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Influence of Environments on The Amount and Stability of Grain Yield in The Modern Winter Wheat Cultivars II. Evaluation of Each Variety

Nikolay Tsenov[1*] **Dobrinka Atanasova**[1] **Todor Gubatov**[2]

[1] Dobrudzha Agricultural Institute, General Toshevo 9520, Bulgaria
[2] Agronom I Holding, Dobrich 9300, Bulgaria

[*] Corresponding author e-mail: nick.tsenov@gmail.com

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ABSTRACT

Cultivars grown at the farmers' fields were selected and tested for three consecutive years at eight locations in Bulgaria, which were representative for the entire territory of the country and had contrasting soil and climatic conditions for crop growing. Significant variations of grain yield were found among the investigated cultivars regardless of their specific response to the year conditions and the location. The interaction genotype x environments was significant and high, and was of non-linear type. The changeable environmental conditions caused different reactions of the cultivars, which allowed dividing them into groups according to the plasticity and stability they demonstrated. The variation in this experiment determined through Principal Component Analysis (PCA reached level four, which is comparatively rare for this trait. On the whole, PC1 had low value (49%), while PC2 was high (16%). There were several cultivars with very high PC2 values, exceeding several times the values of their respective PC1. The percent of variation caused by the environment was significant for grain yield under the conditions of Bulgaria. The investigated cultivars differed not only by grain yield but also by their plasticity and stability under changeable environments, the percent of the genotype effect being about 12 % for the entire experiment. It was found that each cultivar can give high grain yield at high ecological stability regardless of its genetic potential for quality. Best balance between grain yield and stability was found in cultivars Aglika, Demetra, Iveta (first quality group), Galateya, Slaveya (second quality group) and Todora, Kristal and Pryaspa (third quality group).

Keywords: wheat, grain yield, cultivars, genotype x environment, stability.

Abbreviations: **GY** = grain yield, **b_i** = Regression coefficient **(A)**, **σ^2** = Deviation from regression **(A)**, **Residual** = Residual variance **(A)**, **GY-b_i** = General adaptability index **(B)**, **GY-σ^2** = "General stability" index **(B)**, **HV** = Variance of heterogeneity **(C)**, **IN. Corr** = Variance of incomplete correlation **(C)**, **GE** = Genotype x environment interaction **(C)**, **W^2** = Ecovalence (percent of genotype from total variation) **(D)**, **SV** =Variance of stability **(E) (F)**, **Ysi**= Size and stability of the trait **(F)**

Introduction

The study on the interaction of the genotype with the environmental conditions when considering grain yield *(GxE)* is very important for winter wheat due to its genetic and physiological specificity as a crop of the micro climate. Cultivars developed under certain conditions perform best under these conditions and it is difficult for them to compete with cultivars developed in different regions (Tayyar, 2010; Muhe and Assefa, 2011). This makes very important the investigations on the factors which cause changes in the direction and value of the genotype x environment interaction in the breeding of this crop (Tadesse *et al.,* 2010; Rachovska *et al.,* 2011). The breeding efforts are directed toward developing accessions with higher productivity than that of the cultivars already used in practice, which is very difficult against the background of the level already achieved (Tsenov *et al.,* 2009; Aminzadeh, 2010). Therefore the necessity arises to systematically improve the wheat plant by enhancing its tolerance to stress (Boyadjieva *et al.,* 2009; Mohammadi *et al.,* 2010; Arain *et al.,* 2011, Bennett *et al.,* 2012); this has created serious prerequisites for high and stable grain yield over years. Increasing the adaptability of the new cultivars is a main goal of many breeding programs both in spring (Ferney *et al.,* 2010), and in winter wheat (Paunescu and Boghic, 2008; Sharma *et al.,* 2010). Reasons for this are the investigations revealing possibility to combine high stability with high grain yield (Tsenov *et al.,* 2008). In their study Botwright *et al.,* (2011) report very high interaction of the cultivar with the environment, a prerequisite for high adaptability at level of the yield 8 t/ha. Therefore it can be assumed that there are actual possibilities of linear type of interaction of the genotype with the environment that would lead to desirable combination of high yield levels with stability (Aminzadeh, 2010; Tsenov *et al.,* 2011a).

Stability is the ability of the cultivars to express their genetic potential under a wide range of conditions so that the grain yield from the stable genotype is always high even at significantly high genotype x environment interaction (Tsenov *et al.,* 2011b). In the investigations of Purchase (1997), Annicchiarico (2002) there is the definite statement that the analysis on the genotype x environment interaction is important at all levels of the breeding process – from determining of the biotype for a certain region (Dolatabad *et al.,* 2010) and evaluation on the combining ability of the parental components for crossing (Yan and Hunt 2002) to the proper distribution of the most suitable cultivar (Tayyar, 2010).

As already mentioned above, the interaction of the cultivar with the environment is complex and depends on unpredictable conditions and on the behavior of the group and each variety in it. Grain yield from wheat is always strongly influenced by the growing conditions, and the specific expression of each genotype against the background of the behavior of a group of varieties is too complex for specific analysis (Ferney *et al.,* 2006). The more the factors of the environment (year and location), the more complex and multi-layered the interaction is and is therefore impossible to analyze by a single evaluation approach. In this relation Lin *et al.,* (1986) and Becker and Léon, (1988) have developed concepts for proper analysis and interpretation of the results from this type of researches, which are still valid. These concepts, on their part, require the application of several directly opposite statistical parameters which help to make proper interpretation of the genotype x environment interaction and to evaluate the plasticity and stability of the used varieties (Pacheco *et al.,* 2005, Chapman, 2008).

The aim of this investigation was to determine the specific reaction of each genotype involved in the trial under the typical conditions for grain production in Bulgaria by using different and mutually complementary criteria (parameters, indices) for evaluation fro their adaptability and grain yield stability.

Material and methods

The grain yield from 24 Bulgarian wheat cultivars was investigated at 8 locations during 2007-2009. Data were used from post-registration testing of the national Executive Agency of Variety Testing,

Field Inspection and Seed Controlat in 8 locations in Bulgaria (Table 1) out of the total 12 locations investigated and therefore their numbering is incomplete. The methods for conducting the field trial have already been presented in detail in our previous communication (Tsenov and Atanasova, 2013). The reasons for excluding four locations and one season (2010) from the database are explained in it.

The behavior of each investigated cultivar was followed through its grain yield under variable environments (location and season). The ordering of the initial data and their analysis was done with XLSTAT 2009.

The genotype x environment interaction was determined by using three statistical programs specifically suitable for the purpose of this investigation: GEST (Ukai *et al*., 1996), STABLE (Kang and Magari 1995) and GGE biplot (Yan and Kang, 2003). Different aspects of the genotype x environment interaction were analyzed by calculating several of the most common parameters and indices for evaluation and analysis on this interaction grouped and designated as follows:

(**A**) -coefficient of regression [bi], deviation of each cultivar from the regression [σ^2] and residual variation [Residual] according to (Finlay and Wilkinson, 1963),

(**B**) -index of general adaptability (GY-b_i) according to (Vulchinkov and Vulchinkova, 2007) and index of "general stability" (GY-σ^2), suggested **in this investigation** as an additional element of evaluation

(C) -variance of stability [$\sigma^2 i$], heterogeneity variance

[HV], variance of incomplete correlation [IN. Corr], interaction of the genotype with the environment (GE) according to Muir *et al*., (1992)

(D) -ecovalence [W^2i] according to Wricke (1962)

(E) -variance of stability [SV] according to Shukla (1972)

(F) -parameter of yield stability [Ysi] according to the approach of Kang and Magari (1995).

In Tables 4 and 5 a part of the parameters of the groups (**A, B, C, D, E**) are presented as percent from the average level of the respective parameter. This was done with the aim to more precisely compare the data of each cultivar because the absolute values were very close and their direct comparing was very difficult. For informative purpose the mean values of each parameter are represented as absolute value in the last row of each table.

The data from the Principal Component Analysis and the graphic analysis (Jmp 10) are at the basis of the detailed comparison of the ecological plasticity and stability according to the investigated trait of each involved cultivar. For better substantiation of the existing variations between the cultivars, the obtained values of the parameters and indices were analyzed with the help of several additional statistical programs (Statistica 7, Statgraphics XV). They were used to calculate the parameters of the Principal Component Analysis (PCA), of the descriptive statistics, of the correlation values and the variance analysis. Rank correlations (Kendall –Tau) were calculated with the help of the software StatPlus 2009 Professional.

Results and discussion

Figure 1 presents grain yield from the 24 cultivars in a reduced scheme of 8 locations and three years of investigation, as mentioned in the first communication (Tsenov and Atanasova, 2013). The high variation of the character depending on each investigated factor, including the variation caused by the genotype, is evident. Significant differences between the cultivars were observed in all three years; in 2007, when there was a long drought, the differences were highest (Tsenov *et al.,* 2014); with regard to locations, the differences were also clearly outlined (Figure 2). The applied statistical analysis clearly delineated the differences in the data on grain yield depending on the location where the trial was conducted, as well as the low values of the PCA to the second level (66%). According to the data five groups of locations can be differentiated: *(1)*-1(Selanovtsi), *(2)*-2(Pordim), *(3)*-3(Brushlen), 10(Gorski izvor) and 11(Ognyanovo), 6(DAI), *(4)*-8(Burgas), *(5)*-9(Radnevo).

The variation caused by the differences in the conditions over years and locations is the reason for their significant interaction with the cultivar (Table 1); this, on its part, is a sufficient prerequisite for objective evaluation of the behavior of the individual genotype as a level, adaptability and stability of grain yield.

Even after elimination of some of the levels of the individual factors, the interaction of grain yield with the environment was complex, and its variation reached level four of the principal component analysis (Table 3). This was entirely in accordance with the established high effect of heterogeneity indicated in Table 2. The values of the separate components gradually decreased from PCA1 to PCA4, but they were significant and could not be ignored. They showed non-linear type of the genotype's interaction with the environment which made very difficult the evaluation of the individual cultivar with regard to its behavior under the conditions of the environment. It is known that the levels of the first two components are important and provide some information on the stability of the genotype. The evaluation of the variation of each cultivar is represented in Figure 3 through the PCA 1 values.

Variations in the conditions resulting from one of the two factors (year or location) provoked different response of each cultivar according to the mean level of reaction of 4.1%. Lowest was the variation of the standard cultivars (7)-Pobeda and (13)-Sadovo 1, and of cultivars (12)-Sadovo 772 and (18)-Neven. All other cultivars demonstrated variation above the mean value of the group, meaning that their response to the effects of the environmental factors is of linear type. This is expressed in higher grain yield under favorable conditions and *vice versa*. The values of the second component were radically opposite from the point of view of the cultivars. The mentioned cultivars (7), (12), (13), as well as (15)-Aneta and (20)-Yantur had strongly expressed non-linear variation under changeable environments (Figure 4). Exceptionally low were the values of PCA2 in cultivars (4)-Desislava, (5)-Iveta, (8)-Vyara, (10)-Enola and (11)-Miryana. In general this information shows how each cultivar principally changes the trait under variable conditions from favorable to unfavorable for wheat.

For more detailed and specific evaluation of the cultivar's interaction with the environment, it was analyzed by using the most common statistical approaches (Tables 4 and 5). The values of the cultivars for most of the parameters were very similar and therefore the relative values (%) of each genotype were presented, according to the mean value of each parameter. When the values are above 1.06, the percent of the cultivar is high, and when it is below 0.94, the percent is low. According to the "dynamic" or "agronomic" concept, stable is considered a genotype which follows the dynamics of the environmental conditions by changing its character. According to (Becker and Leon, 1988) with this approach more stable is the cultivar which has regression coefficient (bi) about (1) and the lowest possible deviation from the regression straight line (σ^2). According to the data in columns 5 and 6 such were cultivars Demetra, Iveta, Enola, Miryana, Slaveya and Neven. On the other hand cultivars Albena, Pobeda, Sadovo 1, Sadovo 772, Kristal, Svilena and Todora were highly variable by yield in comparison to the rest of the cultivars. Furthermore, the latter cultivars had high values of the parameter in column 7 which is additional evidence for their high variation.

With index (GY-bi) – column 8 and (GY-σ2) – column 9, the situation was the opposite, the higher values revealed higher degree of compromise combination of grain yield with stability. The index (GY-σ^2) is introduced here as an addition to the information provided by the index of general stability (GY-bi), described in detail by (Vulchinkov and Vulchinkova, 2007). The reason for this is that the extraction of the value of the regression coefficient (bi) from the mean value of the trait is not always completely informative from the point of view of the cultivar's deviation from the regression straight line of the group. In our opinion this deviation [σ^2] is also important and at close values of (bi) about 1 (in 12 out of the 24 cultivars) it more correctly reflected the difference in the variation of the individual cultivar, provided that the difference in its variation here was from 33 to 188%. This allowed positioning its values in the group of indices (**B**).

Table 5 presents data on the degree of variation of each cultivar expressed through the different statistical approaches designated in the material and methods section as statistical groups C, D and E. The genotypes were positioned in descending order according to the values of ecovalence [W^2] (Wricke 1962) in column 6. The lower the values of each parameter for a given cultivar, the lower is its variation as a percent against the background of the total variation under the conditions of this experiment. The values of the separate parameters of the groups were almost overlapping although different statistical approaches were used for their calculation, a fact mentioned many times in similar investigations (Tsenov *et al.* 2006). This means that each of the parameters from a given group of approaches can be equally used for evaluation of the genotype. According to these data a half of the cultivars demonstrated low interaction with the conditions of the factors because their percent in the total variation was low. These were cultivars Demetra, Petya and Iveta and the standards Enola and Pryaspa. Highest was the interaction with the environment of the cultivars which are standards: Aglika, Pobeda, Sadovo 1 and the cultivar Sadovo 772. The low values of the ecovalence (W^2) and the variance of stability (SV) in such cultivars as Desislava and Yantar were related to very high values of the parameters of group (C). This fact indicates that these cultivars demonstrate a very complex interaction with the environment and their response cannot be foreseen from the point of view of environmental variations. On the whole it is very high but due to the high values of the three parameters it is not adequate at all to the response of the group of cultivars. Similar are the data on cultivar Viara. The data on cultivars Aneta, Kristal, Svilena and Todora showed very high values of the parameters in groups **(D)** and **(E).** This is an indication for the strong variation of these varieties at low level of interaction with the conditions (low values of [GE])**,** which implies non-linear interaction. Such an assumption is valid for all cultivars which show disagreement of the values of the parameters from group **(C)** with the parameters from groups **(D)** and **(E)**.

Analyzing the data from the different Tables through the well known approaches appropriate for this purpose, we encountered the fact that the data on the respective cultivars disagreed, sometimes considerably, which made the formulation of the correct conclusions on their behavior difficult.

This was the reason for calculating the correlations between the values of the trait and the values of the parameters for evaluation of the genotype's stability and plasticity on the whole (Table 6). Grain yield was in positive correlation only with the regression coefficient ($r=0.780^{**}$). The correlations were negative with the other parameters for evaluation, but not significantly high. It should be so in principle because these parameters investigate and demonstrate the variation and interaction of the trait with the environment and do not relate directly to its level. Similar by value and direction (negative) were the correlations of (bi) and all other parameters for evaluation presented in column 3. The correlations between all other parameters were significantly high and positive (columns 4, 5, 6, 7, 8, 9). Therefore each of these parameters can be used for correct evaluation of the stability and plasticity as a main parameter or in a group with each of the other parameters.

It was a considerable inconvenience in the process of writing the discussion section that the values of the individual statistical parameter for each cultivar showed disagreement by value and direction of expression. The stability and adaptability of the cultivar is highly important and therefore, it was the aim of this investigation. This was the reason for applying one of the integral methods (Kang and Magari 1995*),* the approach of which allows making a compromise evaluation of the level of grain yield and its stability under the conditions of the environment through the values in column 5 of Table 5. Cultivars Todora-(24), Aneta-(15), Neven-(18) and Pryaspa-(22) possessed the best combination between yield and stability, although they showed high variation of grain yield (c.f. Table 3). Cultivars Kristal-(21), Aglika-(1) and Iveta-(5) had excellent combination between high and stable yield, as well as low variance of the investigated factors of the environment. Most unstable were the standards Pobeda-(7), Sadovo 1-(12), Yantur-(20) and cultivar Milena-(6). The data clearly illustrate that when making specific analysis it is possible to identify cultivars with high general adaptability. Although the objectivity and correctness of the method used for evaluation has been demonstrated many times (Plamenov *et al.* 2009; Rachovska *et al.* 2011; Dimova *et al.* 2012) we decided to compare it to a similar and improved statistical method developed by Yan and Kang (2003).

In the recent years this method (Vulchinkov and Vulchinkova, (2007) has been used in many studies for evaluation of the interaction of the genotype with the environment although its objectivity has been criticized with regard to the spatial position of the cultivars (Vulchinkov and Vulchinkova, (2007) its application gives good evaluation on the behavior of specific cultivars or lines and on the suitability of the separate locations for concrete analysis on the productivity or quality of the respective crops (Yan and Rajcan 2002; Ferney *et al.* 2010; Yan and Holland, 2010). According to the investigation of Rubio *et al.* (2004) this method can be successfully used to group the genotypes by phenology and by their ecological origin. Comparing this method to the most widely used traditional approach for analysis of the genotype x environment interaction (Eberhart and Russell 1966) it has been found that it has a number of advantages in determining stable maize hybrids with high grain yield (Alwala *et al.* 2010). Figure 5 shows the spatial distribution of the investigated cultivars through principal component analysis. The cultivars positioned to the right of the blue line (grain yield) and above the red line (stability) possess good combination between stability and size of grain yield. The small red circle on the red line indicates the position of the most suitable yield-plus-stability combination. These were cultivars Iveta-(5), Aneta-(15), Neven-(18), and the two standards Aglika-(1) and Pryaspa-(22). The position of cultivar Todora-(24) showed high yield but lower stability, which was also valid for cultivar Viara-(8). The standard cultivars Pobeda-(7), Enola-(10), Sadovo 1-(12) and Yantar-(20) demonstrated significantly lower and simultaneously unstable grain yield in comparison to the other standards and investigated cultivars. Additional information on which cultivar gave highest grain yield is presented in Figure 6. High grain yield from cultivars Aneta-(15), Neven-(18) and Pryaspa-(22) was obtained at six out of the eight locations, with the exception of DAI and Radnevo. At the same time cultivar Todora showed maximum grain yield at these two locations.

The ranking of the investigated cultivars by the two discussed methods coincided to a large extent, meaning that their ranking in Table 7 can be considered correct. The correlation between the ranking by parameter [Y_S(i)] and grain yield was very strong and positive (Table 8). The presence of negative correlations with all parameters of plasticity and stability (Table 5, column 2) is an indication that during the ranking the effects of the interaction with the environment have been taken into account and that the ranking by yield is different. The correlation of grain yield with the index of general adaptability [GY-bi] was very strong (r=0.956), as well as its correlation with the index [Y_S(i)] (r=0.844). High and positive were the correlations of the index [GY-σ^2] with grain yield (r=0.681), with the index of general adaptability (r=0.672) and the parameter of yield stability [Y_S(i)] (r=0.579).

It follows that by using the values of this new index, ranking with the aim to make evaluation is also possible and entirely correct. The application of each of the two indices separately (Figures 7 and 8) leads to different ranking of the cultivars. This difference was additionally investigated (Table 9) and it was found that the strongest correlation with grain yield showed index [Y_S(i)] (r=0.708**), which was an evidence that it gave considerably lower reading of the effect of variation.

On the other hand, the lack of significant correlation of King's parameter [Y_S] with the two indices implies that their values probably take into account to a greater extent the effect of variation (GxE). Additional evidence for this assumption is provided by the established high values of the correlations of grain yield with the two indices, which, however, had lower values. The relation of parameter [Y_S] with the new index [GY-σ^2] must be strong, because the correlation they showed according to grain yield was similar. When the investigated cultivars demonstrate higher variation as deviation from the regression curve (σ^2) than the variation of their regression coefficients, as in our case, then the suggested index of "general" stability can be correctly used for ranking of the cultivars by grain yield. Its use changes to a certain degree the ranking of the cultivars, but it is not significant against the background of ranking by the other indices, which makes it applicable. The main reason for using the index of "general" stability [GY-σ^2] is the application of the «dynamic» concept of stability when the trait changes as formulated by (Becker and Leon, 1988), according to which the deviation from the regression curve should be as low as possible for the stability of the cultivar to be highest.

The evaluation of the behavior of a given genotype under specific and changeable conditions of the environment provides valuable information on several aspects: how the cultivar responds to changeable conditions, how plastic and adaptable it is under a wide set of environments (locations and seasons) and what is the area of its eventual distribution. This knowledge is important for breeding as well, to apply proper approaches of purposeful selection for specific locations (regions) with similar growing conditions. It is known that cultivars with high adaptability have linear genotype x environment interaction. The cultivars with very high stability usually are not highly productive and therefore it is necessary to use special methods and approaches for combining of high productivity with high stability (Kaya and Taner, 2003; Fan *et al.* 2007). According to the commonly accepted definition, a "stable" cultivar performs comparatively well under unfavorable conditions and not so well under favorable conditions. The breeder's "ideal" cultivar possesses high productivity, shows regression coefficient (bi) approximate to 1 (plasticity) and the lowest deviation of factual data from the regression curve (σ^2) (stability). From this point of view the use of the suggested new index «general stability-[GY-σ^2] is logical and acceptable. The results from a part of the cultivars confirmed the generally accepted thesis of high yield and low stability. Almost all cultivars with the exception of the standard Pryaspa-(22), which are highly productive, demonstrated high variation, i.e. low stability. There are several cultivars with high grain yield also relatively stable under the investigated conditions of the environment; these cultivars most thoroughly met the criterion of the "ideal standard". These were cultivars Iveta-(5), Demetra-(3) and Karat-(17). It can be concluded that the combination of high yield and stability can be achieved in cultivars regardless of their genetic potential for grain quality.

The discussed approaches for evaluation of each particular cultivar according to the data are applicable and complementary. The evaluation on the plasticity and stability of the cultivar is not an easy task, provided that cross interaction of the genotype with the environment has been established (Table 3). Furthermore, the Principal Component Analysis of the data revealed high effect of random factors, which was about 25% from the total variation of grain yield. In this situation the established correlations between the parameters and regularities of the applied approaches are especially valuable because of their statistical significance. The great number of investigated locations and their specific interaction with the year conditions had such high effect on the grain yield that significant differences between the cultivars on the whole were very difficult to determine.

Conclusions

Under the conditions of Bulgaria the interaction of the cultivar with the environmental conditions by grain yield was complex and non-linear, although the percent of the genotype was only about 12 from the total variation of the experiment.

Any cultivar can have high grain yield and high ecological plasticity regardless of its quality potential.

Best balance of grain yield with its stability was found in cultivars Aglika, Demetra, Iveta (quality group A); Galateya, Slaveya (quality group B), Aneta and Karat (quality group C), and Todora, Kristal and Pryaspa (quality group D).

In the investigated group of cultivars there were cases of compromise combination of grain yield with stability at the highest possible levels. In this respect cultivars Aglika, Demetra, Iveta (quality group A); Galateya, Slaveya (quality group B), Aneta and Karat (quality group C), and Todora, Kristal and Pryaspa (quality group D) most completely meet the criterion of the "ideal" cultivar.

Cultivars Sadovo 1-(13) and Pobeda-(7) accepted and used as standards in Bulgaria had the lowest productivity and were most affected by the growing conditions.

Table 1. Geographic position and soil types of the growing locations

No	Location	Coordinates		Altitude (m)	Soil type
1	Selanovtsi, District Vratsa	N43°40’	E24°01’	168	Carbonate chernozem
2	Pordim, District Pleven	N43°23’	E24°51’	183	Less Haplustoll
3	Brushlen, District Ruse	N43°59’	E26°22’	31	Haplustoll
6	DZI, District Dobrich	N43°43’	E28°10’	250	Haplustoll
8	Burgas, District Burgas	N42°32’	E27°27’	25	Haplustoll Vertisols
9	Radnevo, District Stara Zagora	N42°18’	E25°58’	135	Haplustoll Vertisols
10	Gorski izvor, District Haskovo	N42°01’	E25°25’	178	Haplustoll Vertisols
11	Ognyanovo, District Pazardzhik	N42°09’	E24°22’	206	Alluvial meadow

Figure 1. Graphic representation of grain yield as a result from the direct effect of the factor year

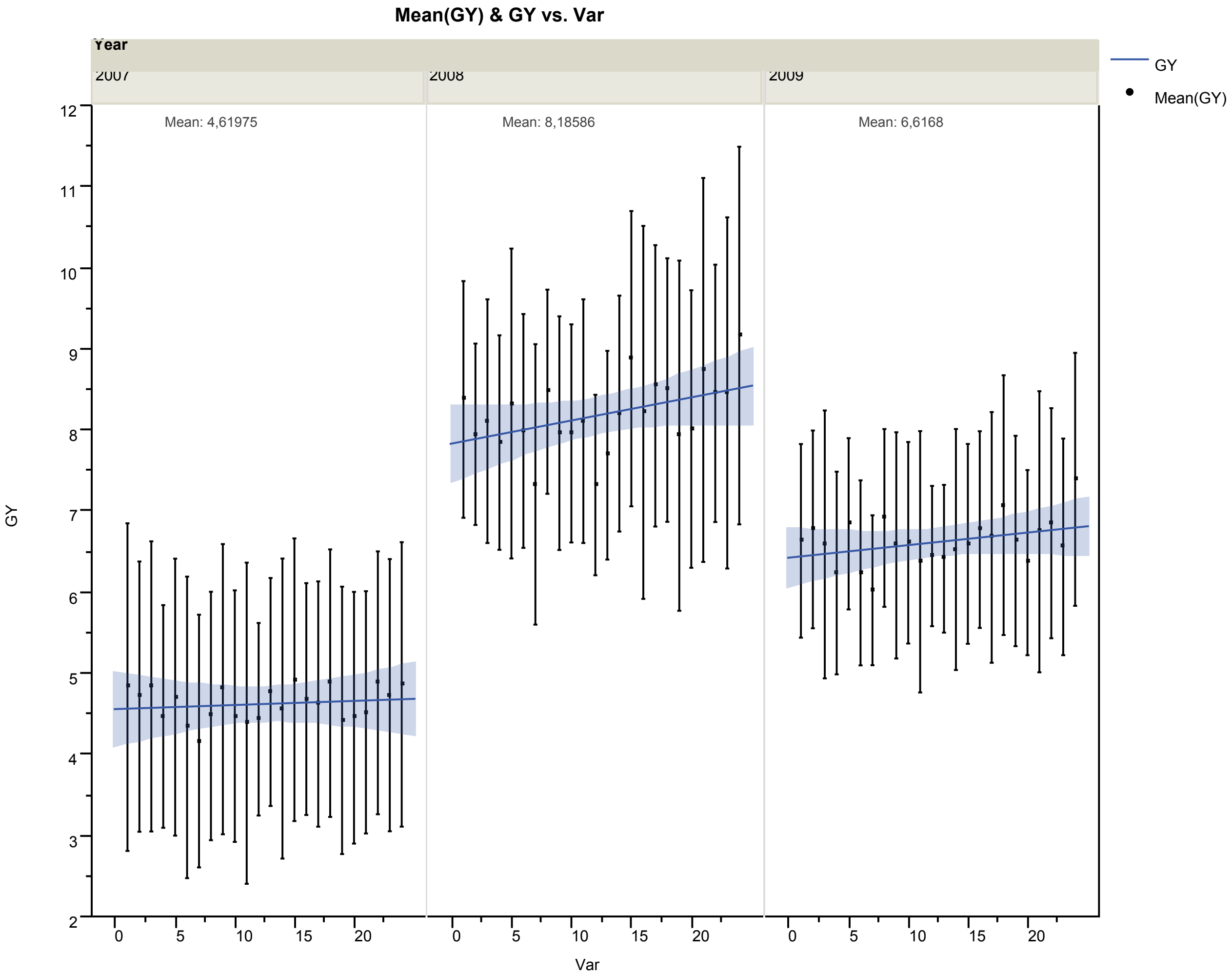


Figure 2. GGE analysis and visualization of grain yield variation according to the location

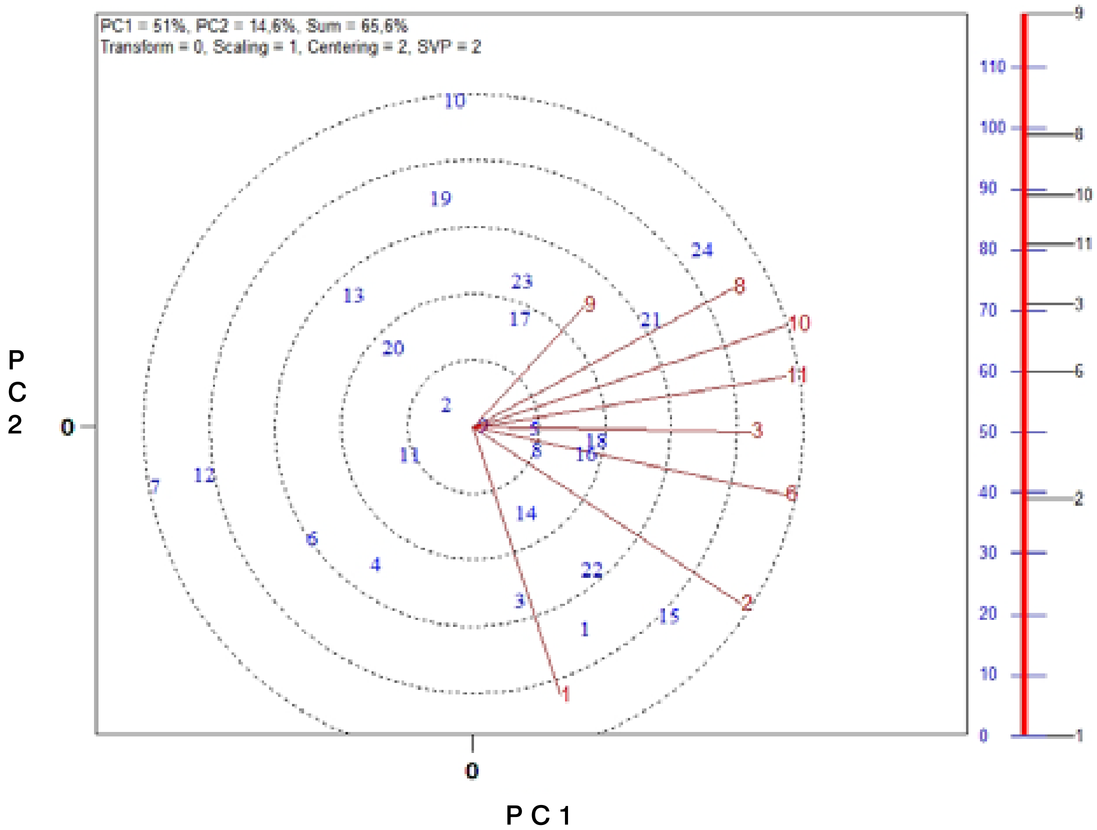


Table 2. ANOVA of the genotype x environment interaction during the three-year period of investigation

Source	**d.f.**	**F**	***p-value***
Genotypes	23	7.93	0.00000
Environments	7	100.23	0.00000
Interaction	192	3.43	0.00120
Heterogeneity	23	1.73	0.00000
Residual	322	0.41	0.00370
Pooled Error	576		

Table 3. Principal Component Analysis (PCA) of grain yield

Components	**F1**	**F2**	**F3**	**F4**
Eigenvalue	1.202	1.020	0.276	0.156
Variability (%)	47.000	16.900	7.157	4.350
Cumulative %	48.400	65.300	72.460	76.800

Figure 3. Principal Component Analysis (F1) of the genotype's contribution (%)

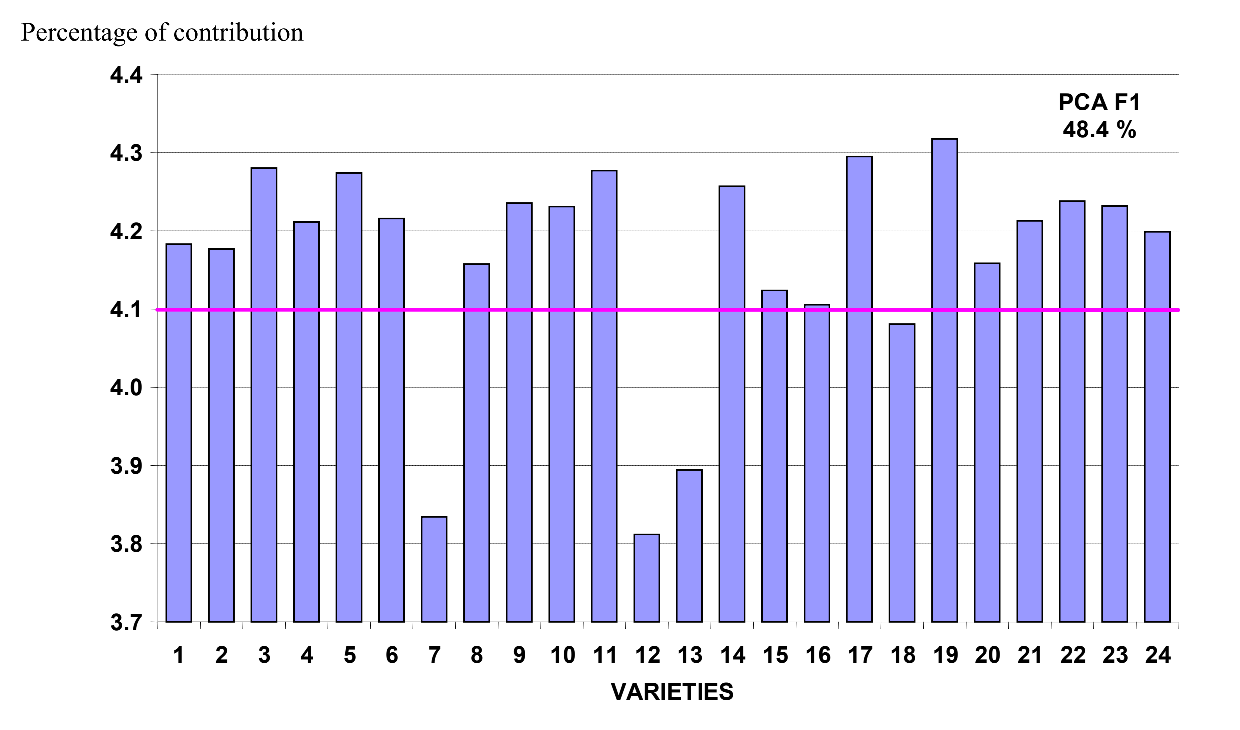


Figure 4. Principal Component Analysis (F2) of the genotype's contribution (%):

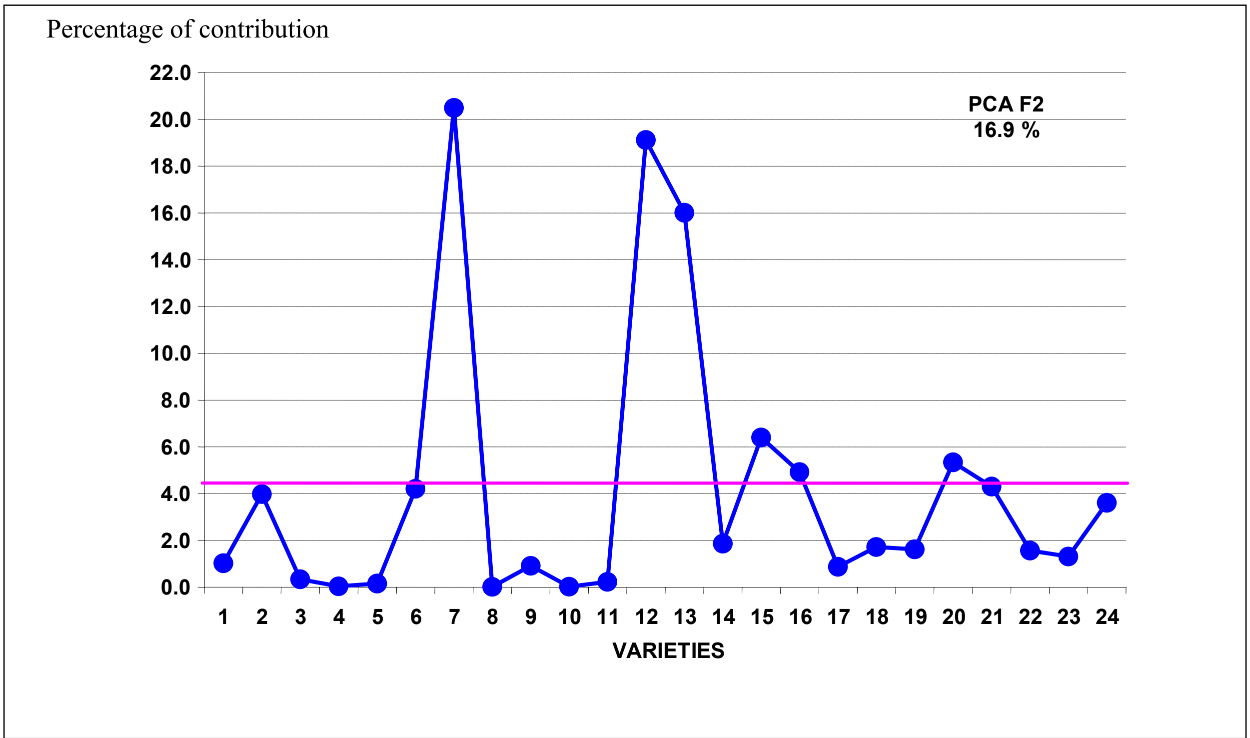


Table 4. Evaluation on the genotype x environment interaction according to the respective mean value of groups **A** and **B**

No	Variety	Group of quality	GY, t/ha	**A** *(Finlay and Wilkinson, 1963)%*			**B** *(Vulchinkov and Vulchinkova (2007)*	
				bi %	**σ2 %**	**Residual %**	**GY-bi**	**GY-σ2**
1	2	3	4	5	6	7	8	9
1	**Aglika***	A	6.53	106	108	131	100	86
2	Albena	A	6.46	93	131	90	101	105
3	Demetra	A	6,67	102	60	76	103	117
4	Desislava	A	6.23	92	105	83	97	103
5	Iveta	A	6.72	103	50	78	104	117
6	Milena	A	6.19	93	82	119	96	84
7	**Pobeda***	A	5.72	84	100	122	89	71
8	Viara	B	6.65	97	121	106	104	101
9	Galateya	B	6.49	96	101	92	101	105
10	**Enola****	B	6.47	99	57	86	100	107
11	Miryana	B	6.30	101	86	80	97	107
12	**Sadovo1****	B	5.90	76	186	109	94	82
13	Sadovo 772	B	6.25	82	182	121	99	84
14	Slaveya	B	6.51	99	60	88	101	107
15	Aneta	C	6.86	107	46	109	106	105
16	Geya1	C	6.65	105	65	111	103	99
17	Karat	C	6.50	108	78	82	99	110
18	Neven	C	6.61	102	33	114	102	96
19	Petya	C	6.35	102	88	76	98	110
20	**Yantar*****	C	6.25	100	86	97	96	96
21	Kristal	D	6.69	119	188	105	101	103
22	**Pryaspa*****	D	6.68	105	65	90	103	110
23	Svilena	D	6.40	112	168	125	97	86
24	Todora	D	7.05	119	154	111	107	108
	Mean (abs. value)		**6.46**	**1.00**	**0.42**	**2.20**	**4.10**	**4.26**

Check varieties*: *- for A group of quality, ** - for B group of quality, *** - for C group of quality*

Table 5. Evaluation on the interaction genotype x environment according to the respective mean value of statistical groups **C, D** and **E**

No	Variety	C (*Muir et al. (1992)*)			D (*Wricke 1962*)	E (*Shukla 1972*)
		HV (%)	**IN. Corr (%)**	**GE (%)**	**W^2 (%)**	**SV (%)**
1	2	3	4	5	6	7
3	Demetra	89	89	89	*72*	*71*
19	Petya	86	86	86	*72*	*71*
5	Iveta	50	50	50	*75*	*73*
11	Miryana	100	100	100	*76*	*75*
10	**Enola****	51	51	51	*82*	*81*
17	Karat	66	66	66	*82*	*81*
4	Desislava	142	142	142	*83*	*83*
14	Slaveya	55	55	55	*84*	*83*
22	**Pryaspa****	62	62	62	*87*	*87*
9	Galateya	54	54	54	*88*	*88*
2	Albena	50	50	50	*89*	*89*
20	**Yantar*****	309	309	309	*92*	*92*
8	Viara	170	170	170	102	102
15	Aneta	52	52	52	106	106
16	Geya1	79	79	79	107	107
18	Neven	66	66	66	109	110
6	Milena	71	71	71	116	116
21	Kristal	54	54	54	118	119
23	Svilena	50	50	50	124	125
24	Todora	50	50	50	124	125
1	**Aglika***	239	239	239	126	127
7	**Pobeda***	60	60	60	127	128
13	Sadovo 772	141	141	141	129	130
12	**Sadovo1****	256	256	256	130	131
	Mean (abs. value)	**4.17**	**4.16**	**8.33**	**4.91**	5.61

Table 6. Pearson's correlation values between the statistical parameters of stability

Variables	**GY**	**bi**	**σ2**	**Residual**	**HV**	**IN. Corr.**	**GE**	**W^2**
1	2	3	4	5	6	7	8	9
bi	0.780**							
σ2	-0.236	-0.120						
Residual	-0.152	-0.058	0.412*					
HV	-0.157	-0.073	0.818***	0.433*				
IN. Corr.	-0.222	-0.127	0.434*	0.993***	0.462*			
GE	-0.229	-0.125	0.628**	0.934***	0.716**	0.950***		
W^2	-0.208	-0.110	0.612**	0.947***	0.696**	0.956***	0.998***	
SV	-0.207	-0.110	0.611**	0.947***	0.695**	0.956***	0.997***	0.999***

Figure 5. Rank of cultivars based on their mean value and stability of locations

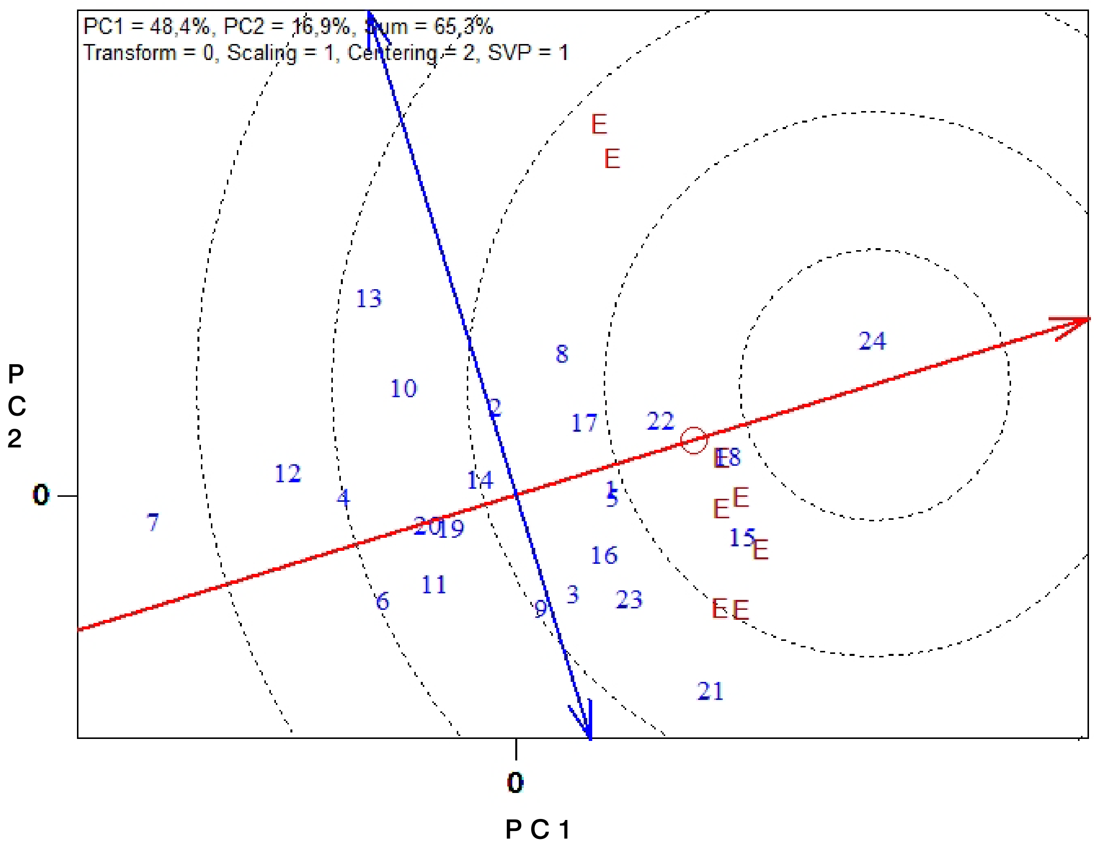


Table 7. Rank of cultivars by grain yield and its stability through the method of F (Kang, 1993)

Number	Variety	GY	GY Rank	Adjustment to R.	F (Y_S)
1	2	3	4	5	6
24	Todora	6.87	24	2	26+
15	Aneta	6.72	23	2	25+
18	Neven	6.64	22	1	23+
22	**Pryaspa***	6.60	21	1	22+
21	Kristal	6.57	20	1	21+
5	Iveta	6.53	19	1	20+
1	**Aglika***	6.53	18	1	19+
16	Geya 1	6.51	17	1	18+
8	Viara	6.49	16	1	17+
3	Demetra	6.43	15	1	16+
17	Karat	6.41	14	1	15+
23	Svilena	6.38	13	1	14+
14	Slaveya	6.36	12	1	13+
2	Albena	6.33	11	-1	10
9	Galateya	6.25	10	-1	9
11	Miryana	6.23	9	-1	8
10	**Enola***	6.23	8	-1	7
19	Petya	6.19	7	-1	6
13	Sadovo 772	6.17	6	-1	5
4	Desislava	6.10	5	-1	4
20	Yantar*	6.10	4	-1	3
6	Milena	6.02	3	-1	2
12	**Sadovo 1***	5.90	2	-2	0
7	**Pobeda***	5.67	1	-2	-1
	Overall mean	6.34			12.6
	LSD (p=0.05)	0.34			

Figure 6. Which cultivar performs best at which location?

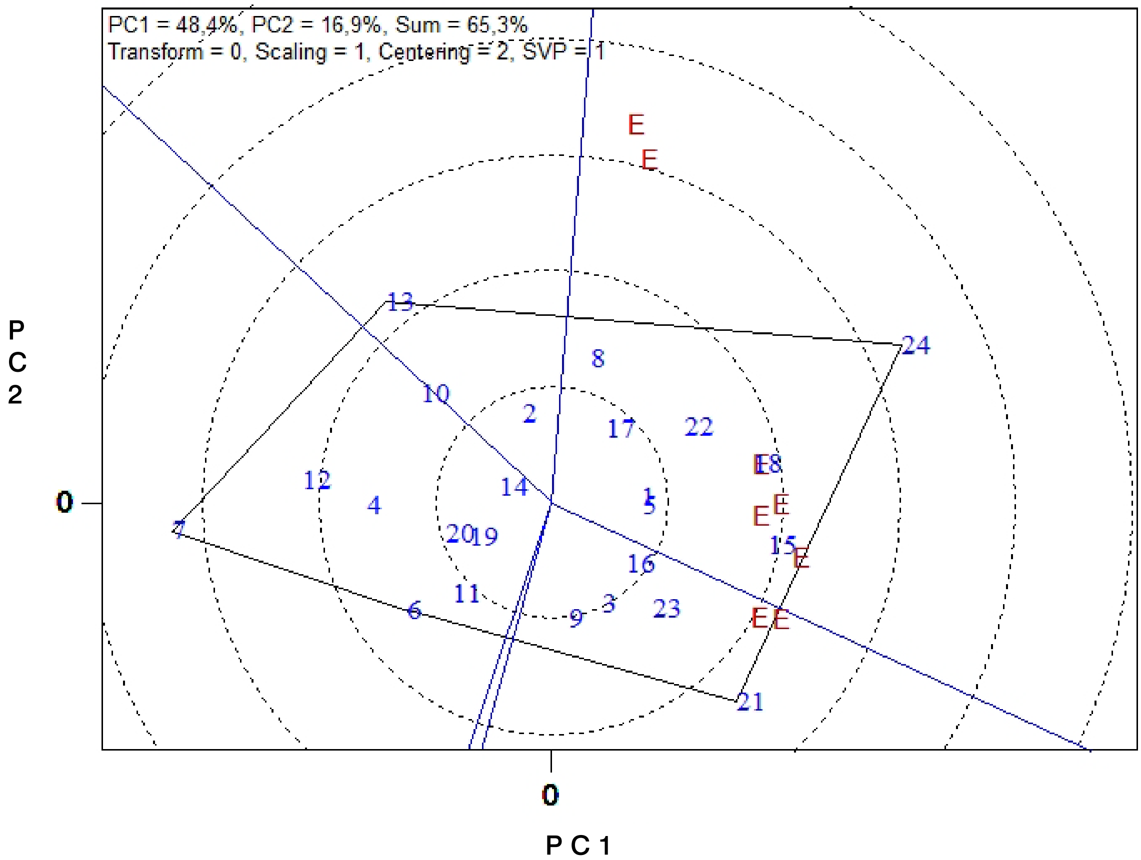


Figure 7. Index of the general adaptability of the cultivar (GY-bi), according to Vulchinkov and Vulchinkova, (2007)

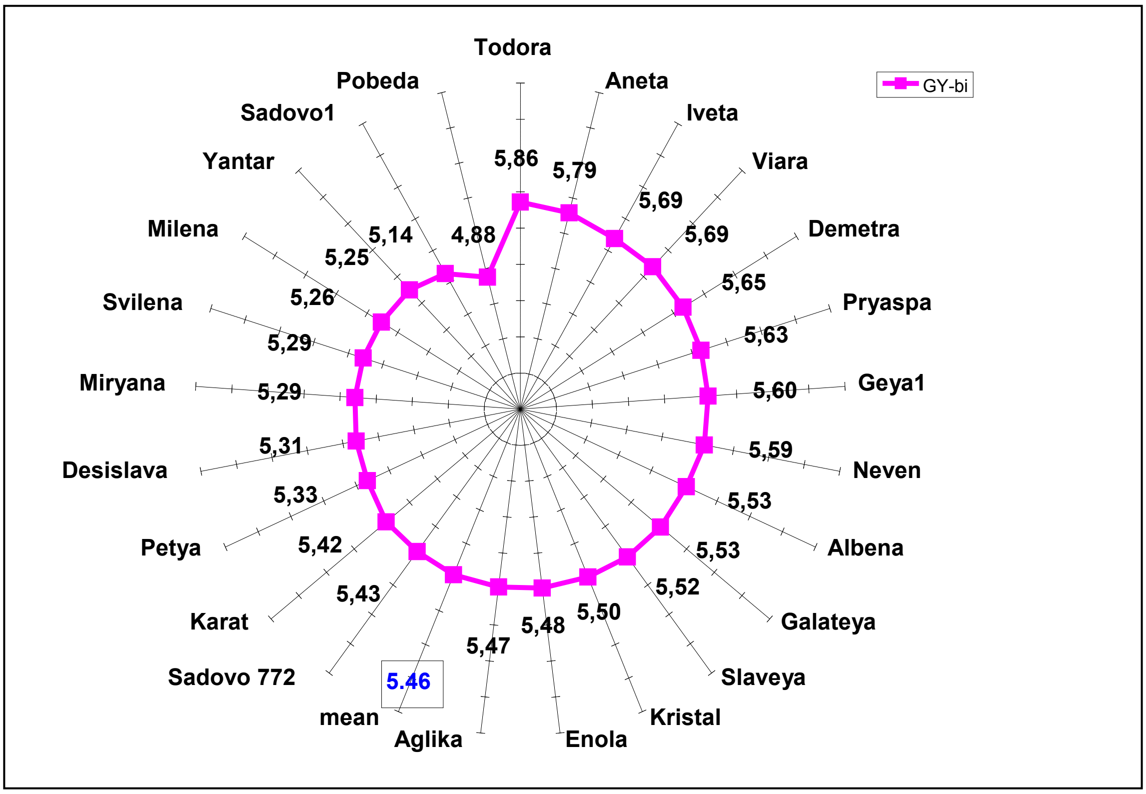


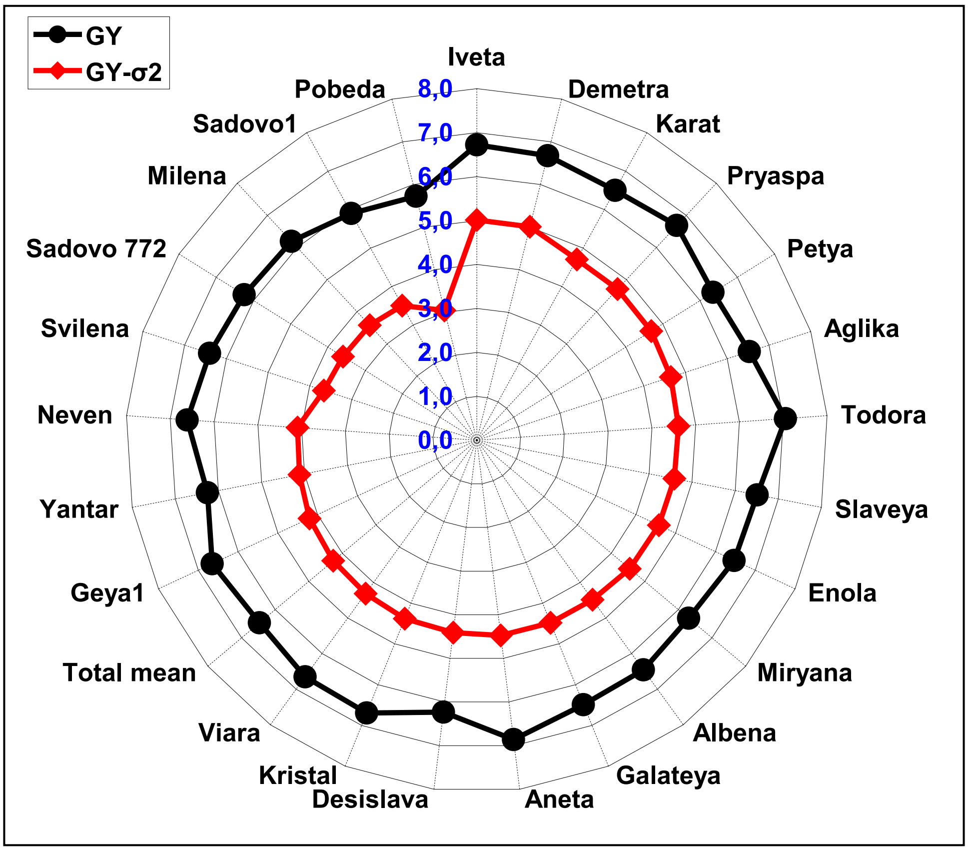
Table 8. Pearson's correlation matrix at the most important parameters of resistance and adaptability of grain yield

Variables	GY			GY-bi			GY-σ²		
	r	p-value	R^2	r	p-value	R^2	r	p-value	R^2
GY-bi	0.956***	0.0000	0.915***						
GY-σ²	0.681**	0.0001	0.763**	0.672**	0.0000	0.651**			
Y_S	0.914***	0.0000	0.835***	0.844**	0.0000	0.713**	0.579**	0.0080	0.629**

Table 9. Kendall -Tau rank correlations of the stability indices with adaptability

Variables	Y_S	p-value	GY	p-value
GY	0.708**	0.0000		
GY-b	0.376	0.0173	0.467**	0.0011
GY-σ²	0.129	0.4273	0.684**	0.0082

Figure 8. Index of general stability [GY- σ²] of each investigated cultivar



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