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Genetics and Breeding

Date of ear emergence: a factor for notable changing the grain yield of modern winter wheat varieties in different environments of Bulgaria

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Abstract. *Wheat is a crop with a very long growing season, during which it is subjected to prolonged exposure to many environmental factors. For this reason, the interaction of genotype with conditions is very common for any character of wheat. This study aims to determine whether the grain yield is affected by the change of the ear emergence date (EED) in various environments. In a four-year period, 30 current for national real grain production winter wheat varieties were studied. The EED and grain yield (GY) were studied as quantitative traits within five locations of the country having various soil and climatic conditions. Using several statistical programs, genotype x environment interaction of two traits was analyzed. The emphasis on data analysis was whether changes of traits due to the conditions were related and that the optimization of the ear emergence date could serve as a breeding tool for increasing grain yield. The date of ear emergence and grain yield are traits that are reliably influenced by growing conditions. The change in the date of emergence is mainly of the linear type, while the grain yield shows linear and nonlinear type changes in the same environmental conditions. It was found that the key roles in the change of characteristics are the conditions of the year, with the relatively weakest impact of the genotype on them. There is a positive relationship between the two traits, although their change depends on environmental factors. Although they change to different degrees and in relation to each other, there is a positive correlation between them. The more favorable the environmental conditions, the weaker the relationship between these two traits and vice versa. Under changing climatic conditions, the change in the relationship between the two traits is a signal of the need to create different varieties by date of ear emergence in order to obtain higher yields in the future.*

Keywords: correlations, ear emergence date, genotype x environment interaction, grain yield, *Triticum aestivum* L.

Introduction

Date of ear emergence is a trait that has a specific impact on the growth and development of cereals (Andersen et al., 2011; Mondal et al., 2020). Winter wheat, in the conditions of the Balkan Peninsula, starts heading after about four months, because that date is measured from January 1 (>120 days). The length of time until the date of ear emergence is strongly influenced by the conditions of the place and the season in which wheat is cropping (Tsenov et al., 2013, 2015, 2017). Meteorological conditions cause the local biotype to accumulate specific alleles of genes that are most suitable for the location for growth and development. The known alleles of vernalization genes in the dominant state determine the spring type and vice versa, those that are recessive define the performance as winter wheat (Klaimi and Qualset, 1974; Stelmakh, 1998; Lukman, 2003). The genes determining the sensitivity of wheat to the length of the day in the spring forms are dominant, and in the winter forms they are recessive (van Beem et al., 2005; McIntosh et al., 2013). It is no coincidence that all authors studying the genetics of wheat development have emphasized the decisive role of both genetic systems (*Vrn* and *PpD*), because they determine the highest possible level of crop adaptation (Worland et al., 1998; Worland and Snape, 2001). According to the study of Kolev et al. (2011), most Bulgarian varieties have identical genetic control factors according to requirements for vernalization and photosensitivity, although they differ significantly according to the date of emergence and the period of grain filling to full maturity (Tsenov et al., 2009; Chamurliyski et al., 2015).

Studies related to the effect of the growing season (date of emergence of the ears) on yield (Blake et al., 2009; Tsenov et al., 2013), quality (Bennett et al., 2012; Tsenov et al., 2014) and tolerance to abiotic stress (Kamran et al., 2014; Mondal et al., 2020) are important in theory and practice. The change of period to ear emergence reflects the adaptation of wheat,

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leading to changes in yield and the stability of the grain in the long term (Mondal et al., 2013; Semenov et al., 2014; Senepati and Semenov, 2020). The shortening of the period to the date of the ear is the reason for the realization of higher grain yield in conditions of high temperatures and soil drought (Donmez et al., 2001; Dodig et al., 2007; Tsenov and Gubatov, 2015). The earlier date of ear emergence (flowering) is associated with higher fertility of the heads, which is the main reason for higher grain yield (Dodig et al., 2007; Slafer et al., 2014).

Under favorable environmental conditions, where the actual grain yield of winter wheat is 10 t/ha, there are studies according to which shortening the period to ear emergence by 4-7 days and extending the period for grain filling with the same number of days would further increase productivity by 15-20% (Griffits et al., 2009). The later date of ear emergence is associated with the accumulation of more biomass in the wheat plant, which in turn is a guarantee of high and stable grain yields (Sip et al., 2010; Raynolds et al., 2012; Gonzalez-Navarro et al., 2015). The date of emergence, which is considered a characteristic showing the length of the growing season of wheat, has a different effect on its productivity, according to the specific conditions for growth and development (Slafer, 2012; Arjona et al., 2019).

Whether global climate changes over the past 20-30 years (Craufurd and Wheeler, 2009; Kamran et al., 2014; Mondal et al., 2020) affect the date of ear emergence and consequently grain yield is an issue that needs to be investigated. It is already proven that weather anomalies during the different seasons and location of cultivation produce a tangible change in the quantitative traits (Tsenov and Gubatov, 2015). Therefore, they are explored to predict the date of ear emergence under various conditions to optimize the adaptation of wheat and stabilize its productivity (Bogard et al., 2014; Al-Ashkar et al., 2020). The collection of additional information on how changes in the trait affect grain yield and how this would help to optimize the length of the growing season is directly related to increasing the productivity of the wheat plant through breeding, as well.

The purpose of this study was to determine whether the yield of cereals from modern varieties of winter wheat (*Triticum aestivum* L.) is influenced by the change in the date of ear emergence, caused by differences in growing conditions.

Material and methods

Plant material

In an ecological field trial consisting of five locations of the study (Gorski Izvor /G. Izvor/ village - Haskovo district, Selanovtsi village - Vratsa district, Radnevo town - Stara Zagora district, Pordim town - Pleven district and Chepintsi village - Sofia district), 30 present for Bulgaria winter wheat varieties were tested for four consecutive seasons (2007-2010). At each location the varieties were grown in a Latin square with a plot size of 10 m^2, in 4 replications each of them. The whole and detailed design of the experiment is described by Tsenov and Gubatov (2015).

Studied traits

Two traits were studied: Ear Emergence Date or date of heading (EED), presented as a number of days from January 1 and Grain Yield (GY). The date of ear emergence is fixed at a time when 75% of the spikes are shown above the flags sheet. Grain yield is defined in full maturity standard grain moisture of 14% of each replication of the field trials.

Statistical analyses

The collected data series for each trait (n=600) were analyzed by various methods of descriptive statistics to identify even the smallest changes caused by growing conditions. The magnitude and change in the ear emergence date were determined using statistical analysis that identified the interaction of the genotype with the environment, such as AMMI and Biplot. Several statistical packages were used as approaches, through which different values and parameters for the individual traits and correlations between them were analyzed (GenStat 17, SPSS 19, BioStat Plus 2009, Statgraphics XVI).

Results and discussion

The analysis of variance, which in such studies is required, shows a significant change of the traits in the described test design (Table 1). The variation of the traits is reliable with the highest level of significance. It is caused by all factors involved in the study that interact strongly with the environment (Table 2). The effect of the genotype is relatively lower than that of other factors, which are much more variable and unpredictable. The strongest variation is a result of the impact of the "year" (season), which is unique as a set of weather conditions (Table 3), followed by the test locations and variety as a main factor, too.

Table 1. Multivariate Analysis of Variance for the traits studied

Trait	SS	*Df*	MS	F	*p-value*	R^2
Ear emergence date	12061.3	239	50.4657	4.42	0.0000	0.577*
Grain yield, kg/ha	1727.64	239	7.22863	3.37	0.0000	0.691*

Legend: SS- Sum of Square, Df- Degree of freedom, MS- Mean Square, F- probability, p-value- Significance, R^2- coefficient of determination

Table 2. Interactions between the main factors and both traits studied

Interactions	Coefficients of determination	
	*η^2	**R^2
EED x Year	0.494	0.681
EED x Location	0.351	0.417
EED x Variety	0.226	0.310
GY x Year	0.441	0.613
GY x Location	0.299	0.424
GY x Variety	0.214	0.402

Legend: GY- grain yield, EED- ear emergence date,
*(η2) is a coefficient of determination by SPSS software (<20 is low value, <0.30 is medium value, >0.30 is high value),
**(R^2)- coefficient of determination by Statgrapics XVI

Table 3. Magnitude of Variance of main factors (%) for all traits

Variance	Year	Location	Variety
df	*3*	*16*	*580*
GY	48.58	38.78	12.64
EED	51.48	40.92	7.61

Legend: GY- grain yield, EED- ear emergence date

The change of both traits, under the influence of environmental factors is very similar. The strongest is the interaction of traits in terms of the "year" and the least with the genetics of varieties. For both characters the impact of the "year" accounted for about 50% of the total variation - 48.6% and 51.5% in EED and GY, respectively. The effect of the "location" of the study is the strongest (38.8% and 40.9% in EED and GY), while the effect of the "genotype" compared to it is significantly weaker, especially in grain yield (7.61%). Although the varieties are selected according to their grain quality, they also differ in the date of ear emergence, too (Tsenov and Gubatov, 2015).

The values of the two traits, grouped according to the two main environmental factors, are significantly different, without exception (Table 4). These differences were found between years of research. Although there are no significant differences between the varieties tested, the differences found in the EED are very clear evidence of the influence of the "year" factor. Moreover, the mean "year" values of both traits change in a very similar way. The increase in grain yield is related to a longer period to ear emergence, i.e. a higher value of the EED. The change in this sense is completely linear and means a high correlation between the two traits.

The clustering of the values of the traits according to the location of the trial showed different patterns. Increase of the date of ear emergence is not always associated with increase of grain yield in a single location. Both grain yield and data of heading date have been shown to differ from year to year and to test locations. The highest yield in Chepintsi location in turn is associated with the highest value of the EED (Table 5). It takes account of the greater difference between the means of locations compared to the overall grain yield. At last, despite some significant differences between the locations, only for Pordim the value differs distinctly from the others.

Table 4. Environment means of traits and scores of years and Multiple pairwise comparisons using the Dunn's procedure*

Year	Ear emergence date		Grain yield	
	Mean	Significance group*	Mean	Significance group*
2007	124.2	a	4.47	a
2008	129.5	b	6.65	b
2010	132.5	c	7.47	c
2009	133.8	d	8.04	d

*The values with the same letters have no statistically proven difference between them

Table 5. Environment means of traits and scores of locations and Multiple pairwise comparisons using the Dunn's procedure*

Location	Ear emergence date		Grain yield	
	Mean	Significance group*	Mean	Significance group*
Gorski Izvor	127.4	b	6.69	ab
Selanovtsi	128.7	a	6.20	ab
Radnevo	129.6	bc	6.00	ab
Pordim	130.9	c	5.97	a
Chepintsi	133.4	d	8.41	c

*The values with the same letters have no statistically significant difference between them at 95% probability

Strong interaction between environmental factors and both studied traits were found in an analysis of variance model of AMMI, calculated by the Gen Stat 15 software (Table 6). The probability of interaction is as high as possible (p=0.0001) for both traits, which fully confirms the data given in the previous tables.

The variation of the traits according to the data in the years and the survey locations presented in Tables 4 and 5 created a precondition for calculating the correlations between them in order to see the nature of the relationship between them. Correlations between the date of ear emergence and grain yield, calculated over the entire study period, by both conventional methods (Table 7) are high and reliable.

Table 6. Multivariate ANOVA table for AMMI model of the traits

Source	df	EED		GY	
Total	599	F	p-value	F	p-value
Years	3	39.41	0.0001	38.88	0.0001
Genotypes	29	16.15	0.0001	4.84	0.0001
Locations	4	7.25	0.0001	4.96	0.0001
Block	14	184.26	0.0001	287.36	0.0001
Interactions	87	2.48	0.0001	2.45	0.0001
IPCA 1	31	4.17	0.0001	4.16	0.0001
IPCA 2	29	2.35	0.0001	1.95	0.0002
Residuals	27	0.69	0.879	1.01	0.454

Legend: GY- grain yield, EED- ear emergence date

Table 7. Different kind of Correlations* between grain yield (GY) and ear emergence date (EED) by year and average for all environments calculated by SPSS

Year	Parameter	Pearson*	Spearman*
2007	*r*	0.563**	0.448**
	p-value	*0.0000*	*0.0000*
2008	*r*	0.436*	0.366*
	p-value	*0.0001*	*0.0002*
2009	*r*	0.159 ^{ns}	0.114 ^{ns}
	p-value	*0.0123*	*0.0201*
Total (2007-2010)	*r*	0.463***	0.386*
	p-value	*0.0000*	*0.0003*

Over the years, however, the values of the two characteristics are very different in order to accept which of them could be considered valid. Therefore, three of the four years were chosen which reliably differ in the two studied features. In general, we can define 2007 as very unfavorable (prolonged drought), 2008 as moderately favorable and 2009 as very favorable for wheat as a crop. This set of conditions is reflected in the average grain yield (Table 4). A positive correlation was found, which had different values during the different years of the study. The tendency is to reduce the correlation between the two traits with the improvement of growing conditions from 2007 to 2009, which even in the latter value is positive but not significant. This means that both traits in the same environment are changed in a different way, which is reflected by their interrelationships. Changing the date of ear emergence affects different grain yield directly dependent on environmental conditions, the earlier date is associated with higher grain yield (Marinciu et al., 2013; Tsenov et al., 2015a; Chen et al., 2020). When growing wheat under conditions of prolonged stress (2007), the correlation between traits is significantly stronger due to significantly lower yields and vice versa, the correlation decreases relatively under favorable conditions (2009). In this case, it is important to note that higher grain yield occurs after a longer period until the ear is directed, regardless of the environment. Similar results have been obtained from studies by Raynolds et al., (2012) and Gonzalez-Navarro et al. (2015), in which there is no correlation between early wheat emergence and grain yield. A longer growing season is associated with a longer grain filling period, which practically reduces the relationship between the date of heading and the final grain yield. The correlations in this study differed significantly as a result of the significant influence of environmental factors on the values of the two traits by years and locations. After all, the correlation between yield and ear emergence date is positive and is evidenced by the result of the applied regression analysis (Figure 1).

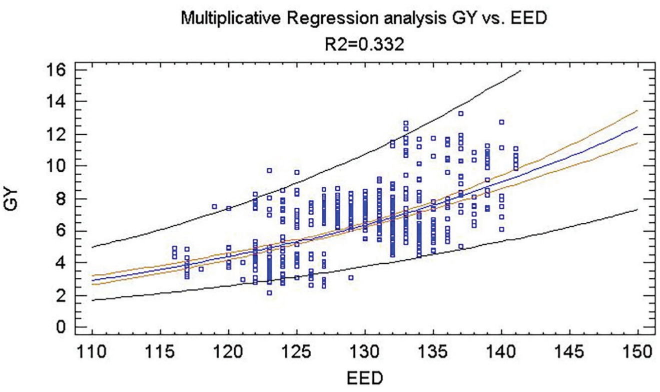

Figure 1. Regression analysis of grain yield vs. ear emergence date

Indeed, the value of the coefficient of determination (R^2=0.332), which indicates the adequacy of the model is not very high, but the figure clearly shows the strong dependence of yield on the date of ear emergence. Additional evidence in the direction of this statement is the location of the two characters on Figure 2. The interaction between the two traits is mostly "linear" because PC_2 values are very low and are only about 10% of those of PC_2. It has been established that the longer the period until the ear emergence, the higher the grain yield in general. These results are contrary to the studies of Donmez et al. (2001), Marinciu et al. (2013) and Tsenov et al. (2015b) which demonstrate the advantage of early lines or varieties in grain yield, particularly with respect to stress.

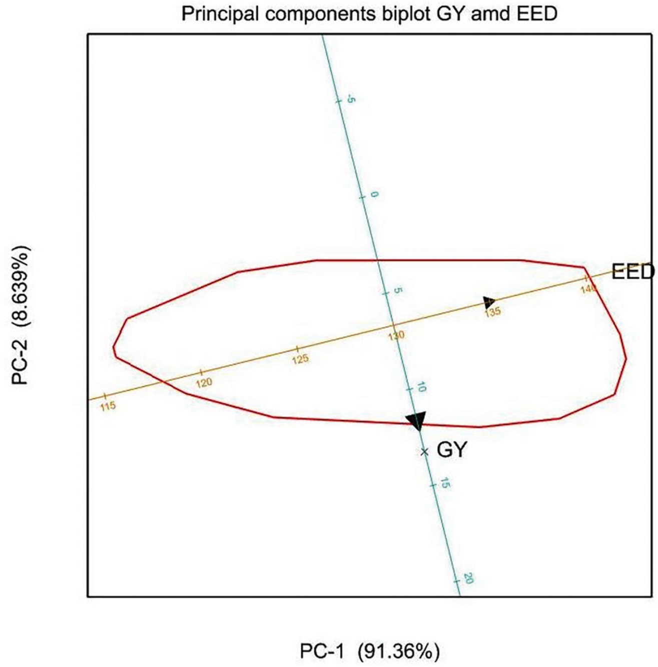

Figure 2. Principal component analysis of genotypes for both grain yield (GY) and ear emergence date (EED)

On the other side, the vegetation period, expressed through EED, is known to be associated with the so-called "fine" tuning of grain yield (Bogard et al., 2014; Langer et al., 2014). This means that in this case the highest possible yield is connected to the ear emergence date within 120-140 days. Hardly higher grain yield is connected with a later date of ear heading (Tsenov et al., 2013). The probable reason is the long grain filling period, which has a large share in the formation of the grain yield, and the correlation with the length of the period to heading is positive, almost without exception (Tsenov, 2009; Jocković et al., 2014). In Bulgaria a long period to ear emergence is associated with the higher stem of the plant (Tsenov et al., 2015a), which in turn does not allow increasing the harvest index, and grain yield from there.

The interaction between two traits, according to their localization in Figure 2, is linear in nature and therefore grain yield could be partially predicted as quantity, according to the date of heading in a particular season (location plus year). Varieties react through their traits appropriately to changing conditions in both directions. However, when an analysis of the main components of the traits is made individually (Figures 3 and 4), they are found to show different behavior depending on the environmental conditions.

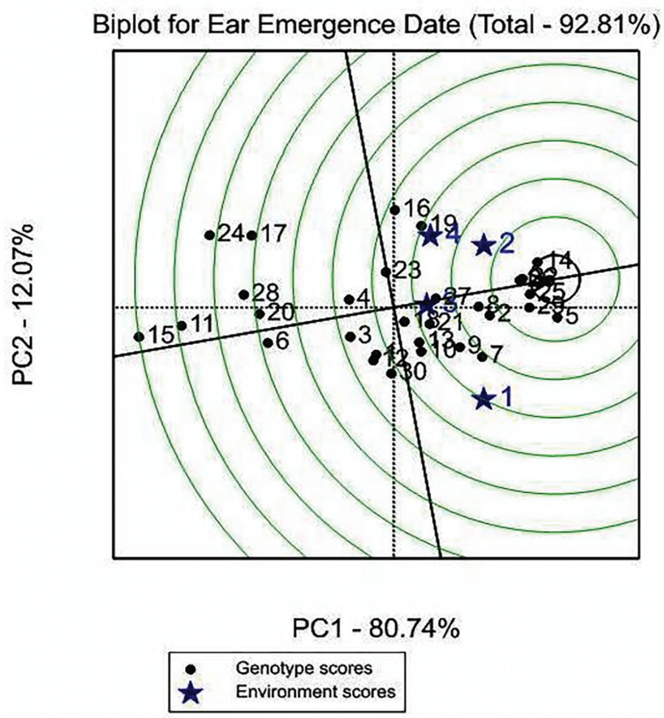

Figure 3. Biplot analysis of varieties for ear emergence date

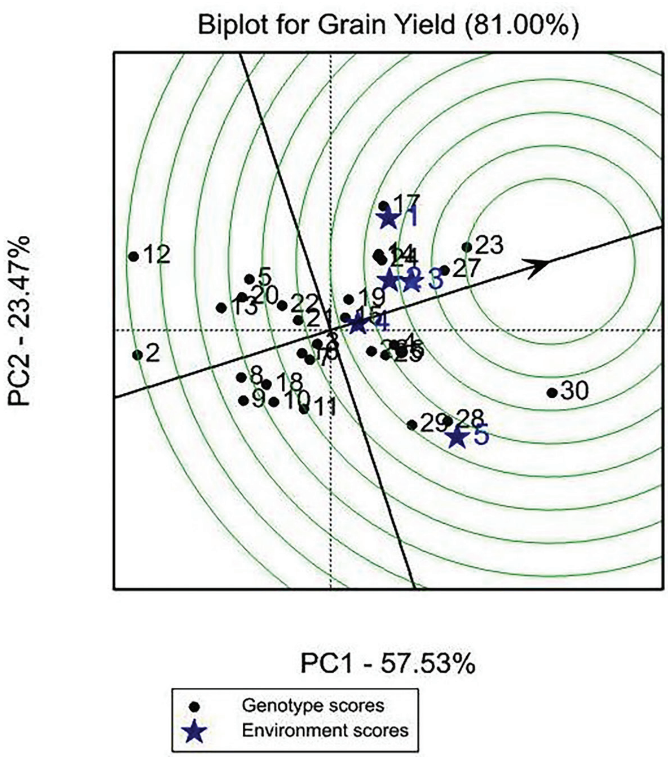

Figure 4. Biplot analysis of genotypes for grain yield

The character date of the change varies significantly more linearly depending on the changing conditions of the year (Figure 3), while in grain yield about ½ of the response to the changing conditions is "nonlinear" (PC_2= 23.47%), relative to PC_1 values, which are 57.5% (Figure 4). This is the reason why the correlation between the two traits varies according to year and location. Similar reaction of grain yield with the conditions is the rule rather than the exception (Hongyu et al., 2014). Such behavior, regardless of environmental conditions, creates an extremely difficult chance to combine high yield with high stability and plasticity in one variety (Racz et al., 2015; Subira et al. 2015). It is therefore difficult to predict whether the earlier date of ear emergence helps reduce the yield and vice versa. Even under conditions of prolonged air and soil drought, later ear heading is related to a higher yield (2007, r= 0.448-0.563). During the changing of growing conditions correlations between both traits decline in yield increase and vice versa. On the other hand, the values of correlations average for the entire period of the study are reliable and analogous to similar studies (Tsenov et al., 2005, 2013, 2020). After several studies of tens of hundreds of varieties and breeding lines in the Balkans, Bulgaria (Boyadjieva and Andonov, 2010; Chamurliiski et al., 2012; Tsenov et al., 2020); Romania (Mustatea et al., 2011) and Serbia (Dodig et al., 2012), to obtain optimum grain yield of over 6 t/ha, the optimal date of ear emergence should be between 130-137 days. The change of EED is accompanied by serious anomalies during the active spring vegetation (Tsenov, 2009) relating to temperature, lack of moisture (Dodig et al., 2012; Marinciu et al., 2013) or resulting differences in plant nutrition (Mladenov et al., 2011).

The performance of the varieties in the experiment through their date of ear emergence and grain yield is different. Several varieties showed high stability against the background of conditions in both traits. Generally, these are varieties that are used for reference in the process of variety testing in Bulgaria (Tsenov and Gubatov, 2015). They are six - 1, 9, 12, 16, 27, 30 (Figures 3 and 4) and cover the full range of date of ear emergence, which are identified as optimal. Therefore, we can evaluate the response of each variety tested by any quantitative trait using the performance of each of the check varieties. These standards are used for comparison by all traits, characteristics and properties of wheat, but not the date of ear emergence (Tsenov et al., 2014). Their varying stability and plasticity and date of ear heading make them desirable in this regard.

Conclusion

The length of the growing season to the date of emergence of the ear (EDD) is significantly affected by environmental conditions. To the greatest extent the sign of EED changes under the influence of the conditions of the year. It is natural that the meteorological conditions of the location are relatively more constant than those of the year. The change in the date of ear emergence is high, but is related almost linearly to the change in the conditions governing the specific level of grain yield during the season. The seasonal changes in the conditions for vernalization and photoperiodism of each variety, caused by the year and the location in interaction with the genotype, ultimately lead to the optimization of its date of heading. Any deviation of a given genotype of that optimum in a season affects negatively its grain yield. Varieties that are used for reference are adaptive to the date of the ear emergence, too. In this context, the conditions in our country are extremely suitable for growing varieties the date of heading of which covers the range of 130-135 days. In turn, this fact, which has not been mentioned so far, is a prerequisite for a correct assessment of the yield of each variety and its change over the seasons through a detailed study of the date of ear emergence.

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