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Genotype x Environment Effects on The Productivity Traits of Common Wheat (*Triticum aestivum* L.) II. Analysis of Genotype Reaction

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Abstract

Situation and purpose: Twenty-seven genotypes were investigated, including four standard cultivars. The aim was to identify the most stable ones among them with regard to productivity under the conditions of both north and south Bulgaria, and to clarify the behavior of the cultivar with regard to grain yield according to the expression of its productivity components.

Methods: To achieve the above aim, various statistical methods and approaches were applied to investigate the correlations of the traits, their variation and effect on grain yield. A method for spatial visualization of the cultivar's behavior was used according to each of the traits depending on the environment of the respective investigated location over a three-year period. An Integral Breeding Assessment was made attempting to explain in detail the effect of the traits on grain yield (its level and stability).

Key results: Each cultivar demonstrated unique behavior with regard to productivity (traits) and to grain yield itself. Their interaction with the environment was significant although there was no direct effect of the year on any of the traits. The year conditions, however, affected the expression of the traits through their interaction with the genotype, which was significant at the highest statistical level. The interactions between the productivity traits and the environment are complex and non-linear which makes the objective evaluation of the cultivar difficult.

Conclusions: The traits varied by degree and direction which caused variation in the interactions both among themselves and with regard to yield. A correct evaluation of the plasticity and stability in relation to productivity can be made by applying an Integral Breeding Assessment (IBA) for each cultivar. The used model cultivars (Aglika, Sadovo 1 and Pryaspa) proved yet again that they have been correctly chosen as criterion for enhancing productivity and its stability.

Key words: bread wheat, grain yield, genotype by environment interaction, components of grain productivity

Abbreviations: GY- Grain Yield; NKS-Number of Kernels per Spike; NPT–Number of Productive Tillers m^{-2}; TKW–Thousand Kernel Weight; CE–Complex Estimation Value; CEC–Complex Estimation, Corrected; IBA–Integral Breeding Assessment; Score–sum of score values of a single trait

Introduction

The variation of grain yield when growing winter wheat cultivars is always different as a result from the strong and constant effect of the environment (Hagos and Abay, 2013, Tsenov et al., 2013). This is the main reason for the various degrees to which the productive potential of each cultivar is being realized. Grain yield depends directly on the expression of several traits which are considered essential for productivity (Yagdi, 2009, Anderson et al., 2011). In their investigations for determining the adaptability of a cultivar, the greater part of the researches are satisfied to only evaluate grain yield by using well known methods and approaches (Pacheco et al., 2005, Chapman, 2008).

There are only a limited number of publications which attempt to study the variations of the traits within the context of grain yield, but this is done by calculating the correlations between them (Aycicek et al., 2006, Gaju et al., 2009). An obstacle for such directs attempts are the different concepts for evaluation of the genotype – statistical and dynamic (Becker and Leon, 1988). The dynamic (agronomic) concept postulates that it is incorrect to study the traits in order to explain the resultant from them (Annicchiarico, 2002). On the other hand, any quantitative trait can be subjected to analysis of its interaction with the environment (Genchev, 2011). Therefore there should be no obstacle for such analysis of the traits, regardless of their being resultant of or not (Tsenov et al., 2013; Slafer et al., 2014). Furthermore, one of the suggested methods for evaluation of the response of the cultivar according to a trait is especially suitable for this purpose (Yan et al., 2000). In spite of some criticism coming from statisticians, it allows easy and convenient analysis on the interaction of the genotype with the environment of any quantitative trait. Almost each component of yield can be at least partially explained by the response of the cultivar, directly depending on the wheat biotype (spring or winter) and the growing conditions (stressful or favorable). Regardless of these facts, a number of authors agree on the assumption that there is a strong effect of the traits number of kernels per spike and number of productive tillers on the response of the genotype to the environment (Dodig et al., 2008, Gaju et al., 2009), in spite of the radically contrasting conditions under which the investigations have been carried out. There is a tendency toward a greater number of investigations on the components of productivity or other agronomy traits (stem height, date to heading, biomass, harvest index) of the grain yield of the cultivar from the point of view of its adaptability (Eid, 2009, Bustos et al., 2013). Slafer et al., (2014) are the most courageous in their assumptions, reporting that the variations of grain yield are due to the number of kernels per area unit, which is most strongly influenced by the number of kernels per spike. They discuss the possibility of strong or weak grain yield increase against the background of wheat adaptability. This can be done by a reasonable compromise combination of the number of kernels per spike with their size and with the number of productive tillers, each breeder considering his model cultivar under the specific stress conditions of the environment (Mondal et al., 2010, Acuna et al., 2011). Under the conditions of Bulgaria, the trait number of productive tillers is now in regress as a result from breeding (Tsenov et al. 2009), which is a shortcoming from the point of view of the specific wheat plant’s biology tending to form tillers. Furthermore, it is directly related to high drought tolerance of winter (Dodig et al. 2006, Chapman et al., 2010) and spring wheat (Parveen et al., 2010), which makes it a major factor for grain yield. In our previous communication (Tsenov et al., 2013) it was found that highest grain yield, regardless of the environmental conditions, is obtained at the compromise combination of the traits number of productive tillers and number of kernels per spike, the grain size not being significant. This allowed us to continue analyzing the specific behavior of each trait and its effect on the adaptability of each investigated cultivar.

The aim of this investigation was to explain the ecological plasticity and stability of each cultivar according to grain yield by the variation of its main traits.

Materials and Methods

Twenty-seven bread wheat cultivars were investigated at four locations in Bulgaria during 2006 – 2008. Grain yield and all productivity elements were studied and analyzed. The methods and approaches were described in the first communication (Tsenov et al., 2013). In this study the data are interpreted with a view of the response of each specific cultivar according to the above traits, as well as its plasticity and stability against the background of the entire investigated group of cultivars. For a more objective approach, when analyzing the effect of the individual traits on grain yield, to each specific cultivar the method of Smiryaev et al., (1992) was applied, modified by Georgiev et al., (2013). It consists in calculating the complex value for each genotype (complex assessment value) which allows determining the place (rank) of each genotype in the investigated group, which is our ultimate aim. The approach involved the calculation of the relative value of the genotype according to the mean value of the group for each individual trait; then these values were summed up to form an assessment that allowed evaluating the genotype against the background of the other genotypes. To make sure this approach was appropriate, we corrected in our database the values of the complex evaluation (CE) by traits with the actual correlations each of them has with grain yield. Thus the corrected complex assessment value was obtained. The correctness of the approach was checked by calculating the correlations between the two values of CE and the values of the traits themselves for the entire group of cultivars. The cultivars’ plasticity and stability against the background of the investigated locations was presented by the computer program GGE biplot 6.5 (Yan et al., 2000).

Results

The correlations between the mean values of the traits and their degree of variation in the trial are presented in Table 1. The variation of the main elements of productivity was radically different. There were significant correlations between grain yield, number of kernels per spike and number of productive tillers, while with thousand kernel weight the correlation was not significant (Tsenov et al., 2013). This, in general, was confirmed by the data over years given in Figure 1.

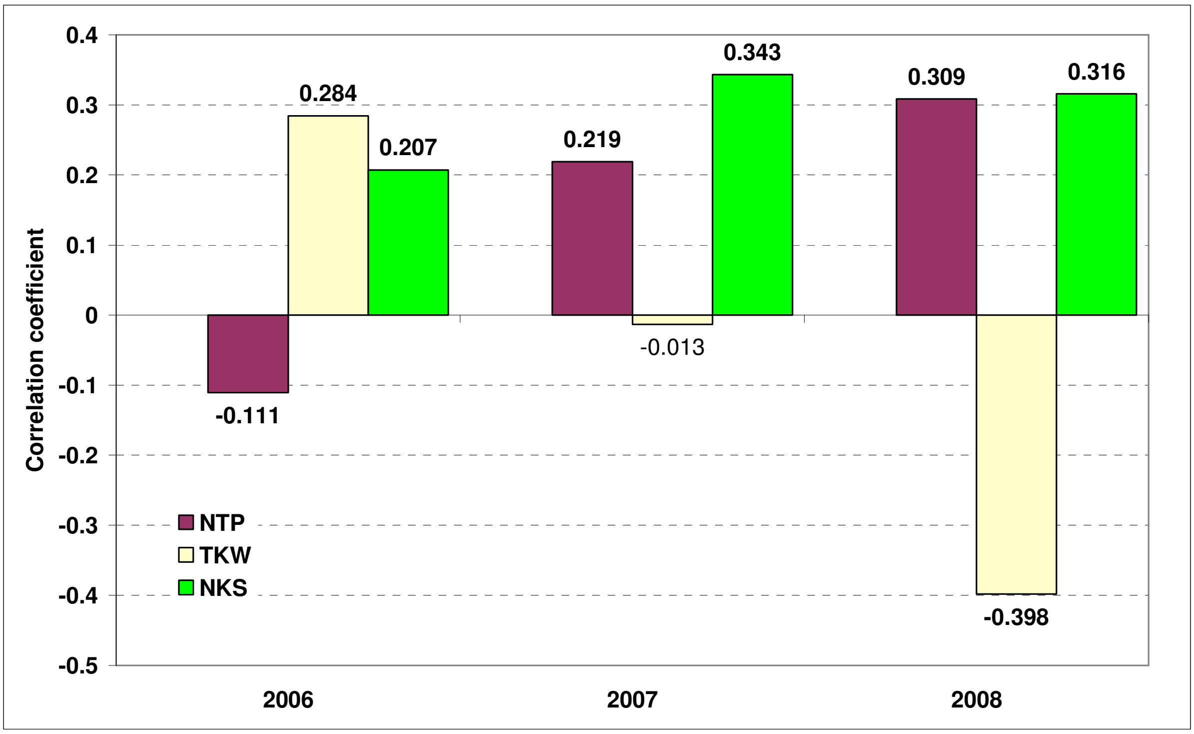

Figure1. Correlations between grain yield and main components of productivity in each year of the study

It is very important to point out that the high variability of the traits did not always affect their correlations with GY. In TKW correlations of radically different values and directions were observed, which was also partially valid for the trait NPT. Only in NKS the correlations were stable and high regardless of the changeable conditions during the respective seasons. There is analogous situation with the correlations over locations. The trait NKS, which has greatest effect on GY, demonstrated highest variability under the specific environments. The high correlation means that the higher the values of the trait are, the stronger their variability. Such high variability was present with the trait TKW. In grain yield the correlation was also significant although relatively low. This means that in some cultivars the high values of GY and NPT are combined with relatively low variability with regard to the environment and vice versa. Having in mind this fact, it can be expected that the cultivar will possess plasticity against the background of high expression of one of the two traits.

Table1. Correlations by Spearman between traits and their variation

Parameter, Trait	NKS	TKW	GY	NPT
Variances	0.806	0.638	0.372	0.331
p-value	0.0000	0.0000	0.0071	0.1230

*Values in **bold** are significant at level of alpha = 0.05*

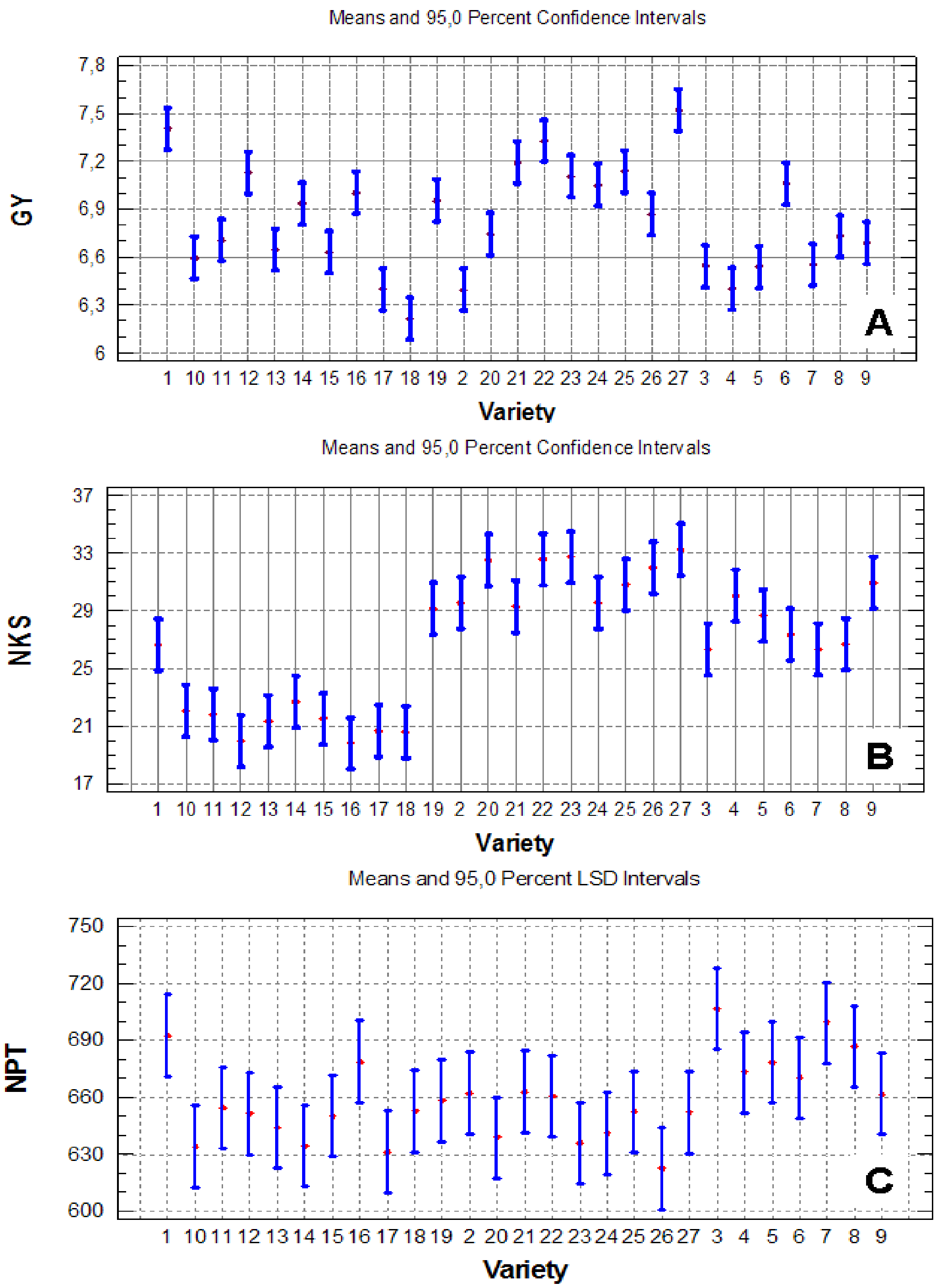

Figure2. Means and variability according to the environments of the varieties studied for (A) grain yield, (B) number of kernels per spike and (C) number of productive tillers

The established correlations showed various degree of variation of the investigated traits when compared. Figures 2 and 3 give dimensional representation of each of the traits by cultivar. NPT had highest variation, followed by GY and probably this affected the low correlations with the levels of the traits.

Cultivars Aglika (1), Todora (27) and Geya 1 (22) demonstrated highest grain yield, while cultivars Pobeda (2), Yunak (17) and Prelom (18) gave lowest yields. Two distinct groups were formed according to the trait NKS: cultivars with high number of kernels per spike (20-27, cf. the numbering in Table 3), and cultivars with lowest number of kernels (10-18). Concerning the number of productive tillers, the situation was very simple, almost all cultivars having similar values of this trait, with the exception of cultivars Aglika (1) and Momchil (3), which had high values, and of cultivar Svilena (26) which had low tillering. Similar was the situation with the trait TKW, only cultivars Aglika (1), Sadovo 1 (8) and Galateya (8) having higher but not significant values in comparison to all other cultivars.

Confronted with this complex situation of different ranking of the cultivars by values of the individual traits, it was impossible to determine which of them possessed stability and plasticity with regard to GY as a result from the expression and variation of the respective traits.

In spite of the considerable variation among the investigated cultivars, there still were significant differences by each of the traits. This allowed analyzing the behavior of each genotype according to each trait against the background of the environments. The data are consequently presented in Figures 4, 5, 6 and 7.

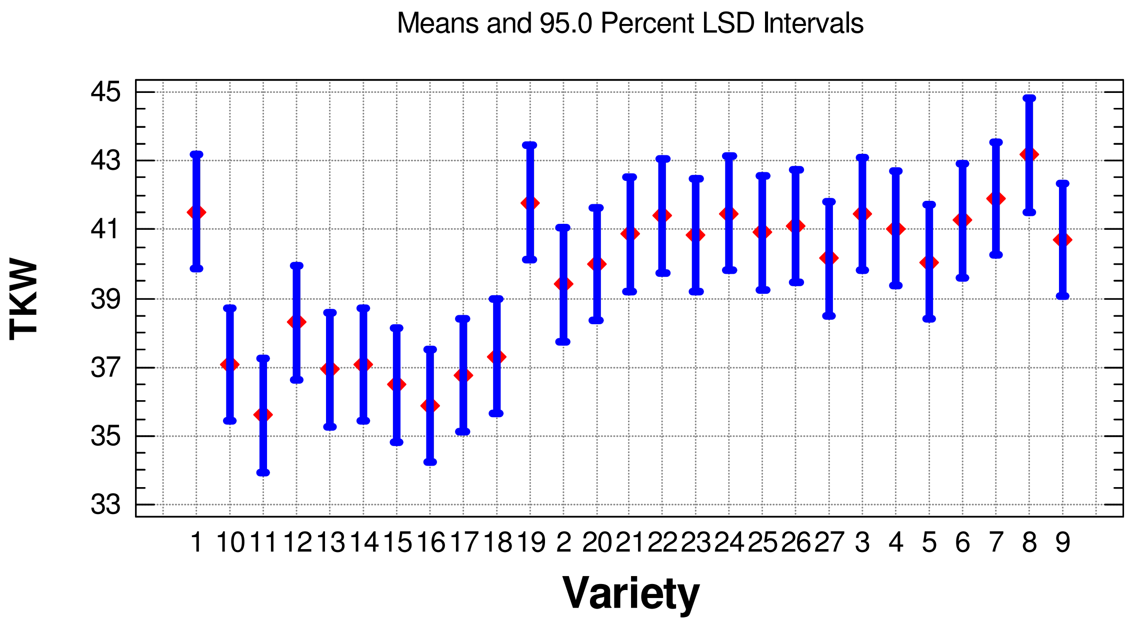

Figure3. Means and variability of the cultivars for thousand kernel weight (TKW) according to the environments

The stability and plasticity of each cultivar in comparison to the group is the most interesting information that the pictures of the individual traits can provide to us. This information characterizes the value of each genotype with regard to both its distribution and to breeding, giving some explanation about its response according to grain yield through the variation of the productivity components.

The positions of the points of the respective cultivars on Figure 4 give information on the specific interaction between the trait and the environments, and also on the behavior of the cultivars under the specific locations. The red arrow represents the trait grain yield, and the blue one – the plasticity (variation) of the cultivar. The small circle on the red arrow shows the optimal and desirable compromise combination of high GY with high plasticity. The greater the distance (marked with lines) from the horizontal line, the less stable the respective genotype is.

The cultivars with similar mean values are marked with concentric circles. According to the rules for visualization of the principle component analysis (PCA), cultivars (1) Aglika, (6) Iveta, Slaveya (12), Galateya (19) and Pryaspa (24) possess excellent combination of high yield with high plasticity under the conditions of the four investigated locations. The conditions at the locations were similar according to the cultivars' response, only location Vratsa (BP) being considerably different. Low and highly variable was the grain yield from cultivars (4) Sadovo 772, (8) Sadovo 1, (11) Enola, (13) Boryana (15) and Zdravko.

With the trait NKS, almost the same regularities were observed with regard to the cultivars and the locations (Figure 5). Location Ognyanovo had conditions considerably different from the rest, and under these conditions the trait had on the whole similar values. At this location there was high stratification of the plasticity and of the level of the trait by cultivars. The following cultivars had the most suitable combination of the two properties: (1) Aglika, (6) Iveta, (12) Slaveya, (16) Katya and (27) Todora. With this trait, the realized mean values of the cultivars were very close (the concentric circles encompass about 70 % of them). Their plasticity, however, was very different. High variation of the values was observed in cultivars (7) Milena, (14) Diamant, (19) Galateya, (21) Karat and (26) Svilena.

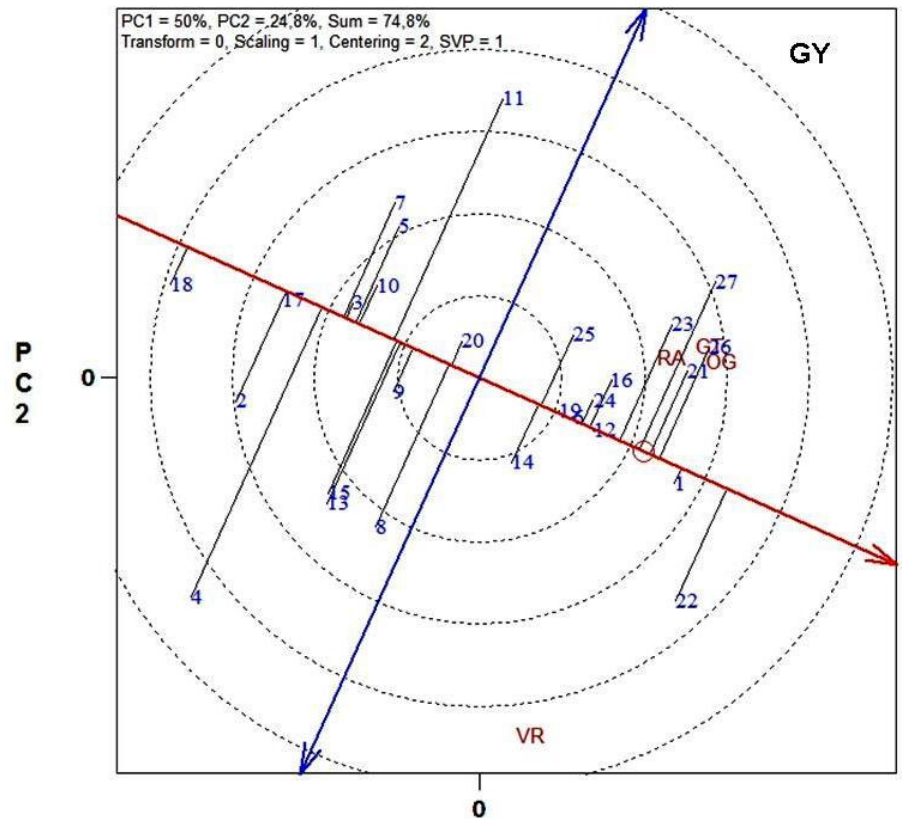

Figure4. GGE analysis and visualization of the variability of the locations for testing grain yield

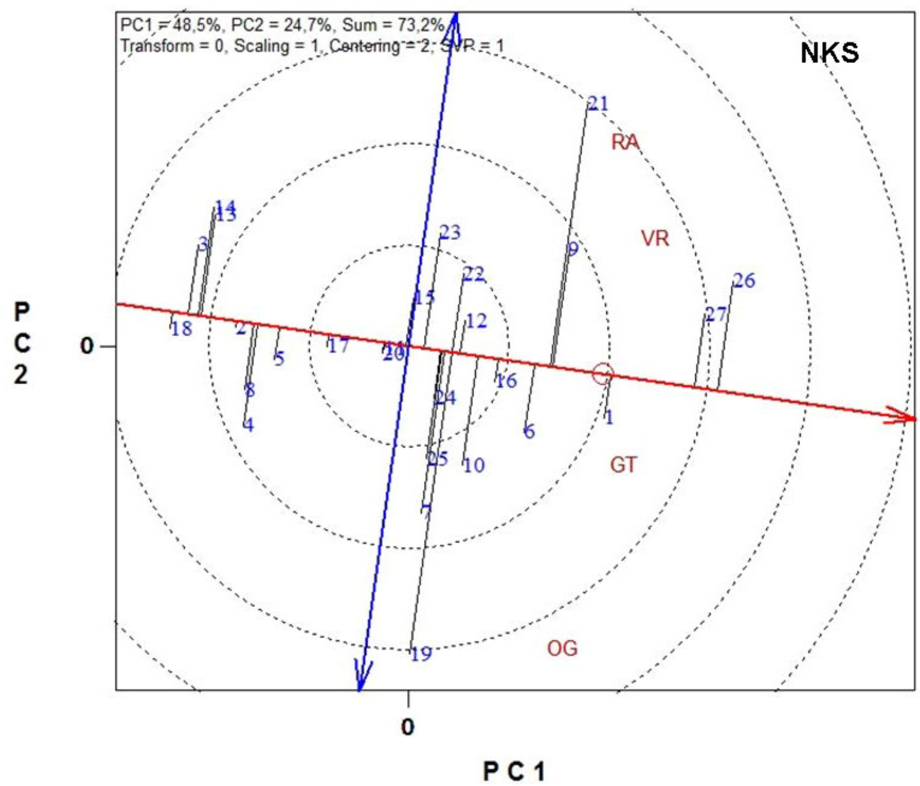

Figure5. GGE analysis and visualization of the variability by location for the trait number of kernels per spike

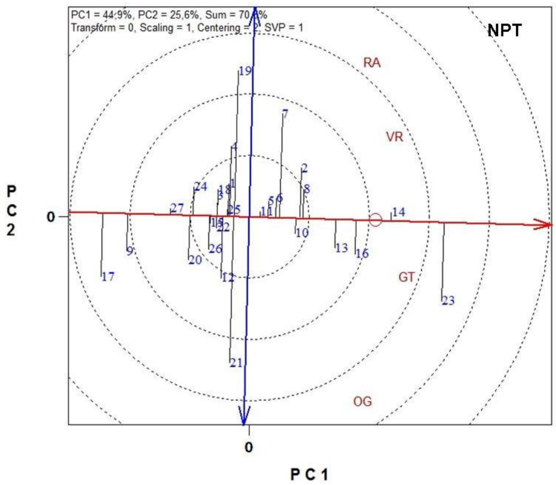

Figure 6. GGE analysis and visualization of the variability by location for the trait number of productive tillers, NPT

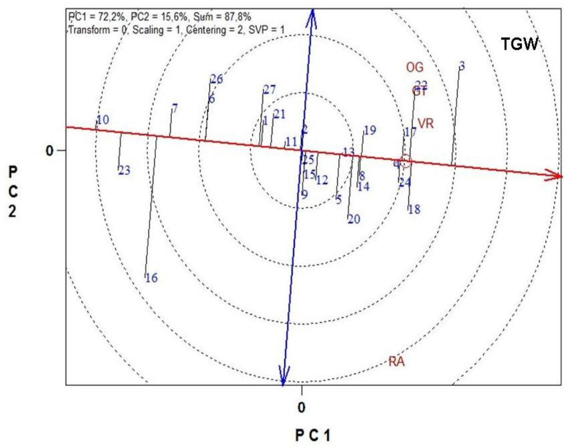

Figure7. GGE analysis and visualization of the variability by location for testing thousand kernel weight number, TKW

Cultivars (8) Sadovo 1, (10) Liliya, (13) Boryana, (14) Diamant and (16) Katya possessed excellent combination between level and plasticity by this trait (Figure 6). A confirmation was observed of the finding we made that there was no significant difference between the cultivars. All cultivars, with the exception of (23) Petya, fell within concentric circles, which was an indication for similar mean values. The variation was very strong and this was the reason for the low plasticity of cultivars (7) Milena, (17) Yunak, (19) Galateya, (21) Karat and (23) Petya. The conditions of the locations caused different degrees of variation: strong in Radnevo (RA) and Ognyanovo (OG) because they are positioned at a significantly greater distance from the center of the coordinate axis, and relatively weaker at the other two locations.

With grain size (TKW), the situation on Figure 7 is considerably more variable concerning the value of this trait and its plasticity by cultivars. Location Ognyanovo was radically different from the rest according to conditions for formation of the trait. The cultivars fell within four different concentric circles, which signified variation of TKW. Cultivars (1) Aglika, (8) Sadovo 1, (17) Yunak, (19) Galateya and (24) Pryaspa demonstrated excellent plasticity. Only in cultivar Yunak this plasticity was related to small-sized grain. Cultivars (3) Momchil, (16) Katya, (20) Yantur, (22) Geya 1 and (26) Svilena showed stronger non-linear interaction with the environment. These cultivars formed large grain, with the exception of Katya which had the smallest grain size in the entire group.

Discussion

The values of the complex estimation in its two variants correlated significantly with the values of the traits, with the exception of NPT (Table 2). The applied approach for complex estimation is correct because the correlations are positive and significant and relevant conclusions can be made for each genotype on the basis of their values. In the case of corrected complex estimation, the correlation of its value in GY was highest (r = 0,750), which is entirely logical with a view of the applied approach. The two traits, NKS and TKW, had significant influence on yield through this corrected value (r = 0,737 and r = 0,681, respectively).

The grain yield of the cultivars was a direct result from the compromise combination between the levels of expression of the individual traits, with only NPT having weaker effect (r = 0,307 ns). The reason for this are probably the similar values of the trait realized by the cultivars involved in the investigation, as well as its strong variation under different environments.

Table2. Correlations by Spearman between traits and the Integral Breeding Assessment (IBA)

Trait	CE	*p*-values	CE (corr)	*p*-values
NPT	0.480	0.1123	0,307	0,1191
GY	0.609	0.0001	0,750	<0.0001
NGS	0.662	0.0000	0.737	<0.0001
TGW	0.837	< 0.0001	0.681	0.0001

*Values in **bold** are significant at alpha=0.05*

The final estimation values for each trait of the cultivars are given in Table 3. They are ranked according to the value of the corrected complex estimation values. The cultivars with highest Integral Breeding Assessment (IBA) have also highest GY. It is a result from the extremely high compromise combination between all main productivity traits. Even without taking into account the ICA values, it is evident that the effect of NKS is most important, followed by TKW, and the effect of NPT is lowest. Cultivar Iveta possessed unique balance, all its traits being around and above the mean values of the entire group of cultivars.

Table3. Relative values of the main traits of each cultivar compared to the overall mean value and ranking by the cultivars' corrected Integral Breeding Assessment value (IBA)

Ranking	Quality group	№ in trial	Variety	GY	NGS	NPT	TGW	ICA**
1	B	19	Galateya	104.8	108.7	100.0	105.4	5.55
2	A	1	Aglika*	108.4	99.3	105.3	104.7	5.47
3	C	21	Karat	105.3	109.2	100.8	103.1	5.46
4	C	22	Geya 1	107.3	121.3	100.4	104.5	5.46
5	D	27	Todora	110.1	123.9	99.1	101.3	5.46
6	A	6	Iveta	105.4	101.9	101.9	104.1	5,12
7	A	7	Milena	95.9	98.1	106.3	105.7	5.00
8	B	8	Sadovo 1*	98.5	99.4	104.4	108.9	4.98
9	B	9	Sadovo 772	97.9	115.3	100.6	102.7	4.87
10	C	20	Yantar*	98.7	121.2	97.1	100.9	4.87
11	D	24	Pryaspa*	103.2	110.1	97.4	104.6	4.87
12	D	25	Kristal	104.5	114.8	99.1	103.2	4.87
13	B	12	Slaveya	104.4	104.3	99.0	98.6	4.77
14	C	23	Petya	104	121.9	96.6	103	4.42
15	D	26	Svilena	100.6	119.1	94.6	103.7	4.42
16	A	3	Momchil	95.8	98.1	107.4	104.6	4.41
17	A	5	Albena	95.7	106.7	103.1	101.0	4.40
18	A	2	Pobeda*	96.3	110.1	100.6	99.4	4.40
19	A	4	Sadovo 552	93.7	112.0	102.3	103.5	4.07
20	B	13	Boryana	97.3	79.5	97.9	93.2	2.45
21	B	15	Zdravko	97.1	80.1	98.8	92.1	2.45
22	B	16	Katya	102.5	73.7	103.1	90.5	2.45
23	B	11	Enola*	98.2	81.3	99.5	89.8	2.15
24	B	18	Prelom	91.0	76.6	99.2	94.1	2.03
25	B	14	Diamant	101.5	84.6	96.4	93.5	2.00
26	B	10	Lilya	96.5	82.1	96.4	93.5	1.54
27	B	17	Yunak	93.7	77.0	95.9	92.7	1.20
			Overall					*4.00*

* Check cultivars, ** ICA – Integrated Corrected Assessment value

This is a prerequisite for realization of high productivity combined with plasticity and stability under changeable environment. Similar behavior of the cultivar during a 5-year investigation has been reported in the study of Chamurliiski and Tsenov (2013), in which there is an excellent combination of high yield with high ecological plasticity determined by the method of Kang (1993). Quite similar is the behavior of cultivar Aglika which possesses variable ecological plasticity and stability by GY in direct relation to the cultivars included in the study and the conditions.

According to Chamurliiski and Tsenov (2013) Aglika possesses combination of GY with plasticity close to the mean value of the group. In another study of Tsenov et al. (2011a), cultivars Aglika and Iveta demonstrated similar behavior, and their high yield (and quality) was combined with excellent plasticity and stability, which, on its part confirmed the definite conclusions made earlier by Tsenov et al., (2006). The results on cultivar Todora (27), Karat (21) and Geya 1 (22) confirmed previous investigations of Tsenov et al., 2011b, Kostov et al., 2011. These cultivars exceeded the well established standards Sadovo 1 (8) and Pryaspa (24). In the final ordering of cultivars they ranked 7th and 11th, respectively. The compromise combination between the traits in their grain yield was also at a high level. Cultivar Sadovo 1 possessed slightly higher plasticity, although GY of Pryaspa was significantly higher. The cultivars with the lowest ICA had relatively the lowest GY, with the exception of Diamant (14). The rest of the cultivars, Enola (11), Prelom (18), Liliya (10) and Yunak (17), had relative values of the traits with 5-15 % lower than the mean value. This characterizes them as having low stability and plasticity under the investigated environments. The standard for productivity Enola (11) also fell within this group. Its behavior was a surprise having in mind the information for its plasticity approximating that of cultivar Pryaspa, as reported previously in the studies of Tsenov et al., 2011a, Tsenov et al., 2011b. It is interesting to note the behavior of cultivar Slaveya in this study. According to several investigations (Tsenov et al., 2010, Tsenov et al., 2011a, Kostov et al., 2011) presenting data from different locations and seasons, this cultivar had expression similar to that of cultivar Aglika. In this study, too, its expression was comparatively good, it's GY and plasticity being similar to that of the standard Pryaspa, and the traits NKS (99.0) and TKW (98.6) being at the mean level of the trial.

Table4. Comparison between Integral Breeding Assessment of mean and stability of trait in some checks and varieties (1. low mean and stability; 2-3 medium mean and stability and 4. High mean and stability)

Variety, Check	ICA	GY	NKS	NPT	TKW	Score*
19. Galateya	5.55	4	2	2	4	12
1. Aglika (check 1)	5.47	4	4	2	4	14
8. Sadovo 1 (check 3)	4.98	2	3	4	4	13
6. Iveta	4.90	4	4	4	3	15
24. Pryaspa (check 4)	4.87	4	2	2	4	14
11. Enola (check 2)	2.15	2	3	3	2	10

* score – sum of score values of a single trait

In conclusion, several important groups of facts can be summarized. The behavior of each cultivar is unique with regard to the traits related to productivity and grain yield itself. Their interaction with the environment is significant, although there was no direct effect of the year (season) in any of the traits. These environments, however, influenced the expression of the traits through interaction with the genotype, which was significant at the highest statistical level (Tsenov et al., 2013).

Grain yield was affected by the expression of the individual traits against the background of the changeable conditions over seasons (for example, drought occurred in 2007, while 2008 was very favorable for the crop). The traits varied considerably, which on its part caused variations in the effect on yield under specific environments. A detailed analysis was done on the plasticity of each trait as a result from the interaction of the genotype with the location of testing. The spatial analysis of the data according to Yan et al., (2000) revealed similar behavior of the same cultivars by the different traits.

Regardless of the established complexity of interactions both in their direction and scale between the investigated factors, the effect of the traits on grain yield (individually and in a group) can be explained by applying specific approaches. This is done by proving the relation between the values resulting from the integral breeding assessment and the values of the traits. Thus the cultivars were divided into three groups: cultivars with high yield in good compromise combination with plasticity, cultivars of intermediate combination, and cultivars with low and unstable grain yield.

In order to make objective and correct conclusions on the value of a given cultivar, it is required to take into account its behavior according to all investigated traits (Table 4). Considering the plasticity and stability of a cultivar together with the level of the trait gives different information on the cultivar. The complex estimation does not properly reflect the presence of variability in a trait, which can be misleading in our efforts. When taking into consideration the variation as well, the cultivars with high assessment (ICA) become closer to the model cultivars. According to the data from Table 4, the first-ranking cultivar Galateya exhibited behavior similar to the standards, while cultivar Iveta demonstrated slightly higher values. Cultivars Aglika and Pryaspa are more suitable for comparative basis due to their high plasticity in combination with high productivity than the other two standards

Conclusions

The interaction between the traits of productivity with the environment was complex and non-linear making the objective assessment of the cultivar very difficult.

The traits varied by degree and direction which caused variation in the interactions, both between the traits and with regard to grain yield.

The use of an integral breeding assessment of each genotype is a possibility to correctly evaluate its plasticity and stability with regard to productivity.

The used standards (Aglika, Sadovo 1 and Pryaspa) demonstrated once again they have been properly chosen as a criterion for higher productivity and stability.

The cultivars with highest productivity exhibited also highest variability under the specific environments, with the exception of cultivar Iveta, which behaved as the most universal variety in this investigation.

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