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Using the GY* trait interaction in ecological field trials to evaluate grain yield of wheat varieties

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Abstract

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Setting and purpose: The purpose of this study is to investigate the possibility of an integral grain yield estimation by taking into account the genotype*environment interaction of yield traits in winter common wheat.

Methods: At three main locations for the grain production in Bulgaria, 40 winter common wheat varieties were studied. Several productivity traits have been studied as follows: height of stem (HOS), number of productive tillers per m^2 (NPT); number of grains per spike (NGS); thousand grain weight (TGW), weights of grain per spike (WGS), the number of grains per m^2 (NGm), total above-ground biomass (TBM), harvest index (HI) and grain yield (GY) itself. A new methodology is used to assess the behaviour of each of the varieties, based on the relationship of its grain yield with some productivity traits, by measuring their change in different environmental conditions.

Key results: The interaction of genotype x environment is essential for each of the tested traits. The variation of each of them is examined against the background of the others, and then evaluated through its relationship to grain yield. An integrated assessment of varieties is applied through the interaction of their traits and yield components (GY*T) with environmental conditions. Nevertheless of the close means of traits in the tested varieties, a significant difference was found between them.

Conclusions: The established Mean Superiority Index (MSI) allows them to be properly stacked and grouped versus check varieties. The approach applied may group successfully varieties by traits that effect grain yields. The reasons for the specific grain yield of each of the varieties are analyzed by the combination of some character, which are dynamically variable according to the environments. Evaluation of a large number of varieties is fully possible by using the GY*trait approach that allows determination of their suitability for production and breeding value, as well.

Keywords: wheat; grain yield; genotype; environment interaction; productivity traits

Introduction

Wheat grain yield is a resultant trait, which itself is highly dependent on the interplay of a variety by environments cause changes according to different seasons and growing locations (Tadesse et al., 2010, Tsenov & Atanasova, 2015). The change in grain yield is the result of a change in those plant traits known to have a direct or indirect effect on it (Eid, 2009; Gubatov et al., 2016). Changing the conditions causes a change in the effect each trait of productivity has on the concrete expression of the GY (Tsenov et al., 2011; Ivanova & Tsenov, 2012; Mandea et al., 2019). Hence, the difficulty in determining the influence of various traits on grain yields arises in conditions provoking significant variation in their values (Tsenov et al., 2008a; Gubatov et al., 2016). On the other hand, this is the reason for researchers to look for “contrasting” environmental conditions causing major changes in the elements of productivity in order to derive maximum useful information about the interrelationships between the traits, however (Mustatea et al., 2009; Ivanova et al., 2011). In order to achieve this, it is imperative that the interaction of the genotype by environment interactions is correctly recorded (Mondal et al., 2013, Van Ittersum et al., 2013).

In their studies, Slafer et al. (2014) argue that a compromise between the number of grains, size of grain and productive tillering, according to the conditions of the region, has a positive influence on the stability of wheat. NGS is important for grain yield, according to studies by Dreccer et al. (2009), Lynch et al. (2017) and Schulthess et al. (2018) carried out under radically different conditions for wheat. The Sadras and Slafer (2012) publications analyze that the NPT is the most variable, and TGW has the lowest variation. In the conditions of the Balkan Peninsula, it has been repeatedly established that NGS (Tsenov et al., 2009; Raykov et al., 2016; Mandea et al., 2019) or NPT have significant influence on grain yield (Tsenov et al., Gubatov et al., 2016; Mirosavljević et al., 2018). The other components of productivity do not significantly effect, or their influence is variable, according to conditions, which is ultimately only informative (Tsenov et al., 2008b, Tsenov et al., 2013). It is already evident that the correlation ships between the traits are not informative enough because they change as a result of their variation as direction and value (Ivanova & Tsenov, 2012). Each change in a trait has an effect on other traits as well as on grain yield, but depends on the unique combination of environmental factors, including varietal response, also. The breeders have always tried to "ignore" these complex interactions between the traits in their quest to combine them into a genotype at the highest possible levels for each one individually. In order for these efforts to be successful, it is necessary to find a way to study the changes in MET in terms of their impact on grain yields. The approaches developed by Yan & Frégeau-Reid, (2008) and Yan & Frégeau-Reid (2018) give new opportunities for accurate and detailed analysis of traits, their change and effect on GY.

So, the purpose of this study is to investigate the possibility of an integral grain yield estimation by taking into account the genotype*environment interaction with grain yield traits of winter common wheat.

Materials and Methods

The study includes 40 varieties of winter wheat developed by the company. They were tested for two seasons 2017 and 2018 at three locations in the country: Paskalevo, Dobrich, with the designation (A); Trastenik, Rousse region, with designation (B) and Straldzha, Yambol district, marked with (C). Each variety is grown in three replications at the plot size of 10 m^2. Data for productivity traits is based on each replication of field trails.

The most important characters related to productivity are analyzed as follows: height stem (HOS), number of productive stems per m^2 (NPT); number of grains per spike (NGS); 1000 grain weight (TGW), grain weight per spike (WGS), number of grains per m^2 (NGm), above-ground plant biomass (TBM), and grain yield (GY). The correlation dependencies between all the traits are determined. This is done in order to establish the power of their influence on grain yield, as well as the relationships between them. The approach of Yan & Frégeau-Reid (2018) is applied, which compares the varieties of a given group to produce the GY values and the values of each trait studied. On the basis of the interaction of variety by conditions, it is established which combination of traits affect the grain yield of each particular variety. In this way, valuable for grain yields traits are distinguished, different for each variety, under specific environmental conditions. The statistical analysis was done using the XLStat 2014 and Statgraphics XVI computer programs.

Results and Discussion

Traits related to the productivity of each of the varieties are presented in Table 1. The primary means data does not give a realistic picture of the value of each genotype versus the standards and relative to each of the other genotypes. The data thus arranged does not reflect the actual variation of each variety, for each trait, not to mention the interaction of the genotype * environment in terms of direction and size (Gubatov et al., 2016). In order to make an effective comparison it is necessary to make an integrated assessment that takes into account these effects.

Given the behaviour of genotype in different growing conditions, this seems very difficult, especially if all the traits affecting the grain yield are taken into account. These inconveniences are "surrounded" by the relatively simple approach suggested by Yan & Frégeau-Reid (2018).In order to apply this approach, it is necessary to establish correlations between grain yield and each of the traits studied (Table 2).

Almost all traits except HOS show positive correlations with grain yield. Those of the traits with the strongest effect on GY exhibit negative correlations between each other, which is logical (NPT/WGS, r = -0.37, $p < 0.0001$; NPT/NGS r = -0.37, $p < 0.0001$; NGm/TGW r =-0.23, $p < 0.0001$ and NGS/TGW r = -0.31, $p < 0.0001$). In the varieties of the study group, it is interesting to note the lack of correlation between trait TGW and trait NPT (r=0.02, $p = 0.6686$). Recent studies of wheat in Romania (Mandea

Table 1. Data on the mean values of the traits of the varieties studied, (*checks)

№	Variety	GY	NPT	TGW	WGS	NGS	NGm	TBM	HI	HOS
		t.ha-1	№	g	g	№	№	t.ha-1		cm
1	LG Anapurna	7.97	719	39.4	1.10	28.0	20321	4.62	0.39	64.1
2	A 38/64	7.10	588	43.3	1.22	28.1	16372	4.74	0.41	81.4
3	A 48/617	7.90	568	40.1	1.39	34.8	19657	4.24	0.39	74.2
4	A 18/74	7.47	607	48.9	1.22	25.0	15267	4.88	0.40	80.9
5	R-1-4-5	7.62	543	40.8	1.41	34.6	18572	3.69	0.39	68.2
6	ACR 48/615	7.92	537	40.1	1.47	36.7	19691	4.00	0.40	73.9
7	06/198-21	7.50	590	45.9	1.27	27.7	16269	5.01	0.40	84.8
8	A 27/320	7.80	549	49.3	1.43	29.0	15833	4.83	0.39	88.0
9	ABC 27/512	8.74	632	44.5	1.39	31.3	19653	5.46	0.40	87.1
10	ABC 28/313	7.60	583	43.0	1.30	30.3	17817	4.82	0.40	82.8
11	Pryaspa*	7.66	573	49.0	1.36	27.9	15642	4.76	0.40	83.6
12	A 37/215	7.68	604	46.9	1.28	27.4	16387	5.14	0.40	85.8
13	06N137-22	8.37	642	50.1	1.33	26.6	16736	6.09	0.41	95.2
14	01/54-84	8.34	652	43.3	1.29	29.8	19238	4.95	0.39	76.3
15	04/255-92-2-1	8.04	584	43.3	1.40	32.3	18577	4.60	0.38	79.9
16	ABC 48/716	9.35	621	43.8	1.51	34.5	21368	5.40	0.39	87.3
17	A 47/415	8.50	566	47.6	1.50	31.7	17890	4.76	0.39	84.2
18	ABC 37/716	7.81	556	47.1	1.44	30.6	16605	4.76	0.39	85.9
19	05N48-22-1	8.26	565	48.3	1.52	31.5	17099	5.05	0.40	90.8
20	05N48-22-8	8.22	608	47.5	1.36	28.6	17321	5.58	0.41	92.7
21	LG Avenue*	8.23	737	39.9	1.11	27.7	20573	4.83	0.39	65.4
22	Aneta	7.70	577	47.2	1.34	28.4	16271	4.74	0.39	82.1
23	Apogej	7.08	564	39.2	1.23	31.2	17874	4.31	0.39	75.7
24	Presyana	8.10	599	42.7	1.34	31.3	18904	4.86	0.39	80.9
25	Ognyana	7.70	526	46.2	1.45	31.4	16572	4.23	0.39	80.4
26	Alisa	8.36	607	49.1	1.36	27.9	17012	5.34	0.40	88.0
27	Bilyana	8.14	567	45.5	1.43	31.5	17821	4.99	0.39	88.9
28	Vyara	8.12	738	38.3	1.10	28.8	21194	6.35	0.41	87.2
29	Neven	7.82	621	42.7	1.28	30.2	18276	4.60	0.39	74.6
30	Ralitsa	8.48	532	47.2	1.61	34.0	17924	4.39	0.38	82.1
31	Riana	8.29	699	42.6	1.18	27.8	19424	6.16	0.40	88.3
32	Tervel	7.74	684	40.8	1.13	27.8	18942	6.25	0.40	90.7
33	Faktor	8.22	658	45.9	1.28	27.9	17937	5.79	0.41	88.6
34	ABC Alfio	8.39	614	52.1	1.39	26.6	16090	5.52	0.41	89.7
35	ABC Lombardia	8.70	621	52.0	1.42	27.6	16770	5.81	0.40	93.8
36	ABC Klauzius	8.88	631	53.2	1.43	27.1	16693	5.93	0.41	94.2
37	ABC Speri	8.40	678	47.2	1.26	26.8	17804	6.22	0.41	91.6
38	**ABC** Zigmund	8.78	614	49.5	1.45	29.3	17716	5.05	0.39	82.6
39	ABC Kolino	7.88	668	41.6	1.21	29.1	18944	5.38	0.40	80.6
40	**ABC** Navo	8.64	621	50.2	1.39	27.7	17177	5.19	0.38	83.8
	Mean	8.09	611	45.4	1.34	29.7	17906	5.08	0.40	83.40
	Sd. Deviation	*1.634*	*128.2*	*4.41*	*0.212*	*4.75*	3741.8	1.149	0.047	8.97

Table 2. Pearson correlations between the simple traits of 40 wheat varieties (averaged for MET)

Variables	GY	NPT	TGW	WGS	NGS	NGm	TBM	HI	HOS
GY		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0271	*0.3121*
NPT*	0.72		*0.6686*	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0083	0.0206
TGW	0.24	0.02		< 0.0001	< 0.0001	< 0.0001	< 0.0001	**0.4256*	< 0.0001
WGS	0.36	-0.37	0.29		< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0447
NGS	0.23	-0.37	-0.31	0.82		< 0.0001	< 0.0001	< 0.0001	0.0002
NGm	0.88	0.71	-0.23	0.22	0.37		< 0.0001	0.0110	< 0.0001
TBM	0.64	0.87	0.26	-0.30	-0.44	0.52		< 0.0001	< 0.0001
HI	-0.12	0.14	*0.04*	-0.34	-0.35	-0.13	0.23		0.0002
HOS	-0.06	-0.12	0.49	0.11	-0.19	-0.28	0.37	0.19	

Below the diagonal - values of correlation coefficients, over the diagonal -values of the p-value. *Values in bold are different from 0 with a significance level alpha = 0.05

et al., 2019) have found similar results with respect to the NPT and NGS. The presence of differences in the components of productivity in the studied varieties and the existing negative correlations between them is why they are difficult to combine in one genotype successfully. The data show a combination of two components of NPT and TGW productivity, among which there is no negative correlation that prevents their breeding.

Hence, varieties with increased NPT and NGS simultaneously could be created. On the other hand, however, the relationship between the NTm and TGW is negative, which means that we have biological limitations in our efforts to increase the grain yield. Mandea et al. (2019) discuss possibilities for reducing the compensation mechanisms governing the productivity components in the grain yield. In this context, the methodology we apply here will

Table 3. Analysis of Variance for GY*T - Type III Sums of Squares

Trait	Source	A:LOC	B:VAR	C:YEAR	A*B	B*C	Residual
	Df	2	39	1	78	78	240
GY*NPT	Mean Square	432.55	3.14	0.539	1.264	0.357	0.405
	F-Ratio	1067.89	7.76	1.57	3.12	1.04	
	p-value	*0.0000*	*0.0000*	***0.2116***	*0.0000*	***0.4125***	
GY*TGW	Mean Square	81.86	1.84	0.820	0.306	0.085	0.087
	F-Ratio	942.58	21.22	14.04	3.53	1.45	
	p-value	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.025*	
GY*WGS	Mean Square	802.56	16.34	9.352	7.961	2.450	2.747
	F-Ratio	292.2	5.95	3.6	2.9	0.94	
	p-value	*0.0000*	*0.0000*	***0.0295***	*0.0000*	***0.6056***	
GY*NGS	Mean Square	38.37	0.61	0.231	0.396	0.115	0.136
	F-Ratio	281.82	4.51	1.76	2.91	0.88	
	p-value	*0.0000*	*0.0000*	***0.1759***	*0.0000*	***0.7424***	
GY*NGm	Mean Square	4026.90	28.23	5.864	15.313	2.774	3.314
	F-Ratio	1215.07	8.52	1.78	4.62	0.84	
	p-value	*0.0000*	*0.0000*	***0.1716***	*0.0000*	***0.7987***	
GY*TBM	Mean Square	26668.30	396.08	36.060	109.667	28.654	31.199
	F-Ratio	854.77	12.7	1.35	3.52	1.07	
	p-value	*0.0000*	*0.0000*	***0.262***	*0.0000*	***0.3506***	
GY*HI	Mean Square	2639.97	14.49	115.768	11.421	12.156	11.169
	F-Ratio	379.61	2.08	16.65	1.64	1.75	
	p-value	*0.0000*	*0.0008*	*0.0000*	*0.0046*	*0.0017*	
GY*HOS	Mean Square	194.00	6.27	1.074	1.371	0.260	0.268
	F-Ratio	723.63	23.39	4.53	5.11	1.1	
	p-value	*0.0000*	*0.0000*	*0.0122*	*0.0000*	***0.3076***	

identify varieties that have similar combinations of traits close to we want to make. Characteristics with negative correlation with yield are included as private ones, and those with positive correlation are presented as work with GY. In our case fnly HI and HOS traits showed negative correlations with GY.

After calculating the values of the traits generally referred to as (GY*Trait) their variance was analyzed to see whether they could be treated as characters, objectively. It is possible to analyze the existing differences between genotypes and because all of them have genotype by environment interaction as a factor with the condition of the loca-

Table 4. Standardized GY*trait values of varieties (varieties are ranking by their Mean Superiority Index (+ MSI)

№	Variety	GY	*NPT	*TGW	*WGS	*NGS	*NGm	*TBM	GY/HI	GY/HOS	+MSI
16	ABC 48/716	9.35	0.46	-0.05	1.02	1.21	0.96	0.56	0.68	0.91	0.83
36	ABC Klauzius	8.88	1.20	-0.32	0.54	-0.04	0.00	0.73	0.21	1.08	0.53
35	ABC Lombardia	8.70	0.94	0.04	0.46	-0.03	0.00	0.62	0.20	0.94	0.45
9	ABC 27/512	8.74	0.24	-0.47	0.40	0.48	0.50	0.44	0.23	0.54	0.40
38	ABC Zigmund	8.78	0.76	0.22	0.56	0.21	0.12	0.18	0.43	0.34	0.37
30	Ralitsa	8.48	0.37	-0.43	0.85	0.68	0.12	-0.24	0.46	0.16	0.34
40	ABC Navo	8.64	0.76	0.19	0.39	0.00	0.06	0.23	0.38	0.32	0.31
17	A 47/415	8.50	0.41	0.09	0.60	0.42	0.09	-0.08	0.28	0.27	0.28
13	06N137-22	8.37	0.57	0.05	0.10	-0.23	-0.08	0.63	-0.02	0.80	0.25
26	Alisa	8.36	0.50	0.18	0.26	-0.03	0.03	0.27	0.14	0.40	0.22
19	05N48-22-1	8.26	0.34	0.11	0.46	0.22	-0.12	0.01	0.05	0.46	0.20
34	ABC Alfio	8.39	0.78	0.19	0.20	-0.29	-0.22	0.34	-0.02	0.54	0.19
37	ABC Speri	8.40	0.31	0.47	-0.13	-0.27	0.04	0.73	-0.06	0.63	0.18
27	Bilyana	8.14	0.04	-0.24	0.27	0.24.	0.03	-0.02	0.03	0.28	0.13
20	05N48-22-8	8.22	0.25	0.15	0.07	-0.09	-0.08	0.26	-0.08	0.53	0.12
31	Riana	8.29	-0.16	0.18	-0.33	-0.13	0.31	0.66	0.01	0.38	0.11
33	Faktor	8.22	0.10	0.10	-0.17	-0.21	0.00	0.41	-0.10	0.34	0.05
24	Presyana	8.10	-0.23	-0.28	0.07	0.28	0.25	-0.06	0.06	-0.12	0.04
14	*1/54-84*	*8.34*	*-0.08*	-0.05	*-0.07*	*0.09*	*0.24*	*-0.02*	*0.09*	*-0.27*	*0.00*
28	Vyara	8.12	-0.65	0.06	-0.61	-0.07	0.55	0.68	-0.09	0.14	-0.01
6	ACR 48/615	7.92	-0.56	-0.58	0.33	0.83	0.26	-0.61	0.08	-0.59	-0.04
15	04/255-92-2-1	8.04	-0.23	-0.55	0.06	0.24	0.04	-0.30	0.09	-0.25	-0.05
8	A 27/320	7.80	0.18	0.01	0.13	-0.16	-0.40	-0.26	-0.08	0.08	-0.07
18	ABC 37/716	7.81	-0.02	-0.53	0.08	-0.05	-0.35	-0.33	-0.07	-0.05	-0.11
3	A 48/617	7.90	-0.58	-0.45	0.03	0.49	0.18	-0.49	0.05	-0.58	-0.13
32	Tervel	7.74	-0.58	0.10	-0.62	-0.31	0.04	0.48	-0.22	0.23	-0.14
25	Ognyana	7.70	-0.10	0.29	0.15	0.06	-0.25	-0.52	-0.06	-0.36	-0.16
21	LG Avenue❷	7.88	-0.44	-0.48	-0.53	-0.14	0.52	-0.05	0.12	-0.88	-0.20
39	ABC Kolino	8.23	-0.45	-0.16	-0.43	-0.16	0.02	0.01	-0.10	-0.28	-0.20
22	Aneta	7.70	-0.01	0.25	-0.19	-0.36	-0.37	-0.28	-0.20	-0.27	-0.24
12	A 37/215	7.68	-0.10	-0.38	-0.34	-0.45	-0.36	-0.12	-0.29	-0.13	-0.25
11	Pryaspa❶	7.66	0.08	0.04	-0.18	-0.43	-0.51	-0.34	-0.23	-0.25	-0.27
29	Neven	7.82	-0.37	-0.06	-0.29	-0.10	-0.09	-0.38	-0.02	-0.63	-0.27
10	ABC 28/313	7.60	-0.49	0.32	-0.30	-0.10	-0.16	-0.31	-0.28	-0.31	-0.28
5	R1-4-5	7.62	-0.63	-0.10	-0.01	0.36	-0.03	-0.85	-0.06	-1.04	-0.32
7	06N198-21	7.50	-0.25	-0.05	-0.41	-0.47	-0.41	-0.22	-0.37	-0.26	-0.34
1	LG Anapurna	7.97	-0.64	-0.04	-0.65	-0.21	0.33	-0.30	0.05	-1.08	-0.36
4	A 18/74	7.47	-0.04	0.06	-0.50	-0.74	-0.54	-0.33	-0.33	-0.50	-0.42
23	Apogej	7.08	-0.99	0.20	-0.62	-0.22	-0.25	-0.63	-0.42	-0.88	-0.57
2	A 38/64	7.10	-0.69	-0.07	-0.65	-0.53	-0.47	-0.48	-0.56	-0.67	-0.58

(+)- MSI- Mean Superiority Index; ❶❷ -check varieties

tions (variety*location) (Table 3). The traits (GY*TGW) and (GY*HI) also show the influence of the “year” as well as the interaction of the “variety*year”.

The next step is to calculate the MSI for each variety to determine the rank of the variety as compared to the rest of the group. In order to establish this index the values of the traits were normalized in the manner indicated in the applied methodology. The varieties examined are rank according to the value of the MSI index (Table 4). The data for each variety are unique and could be compared directly to each other by traits and the calculated index, as well. The value of the MSI index responds to a large extent to the level of GY (r=0.96. R^2=0.92). Therefore, the proposed index can be used to assess the variety, as grain yield and stability under MET.

Similarly, the correlations between GY and GY*T-traits are the same with the exception of TGW (for short. correlations are not presented here). Thus the breeding value of the variety can also be determined by the standardized values of the traits (GY*T). For example, the NPT signifies high grain yield for varieties № 35, 36, 38, 40 (Table 4). The NGS trait is a decisive factor for GY of varieties № 3, 6, 16, 17, 30 and the TGW - for varieties № 10, 37, 38. The very similar GY for varieties ABC Lombardia (35) and ABC 27/512 (9) is the result of a combination of different traits. In ABC Lombardia GY results from a compromise between NPT (0.94) WGS (0.46) are at a relatively high stem (0.94) and high TBM (0.62), in the other variety ABC 27/512. The same yield was due to a significantly higher impact of NGS (0.48) than NPT (0.24). Significantly lower total biomass (0.44) and stem height (0.54). In this way it is possible to make multiple comparisons of both varieties and traits. Numerous levels of comparison between the large number of varieties and analyzed traits that exist make this type of analysis complex and inappropriate.

In response to the environments the varieties could be ranked by score (rank). The most productive and stable are the varieties ABC 27/512 (9), ABC 48/716 (16), ABC Lombardia (35), ABC Klauzius (36) and ABC Zigmund (38), showing high superiority index and GY over 8.5 tha^{-1}. Following are the varieties with a higher yield than the LG Avenue (21), which are also relatively stable in appearance: ABC Navo (40), ABC Alfio (34) and ABC Speri (37). Stable, but not sufficiently high yields compared to those already listed are the varieties Faktor (33) ABC Kolino (39) and Vyara (28), which also have a higher yield than the check. The Aneta (22), Tervel (32) and Neven (29) varieties which have already been validated have yielded grain yield and stability as those of the two check varieties (11) and (21). The advanced breeding lines No 2, 4, 5, 7 and 10 have shown low and variable yields and are likely to be removed from study for this reason.

In order to assist the objective assessment of each particular variety the approach of Yan & Frégeau-Reid (2018) is applied which allows a multilayer comparison by spatially presenting the points of each of them against the background of the traits (Figure 1).

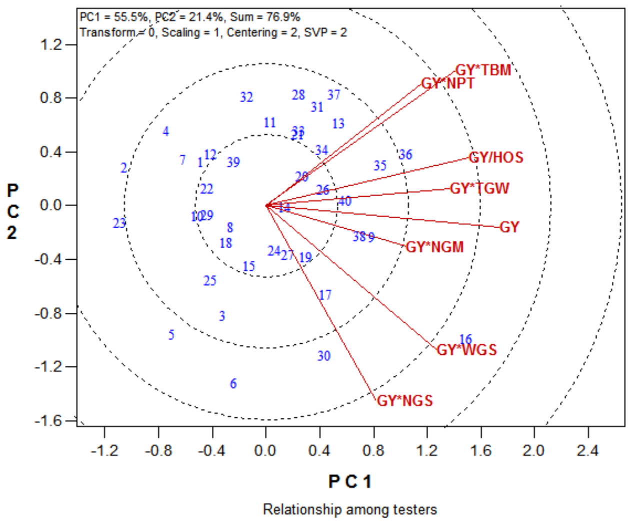

Fig. 1. The tester Vector view of the genotype by yield *trait biplot

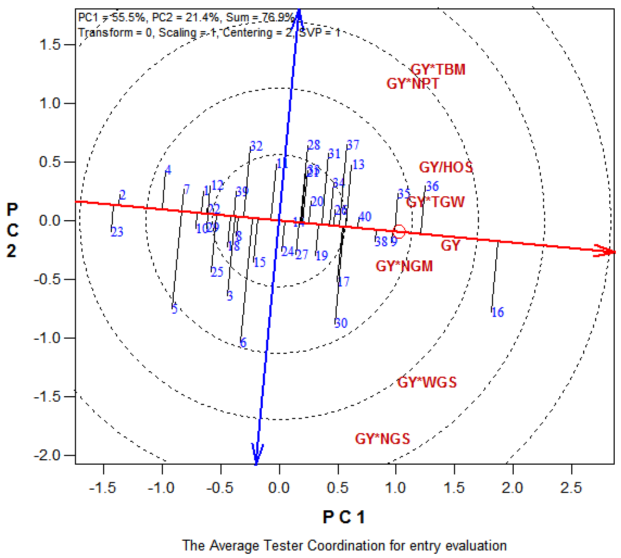

Fig. 2. Average Tester Coordination of the genotype by yield *trait biplot for genotype ranking

The location of the trait Vectors (GY*T) provides information in the following directions: *i)* The traits with the strongest effect on GY are GY*NGM and GY*TGW because the angles between their vectors are the sharpest; *ii)* a significant share on GY also has the traits GY*HOS and GY*WGS; *iii)* the vectors of GY*NPT and GY*TBM have a poor effect on grain yield, despite their strong positive correlations with simple traits values (Table 2); *iv)* A small part of the varieties studied (points) are located around those vectors that could explain their manifestation in detail.

So, varieties 9 (ABC 27/512) and 38 (ABC Zigmund) are located in close proximity to the GY*NGM vector meaning NGM with the greatest effect on their grain yield. In some other varieties 34 (ABC Alfio), 35 (ABC Lombardia) and 36 (ABC Klauzius) the grain yield is a result of a strong NPT effect. The arrangement of these varieties in Figure 1 fully confirms the data for these varieties in Table 4. The same applies to varieties 16 (ABC 48/716) and 19 (05N48-22-1) with respect to the WGS trait. This visual representation can be safely used for this purpose because of the relatively high proportion of the sum of the two components (PC_1+PC_2=76.9%) of the statistical analysis performed by the software product GGE Biplot (Yan, 2001).

The location of the points of the varieties can also be presented in a way that takes into account the degree of variation of each variety (Figure 2). Several varieties can be considered an excellent combination of GY and stability of Yield. These are again varieties 9 (ABC 27/512) and 38 (ABC Zigmund) adjacent to the ATC in which the combination of yield and stability is as much as possible for this trail. Two other varieties are also in this zone 35 (ABC Lombardia) and 40 (ABC Navo), with a higher degree of variation than the previous ones. The most productive variety (Table 4) ABC 48/716 (16) showed significantly more variability than the others. Recognized as the most valuable of yield and yield stability, those varieties have a very good combination between the trait of NGM and TGW, but unfortunately are far from the points of the NPT and NGS vectors. Given that the effect of NPT (r=0.71) on the NGM trait is significantly stronger than that of NGS (r=0.37) (Table 2) there is still much to be done with regard to increasing the NPT of new varieties. Eventual breeding upgrading of the NPT while maintaining the reach of the NGS level may further increase grain yields. It has already been commented that this trait has no negative correlation with TGW, but to increase NGM, it is necessary to proportionally reduce TGW due to the negative correlation with NGM.

After all these analyzes, it is interesting to classify the varieties of GY in different test environments (Figure 3). Their position on the figure shows that only a few varieties could be distorted because their high yields at a given location. Here are varieties 9, 13, 16, 30 and 33 in the A - Dobrich location. In the remaining location and seasons (17 & 18) there are no leaders in the group. Much of the varieties showed the best result in "A" and "C" in 2018 (A18 and C18). The two locations are in between points 9 and 4, so they are not clearly visible. Apparently, much of the new varieties that were awarded, according to the data in the tables, are equally good under favourable conditions (location A) and stress conditions (location C). The difference in GY between the two in the 2018 season is 35% lower yield at "C" location. The great spacing between varieties points and location points is the main reason for establishing a relatively small number of them, both plastic and at the same time high-productive.

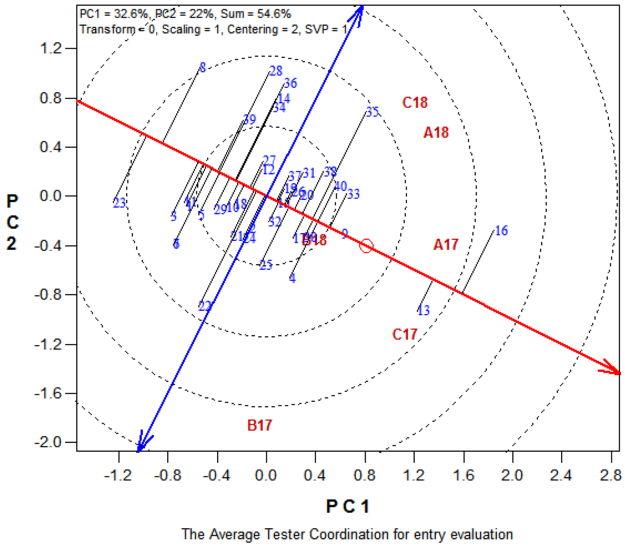

Fig. 3. Genotype main effect and Genotype by Environment interaction (GGE) of grain yield for 40 varieties in 6 environments

Conclusions

In conclusion, we can confirm the authors' thesis that the use of values derived from grain yields and the main components of productivity provides objective information about the score of each variety. In real conditions, a large number of varieties (40) were studied in MET. It was found that the conditions of the locations determined the variation of all the traits studied. This is fully valid for derivative GY*T traits, without exception. The analysis of the behavior of the variety through these traits is entirely possible because their values largely preserve the correlations between the simple traits and their impact on the GY. The approach to using GY*T values, however, provides additional information related to combining yield determining traits. This is especially important for identifying combinations of them in a genotype that are difficult to combine by breeding. Through this simplified model, it is quite possible to carry out a detailed study of a large number of traits, the manifestation of which in interaction with environmental conditions, ultimately have a tangible effect on grain yield. The differentiation of the breeding value of the varieties can be done without direct measurement of the grain yield. Similar attempts have already been made by which explore several principally different approaches to similarly assessing the breeding value (score) of a variety (Bose et al., 2014; Tsenov et al., (2014). Gubatov et al., 2016; Tsenov et al., 2019).The specific approach applied here for a detailed assessment of a variety whose GY is influenced by a set of traits, which in turn are strongly influenced by testing environments, appears to be effective and enforceable. We hope its suitability is likely to be confirmed experimentally by other researchers in the future, because it is helpful for wheat breeding.

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