ASSESSMENT OF GRAIN YIELD STABILITY AND RELIABILITY IN SOME WINTER WHEAT VARIETIES

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Abstract. *Considering the continued and unpredictable variation of climatic condition, the yield stability has become an important topic in wheat breeding. This study evaluated the grain yield of 11 winter wheat varieties with different genetic and ecologic origin during three years, to compare the effects of genotype, year and genotype × year interactions and to determine their stability and reliability for cultivar recommendations. The climatic conditions during the three years had the highest contribution (80.03%) to the yield variability of wheat, while the varieties had a lower influence (11.41%), and the variety x year interaction contributed only with 8.56% to the total variation. In 2020, the climatic conditions were significantly more favorable than in 2018–2019, allowing obtaining yield increases of 33.82-44.20%. Also, in 2018 there was a higher favorability of the growing conditions compared to that of 2019, associated with significant yield increases of 7.75%. The highest yield stability was observed in Boema and Galio varieties, on the background of a non-crossover genotype x environment (GE) interaction. The stability of these varieties has been associated with different yield levels, above the experience mean in Galio and below the experience mean in Boema, respectively. In Akteur and Josef varieties, the yield was strongly influenced by the GE interaction, being associated with lower levels than the experience mean. On the background of high occurrence probabilities (0.75–0.95) of unfavorable environmental conditions for wheat crop, Galio and Laurenzio varieties would have the highest yield reliability, associated with values of 5173–6328 kg/ha (Galio) and 5101–5979 kg/ha (Laurenzio). As such, given the results of all stability parameters, it turns out that the Romanian varieties showed a good adaptation to the local ecological conditions compared to most of the foreign varieties.*

Keywords*: winter wheat, GE interaction, yield, stability, reliability.*

INTRODUCTION

Under the climate changes from last decades, the rainfall and temperatures show large and unpredictable fluctuations during the growing period of wheat crop. The driving forces for this change are due to environmentally-forced growing conditions, such as the incidence of early summer drought, late frost and rainfalls (Macholdt et al., 2017). Improving yield stability of wheat varieties is important to cope with enhanced abiotic stresses caused by climate change that influences crop development and yields, factors accounting for one-third of crop yield variability (Liu et al., 2017, Schmidhuber and Tubiello, 2007, Ray et al., 2015). For farmers, temporal yield stability is relevant because it determines economic predictability and reduces risk (Reckling et al., 2021). Also, yield stability has national and global importance in the context of food security (Kalkuhl et al., 2016).

The grain yield, representing the final product of wheat, is determined by the genotypic potential (G), environmental effect (E) and the genotype x environment (GE) interaction (Yan and Kang, 2002). Analysis of genotype interaction with agro-ecological conditions offers valuable information on the adaptability and stability performance of wheat genotypes. Yield stability stability and wide adaptation is the complex outcome of the reaction of a genotype to changing environmental factors that are increasingly important as the climate at specific locations is becoming more variable over the years (Singh, et al., 2019, Muhleisen et al., 2014).

Low yield stability represents one of the main factors responsible for the gap between yield potential and achieved yield, particularly under unfavorable environmental conditions (Tollenaar and Lee, 2002; Cattivelli et al., 2008). Understanding yield stability and crop performance under suboptimal conditions is key to decreasing the yield gap (Fischer and Edmeades, 2010; Pennacchi et al., 2019). The genotype selection depends on the understanding of the interaction among the genotypes, environment, and crop management practices which can be characterized using statistical methods (Jat et al., 2017; Bishwas et al., 2021).

Among various methods developed to expose patterns of genotype x environment (GE) interaction, (Muir et al., 1992) proposed an algorithm for partitioning GE sum of squares into components assignable to individual genotypes or environments. Therefore, GE interaction can be expressed as imperfect correlation (crossover interaction), or as heterogeneity of variance across different environments (non-crossover interaction).

The additive main effect and multiplicative interaction (AMMI) method combines ANOVA and principal component analysis (PCA) where the sources of variation in the genotype x environment interaction are partitioned by PCA. The AMMI method simultaneously quantifies the contribution of each genotype and environment to the GE sum of squares, and provides an easy graphical interpretation of the results by the biplot technique to simultaneously classify genotypes and environments (Silveira et al., 2013). AMMI separated the pattern from the random error components in the analysis of GxE interactions (Verma and Singh, 2021). The interpretation of results obtained from AMMI analysis is made by using a biplot that relates genotypic means to the first or some of the principal interaction components (Gauch and Zobel, 1998).

The requierd to combines high levels of mean yield and yield stability has led to the development of the yield reliability index, useful for cultivar selection or recommendation for a specific region or environmental conditions (Annicchiarico, 2002).

This study evaluated the grain yield of 11 winter wheat varieties with different genetic and ecologic origin during three years, to compare the effects of genotype, year and genotype × year interactions and to determine their stability and reliability for futher cultivar.

MATERIAL AND METHODS

The research was performed in SCDA Lovrin during 2018–2020, on a chernozem soil. The biological material was composed of 11 winter wheat varieties with different origin: Alex, Boema, Ciprian, Izvor, Glosa (Romania); Laurenzio, Josef (Austria); Akteur, Exotic (Germany); Renan (France); Galio (Italy). The research was organized using a randomized block design with three replications, using plots of $10m^2$. The variation in temperature and rainfall during study is presented in figure 1.

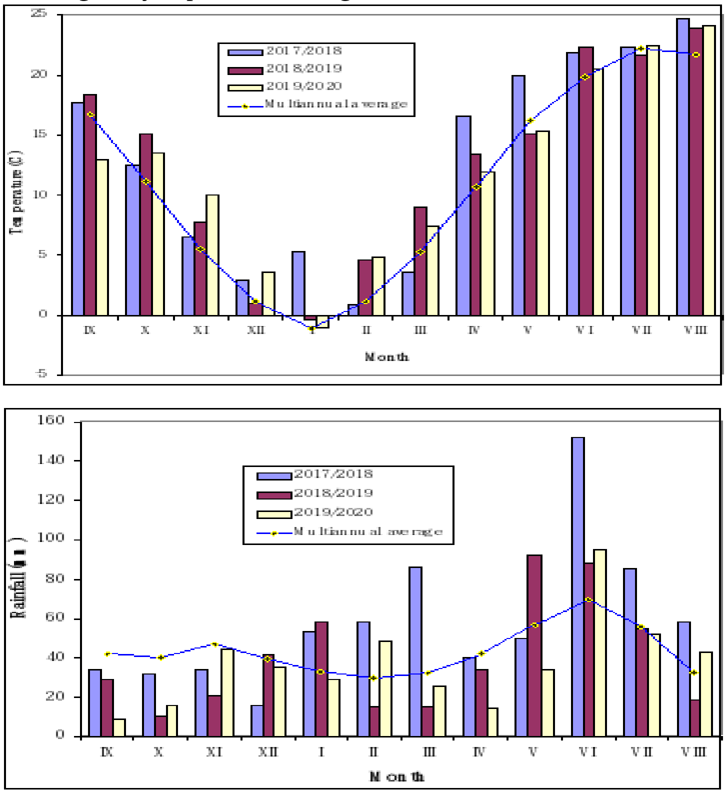

Figure 1. Monthly average temperature and rainfall in Lovrin during 2018–2020

Analysis of variance was performed across the test years to verify the existence of differences between varieties. The multiple range test was used to compare mean yield of different varieties (Ciulca, 2006). To describe the GE interaction, AMMI analysis (Gauch, 1992) was performed, using Matmodel (Version 3) software.

The genotype's contribution to the total sum of squares for GE interaction was estimated, and further partitioned into parts attributed to heterogeneous variance (HV) and to imperfect (IC) using method 2 according to Muir et al. (1992).

The AMMI stability value (ASV) was calculated as previously described by (Purchase et al., 2000). This index express the distance to the origin in a two-dimensional space based on 1 and 2 interaction principal component axis coordinates, considering that lower ASV indicate higher stability.

The sustainability index (SI) was calculated based on the formula of (Babarmanzoor et al., 2009):

SI = [(Y− σn)/YM] x□100, where: *Y* - mean performance of a genotype; σn - standard deviation; *YM* - the best performance of a genotype in any year.

The yield stability index (YSI) was calculated using the formula of (Bose et al., 2014): YSI = RASV + RY, where: RASV - rank of the ASV; RY - rank of the mean yield of genotypes (RY) across environments.

The reliability index was calculated using the formula proposed by (Kataoka, 1963): $I_i = m_i - Z(P)\ Si$, where: m_i - mean yield; S_i - square root of the environmental variance; Z(P) = percentile from the standard normal distribution for which the cumulative distribution function reaches the value P: 0.675 for P = 0.75; 0.840 for P = 0.80; 1.040 for P = 0.85; 1.280 for P = 0.90; and 1.645 for P = 0.95.

RESULTS AND DISCUSSIONS

The analysis of variance based on the AMMI 2 model for wheat varieties in the three years (Table 1) indicates that both genotype (varieties) and environment (climatic conditions over the three years) showed significant influences on production. The climatic conditions during the study showed the highest influence on the variability of production (80.03%), being followed by genotype (11.41%), against the background of a lower influence of the interaction year x varieties (8.56%). This model, based on the first two main components, fully expresses the effect of the year x variety interaction on this character. As such, it is considered relevant to assess the stability of production for the 11 wheat varieties, based on the first two main components.

Table 1. Analysis of variance based on AMMI 2 model for yield of wheat varieties during 2018–2020

Source of variation	SS	DF	MS	F value	SS 1%
Total	161108623	98			
Year	108314221	10	54157111	138.70**	80.03
Variety	15440539	2	1544054	3.95*	11.41
Year x Variety	11582447	20	579122	1.48	8.56 *(100)*
IPCA 1	6069932	11	551812	1.41	*52.41*
IPCA 2	5512514	9	612502	1.57	*47.59*
IPCA residuals	0	0			
Residuals	25771416	66	390476		

* Significant at p < 0.05; ** Significant at p < 0.01

Regarding the effect of climatic conditions on the production of the varieties under study (table 2), the amplitude of 2400 kg is observed on the background of variability of 20.12% during the study period. In 2020, the climatic conditions were significantly more favorable than in the period 2018–2019, allowing us to obtain production increases of 33.82-44.20%. Also, in the conditions of 2018, there is a superior favorability of the culture conditions compared to those of 2019, associated with significant production increases of 7.75%.

Table 2. Mean yield of wheat varieties during 2018–2020

Variety	Year			Variety
	2018	2019	2020	mean
Boema	y 5861±257 ab	y 5067±348 bcd	x 7487±274 cde	6138±514 CDE
Laurenzio	y 6445±247 a	z 5767±233 abc	x 7559±255 bcde	6590±339 ABC
Alex	y 5889±267 ab	y 5333±328 bcd	x 8464±61 abc	6562±516 ABC
Ciprian	y 6111±123 ab	y 5167±312 bcd	x 8326±231 abcd	6535±523 BCD
Glosa	y 6056±234 ab	y 5933±218 ab	x 8863±119 a	6951±518 AB
Izvor	y 5333±96 b	y 5500±237 abc	x 7266±226 e	6033±363 CDE
Josef	x 6111±147 ab	y 4867±192 cd	x 6792±441 e	5923±398 E
Akteur	y 5722±242 b	z 4433±164 d	x 7717±259 bcde	5957±528 DE
Galio	y 6422±386 a	y 6467±176 a	x 8507±372 ab	7132±542 A
Exotic	y 5278±294 b	y 5700±247 abc	x 7767±236 bcde	6248±440 CDE
Renan	y 5139±101 b	y 5500±293 abc	x 7377±285 de	6005±420 CDE
Year mean	5851±121 Y	5430±161 Z	7830±192 X	6370±140

Years LSD5% = 307 kg/ha (X, Y, Z); Varieties LSD5% = 588 kg/ha (A, B, C, D, E); Years x varieties LSD5% = 1019 kg/ha (a, b, c, for horizontal comparisons; x, y, z, for vertical comparisons).

Data represents mean ± SE. Different letters indicate significant differences (p < 0.05)

During the study between varieties, variability of 13.91% of the production was manifested, at an amplitude of 1209 kg/ha, with the limits from 5923 kg/ha in the case of the Josef variety up to 7132 kg/ha for the Galio variety. Based on multiple comparisons, we observe that Galio variety achieved a significantly higher average yield by 9.13-20.41% compared to seven of the varieties. Five varieties achieved average yields of 6500–7000 kg/ha, of which the Glosa variety (6951 kg / ha) stood out, which showed significant increases of 11.27-17.35% compared to other varieties. The lowest levels of production were recorded by the varieties Akteur and Josef, which showed significantly lower values than the varieties Galio, Glosa, Laurenzio and Alex.

Considering the average genotype x interaction, it is observed that in the conditions of 2018 the production registered by the 11 varieties varied from 5139 kg/ha at Renan to 6445 kg/ha at Laurenzio, with an amplitude of variation of 1306 kg/ha, among variability of 7.60% between varieties. As such, the Laurenzio and Gallio varieties showed the highest values in this year's conditions, associated with statistically assured increases of over 12.23-25.41% compared to the Renan, Exotic, Izvor and Akteur varieties. The Romanian varieties Boema, Alex, Ciprian and Glosa with the Josef variety showed similar reactions to the climatic conditions of this year, achieving significantly equal yields.

Regarding the 2019 production, against the background of a slightly higher interpopulation variability than in the previous year (10.16%), the varieties showed values between 4433 kg/ha at Akteur and 6467 kg/ha at Galio, with an amplitude of 2034 kg/ha. Thus, the Galio variety capitalized at a higher level the conditions of this year, achieving significant increases of over 21.26-45.88% compared to the varieties: Alex, Ciprian, Boema, Josef and Akteur. Also in the case of the Glosa variety, there is a higher production by 21.90-33.84% compared to Josef and Akteur. The Akteur variety's production this year was significantly lower than most other varieties except Josef.

Against the background of the 2020 conditions, there is interpopulation variability of 8.06% intermediate to previous years, associated with an amplitude of 2071 kg/ha, between 8863 kg/ha at Glosa and 6792 kg/ha at Josef. Regarding the distribution of production values, six of the varieties produced approximately 7200–7800 kg/ha, and four varieties had yields over 8000 kg/ha. This year, the Glosa variety capitalized on a higher level of cultivation conditions, registering significant increases of 14.11-30.49% compared to seven varieties. At the opposite pole were Josef and Izvor varieties with significantly lower yields than Glosa, Galio, Alex and Ciprian.

Given the effect of climatic conditions during the study on the production of each variety, a grouping of these varieties into three categories is observed. Most varieties, such as Boema, Alex, Ciprian, Glosa, Izvor, Galio, Exotic and Renan, showed a good adaptation to the conditions of 2020, achieving significantly higher yields than those of 2018–2019, significantly equal. Climatic conditions showed the highest influence on the production of the Laurenzio and Akteur varieties, which recorded significant variations in production from one year to the next, with the highest values in 2020 and the lowest in 2019. The Josef variety showed a special reaction. compared to the cultivation conditions during the study period, registering in 2018 and 2020 close and at the same time significantly higher production than in 2019.

Depending on the values of the ASV stability index (Table 3), we observe that highest stability of production was manifested in the varieties Boema and Galio on the background of a genotype x medium interaction of quantitative nature of non-crossover type (non-crossover). In the case of the Josef variety, the production recorded considerable deviations during the study in the presence of a genotype x medium quality interaction, crossover type, while in the Akteur variety the low production stability was associated with a genotype x interaction. quantitative environment.

According to the SI sustainability index, most varieties have values above 61% showing a high sustainability, while only Akteur, Alex, Glosa and Ciprian varieties have a moderate sustainability, among values below 60%.

The YSI production stability index combines stability with the production level so that the low values of this index attest to good stability and a high level of production. In this sense, the most valuable variety is Galio, which recorded the highest average production associated with superior stability to the other varieties, followed by the Boema variety in which the production was proportional to the favorable environmental conditions of the three years. The lowest values of this index were observed in the Josef and Akteur varieties, in which the low yields were associated with high effects of the genotype x medium interaction.

Table 3. AMMI stability values (ASV) sustainability index (SI) and yield stability index for wheat varietie during 2018–2020

Variety	Mean (kg/ha)	Yield ranks	IPCA1	IPCA2	ASV	ASV ranks	SI (%)	SI ranks	YSI	YSI ranks
Boema	6138	*7*	-7.71	-1.59	8.63	*1*	65.51	*5*	8	*2*
Laurenzio	6590	*3*	-13.68	9.69	17.91	*9*	75.22	*1*	11	*6,5*
Alex	6562	*4*	6.98	-13.13	15.21	*5*	57.79	*10*	9	*4*

Ciprian	6535	*5*	-0.95	-14.91	14.95	*4*	59.01	*9*	9	*4*
Glosa	6951	*2*	13.55	-8.23	17.04	*7*	59.72	*8*	9	*4*
Izvor	6033	*8*	4.05	12.92	13.67	*3*	68.29	*4*	11	*6,5*
Josef	5923	*11*	-24.02	5.53	27.01	*11*	72.84	*2*	22	*11*
Akteur	5957	*10*	-6.65	-18.19	19.61	*10*	55.76	*11*	20	*10*
Galio	7132	*1*	5.13	7.75	9.59	*2*	69.84	*3*	3	*1*
Exotic	6248	*6*	13.58	8.53	17.22	*8*	63.30	*7*	13	*8*
Renan	6005	*9*	9.71	11.64	15.80	*6*	65.12	*6*	15	*9*

The two-dimensional diagram (biplot) in figure 2 expresses the relationships between the axes of interaction of the main components (HICP) and the averages of the varieties, respectively the years of study (YAN et al., 2000). Given that the IPCA1 axis expresses approximately 52.41% of the variability of the average genotype x interaction, we observe that highest values of production were recorded in the conditions of 2020. Also, depending on the coordinates of each year, it is found that The conditions in 2018 had a lower contribution on the average genotype x interaction for this character.

Depending on the length and position of the vectors related to the different varieties, it is observed that in the Akteur and Josef varieties this production was strongly influenced by the average genotype x interaction, while the highest stability of production was registered in the Boema and Galio varieties that were the closest to home. The low stability of the Akteur and Josef varieties is associated with below-average yields. In the Alex, Ciprian and Glosa varieties, the average stability was correlated with above-average yields, while in the Renan, Izvor and Exotic varieties, the average stability was associated with below-average yields. The good stability of the varieties Boema and Galio was manifested against the background of different levels of production, respectively, above average in Galio and below average in Boema varieties.

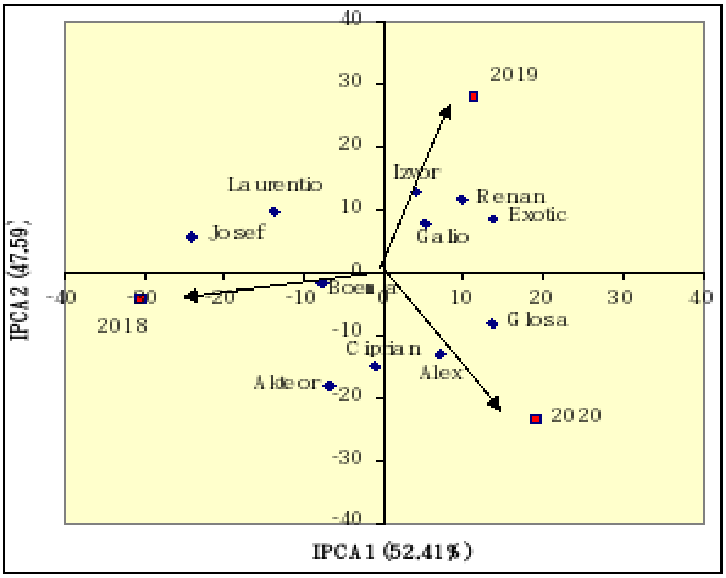

Figure 2. AMMI 2 interaction biplot for yield of wheat varieties during 2018–2020

The reliability index (KATAOKA, 1963) simultaneously assesses both the average level of production under different environmental conditions and its stability against the background of high probability of the occurrence of unfavorable culture conditions. Against the background of a 75% risk in terms of unfavorable conditions for wheat cultivation, the varieties Galio, Laurenzio and Glosa, can produce yields of 5832–6328 kg/ha. In the case of Akteur, Renan and Josf varieties, the variability of climatic conditions has the highest negative impact on production, which is expressed at levels of 4841–5264 kg/ha. Assuming that the risk of adverse conditions is 80%, the varieties Galio, Laurenzio and Glosa would show the highest safety of production, associated with values of 5558–6131 kg/ha. A reduced safety of the production capacity in these conditions would present the Akteur and Renan varieties, which would achieve levels of 4568–4996 kg/ha

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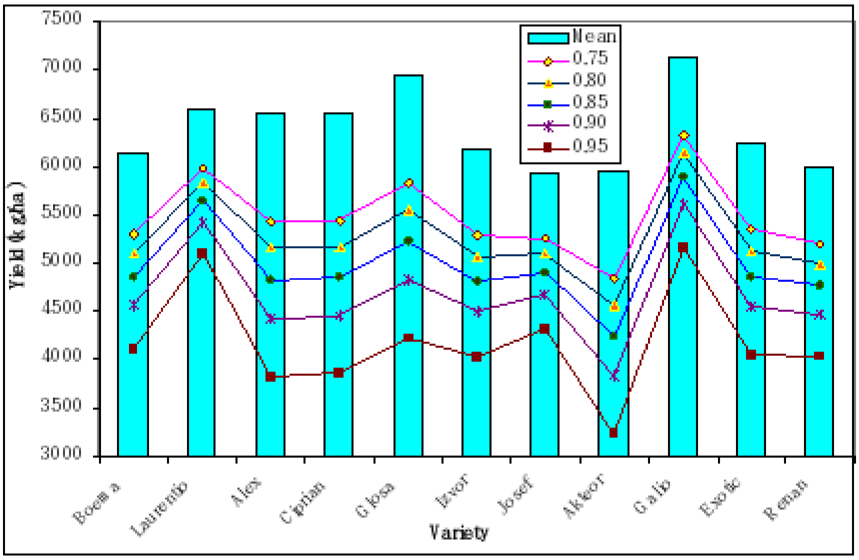

Figure 3. Minimum yield expected at various probabilities (0.75–0.95) of unfavorable environmental conditions

Under unfavorable conditions of up to 85%, only the Galio, Laurenzio and Glosa varieties would show yields above 5000 kg/ha, while the rest of the varieties would show close production levels between 4237 kg/ha at Akteur and 4908 kg/ha to Josef. Against the background of a 90–95 risk of unfavorable conditions for wheat cultivation, only the Galio and Laurenzio varieties can achieve yields of over 5000 kg/ha (5101–5173 kg / ha), while the rest of the varieties would record production between 3236 at Akteror and 4317 kg/ha at Josef.

Table 4. Partitioning of GE interactions through heterogeneous variances (HV) and imperfect correlations (IC) for yield of wheat varieties during 2018–2020

Variety	SS HV	(%)	SS IC	(%)	SS GE	(%)
Boema	82830	4.99	136604	6.21	219434	5.68
Laurenzio	247323	14.90	124903	5.68	372226	9.64
Alex	198421	11.95	128478	5.84	326899	8.47
Ciprian	166892	10.05	159962	7.27	326853	8.47
Glosa	189667	11.42	162354	7.38	352021	9.12
Izvor	137257	8.27	163012	7.41	300269	7.78
Josef	193373	11.65	413088	18.77	606462	15.71
Akteur	187646	11.30	243674	11.07	431320	11.17
Galio	91944	5.54	143003	6.50	234947	6.09
Exotic	75637	4.56	280423	12.74	356060	9.22
Renan	89411	5.38	244914	11.13	334325	8.66
Total	1660400	43.01	2200416	56.99	3860816	100

For these wheat varieties 43.01% of the GE interaction is due to variances heterogeneity, and 56.99% to imperfect correlations. Therefore in the assessment of yield stability, the results of both crossover and non-crossover interactions can be effectively used (Table 4). The unstable performances of wheat varieties associated with yield variation across different environmental conditions are due to the presence of GE interaction (RAMLA et al., 2016).

Based on an imperfect correlation we observed that the lowest crossover interaction were recorded by the varieties Laurenzio and Alex, which showed high constancy of ranks related to yields registered during the three years. High values of deviations between ranks for yield throughout the study period were presented by Josef and Exotic varieties.

Given the heterogeneous variances, it was found that the lowest non-crossover interaction was recorded by Exotic and Boema varieties, which showed lower deviations to the mean yield of each year. The highest non-crossover interaction associated with large deviations to yearly mean of the other varieties was presented by Laurenzio and Alex. Considering the low contribution of varieties Boema and Galio to the GE interaction, these varieties were the most stable across the study period. Also, the Romanian varieties Alex, Ciprian, Glosa, Izvor expressed a low GE interaction, showed a good adaptation to the local ecological conditions.

CONCLUSIONS

The climatic conditions during the three years had the highest contribution (80.03%) to the yield variability of wheat, while the varieties had a lower influence (11.41%), and the variety x year interaction contributed only with 8.,56% to the total variation. In 2020, the climatic conditions were significantly more favorable than in 2018–2019, allowing obtaining yield increases of 33.82-44.20%. Also, in 2018 there was a higher favorability of the growing conditions compared to that of 2019, associated with significant yield increases of 7.75%.

The highest yield stability was observed in Boema and Galio varieties, on the background of a non-crossover GE interaction. The stability of these varieties has been associated with different yield levels, above the experience mean in Galio and below the experience mean in Boema, respectively. In Akteur and Josef varieties, the yield was strongly influenced by the GE interaction, being associated with lower levels than the experience mean.

On the background of high occurrence probabilities (0.75–0.95) of unfavorable environmental conditions for wheat crop, Galio and Laurenzio varieties would have the highest yield reliability, associated with values of 5173–6328 kg/ha (Galio) and 5101–5979 kg/ha (Laurenzio).

As such, given the results of all stability parameters, it turns out that the Romanian varieties showed a good adaptation to the local ecological conditions compared to most of the foreign varieties.

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