.4
3	39.3	54.2	46.7	31.3	41.0	36.1
4	23.8	27.8	25.8	22.9	27.5	25.2
5	22.6	27.2	24.9	22.0	22.3	22.2
6	26.4	29.8	28.1	21.9	28.8	25.3
7	22.8	23.5	23.1	20.7	22.3	21.5
8	48.1	48.4	48.2	35.3	51.2	43.3
9	**49.6**	**59.2**	**54.4**	**45.2**	**49.2**	**47.2**
$\bar{x}$	33.6	38.4	36.0	28.1	33.8	31.0

When looking at average values by genotypes for both locations for the first test year, it is seen that genotype 9 had the highest and genotype 7 and genotype 1, the lowest value of the tested trait. In 2017/18, the average number of grains per ear of all genotypes for the locality Gradiska was also lower compared to the locality Bijeljina.

The highest value of the examined trait for this production season also had genotype 9 and the lowest, at the locality Gradiska, genotype 7, and at the locality Bijeljina genotypes 7 and 5. According to the average values of this trait by genotypes for both locations, the highest average value per ear it had genotype 9 while the lowest value had genotype 7. From this, it can be concluded that genotype 9 showed the best characteristics for this trait for the examined years while genotype 7 showed the worst. In the 2016/17 examined year, the total average mean value of all genotypes of this trait for both localities was 36.0 and was is higher than the total average mean value of all genotypes of the same for the 2017/18 investigated year 31.0.

Al-Tabbal & Al-Fraihat (2012) on 86 barley genotypes had an average value of this trait of 51.9, the minimum mean value of the number of grains per spike was 36.7 and the maximum 73.3. In studies by Garcia de Moral et al. (2002) at six barley genotypes, the mean values of this trait ranged from 18.6 to 23.5 for two-row barley and from 26.1 to 37.6 for six-row barley per spike.

According to the analysis of variance for the number of grains per ear of nine barley genotypes for two localities and two examined years (Table 3), it was determined that year (A), location (B), genotype (C) and year x genotype interaction (AxC) had statistically highly significant influence ($p < 0.01$) on this examined property. The interaction of sites x genotype (BxC) and the interaction of years x sites x genotype (AxBxC) showed a statistically significant influence ($p < 0.05$) on the examined trait.

The year x location interaction factor (AxB) did not have a statistically significant effect on the number of grains per ear.

Table 3. Analyze variance of kernel number per ear of nine types of winter barley

Source of variations	SS	Df	MS	F
Treatment	19,885.6[a]	35	568.2	**31.7****
Year (A)	919.1	1	919.1	**51.2****
Location (B)	1,008.1	1	1,008.1	**56.2****
Genotype (C)	16,551.7	8	2,069.0	**115.3****
Year x Location (AxB)	8.5	1	8.5	0.5 [ns]
Year x Genotype (AxC)	679.3	8	84.9	**4.7****
Location x Genotype (BxC)	360.4	8	45.0	**2.5***
Year x Location x Genotype (AxBxC)	358.5	8	44.8	**2.5***
Error	1,937.8	108	17.9	
Total	183,199.6	144		

Significantly: $p < 0.01$**; $p < 0.05$*; ns no significantly.

Fig. 3 shows the results of the *Duncan test* in the differences in the range of grain number per ear between the examined years (factor A) for nine barley genotypes at two localities in the two examined years. The examined 2016/17 year (interval A) had a higher total average value of all genotypes from both localities of this examined trait compared to the total average value of all genotypes from both localities of the examined trait in 2017/18 (interval B). The graph shows that the *Duncan test* showed a statistically significant difference between the interval A and the interval B for factor A for the characteristic number of grains per ear.

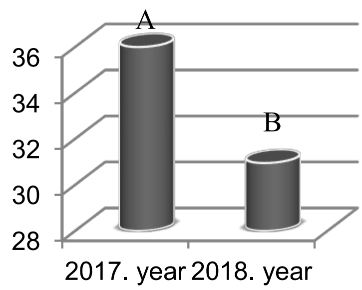

Figure 3. Differences in the range of the number of grains per class between the examined years (factor A).

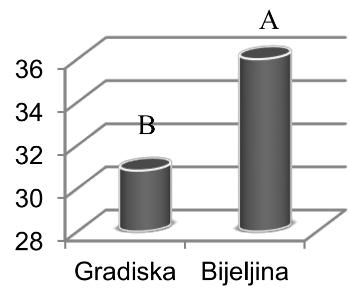

Figure 4. Differences in the range of the number of grains per class between the examined locations (factor B).

The total average value of all genotypes of the examined trait for the Gradiska locality was lower to the Bijeljina locality for both examined years. This can be seen from Fig. 4, where the total average value of the tested trait from Gradiška is marked by the interval B and the higher total average value from Bijeljina is marked by interval A. After comparing the differences of the number of grains per ear between the tested localities year, Duncan's test showed a statistically significant difference between the interval A and the interval B for factor B for the property number of grains per ear.

If we observe differences in the rank of the number of grains per ear between the examined genotypes (factor C), it is noticed that the results of the total mean values of the examined trait by genotypes, according to Duncan's test, are classified into five intervals (Fig. 5). Interval A belongs to genotype 9 which had the highest total average value of the examined trait and its mean value by localities in the two examined years for the number of grains per ear differs statistically significantly from other genotypes.

Genotype 7, which had the lowest mean value of the tested trait, belongs to the interval E and there are no statistically significant differences between it, genotypes 1, 4 and 5. Between genotype 8 and genotype 2 there are no statistically significant differences in mean values of number of grains per ear as and between genotypes 2 and 3.

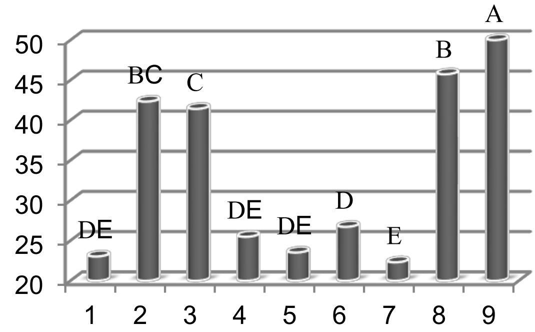

Figure 5. Differences in the range of number of grains per class between the examined nine genotypes (factor C).

Genotypes interaciton

At the interaction of year x genotype for the trait number of grains per ear for examined genotypes, locations and years, Fig. 6 shows that during the first production year the average values of the number of grains per ear by genotypes were higher than in the second production year.

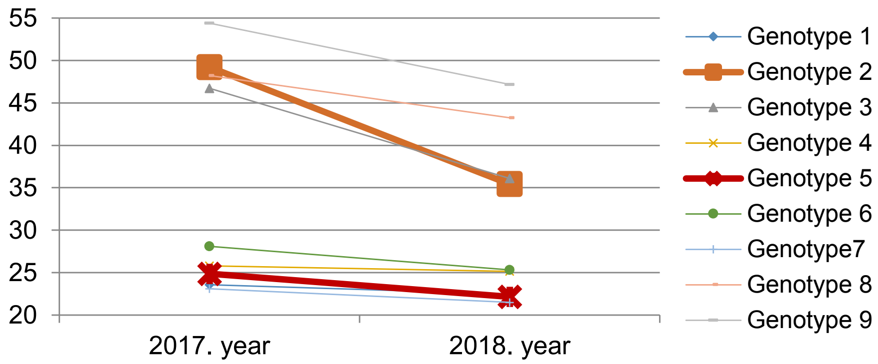

Figure 6. Number of grains per ear - interaction years of investigation x genotype.

Fig. 6 shows that in some genotypes, such as genotype 2 and genotype 3 visible large variation in mean values by localities, so the interaction of years x genotype had a statistically highly significant impact on them for the number of grains per ear. It can be noticed that genotype 4 has the opposite tendency of the mean value of ear length to the years of testing, and the mean values of the examined trait of genotype 5 also deviate from the central tendencies, so they have a strong influence of year x locality interaction. Genotype 9, with the highest mean value of the examined trait, does not interact with any mean value of other genotypes. Genotypes 1 and 5 interact with each other, looking at the mean values of the examined trait by years, they have approximate values as genotype 7, but they do not interact with it. Genotypes 6 and 4 interact with each other and act independently of the values of other genotypes. Genotype 2 interacts with genotypes 8 and 3, while genotypes 8 and 3 do not interact and the year x genotype interaction is not statistically significant for the examined trait.

Fig. 7 shows that at the Gradiska locality the mean values of the number of grains per ear for the examined genotypes in the two-year period were lower in relation to the Bijeljina locality. Variations among the mean values of genotypes by localities were different. When observing the behavior of mean values of genotypes in interaction with localities, it is realized that genotype 9 had the highest mean value of the examined trait and does not interact with any mean value of another genotype. The lowest mean value by localities has genotype 7, which interacts with genotype 1 and genotype 5, and there is a statistically significant influence of the interaction of local x genotype on this trait in the mentioned genotypes.

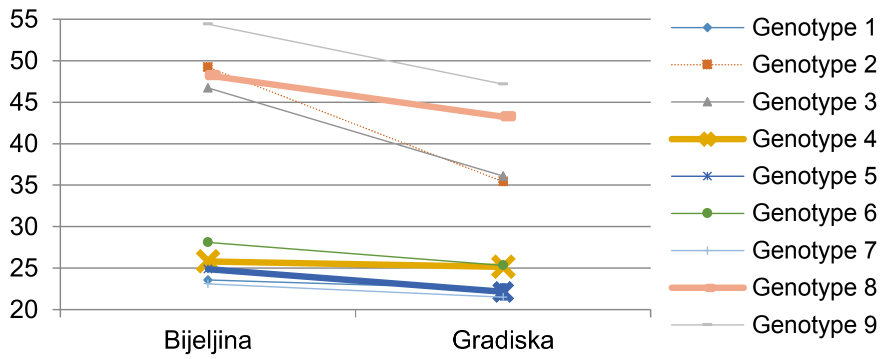

Figure 7. Number of kernels per ear - interaction locality x genotype.

The largest oscillations in the mean value of this trait show genotype 3, genotype 4, genotype 5 and genotype 8 whose mean values of the examined trait vary significantly by localities. Genotype 4 and genotype 6 have mean values of the number of grains per ear. They are also in interactions and have a statistically significant effect of locality x genotype interaction on this trait. There is no interaction with other values of the examined genotypes. The influence between them is not statistically significant. According to the mean values of the number of grains per ear, genotype 2 interacts with genotype 8 and genotype 3 and interacts locality x genotype. For this trait, the statistical difference between them is highly significant, and genotype 8 genotype 3 are not in interaction, and the interaction of locality x genotype between them is not statistically significant.

Fig. 8 shows the relationships between the examined genotypes in the interaction of years x locality x genotype. Table 2 shows that the highest mean value of the number of grains per ear of all genotypes was recorded at the locality Bijeljina 2016/17, then Bijeljina 2017/18, then Gradiska 2016/17 and the lowest at the locality Gradiska in the 2017/18 examined year. Figure 8 shows that the highest mean value of the examined trait was genotype 9 at the Bijeljina site in 2016/17, but the mean value from the Gradiska site in 2016/17 was higher compared to the same from the Bijeljina site in 2017/18. The mean value from the Gradiska 2017/18 locality differs significantly in this genotype compared to other locations. Such a case also resulted in genotype 8, where the mean value of the number of grains per ear is significantly lower at the locality Gradiska 2017/18 compared to the mean values from other locations. The strong influence of the interaction and the influence of the locality on the examined property can be seen here.

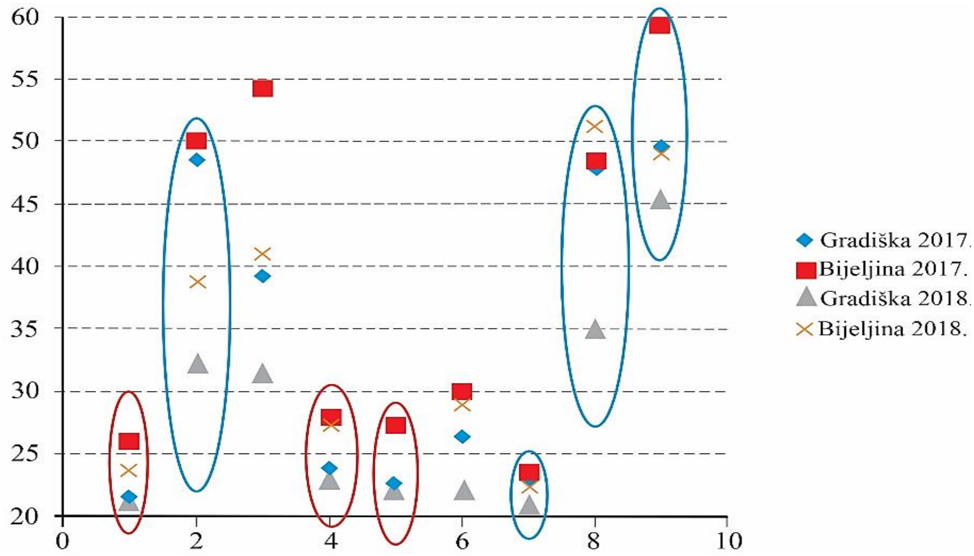

Figure 8. Number of kernel per ear- interaction of tested years x locality x genotype.

The opposite case is with genotype 1, genotype 4, genotype 5, genotype 6 and genotype 7 where the average values of the number of grains per ear from the locality Gradiska 2017/18 do not vary significantly compared to the mean values from other localities. Genotype 8 also deviates from other genotypes since the highest mean value of the examined trait was recorded at the Bijeljina locality in 2017/18, unlike other genotypes whose highest values of number of grains per ear were recorded at the Bijeljina 2016/17 locality. If you look at the mean values by genotypes, it can be seen that they can also be ranked into two groups. Genotype 1, genotype 4, genotype 5 and genotype 7 have approximate mean values of the tested trait for all localities and significant deviations from the average values of genotype 2, genotype 3, genotype 8 and genotype 9. From all the above we can see the strong influence of year x locality x genotype for the test trait.

Cluster analysis

Cluster analysis groups the examined genotypes by similarity based on the examined traits. Cluster analysis is the name for a group of multivariate techniques whose primary purpose is grouping based on certain characteristics that measurement objects possess.

The grouped observations should show a high internal similarity within each cluster as well as a high external difference between the derived clusters.

Fig. 9 shows the grouping by cluster analysis of nine barley genotypes at both localities in a two-year period based on the values of all examined traits. There is an evident existence of two large clusters. The first group consists of genotype 4 and genotype 7. The second group includes genotype 8 and genotype 9. The third group includes genotype 2 and genotype 5, genotype 1 and genotype 6, which are further grouped into cluster number 1. Cluster number 2 includes only genotype 3 which means that the values of all examined traits of genotype 3 are different in relation to the same values of all other genotypes belonging to one cluster.

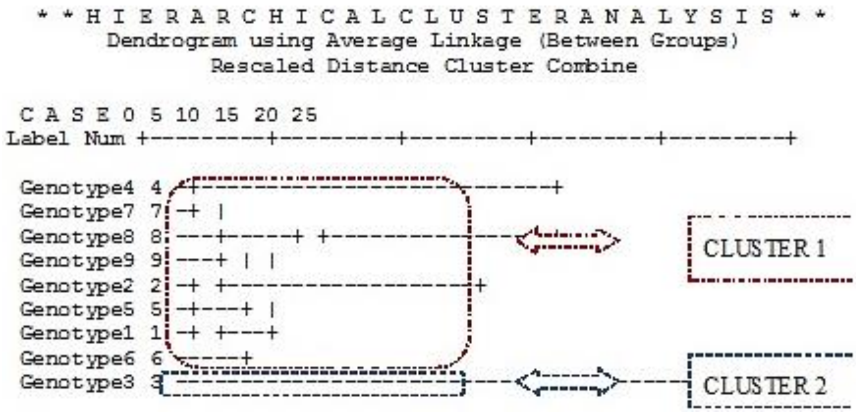

Figure 9. Cluster for nine barley genotypes at two localities in a two - year period.

The cluster of nine genotypes of barley at the Gradiska site in a two-year period based on the values of all examined traits is shown in Fig. 10. The presence of two main clusters can be observed here. The first group consists of genotypes gathered around the values of genotype 5, namely genotypes 1, 6, 5 and 4, and the second group consists of genotypes 7, 2 and 9. These groups are further grouped into cluster number 1. In cluster number 2 include genotype 3 and 8.

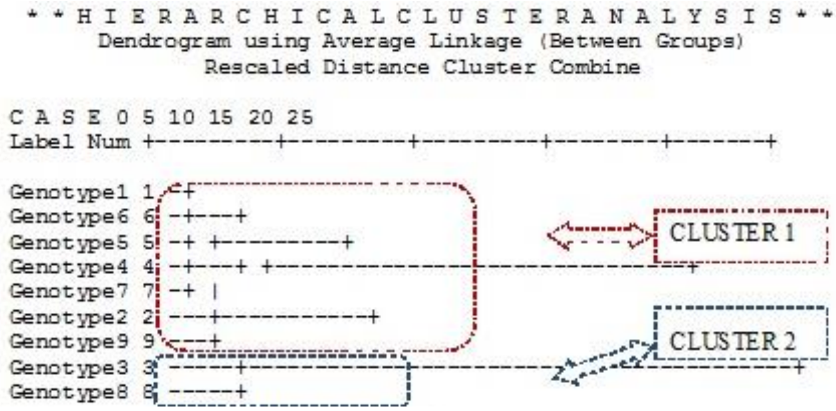

Figure 10. Cluster for nine barley genotypes at the Gradiska locality in a two - year period.

Fig. 11 shows a cluster of examined genotypes for the Bijeljina locality in a two-year period. The presence of two main clusters was observed here. Genotype 1 and genotype 9 have similar test values and belong to the same group while genotypes 5, 3 and 8 form a different group. These two groups are grouped into the first large cluster. Genotypes 2, 4 and 7 are grouped around the values of the examined traits of genotype 6 and form a second cluster.

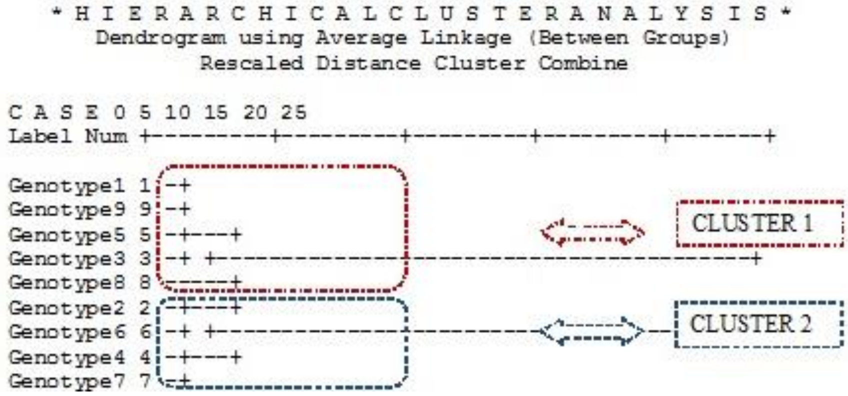

Figure 11. Cluster for nine barley genotypes at the Bijeljina locality in two years.

The cluster for nine barley genotypes at two localities for the first examined year is shown in Fig. 12. The first group is concentrated around the values of all examined traits of genotype 5. This group consists of genotypes 6, 7 and 4, which is the first cluster. The second group consists of genotypes 8, 9, 2 and 3 and the third, genotype 1. They are further grouped into cluster number 2.

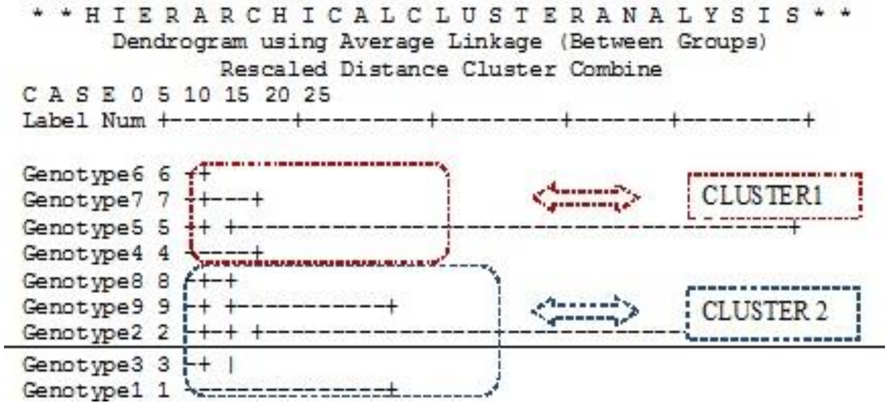

Figure 12. Cluster for nine barley genotypes at two localities in the 2016/17 vegetation seasons.

Fig. 13 shows the cluster for nine barley genotypes at two localities in the surveyed 2017/18. years. The presence of two clusters was noted. The first group according to the similarity of the values of all tested traits consists of genotypes 1, 8, 5 and 6, and the second genotypes 9, 2, 4 and 7. These two groups are combined into the main cluster no. 1. The second cluster belongs to genotype 3, which with its values of all examined traits, significantly deviates from the values of genotypes from cluster no.1.

From the cluster analysis, it can be concluded that genotype 5 is positioned quite well according to the examined values. This genotype on each chart belonged to the first cluster with higher values of the examined traits. This means that in the examined years and at the examined localities it showed standard values. Genotypes 4, 6 and 7 belonged to the first cluster on all graphs except the cluster for the Bijeljina locality, while genotype 9 was also positioned in the first cluster according to the localities in 2017/18. It was only positioned in the second cluster in 2016/17. Genotypes 2 and 8 varied a lot, and genotype 3, according to the values of the examined traits, belongs to the second cluster on all graphs except for the locality of Bijeljina.

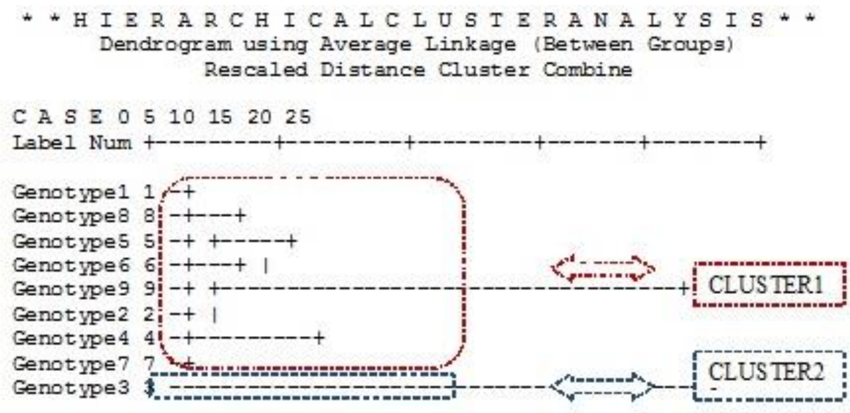

Figure 13. Cluster for nine barley genotypes at two localities in the 2017/18 vegetation Seasons.

CONCLUSIONS

The highest total average grain yield at both sites and both years of testing was achieved by genotype 3 (8,767.99 kg ha^{-1}), and the lowest genotype 7 (6,075.85 kg ha^{-1}), which is significantly higher than the average yield in production in our country (3150 kg ha^{-1}). This has shown that, with the selection of quality genotypes, the application of quality agrotechnics in our agroecological conditions, the yield can be raised.

The determined interaction parameters show no interaction relations between the examined years to individual localities. There is a statistically significant interaction relationship between location and genotype, as well as between location, genotype, and year. A highly significant interaction effect was observed between year and genotype.

UPDMA cluster analysis was used to construct a dendrogram which classified 9 genotypes into two main groups. Based on the cluster analysis, genotype 3 is separated into a separate cluster. The highest yield was achieved with this genotype, so it can be stated that in this way a genotype with better characteristics can be identified.

REFERENCES

Ahmadi, J., Mohammadi, A. & Mirak, T.N. 2012. Targeting Promising Bread Wheat (*Triticum aestivum* L.) Lines for Cold Climate Growing Environments Using AMMI and SREG GGE Biplot Analyses. *J. Agr. Sci. Tech*. **14**, 645–657.

Al-Tabbal, J. & Al-Fraihat, A. 2012. Genetic variation, heritability, phenotypic and genotypic correlation studies for yield and yield components in promising barley genotypes. *Journal of Agricultural Science* **4**(3), 193–210.

Annicchiarico, P. 2002. Genotype 9 Environment interactionschallenge and opportunities for plant breeding and cultivar recommendations. *FAO Plant production and protection paper*, 174.

Arisnabarreta, S. & Miralles, D.J. 2008a. Critical period for grain number establishment of near isogenic lines of two - and six - rowed barley. *Field Crops Res.* **107**, 196–202.

Arisnabarreta, S. & Miralles, D.J. 2008b. Radiation effects on potential number of grains per aer and biomass partitioning in two - and six - rowed near isogenic barley lines. *Field Crops Res.* **107**, 203–210.
Arshadi, A., Karami, E., Sartip, A., Zare, M. & Rezabakhsh, P. 2018. Genotypes performance in relation to drought tolerance in barley using multi-environment trials. *Agronomy Research* **16**, 1–17.
Babic, V. 2006. *Evaluation of genotype × environment interaction for grain yield of commercial ZP maize hybrids.* Master's thesis. University of Novi Sad. Procena interakcije genotip × sredina za prinos zrna komercijalnih ZP hibrida kukuruza. Magistarska teza. Univerzitet u Novom Sadu (in Serbian).
Barczak, B. & Majcherczak, E. 2009. Effect of varied fertilization with sulfur onselected spring barley yield structure components. *Journal of Central European Agriculture* **9(2008) No 4**, 777–784.
Basford, K.E. & Cooper, M. 1998. Genotype x environment interaction and some consideration of their implication for wheat breeding in Australia. *Australian Journal of Agricultural research* **49**, 153–174.
Cattivelli, L., Ceccarelli, S., Romagosa, I. & Stanca, M. 2002. *Abiotic stresses in barley: Problems and solution*. Barley: Production, Improvement and Uses, 282–302.
Ceccarelli, S. 1996. *Positive interpretation of genotype by environment interactions in relation to sustainability and biodiversity*. In: Cooper M, Hammer GL (eds) Plant adaptation and crop improvement. CABI, Wallingford, UK, 467–486.
Dawson, I.K., Guarino, L. & Jaenicke, H. 2007. Underutilised plant species: impacts of promotion on biodiversity: Position paper *No.* **2**. *The International Centre for Underutilised Crops*.
Doehlert, D.C. & McMullen, M.S. 2000. Genotypic and environmental effects on oat milling characteristics and groat hardness. *Cereal Chem* **77**, 148–154.
Doehlert, D.C., McMullen, M.S. & Hammond, J.J. 2001. Genotypic and environmental effects on grain yield and quality of oat grown in North Dakota. *Crop Sci.* **41**, 1066–1072.
Dofing, S. & Knight, C.W. 1994. Yield Component Compensation in Uniculm Barley Lines. *Agronmy Journal* **86**, 273–276.
Ebdon, J.S. & Gauch, H.G.Jr. 2002. Additive main effect and multiplicative interaction analysis of national turfgrass performance trials. *Crop sci.* **42**, 489–496.
Gallagher, J.N., Biscoe, P.V. & Scott, R.K. 1975. Barley and its environment V. stabillity of grain weight. *Journal of Applied* ***ECO-o1-2Y***, 19–336.
Garcia del Moral, L., Belen Garcia del Moral, M., Molina-Cano, J. & Slafer, G. 2002. Yield stability and development in two and six-rowed winter barleys under Mediterranean conditions. *Field Crops Research* **81**(2003), 109–119.
Glamoclija, D. 2004. *Posebno ratarstvo*. Draganic, 309 pp.
Hasanuzzaman, M., Hossain, M.A., Teixeira da Silva, J.A. & Fujita, M. 2012. *Plant response and tolerance to abiotic oxidative stress: antioxidant defense is a key factor* V. Bandi, A.K. Shanker, C. Shanker, M. Mandapaka (Eds.), *Crop Stress and its Management: Perspectives and Strategies. Springer,* The Netherlands, 261–315.
Hossain, A., Lozovskaya, M.V., Zvolinsky, V.P. & Tutuma, N.V. 2012. Effect of soil resources and climatic factors (temperature) on spring wheat and barley in the northern Bangladesh and southern Russia. *International scientific and practical conference on problems of environmental management and conservation of ecological balance in the arid zones‖. Salt Zaymische, Chorniarsky district, Astrakhan State, Russia, from 16–18 May. Hunt R.G.* (1978): Plant growth analysis. Edward Arnold
Hühn, M. 1990. *Nonparametric estimation and testing of genotype × enviroment interactin by ranks*. In: M.S. Kang (eds) Genotype by Enviroment Interaction and Plant Breeding. Louisiana State University Agricultural Center. USA, pp. 69–93.

Jana, S. & Wilen, R.W. 2005. *Breeding for abiotic stress tolerance in barley*. In: M. Ashraf, and P.J.C. Harris, eds. Abiotic Stresses. Plant Resistance Through Breeding and Molecular Approaches, pp. 491–511. Haworth Press, New York. Jones, H.G. (1983).

Kang, M.S. 1990. *Genotype by Enviroment Interaction and Plant reeding*. Louisiana State Univerity Agricultural Center, Baton Rouge, Louisiana, 221–243.

Karahan, T. & Akgun, I. 2020. Selection of barley (*Hordeum vulgare*) genotypes by GYT (genotype × yield × trait) biplot technique and its comparison with GT(genotype × trait). *Applied Ecology and Environmental Research* **18**(1), 1347–1359.

Kaydan, D. & Yagmur, M. 2007. A research on yield components of some two rowed barley varieties (*Hordeum vulgare* convar. *distichon)* in Van ecological conditions. *Journal of agricultural science* ISSN: 1300-7580, 269–278.

Kendal, E., Karaman, M., Tekdal, S. & Doğan, S. 2019. Analysis of promising barley (*Hordeum vulgare* L.) lines performance by AMMI and GGE biplot in multiple traits and environment. *Applied Ecology and Environmental Research* **17**(2), 5219–5233.

Mirosavljevic, M., Przulj, N., Momcilovic, V., Hristov, N. & Maksimovic, I. 2015. Dry matter accumulation and remobilization in winter barley as affected by genotype and sowing date. *Genetika* **47**(2), 751–763.

Oral, E., Kendal, E., Kilic, H. & Dogan, Y. 2019. Evolation barley genotypes in multi-environment trials by AMMI model and GGE biplot analysis. *Fresenius Environmental Bulletin* **28**(4A), 3186–3196.

Pouraboughadareh, A., Naghavi, M. & Khalili, M. 2013. Water deficit stress tolerance in some of barley genotypes and landraces under field conditions, *Not Sci Biol.* **5**(2), 249–255.

Przulj, N. & Momcilovic, V. 2012. Spring barley performances in the Pannonian zone. *Genetika* **44**(3), 499–512.

Przulj, N., Momcilovic, V. & Mladenov, N. 2001. Dynamics of grain filling of winter two-row barley. Proceedings of the Institute for Agriculture and Vegetables. Dinamika nalivanja zrna ozimog dvoredog jecma. *Zbornik radova Instituta za ratarstvo i povrtarstvo*, Novi Sad **35**, 175–184 (in Serbian).

Schillinger, W.F. 2005. Tillage method and sowing rate relations for dryland spring heat, barley and oat. *Crop Sci.* **45**, 2636–2643.

Stanca, A.M., Romagosa, I., Takeda, K., Lundborg, T., Terzi, V. & Cattivelli, L. 2003. *Diversity in abiotic stresses*. In R. von Bothmer, H. Knüpffer, T. Van Hintum and K. Sato (eds.). Diversity in Barley (*Hordeum vulgare* L.). *Elsevier*, Amsterdam, pp. 179–199.

Tester, M. & Langridge, P. 2010. Breeding Technologies to Increase *Crop Production in a Changing World. Science (American Association for the Advancement of Science)* **327**(5967), 818–822.

Voltas, J., van Eeuwijk, F.A., Igartua, E., Garcia del Moral, L.F., Molina-Cano, J.L., Romagosa, I. 2002. Genotype by environment interaction and adaptation in barley breeding: basic concepts and methods of analysis. In: Slafer, G.A., Molina-Cano, J.L., Savin, R., Araus, J.L. and Romagosa, I. (eds.). *Barley Science: Recent Advances from Molecular Biology to Agronomy of Yield and Quality*. Haworth Press, Binghamton, NY., pp. 205–241.

Voltas, J., van Eeuwijk, F.A., Sombrero, A., Lafarga, A., Igartua, E. & Romagosa, I. 1999. Integrating statistical and ecophysiological analysis of genotype by environment interaction for grain fi lling of barley in Mediterranean areas I. Individual grain weight. *Field Crop Res*. **62**, 63–74.

Zare, M., Azizi, M.H. & Bazrafshan, F. 2011. Effect of drought stress on some agronomic traits in ten barley (*Hordeum vulgare*) cultivars. *Tech. J. Eng. Pplied Sci*. **1**, 57–62.