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EFFECT OF THE ENVIRONMENTS ON THE PRODUCTIVITY-RELATED CHARACTERS IN COMMON WINTER WHEAT

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Abstract

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Aims: In order to determine the effect of the characters, which are in high correlation with grain yield under contrasting conditions of growing, the nature of the interaction of the cultivar with the growing conditions was analyzed.

Methods: Bulgarian wheat cultivars were investigated during four successive years at five locations within the country. The locations were chosen to cover the variety of soils and climate in all grain-production regions of Bulgaria. The complex interaction of the genotype with the environment was analyzed in relation to three characters – grain yield, and two characters (date to heading and number of grains per spike) with determining effect on it. Different statistical approaches were used to analyze the interaction of these characters with the environment and their effect on grain yield.

Key results: The genotype x environment interaction was significantly high according to the factor year, as well as to the factor location of testing. The interaction year x location was low and insignificant. The variation determined in this experiment through principal component analysis reached third level, which complicated the assessment of the individual cultivars by two of the three investigated characters. Only with date to heading predominant linear interaction of the genotype with the environment was observed, which allowed determining of the cultivars' stability by this character.

Conclusions: Grain yield can be correctly evaluated against the background of contrasting environmental conditions, through characters in positive correlation with it. In our case, these were the date to heading and the number of grains per spike. Each of the investigated characters revealed different nature and direction of the genotype's interaction with the environment. It is possible, through the established regularities, to objectively evaluate the cultivars which differ from the group mean. It is demonstrated how the stability of the grain yield is related to the stability of another two characters in the same cultivars.

Key words: wheat, grain yield, date to heading, genotype x environment, stability

Introduction

According to the theory of the genotype x environment interaction, final resulting characters such as grain yield should be subjected to this type of analysis (Lin et al., 1986).

This is basically a valid approach, although not entirely applicable to breeding. There is a recent increase in the number of experiments aimed at analyzing the effect of the productivity components or other agronomic characters (stem height, date to heading, etc.) on the grain yield of the cultivar resulting from the interaction with the environment (Eid, 2009; Bustos et al., 2013). The efforts of the researchers show that almost any component of the yield can to a certain extent explain the behavior of the cultivar in direct relation to the wheat's biotype and the conditions of growing (Slafer et al., 2014). However, a number of authors are univocal that there is a constant influence of the characters number of grains per spike and number of productive tillers on the

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resulting response of the genotype to the environment with regard to productivity. (Dodig et al., 2008; Gaju et al., 2009). The role the number of grains per spike play for the better adaptability of the genotype is highlighted in the investigations of Bancal (2008) and Dreccer et al. (2009). They found out that this character does not compete significantly with the processes of the crop's growth and development, which is highly important for the end grain yield.

In the Bulgarian biotype, the number of grains per spike has highest effect on the grain yield (Tsenov et al., 2013, Tsenov et al., 2014). The investigations in the neighboring countries Serbia (Dreccer *et al.,* 2009) and Romania, (Mustatea et al., 2009) indicate that under similar climates the effects of the characters on yield are identical. Furthermore, almost all traits allowing for efficient selection in the process of breeding have more or less a significant effect on the grain yield regardless of the variable environmental factors, the location of growing and the specific season. From the point of view of date to heading, the situation is more controversial. In the studies of Tsenov and Gubatov (2016), the character date to heading has ostensible positive effect on the grain yield and some productivity components, such as number of grains per spike, in an ecological experiment involving variable environments. On the other hand, the relationship between the date to heading and grain yield is also variable and directly dependent on the location and the investigated conditions under drought or high temperatures during grain filling, the earlier date to heading guarantees higher grain yields (Mondal et al., 2013; Tsenov et al., 2009). On the contrary, under favorable conditions, especially under irrigation, the genotypes with earlier date to heading are more advantageous (Griffits et al., 2009; Reynolds et al., 2012; Bustos et al., 2013). According to Slafer et al. (2014), there is a balance between the yield components under competitive conditions, which can be altered toward additional increase of yield.

The question arises if it possible to explain the variation in grain yield by its correlation with the characters with direct effect on it, no matter how changeable they are. To answer this question, we should have information about the effect of the character on the main productivity components in the context of their actual change as a result from the interaction with the environmental conditions. There is available data on this topic, but it does not take into account the effect of the environment on the productivity components, which, on its part, alters the balance between them and has a respective direct effect on their correlations (Bustos et al., 2013, Keshavarzi et al., 2013).

The aim of this investigation was to analyze the effect of the date to heading and the number of grains per spike within the context of grain yield variation resulting from the conditions of the environment, under contrasting growing environments.

Materials and Methods

General setting of the experiments

Twenty-four common winter wheat varieties developed in Bulgaria were investigated. Nineteen of them (Table1) were released by the company Agronom I Holding, and three cultivars (Laska, Svilena and Iveta) are distributed by this company according to a license agreement with Dobrudzha Agricultural Institute – General Toshevo. Cultivars Enola and Pryaspa were used as standards.

The data presented in this investigation are from field trials carried out for a 4 years, and consider grain yield-related characters. The testing locations were chosen to be represen-

Table 1
Groups of varieties for testing the productivity traits

№	Cultivar	Origin	Group of quality	№	Cultivar	Origin	Group of quality
1	TERVEL	Agronom	A	13	RIANA	Agronom	B
2	A 15/89	Agronom	A	14	TOPOLITSA	Agronom	B
3	IVETA*	DAI-Agronom	A	15	OGNYANA	Agronom	B
4	APOGEJ	Agronom	A	16	ENOLA*	DAI	C
5	LASKA	DAI-Agronom	A	17	ALEXA	Agronom	C
6	DAGEYA	Agronom	A	18	ALISA	Agronom	C
7	SAMUIL	Agronom	A	19	AP VELIKA	Agronom	C
8	BILYANA	Agronom	B	20	BUL ANETA	Agronom	C
9	NEVEN	Agronom	B	21	VYARA	Agronom	C
10	FAKTOR	Agronom	B	22	SVILENA	DAI-Agronom	C
11	PRESYANA	Agronom	B	23	HELA	Agronom	C
12	RALITSA	Agronom	B	24	PRYASPA*	DAI	C

* - check varieties

tative for the respective grain-production regions of Bulgaria. The cultivars involved in the investigation belong to three major quality groups, ranked and given respective numbers in the experiment.

Methods and field experiment designs

The analyzed data are from a unified field experiment based on the three main factors typical for such kind of investigations: genotype (G), year (season) conditions (E) and location of testing (L).

The experiments were designed by the Latin square method in three replications, against the background of the 24 investigated cultivars. At each of the chosen locations, the cultivars were grown in 10 m^2 plots. At each location, the requirement to provide equal conditions for each cultivar involved in the design was strictly observed. This included planting on the same date, equal nutrition (fertilization) and cares during the entire growth season, till harvesting of the plots.

Each of the testing locations had unique combinations of soils and climate (Table 2). Since each location is considered as a complex of specific and typical features of the environment, characterizations of these locations is not given. The location is adopted just as a factor for the purposes of statistical analysis, though of as “fixed”. This is how the location factor is treated in the greater part of the “classical” investigation on this topic.

On the other hand, the year conditions are considered a “random” factor since the meteorological conditions are unpredictable by the nature of their combination of temperature, moisture and light. Characterization of the conditions is not given for this factor, too; its influence is considered basically the same for each investigated genotype. Therefore, in the statistical analyses these two factors were analyzed as a group, through their effect on the expression of the investigated character. The comparison of each factor was based on the mean expression of the character under it. Each statistical hypothesis for comparison between the investigated cultivars by a separate character or index was based on the variation of the factor’s mean.

Investigated characters

The DH characters are presented as number of days from 1st January of the respective year till heading. Grain yield is presented in ton/ha after harvesting, based on a single plot. All other characters related to productivity were calculated on the basis of measurements of samples taken with a square frame (1/4 м^2) from each separate plot of the experiment. 1000 kernel weight was analyzed after counting a random sample of 500 grains from each plot. On the basis of the above two characters, the character number of kernels per spike (NKS) was calculated. In this investigation, the data on the characters grain yield, date to heading and number of kernels per spike were chosen for analysis because of their highest correlation in the experiment.

Statistical methods and approaches, and software

Several statistical programs were used; they can be divided into three basic groups according to the information they provide: 1). Establishing presence of effect of the environment on the expression of the characters, or the so-called genotype x environment interaction (GEST 98; Statgraphics Centurion XVI); 2). Analyzing the regularities of the genotype x environment interaction in the three investigated characters (IBM SPSS Statistics 23; STAR, 2.0.1); 3). Determining the stability and plasticity of each investigated genotype for each of the analyzed characters using the statistical packages GenStat 15 and GGEbiplot, 6.31.

Results

Out of the total of 10 investigated characters related to yield, 6 had significant effect on it (Figure 1) to various de-

Table 2
List, designation and coordinates of the environmental factors studied

№	Location	Designation	Coordinates	
1	Paskalevo, Dobrich	DC	N 43^{0}38‘47“	E 27^{0}48‘40“
2	Trastenik, Rouse	TR	N 43^{0}37‘40“	E 25^{0}51‘37“
3	Svistov, V. Tarnovo	VT	N 43^{0}36‘30“	E 25^{0}30‘02“
4	Djinot, Yambol	YM	N 42^{0}24‘33“	E 26^{0}37‘33“
5	Plovdiv	PL	N 42^{0}08‘13“	E 24^{0}48‘22“
	Year, season		Traits studied	
1	2009	2009	Grain yield (GY), date of heading (DH), number of grains per spike (NGS)	
2	2010	2010		
3	2011	2011		
4	2012	2012		

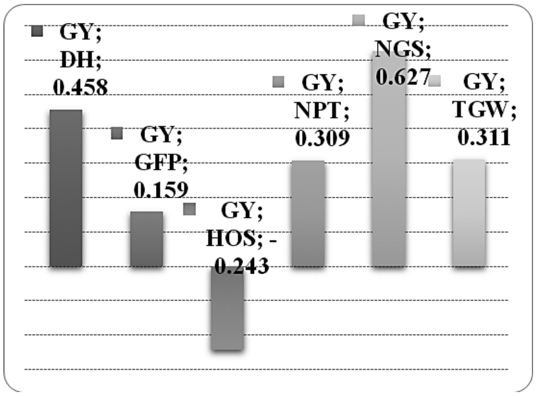

Fig. 1. Correlations between grain yield and some traits directly related to its performance

grees, averaged for the entire experiment. Highest positive effect on grain yield was found for the characters number of grains per spike (NGS) and date to heading (DH).

The other two characters of primary importance for building up of productivity, number of productive tillers (NPT) and thousand grain weight (TGW), also accounted for a considerable percent, with correlations about 0.310. Significant high and negative was the correlation of yield with height of stem (HOS) meaning that this character also needs investigation.

Due to the assumption than each of the two characters, date to heading and number of grains per spike, probably influences through their variation grain yield to some extent, they were involved in the investigation to clarify as thoroughly as possible this variation and its effect on grain yield under as variable environments as possible during the four-year period of the experiment.

The analysis of variances of the three characters revealed significant interaction between the investigated factors of the environment – season, location of testing and genotype (Table 3). Worth noting is the lack of actual interaction between

Table 3
ANOVA, Type III Sums of Squares by General Linear Model for grain yield, date of heading and number of grains per spike

Trait	Df	Mean Square	F-Ratio	*p-value*
Main effect	A:Location			
GY	4	97.01	320.87	0.0000
DH		495.17	272.98	0.0000
NGS		444.17	34.62	0.0000
Main effect	B:Year			
GY	23	274.24	907.04	0.0000
DH		2067.01	1139.5	0.0000
NGS		3747.87	292.15	0.0000
Main effect	C: Genotype			
GY	3	1.04	3.44	0.0000
DH		32.01	17.65	0.0000
NGS		61.57	4.8	0.0000
Interaction	A * B			
GY	92	0.30	1.01	0.4712
DH		2.37	1.31	0.0515
NGS		12.42	0.97	0.5645
Interaction	A * C			
GY	12	44.32	146.6	0.0000
DH		223.32	123.11	0.0000
NGS		321.36	25.05	0.0000
Interaction	B * C			
GY	69	0.67	2.23	0.0000
DH		4.28	2.36	0.0000
NGS		16.98	1.32	0.0609
	Residual			
GY	276		1.30	0.0003
DH			1.81	0.0021
NGS			12.83	0.0000

the factors location and year (A*B) in all three investigated characters. On the other hand, the genotype demonstrated high interaction with the other two factors (A*C; B*C) at the highest possible statistical level (*p=0.0000*). Interaction between all three factors was not found and therefore is not given in the Table. Due to the high variation of all three characters, the residual error of the experiment was also significant. Against this background, the analysis of the three characters was entirely objective due to the high interaction of the genotype with the environment. This high variation of the characters provokes the question if there is difference in their means across seasons and locations of testing.

The data from Table 4 can give an answer to this question; in it the differences between the means of the characters were analyzed by factors – year and location. Four statistical groups were formed for the grain yield from the five locations of testing (*a-d*). This character varied from 5.94 t/ha (Veliko Tarnovo) to 8.34 t/ha (Dobrich). The grain yield from only two locations was similar – Veliko Tarnovo and Yambol. The values of the character were statistically different across years. They were highest in 2010 (7.94), and lowest – in 2009 (4.50). This means that the environmental factor had ostensible and largely determining effect on the character within the same group of tested cultivars. The situation with the character date to heading was analogous. According to the locations of tasting, five different groups of means were differentiated out of five possible. According to the seasons of testing the situation was the same – four groups were formed for the four years of investigation.

The character number of grains per spike varied considerably less by factors. In this case there were only two groups by location and two groups by season. Lowest number of grains per spike was formed in 2009 – only 16.8 at locations Trastenik and Veliko Tarnovo. It is interesting to note that in spite of the lower grain yields at locations Plovdiv and Yambol, the number of formed grains was similar to that at location Dobrich, where the highest yield was registered.

The variation of characters under the great diversity of growing conditions allows a possibility for analysis on the nature of the cultivar x environment interaction. Such evaluation would help to determine the essence of the character variation under this dynamics of season and testing locations. Data on this interaction are given in Figure 2. According to the principal component analysis, the greater the percent of the second (PC_2) and third (PC_3) components, the greater is the percent on non-linear variation in the group according to a certain character, in reverse relation to the first component (PC1). In this kind of investigations it is assumed that if PC1 is within or above 65-75 %, the non-linear (PC2……PCn) interaction can be ignored as percent.

Grain yield varied inadequately (in a non-linear manner) with the changeable testing conditions. The sum of PC_2 and PC_3 amounted to about 35 %; this was a significant percent in comparison to 49 % of PC_1. The implication is that the greater part

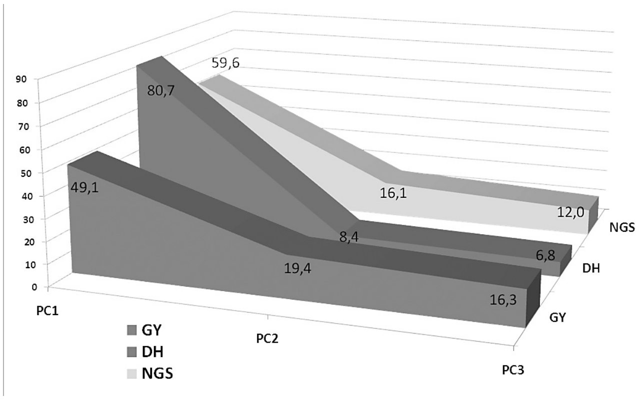

Fig. 2. Principle component analysis of each of the three studied traits

Table 4
Differences between the traits means according to the effect of test factors of the environment

Location	GY	*p-group**	DH	*p-group**	NGS	*p-group**
Dobrich	8.34	*d*	133.4	*e*	26.3	*b*
Plovdiv	6.19	*b*	129.8	*c*	26.8	*b*
Trastenik	6.66	*c*	131.0	*d*	22.9	*a*
V.Tatnovo	5.94	*a*	128.8	*b*	22.7	*a*
Yambol	5.97	*a*	127.5	*a*	27.0	*b*
2009	4.50	*a*	124.4	*a*	16.8	*a*
2010	7.94	*d*	129.8	*b*	27.9	*b*
2011	6.65	*b*	133.8	*d*	27.5	*b*
2012	7.40	*c*	132.5	*c*	28.4	*b*
Overall mean	*6.62*		130.1		25.1	

* LSD=95.0 %

of the cultivars changed their grain yield in a direction different from the changes in the environmental conditions. Tsenov and Atanasova (2013) and Tsenov et al. (2016) reported analogous results from similar investigations in another set of cultivars and testing locations. One possible explanation is that each cultivar possesses different adaptability and reacts in unpredictable way to the variations of the environment through its grain yield. This is the main reason for a number of researchers to recommend taking into account the "noise" coming from the growing conditions when ranking the cultivars according to the value of a certain character, i.e. taking into account its plasticity (Tadesse et al., 2010; Van Ittersum et al., 2013).

With the date to heading, each of the cultivars from the group obviously reacted adequately to the changes in the environmental conditions. In this character only about 15% from the variation was due to non-linear interaction as compared to about 80% linear one. The probable reason lies in the ability of the genotype to adapt its heading to the environment in such a way, as to keep the genetic differences between the cultivars even under drastic change in the environment: 133 days (location Dobrich) as compared to 127 days (location Yambol).

Tsenov and Gubatov (2016) found that principal component analysis to a location as a factor, the interaction of traits and conditions is mostly linear PC1 = 82.3%, while according to the calculation by the season, it was only 59% at PC2 = 31.6%. According to the authors, this was due to the stronger effect of the location in comparison to the year. In this investigation, the situation was exactly the opposite, the location having considerably higher effect on the variation of the character.

With the character number of grain per spike, both types of interaction were observed. The percent of its non-linear part was about 28 %, which was significant and constituted about ½ of the percent of the linear interaction (PC_1= 59.6 %).

Discussion

In breeding, it has always been important to determine the reaction (behavior) of a cultivar under a wide range of environments. In this investigation, the "environments" were 9 in total – five locations and 4 years. This implies investigation on the stability of the individual characters in each genotype, apart from their mean values. To determine any

Table 5

Descriptive statistics of variety significant differences for the traits

№	Variety	GY	p-group*	DH	p-group*	NGS	*p-group**
1	Tervel	6.99	i	130.2	cd	27.5	ghij
2	A 15	6.15	a	131.2	efghi	23.4	abc
3	Iveta*	6.37	abcd	130.8	defg	23.8	abcd
4	Apogej	6.83	fghi	129.5	c	25.7	defgh
5	Laska	6.48	abcde	130.2	cd	24.0	bcde
6	Dageya	6.87	ghi	128.5	b	26.1	efghi
7	Samuil	6.58	cdefgh	130.8	defgh	23.1	ab
8	Bilyana	6.34	abc	130.8	defg	23.1	ab
9	Neven	6.73	efghi	131.3	fghi	26.0	efghi
10	Faktor	6.47	abcde	130.3	cd	24.9	bcdef
11	Presyana	6.55	bcdefg	127.6	a	25.4	cdefg
12	Ralitsa	6.22	ab	129.5	c	21.7	a
13	Ryana	6.46	abcde	130.2	cd	24.1	bcde
14	Topolitsa	6.84	fghi	131.7	i	28.2	ij
15	Ognyana	6.71	defghi	127.1	a	24.5	bcdef
16	Enola*	6.57	cdefgh	130.4	de	24.1	bcde
17	Alexa	6.90	hi	128.4	b	27.7	hij
18	Alisa	6.73	efghi	130.4	de	24.2	bcde
19	Velika	6.56	cdefgh	130.5	de	25.4	cdefg
20	Aneta	6.48	abcde	128.5	b	26.6	fghi
21	Vyara	6.52	bcdef	131.6	hi	25.2	bcdef
22	Svilena	6.74	efghi	131.6	hi	25.2	bcdef
23	Hela	6.79	fghi	131.2	ghi	29.0	j
24	Pryspa*	6.98	hi	130.5	de	24.9	bcde
	Total	6.62		130.1		25.1	

* Method: 95.0 percent LSD

statistical differences between the individual cultivars by each of the characters will be very difficult (Table 5).

Even the performance of each genotype against the background of the locations included in the investigation, considered within the entire range of its variation according to a given character, can not give an answer to the question which cultivar is more stable, in comparison to the others (Figures 3, 4 and

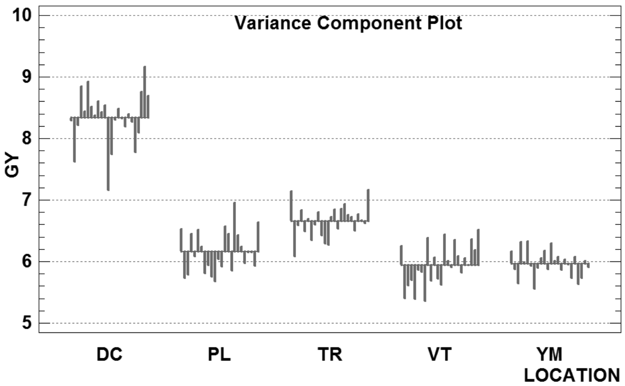

Fig. 3. Degree of variation of the grain yield in locations of study

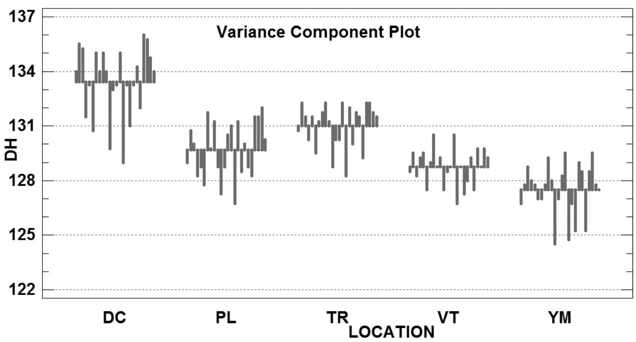

Fig. 4. Degree of variation of date of heading in locations of study

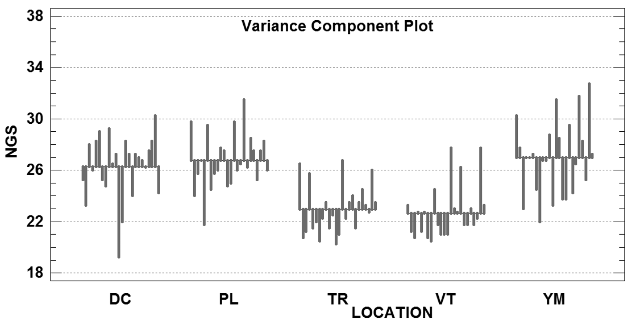

Fig. 5. Degree of variation of number of grains per spike in locations

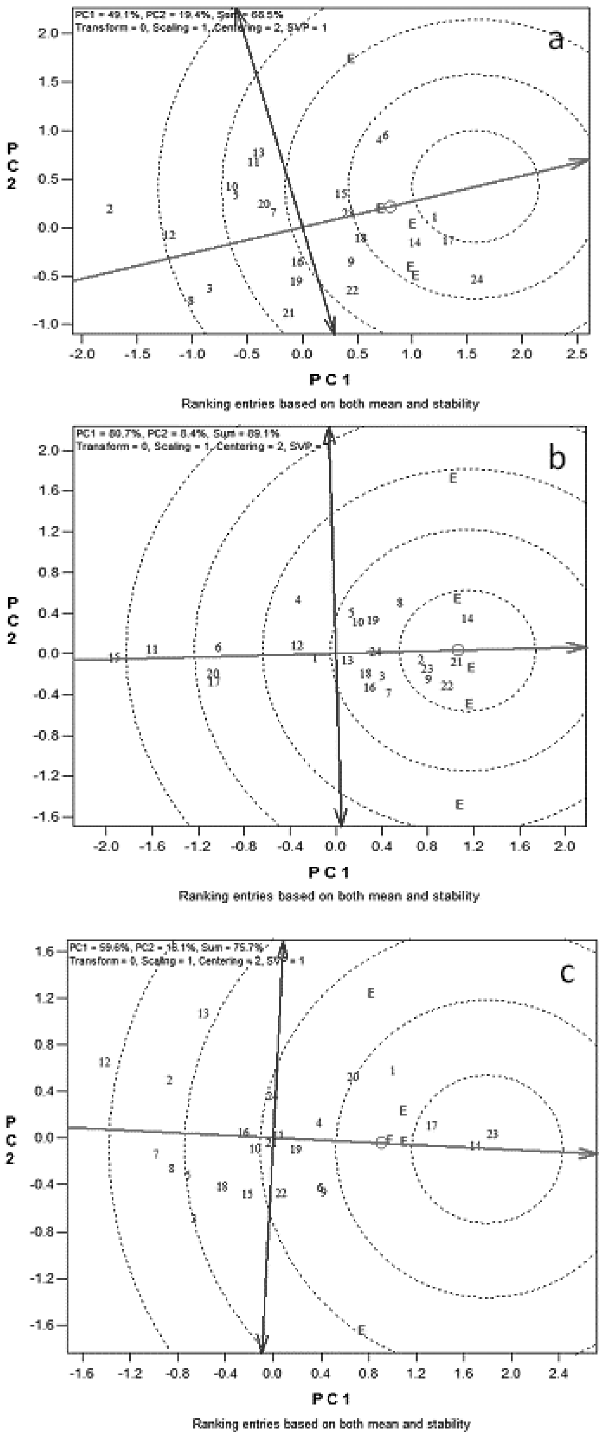

Fig. 6. Spatial clustering of varieties on the magnitude and stability of grain yield (a); date of heading (b) and number of grains per spike (c) by principle component analysis

Table 6
Ranking of first four varieties of every traits by the AMMI selections per environment

Location	Trait	Mean	Score	*Ranking the first four*			
				1	*2*	*3*	*4*
	GY	6.16	0.532	**17**	**24**	1	14
Dobrich	DH	129.7	-0.909	**23**	21	7	2
	NGS	26.7	0.389	14	**17**	1	**23**
	GY	8.34	-1.169	**23**	6	4	22
Plovdiv	DH	133.4	-1.362	22	21	9	3
	NGS	26.2	2.089	**23**	9	6	14
	GY	6.65	0.221	**24**	**17**	1	14
Trastenik	DH	131.0	0.244	14	21	22	23
	NGS	22.9	0.002	**14**	23	17	1
	GY	5.94	0.257	**24**	**17**	14	1
V.Tarnovo	DH	128.8	-1.290	14	8	23	21
	NGS	22.6	0.185	**14**	23	**17**	1
	GY	5.96	0.160	4	6	13	1
Yambol	DH	127.5	0.730	**14**	22	9	19
	NGS	26.9	-2.665	23	20	13	1

5). Each genotype gave different yields in the respective testing locations; this affected its mean value to various degreed, as evident from the comparison of all genotypes.

Therefore, a number of statistical approaches are applied to evaluate the "noise" of the environment on the expression of the cultivar's character in order to rank the cultivars correctly (Tsenov et al*.,* 2016)

In this investigation, the focus was on determining the genotype x environment interaction in grain yield and in the characters which have highest effect on grain yield. The question if the interaction of the two characters with the environment ranks the cultivars in a way similar to their ranking by grain yield in the different testing locations is a fundamental one. Its answer is significant in the undertaking to evaluate the characters which influence grain yield with a view of its more detailed analysis.

The program GenStat 15, through its AMMI module, allows ranking of the first 4 best performing cultivars by a certain character at each location (Table 6). These data demonstrate the relationship between the characters against the background of each genotype. Cultivars No 14 (Topolitsa), 17 (Alexa) and 23 (Hella) showed the highest and most stable productivity (grain yield) in almost all locations of testing. They occupy one of the 4 first places also by the characters date to heading and number of grains per spike in most of the investigated locations. Location Yambol was an exception; there other varieties were most productive, No 1 (Apogey) and 6 (Dageya). At the rest of the locations, the same cultivars were ranked by all three investigated characters. This is an indication for an existing possibility to evaluate the genotype by grain yield, through investigating its interaction with the environment in other characters. This is essential information because it explains, to a certain extent, the obtained yield against the background of the complex changeable environment.

Additional evidence in support of these assumptions comes from the special distribution of the points representing the individual cultivars in the Biplot analysis of the respective characters (Figure 6). The imaging of the points of Topolitsa (14), Alexa (17) and Hella (23) is clear and distinct, marking similar expression of the three characters under dynamic changes of the environment. The expression of cultivar Tervel (1) was analogous; it was slightly more changeable than them, showing, however, the highest mean grain yield.

Cultivars (11) Presiyana, (12) Ralitsa and (13) Ryana were at the opposite side, with low values of the characters. These cultivars demonstrated high level of variation of the three characters regardless of their relatively high grain yield. The spatial analysis of the three characters with the program GGE Biplot was very useful in the evaluation of the expression of a given cultivar in comparison to each cultivar from the same group. Furthermore, this analysis gives an idea also about the direction of the genotype's interaction under the conditions of the experiment. The cultivars represented by the points closest to the red circle on the red almost horizontal line, were most stable and adaptable according to the respective character. This visualization demonstrates the very similar behavior of several cultivars according to the three characters.

In conclusion, grain yield can be correctly evaluated against the background of contrasting environments also through characters in positive correlation with it. Good examples are the date to heading and the number of grains per spike. In spite of the different regularities of their interaction with the environment, it is ultimately possible to use them for objective assessment of certain cultivars not fitting in the scheme. This is a valuable approach for complex evaluation of the genotype according to the environment and according to a multitude of other cultivars. The possibility for evaluation of the genotype through the date to heading was realized successfully by (Grogan et al., 2016) under many variable environments in the USA. It is completely possible to find out a cultivar with high grain yield realized through relatively minimal variation (genotype x environment interaction) by using the statistical approaches considered in this paper.

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