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RESEARCH ARTICLE

INFLUENCE OF ENVIRONMENTAL CONDITIONS ON THE PERFORMANCE OF THE VEGETATION PERIOD IN WINTER COMMON WHEAT (*TRITICUM AESTIVUM* L)

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Abbreviations: [EDD] - Ear Emergence Date, [GFP] –Grain Filling Period, [VP]-Vegetation Period, AMMI-Additive Main effect and Multiplicative Interaction, GEI – Genotype x Environment Interaction

ABSTRACT

The housing conditions are a major factor to change all the traits of bread wheat pertaining to the quality and yield of grain. Whether this is true for the growing season of winter wheat, which is one of the longest in agricultural crops. The aim of this study was to establish the influence of contrasting environmental conditions on the change of basic periods of vegetation, which have a direct connection with the grain yield. Thirty varieties of winter wheat grown in production were studied. They have all the necessary variety of traits and properties of wheat to obtain the maximum possible yield of grain in the country. Cultivars are tested in four consecutive seasons 2007, 2008, 2009 and 2010 in the five locations of Bulgaria, covering all possible variety of soil and climatic conditions for growing wheat. The characters of ear emergence date [EED], grain filling period [GFP] and vegetation period [VP], as major periods of whole wheat vegetation are studied. Data were analyzed using a number of specialized software programs to establish the genotype with the environment interactions. At all traits strong interaction of genotype with the environment is found. The values of the three characters change fairly heavily under the influence of environmental factors. Especially noticeable is the effect of location for vegetation period (VP) and the period of grain filling. In general, the date of the ear emergence change more strongly by the terms of the season and the effect reaches about 50% of the total variation of the trait. Although trait means in the tested varieties are very close, they change the background of the various combinations between the two factors of the environment is so strong that it reaches almost 20% in GFP. The last one is changed greatly in both studied factors. Therefore, it is very convenient for a precise assessment in response to specific genotype in clarifying its impact on the formation of yield and grain quality.

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INTRODUCTION

The vegetation period in the common wheat is a special quantitative trait. The reasons for this are few and are rarely touted by researchers (Worland 1996, Eagles *et al*., 2009; Blake *et al*., 2009). First, vegetation period is very long and from sowing to full maturity are set from 70 to 300 days (Worland and Snape, 2001). Because here it comes to talking about the winter wheat growing season of over 200 days (Snape *et al*., 2001, Tanio *et al*., 2006). In practice winter wheat has the longest growing season in annual crops. In spring type of wheat due to shorter growing periods ranging from 70-100 days sometimes and analyze the entire growing season, as a separate trait (Mondal *et al*., 2013). Secondly because it is too long and therefore difficult to analyze and study as a factor (trait), it is divided into several different periods which have an effect on the formation of yield and grain quality.

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These are ear emergence date (EED), date of flowering (DF), a grain filling period (GFP) and vegetation period (VP), which are interpreted as separate and "independent" of each other quantitative traits (Worland *et al*., 1998, Griffits *et al*., 2009). Thirdly wheat crop is characterized by stepwise development (Stelmakh, 1998). This means that we should distinguish growth from the development taking place in the different biological stages (Distelfeld and Dubcovsky, 2009).

These features of the crop associated with vernalization requirements and photoperiodic response, which inevitably have a direct impact on the end result - grain yield (Stelmakh, 1998, Langer *et al*., 2014). The unique combination of genetic factors for vernalization, photoperiodizm and meteorological conditions ultimately depends on how long will the vegetation periods (van Beem *et al*., 2005). Fourthly this passed now to sign up to ear emergence date (EED), is a very rare object of study for himself and almost always against the other major traits, characters or properties that have a direct or indirect relationship with tolerance to biotic and abiotic stress, productivity or quality of grain (Mandal *et al*., 2010, Bennett *et al*., 2012a). Preferred research object is a trait GFP, because it is directly related to grain yield under stress (Mandal *et al*. 2010, Jocković *et al*., 2014). These few traits are rarely object of research as the main focus, especially in the breeding trials (Kamran *et al*., 2014). Studies on their interaction with environmental conditions are very rare (Donmez *et al*., 2001, Muhe & Assefa, 2011, Temesgen *et al*., 2015).

Observations that I conducted as phenology of over '30 give me reason to say that the ear emergence date and grain filling period are strongly influenced by the conditions of the place and the season in which the crop is growing (Tsenov *et al*., 2013, Tsenov *et al*., 2015). Every season is a unique combination of conditions that never repeat as temperature, humidity and light as a manifestation and duration of exposure over different phenophases of the vegetation period (Yan & Hunt 2001 Cockram *et al*., 2007). The study of the impact of growing conditions on these traits associated with ear emergence date of the period for filling the grain would provide valuable information for breeding of wheat against the backdrop of global climate change over the last 20 years (Kamran *et al*., 2014). In a large number of published research highlights the role of the vegetation period (ear emergence date) on the grain yield (Blake *et al*., 2009, Tsenov *et al*., 2013), grain quality (Bennett *et al*., 2012b, Tsenov *et al*., 2014) and tolerance to abiotic stress (Mondal *et al*., 2013, Kamran *et al*., 2014). All this makes the examination of the change of the vegetation period necessary from the standpoint of building a proper breeding strategy to further optimize and change its duration. The purpose of this study was to investigate the effect of environmental conditions on the appearance and the change of several traits associated with the vegetation period of winter wheat.

MATERIALS AND METHODS

Plant material

Thirty varieties of winter wheat grown in real production are studied for four years at five locations in the country (Table 1). The varieties are pre-selected according to quality of grain from each group involved in 10 varieties. The five locations were selected from a total group of 10 where data for traits are available. Selected four consecutive seasons (2007-2010) are contrasting according to weather conditions, which is a good prerequisite for causing variation in traits and assessment of their change. Group of varieties is grown in field trials of randomized block (Latin square) in size of the harvested plot of 10 m^2, in four replications.

Studied traits

The basis of the study are several traits associated with the vegetation period of winter wheat: (EED) Ear Emergence Date, presented as a number of days from January 1; (GFP) grain filling period - number of days from flowering to physiological maturity and vegetation growing period (VP) in days from sowing to full maturity (harvesting). Ear Emergence Date is fixed at a time when 75% of the ears (spikes) are shown above flags sheet. The end of the period for filling the grain is reported as 75% of the spikes have reached physiological maturity. The values of the characteristics are determined on the basis of a single plot subject to the exact time, in each variety (Table 2).

Statistical analysis

The collected data were analyzed by methods of descriptive statistics to identify even the smallest changes caused by growing conditions. The behavior of different varieties by earliness is determined using statistical analyzes that measured the interaction of genotype with the environments as AMMI model. For the analyses several statistical packages were used, which are determined by different values and parameters for individual traits (GenStat, GEST98, BioStat).

RESULTS

Analysis of variance, which is obligatory in similar studies of the factors involved in experiments (Table 3) shows strong variability of the three studied characters. This data is sufficient to be fully analyzed, the result of which is in Table 4.

The application of a comparison between the average values of varieties on the basis of all the data shows, between them there

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

Code	Location	Soil type	Altitude, m	Coordinates	
1	Selanovtsi, District Vratsa	Carbonate chernozem	168	N 43°40'	E 24°01'
2	Pordim, District Pleven	Less Haplustoll	183	N 43°23'	E 24°51'
3	Radnevo, District Stara Zagora	Haplustoll Vertisols	135	N 42°18'	E 25°58'
4	Gorski izvor, District Haskovo	Haplustoll Vertisols	178	N 42°01'	E 25°25'
5	Chepintsi, District Sofia	Alluvial meadow	515	N 42°43'	E 23°26'

Table 2. Surveyed traits and time for measuring by Zadoks scale

Trait code	Trait full name	Zadoks code
EED	Ear emergence, days	55-60
GFP	Grain filling period, days	60-90
VP	Vegetation period, days	10-99

Table 3. Analysis of Variance for the traits studied (df=347)

Trait	MS	F-Ratio	p-value	R^2
Ear Emergence Date (EED)	50.4657	4.42	0.0000	0.577*
Grain Filling Period (GFP)	94.8141	2.14	0.0030	0.545*
Vegetation Period (VP)	254.725	2.43	0.0012	0.586*

is no significant difference, with a few exceptions in the trait EED, relating to a limited number of varieties (No 2, 12, 20 and 28). The data show that there are no differences between varieties, although they exist (Tsenov, 2009). In this situation, the question arises whether the trait change in environmental conditions, having no differences between varieties? Answer to this important issue is given when data are grouped according to factors year and location of the study. There have been significant differences (95% LSD) between them in all investigated traits of growing season for wheat (Table 5). Only in a few cases in grouping test locations values of the traits are similar - Selanovtsi and Radnevo for EED; Selenovtsi and Radnevo for GFP; Selenovtsi and Chepintsi for VP. The interpretation of the data thus indicates a strong change on their phenotypic means of the characters due to the impact of the conditions of the year or location.

Table 4. Means of traits and Multiple pairwise comparisons by Dunn's procedure[#] for cultivars

№	Trait	Ear Emergence Date		Grain Filling Period		*Vegetation Period*	
	Cultivar	mean	*Sig. group#*	mean	*Sig. group#*	mean	*Sig. group#*
1	Aglika*	129.8	*ab*	43.6	*a*	227.5	*a*
2	Albena	131.1	*b*	44.2	*a*	228.3	*a*
3	Demetra	129.9	*ab*	43.7	*a*	228.0	*a*
4	Desislava	130.7	*ab*	44.4	*a*	228.5	*a*
5	Galateya	129.6	*ab*	42.6	*a*	227.3	*a*
6	Iveta	130.3	*ab*	44.3	*a*	227.9	*a*
7	Milena	130.4	*ab*	45.7	*a*	228.6	*a*
8	Apogej	130.2	*ab*	44.6	*a*	227.8	*a*
9	Pobeda*	130.0	*ab*	43.7	*a*	227.9	*a*
10	Troya	128.7	*ab*	43.7	*a*	227.4	*a*
11	Boryana	128.7	*ab*	44.6	*a*	227.7	*a*
12	Enola*	128.2	*a*	43.2	*a*	227.4	*a*
13	Karina	129.8	*ab*	45.2	*a*	228.7	*a*
14	Laska	129.9	*ab*	45.9	*a*	228.7	*a*
15	Miryana	130.0	*ab*	46.5	*a*	229.1	*a*
16	Sadovo 1*	129.0	*ab*	45.4	*a*	228.2	*a*
17	Sadovo 772	129.6	*ab*	44.0	*a*	227.8	*a*
18	Slaveya	130.6	*ab*	44.5	*a*	228.9	*a*
19	Vyara	130.0	*ab*	44.7	*a*	228.6	*a*
20	Zlatitsa	131.9	*b*	44.9	*a*	229.1	*a*
21	Aneta	130.6	*ab*	44.5	*a*	229.1	*a*
22	Geya 1	130.1	*ab*	46.0	*a*	228.6	*a*
23	Karat	129.6	*ab*	44.3	*a*	227.7	*a*
24	Kristal	129.5	*ab*	42.5	*a*	227.1	*a*
25	Neda	129.9	*ab*	44.9	*a*	228.3	*a*
26	Neven	131.3	*b*	44.7	*a*	228.7	*a*
27	Pryaspa*	130.5	*ab*	43.9	*a*	227.8	*a*
28	Svilena	128.1	*a*	43.9	*a*	226.6	*a*
29	Todora	129.8	*ab*	43.2	*a*	227.8	*a*
30	Yantar*	131.3	*ab*	44.6	*a*	228.4	*a*

* Check varieties

Table 5. Environmental means of traits and Multiple pairwise comparisons using the Dunn's procedure* for main sources of variation

Trait	EED		GFP		VP	
Factor	mean	Sig. group*	mean	Sig. group*	mean	Sig. group*
Year						
2007	124.2	a	46.3	b	227.3	b
2008	129.5	b	50.0	a	234.8	c
2009	133.7	c	46.0	b	224.0	a
2010	132.46	d	35.3	c	226.5	ab
Location						
Selanovtsi	129.6	b	46.1	b	237.3	d
Pordim	130.9	c	41.5	a	230.9	c
Radnevo	128.6	b	46.6	b	223.5	b
Gorski Izvor	127.4	a	45.9	b	212.7	a
Chepintsi	133.3	d	41.9	a	236.2	d
Grand mean	129.9		44.4		228.2	

Table 6. Descriptive statistics of vegetation traits

Stat. parameter, Trait	Measure	EED	GFP	VP
Mean	days	129.9	44.4	228.2
Standard deviation	days	5.19	9.36	14.45
Coeff. of variation	%	5.99	21.01	6.34
Minimum,	days	116.0	19.0	185.0
Maximum	days	141.0	69.0	248.0
Range	days	25.0	50.0	63.0

Terms of the year, as a source of variation, causes the strongest contrast between the values of the trait EED, during the four years we have fairly different values. In the other two traits we have three groups of authenticity. The lowest difference of VP, where only between 2008 and 2009 there was a significant difference in values. Almost similar is the situation at the location as a factor. Again, the most noticeable differences is in trait, EED (four groups of assurance by 5 points), and the lowest is the change in GFP, only two groups of five possible.

Table 6 presents data from basic statistical parameters, an average of the entire database, including the years and locations to a test consisting of 600 single measurements. Of these, clearly shows the variation that exists at each of the investigated characters. Changing the traits expressed by the breadth of their variation (Range) is strong. In EED breadth of variation of 25 days is a serious difference after knowing that this one is genetically highly heritable and should be more stable in different growing conditions (Tsenov and Tsenova, 2011, Mondal *et al*., 2013). In the other two traits the spread of the variation is even stronger (50 and 63), respectively for GFP and VP. The variation of the characteristics EED and VP is about 6%. The strongest variation of the values in the GFP, wherein the coefficient of variation of up to 21 %, and the spread of variation exceeds its minimum value of 19 days. Overall, this is a huge variation against the average of traits and approaching the values of variation of populations created by combining contrasting varieties (Tsenov, 2005). In a study of spring wheat Laghari *et al*., (2010) and Mondal *et al*., (2013) in a number of test conditions, establish low variation in the date of ear heading in the range of 3-4%. Perhaps this striking difference is due to the different biology of the winter compared to spring wheat, which causes the length of those traits to be different.

Having established that two factors cause variation of credible traits it is interesting to know which of the two has a decisive impact of variation in traits. According to data from Table 4, the year is shaping up as a strong factor in the variation of the characters. The data in Table 7 provide additional information in this regard. According to them the year affects all traits, for EED has a decisive importance for its variation. The other two traits are affected significantly more strongly on the location of cultivation, 62% and 75% of the total variation for traits GFP and VP, respectively. The share of the variety of its genetics is the most weak, with values between 5.5% and 12.6% in individual traits.

Table 7. Magnitude of Variance of main factors (%) for all traits (Statgraphics)

Variance	Year	Location	Variety
df	3	4	29
EED	48.58	38.78	12.64
GFP	27.76	61.91	10.33
VP	15.33	75.54	5.46

The variation is fairly, but is there an interaction between environmental conditions and varieties in the target traits. If there is, what is its nature and direction, after the variety show negligible small share in the mean of traits? The reaction of the mean values of the traits with the factors of the environment and there is sufficiently expressed (Table 8). Strong is the interaction between factors, which further complicates the interpretation of their influence.

Table 8. Significance (*p-value*) of Variations and Interactions for studied traits

Source	df	EED	GFP	VP
Intercept	*1*	*.000*	.001	.000
A: Year	3	.001	.111	.017
B: Location	4	.134	.003	.111
C: Variety	29	.015	.173	.146
A * B	12	.000	.000	.000
A * C	87	.000	.000	.000
B * C	116	.032	.150	.073
A * B * C	348	.987	.967	.897

The effect of variety is the most weak in comparison with other factors under traits GFP (*p=0.173*) and VP (*p=0.146*). Complex and multi likely impact of each trait separately and in combination with others. Interaction between the three main factors (A * B * C), as expected logically missing, despite the large number of measurements (n=600). The probable explanation for this should be sought in such a strong interaction of each factor as the sole result of which leads to the huge scale superimpose variance, which is virtually impossible to be proven. Similarly, strong interactions between single environmental factors for EED was established by Chamurliyski *et al*., (2015) and Aycicek and Yildirim, (2006).

DISCUSSION

Interaction that found in the analysis of variance determined the traits as many variables, although among the surveyed species not observed significant differences in all three characters. Similar results for the lack of difference between the tested varieties of ear emergence date reported by Dechev (2005) in a study of durum wheat.

In a similar study, Laghari *et al*., (2010) reported large differences between varieties, date of ear emergence and physiological maturity although the site is spring wheat with significantly lower values of these traits. Variation in traits is caused by location of the study and season as well with their particular weather conditions. It is expected under the background of various soil and climatic conditions of locations used (Tab.1). Following these environments, any change in the conditions of the year caused a strong enough change in the values of traits (Table 9).

Application of AMMI approach clearly establishes once again the strong interaction between the value of the traits and the environments at the highest statistical level. It is interesting to note the complex interaction between conditions and expression of the trait in that part, which is related to the non-linear nature (IPCA2). For all three characters this parameter is reliably expressed, which means the different varieties overreacting to changing environmental conditions. Similar results were reported by (Sadras and Slafer 2012). This is quite logical amid contrasting conditions of the locations, which is clearly visible when comparing their scores ratings, obtained from the principal component analysis (Table 10).

Table 9. ANOVA of AMMI model for the traits studied

Trait / Source	df	Ear Emergence Date		Grain Filling Period		Vegetation Period	
		F	p-value	F	p-value	F	p-value
Years	119	39.41	<0.001	60.46	<0.001	130.30	<0.001
Locations	3	7.25	<0.001	3.04	<0.001	6.41	<0.001
Genotypes	29	16.15	<0.001	2.60	0.0288	2.57	0.0377
Block	16	184.26	<0.001	740.07	<0.001	1859.01	<0.001
Interactions	87	2.48	<0.001	4.27	<0.001	1.33	0.0234
$IPCA_1$	31	4.17	<0.001	9.76	<0.001	2.01	0.0011
$IPCA_2$	29	2.35	<0.001	1.36	0.1045	1.37	0.0977
Residuals	27	0.69	0.8798	1.10	0.3382	0.90	0.6756

Table 10. Location means and scores by AMMI model

№	Trait / Location	EED			GFP			VP		
		$IPCA_1$	$IPCA_2$	Variance	$IPCA_1$	$IPCA_2$	Variance	$IPCA_1$	$IPCA_2$	Variance
1	Selanovtsi	1.290	-1.016	17.10	0.405	1.586	36.31	-0.356	1.259	24.1
2	Pordim	-0.054	-0.137	7.41	1.427	0.106	149.83	1.489	0.705	77.0
3	Radnevo	-1.325	-1.038	0.055	-0.618	174.78	0.456	-1.753	186.0	17.57
4	Gorski Izvor	-1.114	1.169	26.12	0.232	-1.292	36.47	0.362	-0.090	264.3
5	Chepintsi	1.204	1.023	47.30	-2.121	0.217	20.06	-1.951	-0.119	80.0

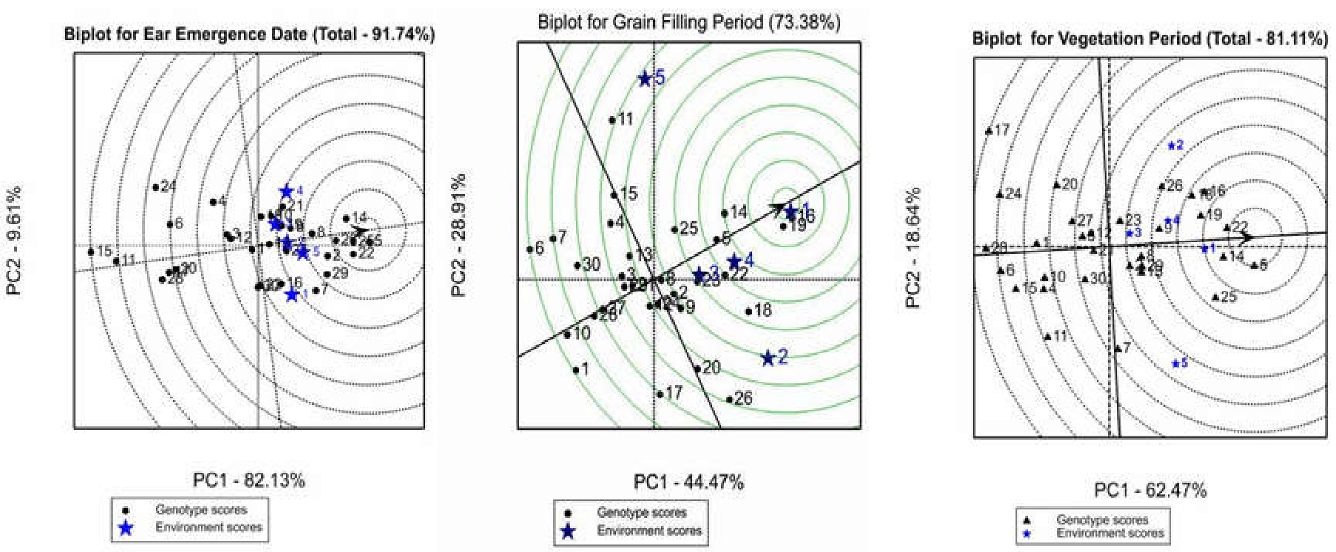

Figure 1. Biplot scores and stability of 30 wheat genotypes for trait by location interactions

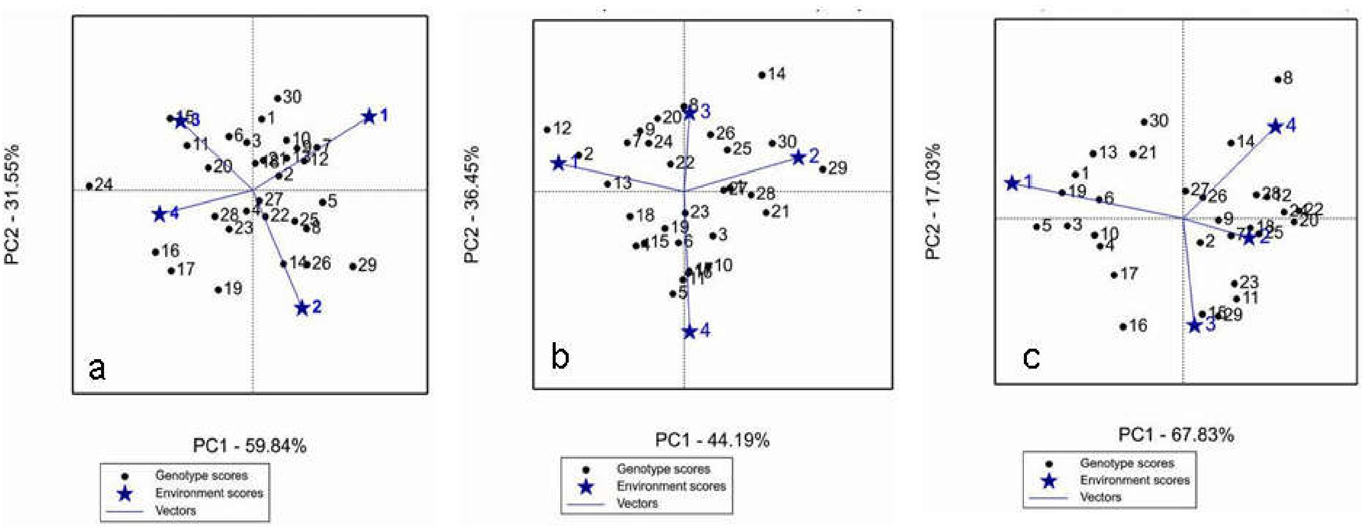

Figure 2. AMMI biplot for year by trait (a-EED, b-GFP, c-VP) interactions

Large differences in the values of the locations are highlighted by the very strong difference in variance of the traits in them. For EED these differences reach a difference of about eight times (7.41 Pordim; Chepintsi 47.3). For GFP, the difference between minimum and maximum variance is nearly 9 times. According to the presented data on the analysis of the vegetation period of winter wheat we can separate locations of relatively stable (Selanovtsi) and highly variable (Radnevo). Examination of other characters, in the same stations, shows radically different patterns on their variation (Tsenov *et al*., 2013, Tsenov *et al*., 2014). What is important for us as researchers, when the conditions of location cause traits variability or vice versa? Answer to this question is given partly in studies (Yan and Hunt 2001, Mandal *et al*. 2010, Roostaei *et al*., 2014). According to these data, the three morphological traits is changed greatly, which in turn is a prerequisite for an objective assessment of the stability of the different periods of the growing season of winter wheat. The reaction of the examined varieties by the means of location as a result of the environments of the season shows diametrically different direction.

Logically after changing of the conditions the tested varieties to respond (interact) differently. The sum of this different direction of reaction is likely reason for this unexpectedly strong variation and inability to differences between varieties. The direction of variation is clearly visible in Figure 1, for the EED, GFP and VP, respectively. According to the magnitude of the second component of the PCA, (PC2) the most strongly nonlinear genotype x environment interactions are in GFP (44.47%) and the lowest for EED (9.61%). In Figure 2 respectively, the difference between the values of the surveyed locations is the most powerful and their points are located throughout the coordinate system. Conversely, EED location points are located very close each other (Figure 1). The place of the location points of the figures is consistent with the data in Table 4 in which the lack of significant difference between genotypes is due precisely to this huge variation, which is the result of a nonlinear interaction.Aycicek and Yildirim, (2006) found that differences between the tested varieties of them in terms of ear emergence date is reliable. In their study the interaction between the two factors: the year and the location are weak and irrelevant and location has a decisive share of the total variance. The sum of two components with for GFP (73.38%) implies the presence of a third component of the interaction (PC3). If this is true it increases the magnitude of the nonlinear interaction. In the main components of wheat productivity, study of Tsenov *et al*., (2013) established a highly non-linear interaction with the conditions in those locations of the test. Weak (as compared to the other two attributes) variation of the attribute as a result EED is the strong linear change of the trait (PC1 = 82.13%). Completely analogous results obtained in the study of Chamyrliski *et al*. (2015), in which the effect of the year is decisive (87.7%) of EED. Nonlinear interaction is probably the reason for the variation of the feature VP (PC2 = 18.64%), which is about 1/4 of the total variation. In this character whose values are highest (228 days) makes sense for the presence of such a complex interaction of genotype with the environment. Do not forget that during the winter months the differences between active temperature sums (GDD) are very different in years and strongly influence EED trait (Tsenov, 2009). However, the difference between the means of the locations those of years and partly of varieties are essential and are also associated with variation. In implementing the principle component analysis based on the conditions of the year picture of the interaction at any character changes (Figure 2). That which is essential is considerably strong nonlinear interaction, expressed by PC2. So at EED, it amounted to 31.5%; GFP is at 36.5%, with VP, PC2 is 17.0%. Given that already stated that the year has somewhat less effect on traits compared with locations one can be concluded that it is different in nature. Nonlinear part in the trait EED constitutes about 50%, while for GFP is about 80% of the linear one. In the VP trait the second components remained almost the same share as in the analysis on the base of locations. Given that the relationship between EED and GFP is very strong Tsenov, (2009) the variation of the second trait is a bit unexpected after the first variation is normal. This means radically different response of genotype with respect to the duration of the two periods under changing environments. Substantial change to the length of time grain filling caused by temperature anomalies during this period (Tao *et al*., 2015r Jocković *et al*., 2014), which are a result of global climate change.

Finally, it can be concluded that the change of important traits associated with different growing periods of winter wheat is essential. The three studied characters interact strongly with the terms of the season and the location of experiment. Variations which cause these conditions are huge and have a different character in each trait individually. In EED observe differences among all the experience factors are due of genotype, year and location. The most significant in the interaction between the terms is the year and lowest values range of genotype. Information obtained fully coincides with the opinion of a number of researchers, according to which variation of this feature is relatively low compared to the other components of productivity in wheat (Donmez *et al*. 2001, Singh *et al*., 2015). The most variable is the GFP that is the most directly related to the productivity of winter wheat (Jocković *et al*., 2014, Singh *et al*., 2015). Its change is the most complicated and unpredictable, which in turn would hamper the eventual study of the reaction of a variety. Changing the GFP is very different in winter wheat from the information that is published for spring type of wheat (Laghari *et al*., 2010, Mondal *et al*., 2013). In this trait strong phenotypic variation is related to the non-linear nature of the interaction between variety and environmental conditions whose share reaches 80% of that of the linear character (PC2). Laghari *et al*., (2010) and Jocković *et al*., (2014), show that the longer period of grain filling is connected with significantly higher grain yield. So it is the same in this study, the results of which will be published separately. In VP, which is one of the least studied traits in wheat, the reasons for which I pointed out in the introduction, the regularities are also interesting for analysis. It is strongly influenced by the place of study (Tab. 10) the difference in its change in different locations is huge (24.1 to 264.3 in Selanovtsi in Gorski izvor, respectively). Change is very strong, and in different years of study (Figure 2). Changing the values of the trait is primarily due to the linear interaction between genotype and the environment as part of the nonlinear interaction that accounts for about ¼ of the first and is also essential for him.

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