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GENOTYPE × ENVIRONMENT INTERACTION AND GRAIN YIELD STABILITY IN DURUM WHEAT GENOTYPES

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Abstract

The aim of this study was to establish the genotype by environment interaction for grain yield and the phenotypic stability of 27 durum wheat genotypes. The study was conducted on the experimental field of the Field Crops Institute - Chirpan. The studied genotypes were set in a randomized block design in four replications with replication size of 15 m². The trait yield for 27 varieties has been observed during a three-year period (2015-2017). The local growing technology for durum wheat was applied. Analysis of variance, stability analysis and cluster analysis were used. Significant influence of genotype, environment(year) and genotype by environment interactions on the grain yield was established. The environment(year) has the greatest influence on the expression of grain yield. According to the simultaneous assessment for high yield and stability by Kang, genotypes were ranked as follows: D-8159, D-8148, Reyadur, Saya, D-8032, D-8031, D-8036, D-8040 and D-8091. From the obtained results it is possible to create a strategy for increasing the yield of durum wheat and create new stable varieties.

Key words*: durum wheat, genetic distance, genotype by environment, grain yield, phenotypic stability.*

INTRODUCTION

Agricultural products and especially cereals provide about 20% of human calories and protein worldwide. Durum wheat products are used entirely for human nutrition and are suitable for people with various dietary needs. The yield has a complex structure of different components, all of which show quantitative inheritance due to polygenic systems (Vaezi et al., 2000; Foroozanfar & Zeynali, 2013). The increasing wheat productivity is an important step in feeding a rapidly growing population (Rizkalla et al., 2012). This can be achieved by creating new high-yielding varieties and applying new technologies in their cultivation. The new varieties should show higher values of yield and its components. The breeding for stable yields is also important, it allows genotypes to be grown more widely in different conditions. The purposeful breeding activity for the improvement of durum wheat in Bulgaria began in the 30s of the last century at the Field Crops Institute - Chirpan. Since then, a large number of varieties have been created, through which the yield potential of the culture in our country has been constantly increased.

Studies of wheat genotypes in different weather conditions is the main method for determining their stability and adaptive potential. The development and creation of genotypes with high adaptive potential is a major goal of breeding programs. When changing the growing conditions, it is possible for phenotypic traits to change their values in different directions. Phenotypic traits of genotypes do not need to show the same values in different agroecological conditions (Ali et al., 2003). Some genotypes perform well in one or two years, but in others they do not perform as well (fail). This is due to the genotype-environment interaction, which affects the stability of the genotype under different conditions (Arshaf et al., 2001). The genotype-environment interaction is important because the environment has a significant role in the manifestation of yielding genotypes under different growing conditions. Shah et al. (2009) found highly significant differences for genotypes on all studied traits, and also noted the interaction of genotypes with location, genotypes with year and genotypes with year and location. The genotype-environment interaction is an important factor in the variation of economic traits (Nurminiemi et al., 2002). The response of different yield genotypes to changing environmental conditions is essential to determine their economic value and their further use as varieties or donors in different breeding programs (Sinebo, 2005).

The assessment of phenotypic stability makes sense only in the presence of a significant genotype-environment interaction (Hussein et al., 2000). There are several types of methods for assessing phenotypic stability, which are mainly divided into variance, regression, nonparametric and parametric. Many of them have been applied to durum wheat in the world and in our country (Rharrabti et al., 2003; Mohamed et al., 2013; Dragov & Dechev, 2015). Some researchers emphasize that the interaction of the genotype with the conditions of the year in terms of yield in durum wheat is most pronounced. According to Mustatea et al. (2009) new high-yielding varieties must have high yields and high stability. Many studies have been conducted to establish the stability of wheat genotypes in different years (Rasul et al., 2006; Parveen et al., 2010; El-Ameen, 2012). Different parameters are known for assessing phenotypic stability (Eberhart & Russell, 1966; Shukla, 1972), but the Kang (YSi) parameter has emerged as the reliable method for simultaneously assessing yield and stability (Kang, 1993).

The present study aims to establish the genotype-environment interaction in grain yield and the phenotypic stability of 27 durum wheat genotypes. Certain parameters for the stability of genotypes will allow the select more stable and better adapted varieties.

MATERIALS AND METHODS

The study was conducted in three consecutive years (2015-2017). In terms of meteorology, 2015 is characterized by higher temperatures and significantly more precipitation than the multi-year norm. The second year of testing 2016 is characterized by higher temperatures and below-normal precipitation compared to the multi-year period. The third year of testing 2017 is characterized by temperatures around the norm and less precipitation compared to the multi-year period. The experiments were based on soil type Pellic Vertisols in field conditions in the experimental field of the Field Crops Institute - Chirpan. The studied genotypes were set by a randomized block desing in four replications with large ones on the experimental plot of 15 m^2. The accepted local technology for growing durum wheat has been applied, and the predecessor is spring peas. The main fertilization is with 10 kg/da of active substance phosphorus and feeding in spring with 10 kg/da of active substance nitrogen. To control wheat and deciduous weeds, a herbicide treating with a combination of two herbicides was carried out.

Explored genotypes with old and new varieties created in FCI - Chipran and the most promising breeding lines: Zvezditsa, Progres, Deyana, Tserera, Beloslava, Vazhod, Deni, Predel, Elbrus, Trakiets, Victoriya, Kehlibar, Raylidur, Saya, Reyadur, D-8161, D-8159, M-674, D-8040, D-8091, D-7763, D-8036, D-8148, D-7553, D-8032, D-8159 and D-8031. All varieties and breeding lines are created in FCI - Chirpan. Some of the varieties were created by the method of experimental mutagenesis, and others by combining breeding. Advanced breeding lines are created by the method of combined breeding.

Grain yield in kg/da was monitored on all genotypes and the obtained results were included in statistical analysis. Analysis of variance (ANOVA) was performed and various stability parameters were calculated: σ^2_i - (Shukla, 1972), S^2_i - (Shukla, 1972), W_i - (Wricke, 1962), YS_i - (Kang, 1993). For the last two analyzes, the Stable program developed by Kang & Magari (1995) was used. The cluster and PC analysis was performed using the software product Statistica 10. The cluster analysis was performed according to Ward (1963).

RESULTS AND DISCUSSIONS

The yield is a major quantitative trait complex formed by all other traits related to his expression. It is a leading trait in breeding programs and its breeding improvement is of paramount importance. The main goal of breeding programs is to obtain varieties with high yield potential (Petrovich et al., 2012).

Yields by year and average for the three years are presented in Table 1. The highest yield in the first year of the study has the line D-8031, the average yield in 2015 was 533.3 kg/da. The highest yield in the second year of research is D-8159, the average value in 2016 was 298.2 kg/da. In the third year of the study, the highest yield was achieved by the line D-8159, and the average yield in 2017 was 586.4 kg/da. The genotypes D-8031, D-8159, D-8032, Reyadur, Saya, D-8148, D-8036 and D-8091 have high yields over 500 kg/da on average for the three years (Table 1).

Table 1. Yield by years and average for three years (2015-2017)

Genotypes	Yield 2015 kg/da	Yield 2016 kg/da	Yield 2017 kg/da	Average yield kg/da
Zvezdtitsa	380.7	206.4	529.3	372.1
Progres	452.9	183.5	512.5	382.9
Deyana	474.0	220.6	562.5	419.0
Tserera	422.7	276.2	599.2	432.7
Beloslava	499.8	179.9	649.7	443.1
Vazhod	501.6	180.7	593.8	425.4
Deni	504.4	225.7	505.5	411.9
D-8161	510.9	357.9	477.8	448.9
Predel	522.0	248.2	584.7	451.6
Elbrus	489.6	256.6	625.3	457.2
D-8195	548.4	321.8	461.7	443.9
Trakiets	547.8	258.8	584.3	463.6
M-674	538.2	302.1	564.0	468.1
Viktoriya	594.4	287.2	505.8	462.5
Kehlibar	542.2	310.9	594.3	482.5
Raylidur	534.9	279.7	659.5	491.4
D-8040	528.7	379.7	592.3	500.2
D-8091	524.9	364.7	666.2	518.6
D-7763	536.9	270.5	632.5	479.9
D-8036	579.3	331.1	604.2	504.9
D-8148	607.3	376.4	646.3	543.3
D-7553	592.7	368.7	535.7	499.0
Saya	588.8	336.7	636.4	520.6
Reyadur	603.5	370.4	626.2	533.4
D-8032	562.7	364.9	626.8	518.1
D-8159	589.1	408.5	681.2	559.6
D-8031	621.8	382.9	576.5	527.1
Mean	533.3	298.2	586.4	472.6
Mean error	11.1	13.4	11.4	9.27

The standard variety Predel has an average value of three years of 451.6 kg/da. The genotypes realized yields over 500 kg/da are the new lines created in FCI-Chirpan and the two relatively new varieties Reyadur and Saya. It is noteworthy that the advanced lines for the most part exceed the standard varietie Predel and are a good basis for creating new durum wheat varieties. Compared to the average yield per year, the third year of testing is the most appropriate, where the genotypes have achieved the highest yields expressed by the average of all of them.

The results of the analysis of variance are represented in Table 2. The calculated F criteria show the presence of significant influence of the environment (781.1**), as well as the genotype - environment interaction (4.38**). Genotypes also have significant influence (2.04**). The environment has the greatest influence on the expression of grain yield with 77% of the total. Genotypes and genotype - environment interactions have an approximately equal share - about 11%. Genotypes have a greater influence. Genotype – environment interaction is significant for the trait grain yield of durum wheat (Akcura et al., 2005; Nsarellah et al., 2011). The presence of genotype - environment interaction makes it particularly difficult to conduct an effective selection of a genotype by phenotype for this trait. This result proves the urgent need for a long-term study of productivity or the statistical method of phenotypic stability of yield in durum wheat genotypes. A similar conclusion has been reached by other researchers in durum wheat (Nsarellah et al., 2011; Mohamed et al., 2013).

Table 2. Analysis of variance (ANOVA) for yield in durum wheat

Source	df	Sum of squares	Mean squares	F	η^2 %
Total	80	4767474			
Genotypes (G)	26	550080	21156.92	2.04 **	11.54
Environ-ments (E)	2	3680610	1840305	781.1 **	77.20
Interaction (G x E)	52	536784	10322.77	4.38 **	11.26
Heterogenity	26	263083.5	10118.6	0.96 n.s.	
Residual	26	273700.5	10526.9	4.47 **	5.74
Pooled error	156		2356		

* - $P \leq 0.05$; ** - $P \leq 0.001$; n.s. – no significant

The yield stability parameters are presented in Table 3. It should be noted that the Shukla stability variances σ^2_i and S^2_i and the Wricke ecovalence W_i estimate the variation over the years. Their higher (and significant) values indicate lower stability, and conversely, small nonsignificant values indicate high stability. The values of σ^2_i and S^2_i according to Shukla and W_i according to Wricke in our study are low and nonsignificant for M-674, Kehlibar, D-8148 and Saya, which evaluates them as stable. The Kang (YS_i) stability parameter was calculated for a complex assessment of yield and stability. It combines favorable values of yield and stability, with higher values marked with a plus being both stable and valuable. The Kang test evaluates both yield and stability, so it is not just a parameter for assessing stability. Its values are of non-parametric type, i. e. of rank type. In this case, not only the yield as a value, but also its stability in the given period is of great importance. According to Kang's YS_i, in our study, the lines with the best combination of high yield value and stability, i. e. high rank, are: D-8159, D-8148, D-8032, D-8031, D-8036, D-8040 and D-8091 and the varieties Reyadur and Saya (Table 3). Lines D-8159 and D-8032 are recognized as new varieties of durum wheat by the Exclusive Agency of Variety Testing, Seed Control and Approbation, Bulgaria. The D-8032 line is recognized as a new durum wheat variety under the name Heliks (Dragov et al., 2019). The D-8159 line is recognized as a new durum wheat variety under the name Deyche. Another line D-7763 is recognized as a new durum wheat variety under the name Viomi. Although it does not have a stable and high yield, it has a high resistance to diseases and high yellow pigments. The three varieties are entered in the variety list of Bulgaria and Europe. In view of the overall assessment, the D-8148 line is valuable. With regard to these results, it is possible to offer the D-8148 line for a new durum wheat variety. The varieties Saya and Reyadur were recognized in 2016 and are included in the variety lists of Bulgaria and Europe and at that time are included in the system of seed production and the institute had seeds from them. These results are prerequisites for the inclusion of the above-mentioned varieties in intensive hybridization and obtaining new genotypes with their participation, which exceed the standard in biological and economic qualities.

Table 3. Stability parameters for yield in durum wheat

Genotypes	σ^2_i	S^2_i	W_i	YS_i
Zvezditsa	8259.6 *	16886.5 **	16060.2	-6
Progres	1571.7 n.s.	-351.93 n.s.	3675.3	-1
Deyana	2763.7 n.s.	1605.6 n.s.	5882.7	2
Tserera	14030.9 **	28392.3 **	26747.8	-2
Beloslava	28590.8 **	9700.76 *	53710.7	-1
Vazhod	14156.6 **	750.0 n.s.	26980.6	-5
Deni	1683.7 n.s.	3280.1 n.s.	3882.6	1
D-8161	20588.1 **	4769.5 n.s.	38890.8	1
Predel	2216.3 n.s.	-302.4 n.s.	4869.0	10
Elbrus	8125.4 *	10329.97 *	15811.7	7
D-8195	19830.5 **	22050.9 **	37487.8	0
Trakiets	2269.3 n.s.	86.98 n.s.	4967.2	13+
M-674	-3.47 n.s.	108.96 n.s.	758.2	14+
Viktoriya	14222.7 **	28493.9 **	27103.1	4
Kehlibar	-379.2 n.s.	-353.76 n.s.	62.3	18+
Raylidur	8445.3 *	6977.1 n.s.	16404.2	15+
D-8040	6126.6 n.s.	1139.64 n.s.	12110.2	20+
D-8091	7788.7 *	15538.0 *	15188.2	20+
D-7763	5008.0 n.s.	2105.3 n.s.	10038.8	17+
D-8036	-55.0 n.s.	294.524 n.s.	662.6	21+
D-8148	-313.2 n.s.	-375.8 n.s.	184.6	28+
D-7553	102345.2 **	118331.8 **	190292	-4
Saya	-66.10 n.s.	-418.54 n.s.	642.2	25+
Reyadur	215.62 n.s.	250.19 n.s.	1163.9	27+
D-8032	720.3 n.s.	444.96 n.s.	2098.7	23+
D-8159	2395.9 n.s.	3851.8 n.s.	5201.5	30+
D-8031	8182.7 *	10640.6 *	15917.9	22+

* - $P \leq 0.01$; ** - $P \leq 0.001$; n.s. – no significant

Figure 1 represent the dendrogram from the hierarchical cluster analysis of the studied lines and varieties in terms of grain yield per da based on the results of the studied period. Initially, the genotypes studied were divided into two clusters. One includes the old (old and modern varieties) and new varieties (new varieties and some breeding lines) coming from the breeding program of FCI-Chirpan. The other cluster includes the advanced breedings lines and the two newest varieties Saya and Reyadur created by the method of sexual hybridization (advanced breedings lines and the latest varieties). At a sufficient level of reliability, the cluster of varieties is divided into two subclusters and essentially those subclusters represent the two strands of the FCI-Chirpan breeding program (experimental mutagenesis and combinatorial breeding). Figure 1 shows three clusters genetically distant from each other. When cluster analysis is performed on the basis of data obtained from different environments (years), to a large extent its values include the stability of the values of the trait. The new varieties created in the FCI fall into one cluster, while the standard variety Predel falls into the subcluster of the new varieties. The figure shows that the promising genotypes (advanced lines and latest varieties) of durum wheat fall into a separate cluster. This shows that they are genetically distant from previous varieties. Probably the new durum wheat breeding lines, created in recent years under changed weather/meteorological conditions, are better adapted to obtain high results. The results of the cluster analysis and the distribution of genotypes in the dendrogram can serve for the correct use of the genotypes in the hybridization scheme of the breeding program. Both genotypes D-8148 and Saya identified as stable fall into the same cluster. This suggests that hybridization between them would lead to faster equalization but less breeding advance in terms of yield. On the other hand, these two varieties are in a different cluster with the proven variety Predel standard in terms of biological and economic qualities. Crossing the two stable genotypes with the Predel variety would lead to greater breeding advance, but it will have a longer decay time. They are enough far away and in the decaying generations of these hybrid combinations it is possible to obtain heterosis and a longer time to conduct a selection in order to select more diverse forms. In conducting the breeding advance, we should take into account the genetic distance of the genotypes included in the combining breeding. Genetically closer parents need to be combined to achieve faster success. In order to achieve greater breeding advance in economically important qualities, it is advisable to cross genetically more distant parents (from different clusters). The authors Khodadadi et al., 2011 reach the same conclusion in the breeding strategy. Upon closer examination of the dendrogram, it can be seen that genotypes defined as both stable and yielding are in the same cluster. This shows that cluster analysis can also be used to group genotypes by stability, but it is important that stability is determined in advance by standard methods.

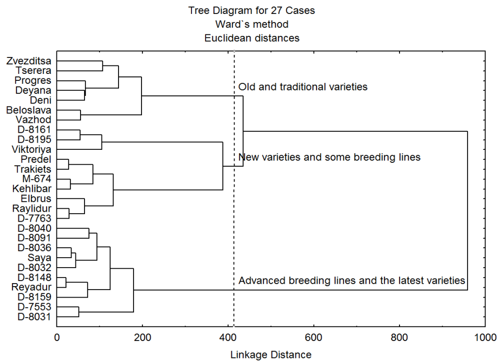

Figure 1. Dendrogram of cluster analysis for 27 durum wheat genotypes by grain yield

In the analysis of experimental results, especially for an important trait such as yield, PC analysis is also applied. The results of this analysis are presented in Figures 2 and 3. The graphical expression of PC genotype analysis is shown in Figure 2. According to Valkova & Dechev (2012), the most stable genotypes are in the quadrant of the positive values of the two main components, which largely coincides with our results for the Shukla (1972) stability assessment. It is accepted that PC1 is related to the linear effects of genotype variation and PC2 to the nonlinear part of the variation. At the same time, it is known that the stability parameters of Shukla - σ^2_i and S^2_i - are accepted in a similar way.

Logically, we come to the construction of Figure 3 with the location of the points of the genotypes in the coordinate system PC1 to grain yield. The genotypes located in the upper right (positive) quadrant of the coordinate system are of the greatest interest for the breeding. As can be seen from the data in Figure 3, the most valuable in terms of breeding, combining high yield and high phenotypic stability are the genotypes D-8159, D-8148, D-8032, Saya, D-8091 and others.

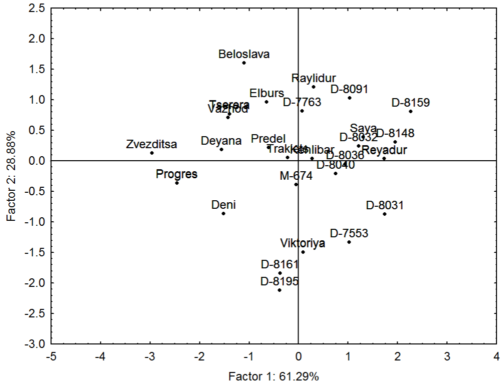

Figure 2. PC analysis for 27 durum wheat genotypes

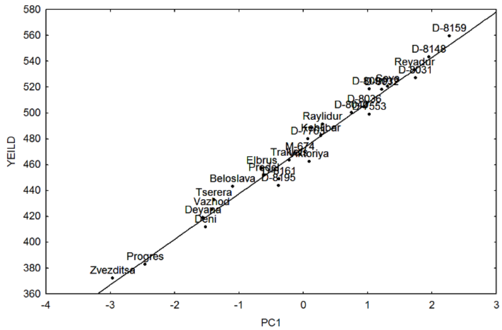

Figure 3. Relation of PC1 to yield in coordinate system

This almost completely coincides with the results of the yield - stability (YS_i) parameter of Kang and the corresponding group in the cluster analysis. Therefore, PC analysis can be used successfully to assess the phenotypic stability of genotypes on a given trait and to draw conclusions about their breeding value.

CONCLUSIONS

Significant influence of genotypes, environment (year) and genotype - environment interaction in the expression of the grain yield has been established. The greatest importance is due to the environment (year) as it occupies 77.20 % of the total variation in grain yield. The significant influence of the genotype-environment interaction allows for stability analyzes and adequate interpretation of the results. According to the Kang (YS^i) stability parameter, lines D-8159, D-8148, D-8032, D-8031, D-8036, D-8040 and D-8091 combine stability and high yield. These lines are of interest to the breeding program. The D-8159 line has the highest average yield and the highest rank. It is the latest variety created in FCI-Chirpan under the name Deyche. Cluster and PC analyzes can be used for preliminary stability assessment, but stability must be determined in advance by standard methods. Cluster analysis can be used to create a hybridization scheme according to the distance of the genotypes.

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