Tendencies in the reaction of the yield of Bulgarian triticale cultivars under contrasting environments

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Abstract

It is essential for the efficiency of the breeding process in crops such as triticale, which possess complex genomes, to correctly determine the interaction of the studied genotypes with the conditions of the environment. In a large number of researches, a rather contrasting nature both of the periods and the used locations is often observed. This gives ground for incorrect interpretations and leads to lower efficiency of the breeding programs. In order to avoid the shortcomings of most models applied for evaluation of the genotype x environment interaction, a model was elaborated allowing for assessment of the stability and adaptability of a set of differing genotypes grown under contrasting conditions of the environment. The model was based on actual data obtained during five successive harvest years on the yield of 16 triticale genotypes. These data showed that the stability according to the period favorable for growing may vary considerably depending on the peculiarities of the specific contrasting period. It was found out that the cultivars characterized with lower productivity such as AD-7291, Vihren and Rakita also demonstrated lower response to the environmental conditions in comparison to the favorable period, while the cultivars with very high production potential (Irnik, Borislav) were characterized with very low stability based on the applied model. In cultivars Atila, Bumernag, Doni 52 and Blagovest, a moderate combination of high productivity and stability of reaction was observed, which makes them suitable from a breeding point of view for growing under variable soil and climatic conditions in Bulgaria.

Key words: triticale; genotype x environment interaction; tendencies

INTRODUCTION

One of the most important requirements, which the new cereal cultivars should meet, is to realize stable yields regardless of the changeable conditions of the environment (Sharma et al., 2010; Malla et al., 2010; Tsenov et al., 2014; Tsenov & Gubatov, 2019). From a breeding point of view, such a requirement is an extremely labor-consuming task since yield is a complex value influenced by a large number of biotic and abiotic stress factors (Thyri et al., 2016). On the other hand, the yield value is related also to the applied technology for growing of the crop and the interaction with the environment. The complex interactions, which are formed within the system genotype-environment-agronomy practices (Rozbicki et al., 2015; Paderewski et al., 2016) make it even more difficult to carry out a purposeful breeding process since clarifying the nature of all the factors involved is a time-, resource-, and labor-consuming process (Tsenov et al., 2013). This poses the question how to combine the contemporary requirements to the cultivars with the dynamic but time-consuming nature of breeding.

Triticale, as a typical amphidiploid crop, a product of wide hybridization (Baychev, 1990), is burdened with additional difficulties with regard to its breeding process due to its biological peculiarities (Kavanagh & Hall, 2015). This is related to the fact that the more complex a given genotype is, the stronger its interaction with the environmental conditions will be, and the more difficult it will be to determine the tendencies in its response under certain meteorological conditions. Dhindsa et al. (2002) pointed out that in the triticale genotypes they investigated under four different types of growing conditions, a very high and significant interaction of the factors genotype and environment was observed with regard to the yield and its components. According to the authors, these values have significant effect on the breeding process in this crop since they do not allow adequate evaluation of the genetic parameters in triticale. Kendal & Sayar (2016) also reported the presence of a strong interaction of the two factors in yield and various parameters when investigating twenty-three triticale genotypes. Gelalcha et al. (2007), Dogan et al. (2011), Lule et al. (2014), Akbarian et al. (2011), Kaya & Ozer (2014), Kumar et al. (2014), Milgate et al. (2015), Kendal et al. (2016) came to similar conclusions. Ramazani et al. (2016), under detailed differentiation of the environmental conditions while investigating 20 triticale lines, pointed out that since there was no significant effect of the genotype on the yield, then in practice significant interactions of the genotype with both the location and the factor year of investigation were not observed. Similar results were obtained also by Dogan et al. (2009). The results of different researchers show that the individual genotypes are characterized with certain levels of stability and adaptability to specific conditions of the environment (Barnett et al., 2006; Goyal et al., 2011; Kirchev et al., 2016; Kirchev & Georgieva, 2017; Mut & Köse, 2018; Bilgin et al., 2018; Kendal et al., 2019; Abdelkawi et al., 2020).

The contrasting growing conditions, on the other hand, were characterized with sharp distinction of a certain period or location from the rest, thus changing to a considerable degree the value of the yield and its components (Tsenov et al., 2008; Parveen et al., 2010; Baychev, 2013a; Stoyanov, 2018; Aseeva & Zenkina, 2019). Such peculiarities of the local meteorology are difficult to predict and are characterized with various duration and intensity. Such specific aspects could be drought, which is untypical for a given period, intensive rainfalls of uneven distribution, sharp influx of cold air masses, untypical intermittent rainfalls of daily occurrence, a combination of intensive rainfalls and very high air temperatures. Under the conditions of Dobrudzha region, such phenomena are related to considerable changes in the values of the economically important parameters with regard to the cereal crops (Tsenov et al., 2012; Stoyanov, 2018). A very important characteristics of theirs is that they strongly distort the obtained data (no normal distribution), which often influences the used parametric methods and models for determining the genotype x environment interaction and the related stability of the genotypes (Tsenov et al., 2013). This does not allow for adequate grouping of the investigated set of cultivars according to yield and stability, which are of key significance for the breeding process.

The aim of this study was to develop a model for reading of tendencies in the response of a group of investigated genotypes under contrasting conditions of the environment and to apply this model to actual data obtained from growing of Bulgarian triticale cultivars.

MATERIALS AND METHODS

Plant material

To fulfill the above aim, eleven Bulgarian triticale cultivars, presented in Table 1, were used. They were grown as a whole-area crop, in trial plots of 10 m^2, in four replications according to a standard block design within a competitive varietal trial. Sowing was mechanized within the standard dates for triticale at density 550 seeds per m^2. Besides the above cultivars, the competitive varietal trial also included the standard triticale cultivars AD-7291, Vihren and Rakita, as well as the world standards Lasko and Presto. The trial plots were harvested at full maturity, reading the yields from each of them separately.

Growing conditions

The experiment was carried out for five successive harvest years - 2014/2015, 2015/2016, 2016/2017, 2017/2018, 2018/2019. The presented data on the mean monthly air temperature and the sum of precipitation (Table 2) shows the contrasting nature of the investigated periods. The highest differences according to the long-term tendency with regard to air temperature were observed during December – March, and with regard to precipitation – in December and May. The differences in these periods are sufficient ground to consider that the vegetation during the respective years occurred differently. This is also supported by the specificity of

Table 1. Cultivars used during the period of study

No	Name	Origin	Year of registration
1	Kolorit	BGL “S” – BGC / 568-343	2005
2	Atila	AD 8x(Ep 1034/79 x Harkovska 60) / F_1[F_1(Yuzhnaya zrya / Harkovska 60) / 804-503]	2007
3	Akord	MT-3 / F_2 populations	2007
4	Respekt	1262-12-2-10 / Veleten	2008
5	Bumerang	LP 3090.91 / 2853-1044	2009
6	Irnik	5252 - 131 / 2853-1044	2011
7	Dobrudzhanets	Chrono / 2853-1044	2012
8	Lovchanets	F_1 (Tornado / 3493-699) / Zaryad	2013
9	Doni 52	5279-131 / 3370-190	2014
10	Blagovest	32/99 / Zaryad	2015
11	Borislav	46/95-96 / 129/98	2016

Table 2. Average monthly temperatures and Total monthly precipitation during the investigated period

Parameter	Year	Sep	Oct	Noe	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
AMT, ºC	2014/2015	17.5	11.2	5.6	3.1	1.4	2.0	5.0	10.1	16.4	19.4	22.4
	2015/2016	19.5	10.9	9.3	3.4	-0.8	7.3	6.8	13.2	14.7	20.9	22.8
	2016/2017	18.1	10.6	6.5	-0.6	-4.1	2.0	7.3	8.7	15.0	20.2	21.8
	2017/2018	19.0	11.8	7.5	4.7	1.7	1.1	4.6	13.4	17.7	20.4	22.2
	2018/2019	17.7	13.3	5.4	1.2	1.0	3.5	8.2	9.0	16.0	22.3	22.0
	1960/2019	16.9	11.7	6.8	2.0	-0.2	1.1	4.7	9.9	15.2	22.0	21.4
TMP, mm	2014/2015	31.4	57.9	33.2	87.0	33.2	79.5	67.7	8.5	12.9	31.3	27.2
	2015/2016	20.8	78.3	55.1	0.4	86.3	40.7	52.7	20.8	117.1	55.7	2.8
	2016/2017	35.8	72.2	43.3	12.5	48.4	27.4	48.9	38.4	29.0	87.7	66.3
	2017/2018	69.9	50.5	57.2	55.8	75.4	48.8	4.9	30.9	90.8	59.6	59.6
	2018/2019	54.7	11.7	66.2	43.8	19.2	16.3	16.1	49.4	31.7	37.5	54.0
	1960/2019	46.3	42.1	43.4	41.7	36.9	34.2	35.6	40.5	52.1	58.7	52.2

AMT – Average monthly temperature; TMP - Total monthly precipitation

each year, presented in Table 3. Certain events and processes are clearly outlined in a meteorological aspect; they are of single-occurrence character, do not re-occur in certain periods and are capable of strongly influencing the physiological processes in the plant organism.

Worth mentioning are growing years 2015/2016, 2017/2018 and 2018/2019, in which respective extremely intensive and long-lasting rainfalls were observed in May (2015/2016), untypical daily intermittent rainfalls in July (2017/2018) and severe droughts during February-March (2018/2019). At the same time, most favorable for growing of triticale were the conditions in 2014/2015, when the lowest number of negative events were registered during the vegetative growth of the plants.

Table 3. Meteorological specificity of the investigated period with effects on the development of the plant organism

Year	Meteorological specificity
2014/2015	Short drought at the beginning of May
2015/2016	Cold weather at the beginning of May, Intensive rainfalls in May, Highly intensive and long-lasting rainfalls in June
2016/2017	Low temperatures and annual rainfalls in October and November, Very low temperatures in January and February
2017/2018	Severe drought during August - October, Daily intermittent rainfalls in July
2018/2019	Severe drought in October, Extreme severe drought in February and March

Elaborating a model

The contrasting nature of the investigated periods gives ground to divide them as favorable, comparatively favorable, unfavorable and extremely unfavorable. To the first group belongs only year 2014/2015, to the second – 2016/2017, to the third – 2017/2018, and to the fourth – 2015/2016 and 2018/2019. Based on these groups, the main hypothesis of the elaborated model was constructed. If a given genotype is characterized with higher stability of yield, its productivity during the unfavorable period will be less different from the stability during the favorable period (according to the biological concept of stability by Becker & Leon (1988)). This hypothesis can be graphically presented as Figure 1. The red line in the figure is a 45° vector, on which (or close to which) the most stable genotypes should be located when comparing them by yield during the favorable period (*Yn*), along the abscissa to the yield during the unfavorable period (*Ys*) along the ordinate.

The perpendicular distance (*Dx*) from a certain genotype (point A) to the red line will in this case reflect the degree to which this genotype is more or less stable in comparison to the favorable period. The higher values of this parameter would be interpreted as lower stability, and the lower – as higher stability. The value of *Dx* can be calculated from the values of *Yn* and *Ys* according to the dependencies in formula 1.

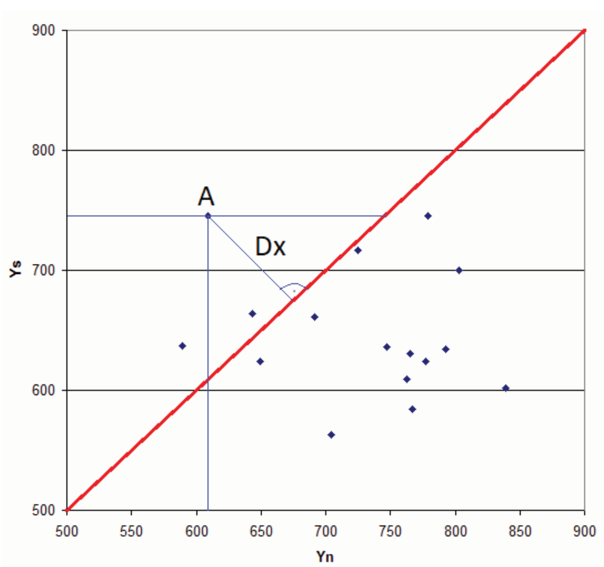

Figure 1. Graphic interpretation of the main hypothesis of the elaborated model

$$Dx = \sqrt{\frac{(Yn - Ys)^2}{2}} \qquad (1)$$

It should be emphasized that *Dx* gives an idea about the stability of a genotype according to the investigated favorable period only in terms of value, without representing the direction. This is important since a given genotype can be positioned both under and above the 45° vector. The genotypes above it are those, which during the unfavorable period realized higher values in comparison to the favorable period. The genotypes below the vector realized yields during the unfavorable period, which were lower than the yields in the favorable period. Therefore, it is necessary to find out the direction of the genotype's stability change. The calculated parameter s45 according to formula 2 gives an idea both about the value and the direction of stability of a given genotype according to the favorable period.

$$s45 = \frac{|Yn - Ys|}{Yn - Ys}.Dx \qquad (2)$$

Just like the AMMI biplot analysis, in which the values of IPCA1 and the mean productivity of a genotype are graphically compared, s45 can also be represented in a similar way, comparing it to the ***mean yield*** from the two compared periods (the investigated specific contrasting period and the chosen basic – favorable period). Such a graph would take the form of Figure 2.

The presented interpretation allows taking into account the behavior of the studied genotypes when comparing even only two contrasting periods (or locations), which is practically impossible in the greater part of the applicable models for investigation of the genotypic stability. On the other hand, in the greater part of the methods and models, stability is based on a specific group of genotypes under a specific set of environmental conditions. This causes, when averaging results strongly influenced by single local phenomena, strong disguising of certain tendencies and obtaining of distorted data. The use of s45, since it is based on results for two compared periods, does not allow such distortion of the mean values. Simultaneously, when using information for more than two compared periods, it is possible each unfavorable or contrasting period to be compared to the data of the favorable one. This allows forming a ***model tendency*** about how the stability based on favorable-unfavorable periods changes according to certain conditions of the environment.

The model thus developed was applied to actual data on the yield from the studied triticale genotypes. It is a peculiarity of the response of yield under certain conditions that a strong effect of the genotype x environments interaction is observed, as confirmed by our previous researches on the investigated genotypes (Stoyanov & Baychev, 2018). This interaction is able to disguise to a considerable degree the actual behavior of the genotypes, especially under sharply contrasting conditions, as were the conditions presented in this investigation.

According to Osei et al. (2018), the interaction can be of two main types: crossover and non-crossover. Especially strong distortion of the information

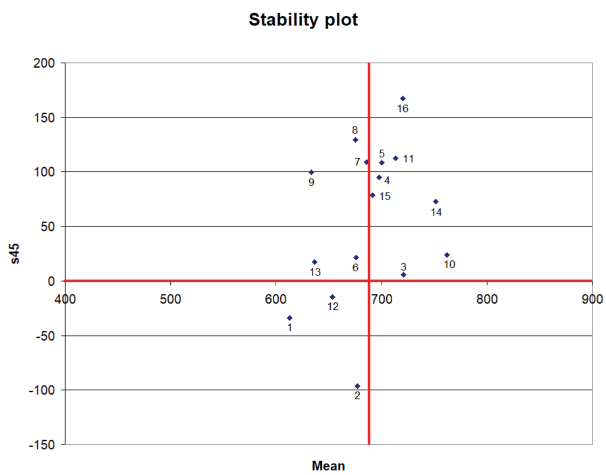

Figure 2. Biplot combining the values of s45 and the mean yield from the compared periods

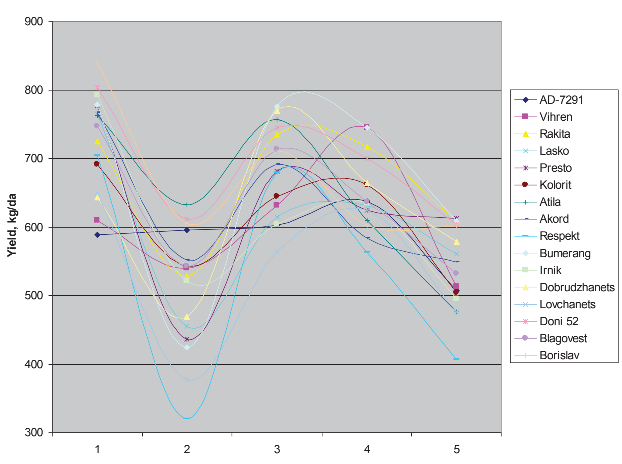

Figure 3. Schematic presentation of the genotype x environment interaction for actual yield data

that makes impossible the interpretation of the obtained results is caused by crossover-interaction.

Such types of interactions are the stronger, the higher the number of the genotypes are and the more variable the conditions of the environment, where there genotypes were grown, are (Figure 3).

In this respect, the values of s45 are also saturated with such interactions and the proper clarification of the tendencies in the response of a certain set of cultivars is in practice impossible. In order to determine the tendencies in the response of a set of genotypes under certain conditions of the environment, the s45 values were transformed on the basis of the mean values of Dx for each genotype from all periods and the main values of all genotypes during a specific period. The transformation was done according to formulae 3, 4 and 5:

$$z45_{ij} = \sqrt{Dx_i . Dx_j} \quad (3)$$

$$Dx_i = \frac{\sum_{j=1}^{E} Dx_{ij}}{E} \quad (4)$$

$$Dx_j = \frac{\sum_{i=1}^{G} Dx_{ij}}{G} \quad (5)$$

where

Dx_i – mean values of the ith genotype in E number of environmental conditions

Dx_j – mean value of the jth type of environmental conditions in G number of genotypes

Dx_{ij} – value of the ith genotype in the jth type of environmental conditions

G – number of investigated genotypes

E – number of investigated types of environmental conditions

$z45_{ij}$ – transformed value of the ith genotype in the jth type of environmental conditions

Such transformation is based on the mean values in a specific group of genotypes and specific conditions of the environment, which is also one of the shortcomings of most models and methods used to determine stability. Nevertheless, since the developed model is based on differences with chosen basic (favorable) period, and not on direct yield values and in practice there are no averaged yield values, the shortcomings with regard to the use of data from contrasting periods are alleviated to a certain degree. On the other hand, the use of such a type of model allows presenting the stability ***as a tendency*** and not a single value, thus additionally solving the problems related to data from contrasting periods. The application of the above transformations with regard to the behavior of specific genotypes is considered in detail in the Results and the Discussion sections, using actual data.

RESULTS

The results from the application of the developed model are graphically presented in Figures 4, 5, 6 and 7. Significant differences were observed between the individual graphs related to both the contrasting expressions of the weather and to the varied interaction of the separate investigated genotypes with the different conditions of growing. It should be emphasized that the results from each graph are based on ***comparison of a specific contrasting period to a preliminary chosen basic (favorable for the growing of the crop) period***. Therefore, the stability based on parameter s45 calculated for each contrasting period may vary within a certain range depending on the differences observed between the specific period and the chosen basic period.

The data obtained on the unfavorable growing year 2015/2016 (Figure 4) according to the favorable period (2014/2015) showed that cultivars AD-7291, Vihren and Atila were characterized by values of s45 closest to zero. Cultivars Rakita, Kolorit, Akord, Dobrudzhanets, Doni 52, Blagovest and Borislav responded to the differences in the growing conditions considerably stronger. Highly susceptible reaction to the unfavorable period was registered in Irnik, Lovchanets, Lasko, Presto, Bumerang and especially in cultivar Respekt. Among the investigated cultivars, only AD-7291 responded positively to the conditions of growing year 2015/2016 by realizing higher yield according to the favorable period, and the s45 values of this cultivar were respectively negative. The best combination of productivity and stability in comparison to the favorable period was observed in cultivars Rakita, Atila, Akord, Doni 52, Blagovest and Borislav. According to the results thus presented, cultivars Lovchanets and Respekt were with the most unfavorable combination between stability and productivity.

Considerably more different was the response to the conditions of the environment with regard to stability in growing year 2016/2017 according to the period favorable for the development of triticale (Figure 5). Cultivars AD-7291, Vihren, Rakita, Kolorit, Atila, Respekt, Bumerang, Doni 52 and Blagovest were with the most stable reaction to the con-

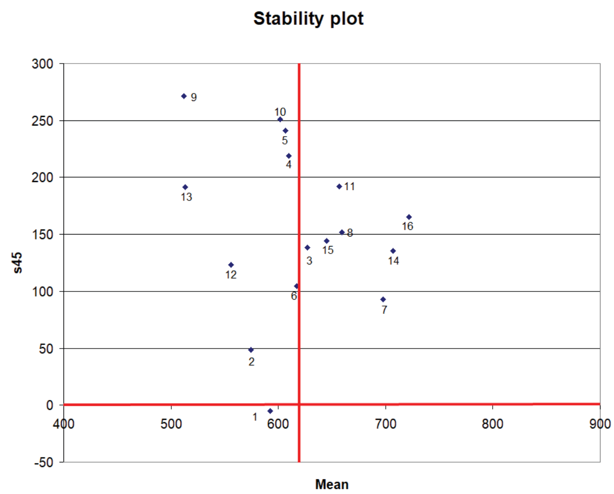

Figure 4. Biplot combining stability based on parameter s45 and mean productivity during the two compared periods 2014/2015 and 2015/2016

1. AD-7291; 2. Vihren; 3. Rakita; 4. Lasko; 5. Presto; 6. Kolorit; 7. Atila; 8. Akord; 9. Respekt; 10. Bumerang; 11. Irnik; 12. Dobrudzhanets; 13. Lovchanets; 14. Doni 52; 15. Blagovest; 16. Borislav

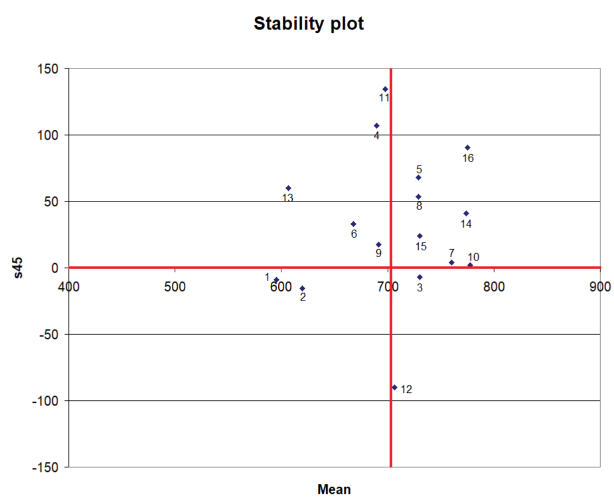

Figure 5. Biplot combining stability based on parameter s45 and mean productivity during the two compared periods 2014/2015 and 2016/2017

1. AD-7291; 2. Vihren; 3. Rakita; 4. Lasko; 5. Presto; 6. Kolorit; 7. Atila; 8. Akord; 9. Respekt; 10. Bumerang; 11. Irnik; 12. Dobrudzhanets; 13. Lovchanets; 14. Doni 52; 15. Blagovest; 16. Borislav

ditions of 2016/2017. Much more susceptible were cultivars Lasko, Presto, Akord, Irnik, Dobrudzhanets, Lovchanets and Borislav. A very strong negative reaction was registered in cultivar Dobrudzhanets. Negative, but to a considerably lesser degree, was also the response to the conditions of the environment of the standard cultivars AD-7291, Vihren and Rakita. The reaction of Bumerang in this period, as compared to the favorable one, was in practice tending towards zero. This showed that the productivity of the cultivar during the two periods was entirely identical and the two types of combinations of the environmental conditions had similar effects on its productivity. The best combination between productivity and stability was observed in Rakita, Atila, Bumerang, Doni 52 and Blagovest. A very unfavorable combination of yield with stability was determined in Lasko, Irnik and Lovchanets. In cultivar Dobrudzhanets, although low and negative stability based on parameter s45 was determined, the productivity was considerably higher in this period. Low stability tending towards the high values, but productivity significantly above the average, was registered in cultivar Borislav. These results showed that the cultivar was highly productive, but the conditions of the environment had a strong effect on the yield values.

Completely different was the response of the studied triticale cultivars during growing year 2017/2018 according to the favorable period 2014/2015 (Figure 6). In six (AD-7291, Rakita, Kolorit, Bumerang, Dobrudzhanets and Lovchanets) out of the sixteen investigated genotypes, s45 values were observed, which tended to a high degree toward zero. Cultivars Lasko, Presto, Atila, Akord, Respekt, Irnik, Doni 52, Blagovest and Borislav responded strongly to the conditions of 2017/2018 in comparison to the favorable period. A specific response was observed in cultivar Vihren, in which the s45 values were very high but negative. Negative were also the values in cultivars AD-7291 and Dobrudzhanets. This was an indication that these genotypes formed higher yields in comparison to the favorable period. The best combination of productivity and stability was observed in Rakita, Bumerang and Doni 52. Weak combination of productivity and stability was registered in Atila, Akord and Respekt. Low stability but high yields were determined in Irnik, Doni 52 and Borislav. Worth mentioning is cultivar Irnik, the yields of which were rather variable during the individual periods. Although significant differences were observed according to the favorable period, its productivity remained above the average even under very strong influences, as observed in

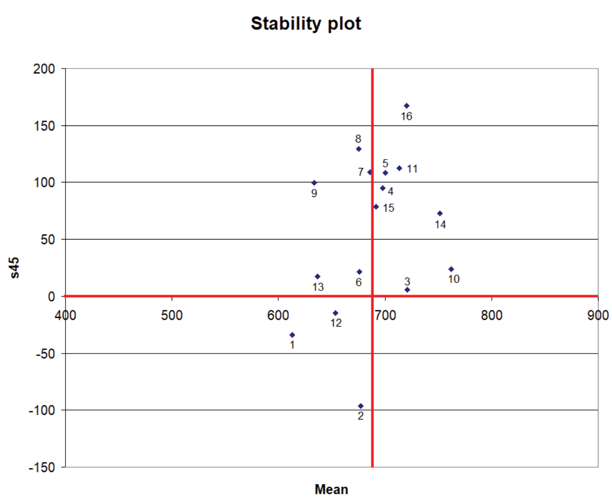

Figure 6. Biplot combining stability based on parameter s45 and mean productivity in the two compared periods 2014/2015 and 2017/2018

1. AD-7291; 2. Vihren; 3. Rakita; 4. Lasko; 5. Presto; 6. Kolorit; 7. Atila; 8. Akord; 9. Respekt; 10. Bumerang; 11. Irnik; 12. Dobrudzhanets; 13. Lovchanets; 14. Doni 52; 15. Blagovest; 16. Borislav

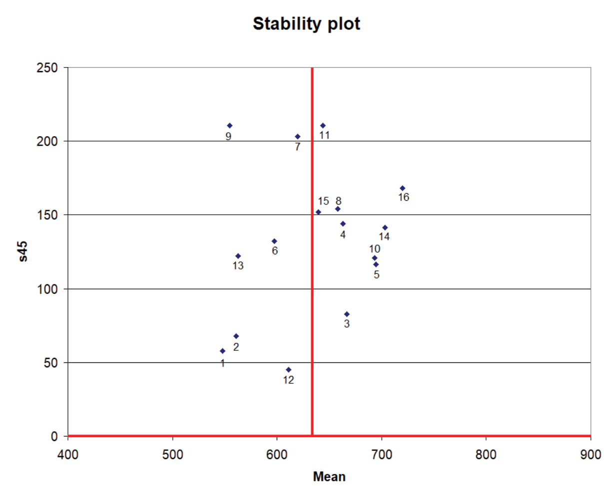

Figure 7. Biplot combining stability based on parameter s45 and mean productivity in the two compared periods 2014/2015 and 2018/2019

AD-7291; 2. Vihren; 3. Rakita; 4. Lasko; 5. Presto; 6. Kolorit; 7. Atila; 8. Akord; 9. Respekt; 10. Bumerang; 11. Irnik; 12. Dobrudzhanets; 13. Lovchanets; 14. Doni 52; 15. Blagovest; 16. Borislav

2017/2018. Cultivar Rakita was with similar productivity, but at significantly higher stability.

Highly negative stability reactions were determined in comparing the favorable period to growing year 2018/2019.

The drought during this period caused high decrease of yields, which were rather different from the yields in 2014/2015 and to respective very high values of parameter s45. Negative values were not registered since neither of these genotypes reacted positively to the conditions of the environment during the investigated period. In practice there were no values approximation zero; this was an indication that, as a whole, the investigated genotypes were not adapted to such contrasting conditions. Nevertheless, the standard cultivars AD-7291, Vihren and Rakita were again with the highest stability according to the favorable period. Noteworthy is the reaction of cultivar Dobrudzhanets, the stability of which, based on the favorable period, was the highest (the lowest s45 value). All other cultivars can be determined as extremely unstable during growing year 2018/2019, i.e. they interacted very strongly with the specific conditions of the environment.

DISCUSSION

The presented results on the combining of productivity and stability under specific conditions of the environment did not allow directly determining a tendency with regard to the response of a given genotype to contrasting conditions. Only the standard cultivars AD-7291, Vihren and Rakita were an exception; regardless of the conditions, they were characterized with higher stability and lower interaction with them. The absence of a general tendency can also be inferred by the s45 curves of the separate investigated cultivars (Figure 8). The crossover interaction between the individual cultivars is clearly observable. Such data considerably impede the grouping of the cultivars in a certain way, or the determining of their breeding or practical values.

Similar data with regard to the interaction of the genotype with the environment have been reported by a number of researchers (Gelalcha et al., 2007; Dogan et al., 2011; Akbarian et al., 2011; Lule et al., 2014; Kaya & Ozer, 2014; Kumar et al., 2014; Milgate et al., 2015; Kendal et al., 2016) when investigating various genotypes of spring and winter triticale under different conditions of the environment, including contrasting periods of growing, as well as locations with considerably differing environments. The data in the greater part of these reports show the definite presence of crossover interaction. However, a close analysis of the data from the separate periods allows clarifying certain correlations between the individual cultivars.

In our previous research on the same set of genotypes, using AMMI-analysis but under different conditions of the environment (Stoyanov & Baychev, 2016a), similar results were registered concerning the behavior of the cultivars. In another previous investigation of ours (Stoyanov, 2018) it was found out that the most stable cultivars combining high productivity and stability were Akord and Doni 52. The results we obtained in this experiment, on the other hand, allow claiming that under considerably more contrasting conditions of the environment, as in growing years 2017/2018 and 2018/2019, the two cultivars significantly conceded both by stability and productivity to such cultivars as Rakita and Bumerang. Cultivars Akord and Doni 52, during each of the investigated contrasting periods (Figures 4-7) were marked by a very interesting tendency: Akord was with lower stability in comparison to the favorable period and with lower productivity, while Doni 52 was more stable and with higher yields according to growing year 2014/2015. The two cultivars responded very sim-

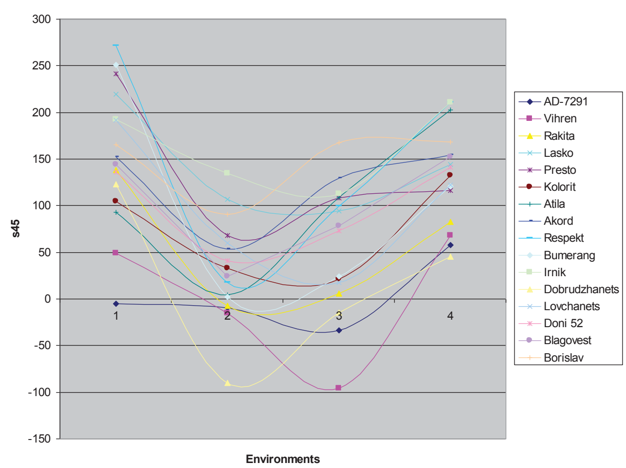

Figure 8. Change in the values of parameter s45 with regard to the separate periods compared to the favorable year 2014/2015

Environments compared to the favorable 2014/2015: 1. 2015/2016; 2. 2016/2017; 3. 2017/2018; 4. 2018/2019 ilarly, which places them in similar positions, regardless of the investigated period. Stoyanov (2018) also emphasized the high stability of cultivar Rakita. This can be easily and clearly determined by the results we obtained. Cultivar Rakita is usually positioned close to the abscissa in the graphs, and only in extremely unfavorable conditions reacts considerably stronger with the environment. Quite different, however, was the behavior of the standard cultivars AD-7291 and Vihren and of cultivar Kolorit to the behavior of the cultivars reported by Stoyanov (2018). This was due to several major reasons. First, all three cultivars responded in a rather variable manner to changes in the environmental conditions. This is very clearly observable in cultivar Vihren – from highly positive to strong negative stability based on parameter s45. On the other hand, the response of these cultivars was not so high in comparison to the reaction of the rest of the cultivars, which, in the model we used, was registered as a significantly higher stability. Such results support the assumption that the higher stability of a given genotype is often related to lower productivity (Sharma et al., 2010; Tsenov et al., 2013). Such variation in the response of yield can be seen in cultivar Dobrudzhanets, too. In this cultivar, the values of the differences between the contrasting periods and growing year 2014/2015 were not very high, which also indicated a certain higher stability according to the favorable period in comparison to the other investigated genotypes.

Figure 8, presenting the values of parameter s45 for the separate investigated contrasting periods, allows determining the strength of the interaction of a specific genotype with the conditions of a given year. The closer the value is to zero, the better the genotype is adapted to the specific environmental conditions and the more stable is according to the favorable period, i.e. its interaction with the specific conditions is weaker. In practice, cultivars Respekt, Bumerang and Irnik had stronger interaction with the conditions of 2015/2016; with the conditions of 2016/2017 – Respekt, Irnik and Borislav; with the conditions of 2017/2018 – again Respekt, Irnik and Borislav; with 2018/2019 – cultivars Atila, Respekt, Irnik and Borislav. Such a tendency relates to the fact that these cultivars (Respekt, Irnik and Borislav) possess high productivity potential that could be realized within a comparatively narrow range. Respekt is an extremely cold-resistant cultivar, considerably late in development and it often suffers from the high temperatures in May and June during the grain filling period (Baychev & Petrova, 2007; Stoyanov et al., 2017). Irnik is characterized with a very high number of grains in spike and requires very good conditions during grain filling (Baychev, 2013b; Stoyanov, 2018). On the other hand, Borislav is a cultivar with very high productivity potential, which main component is 1000 kernel weight (Baychev et al., 2016; Stoyanov & Baychev, 2016b; Stoyanov, 2018). In periods when grain is not capable of good filling, Borislav cannot realize its productivity potential. These peculiarities of the cultivars show that their strong interaction with the conditions of the environment is related to the fact that they are not sufficiently adapted to the changes in the environment during the grain filling stage.

Although some regularities can be found after thorough analysis of the separate investigated periods, it is practically impossible to give advantage to a certain genotype based on the results thus presented. Figure 9 shows a graph of the transformed values of s45 according to the methodology described in the Material and Methods section. The obtained results allowed dividing the cultivars into distinct groups by their stability under contrasting conditions according to the investigated basic (favorable) period, as well as by their adaptability to specific growing conditions. The lower a giv-

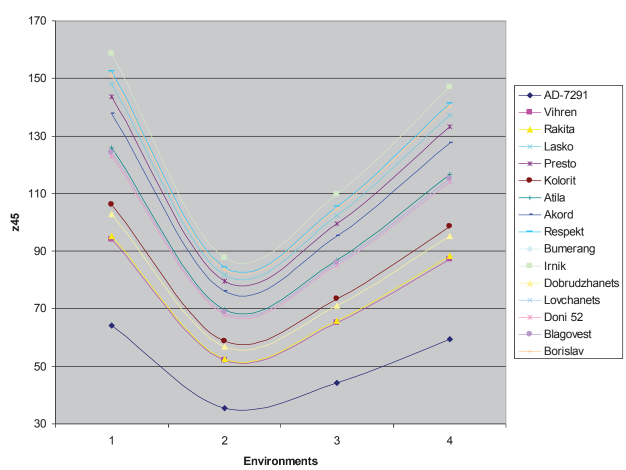

Figure 9. Change in the values of parameter z45 with regard to the separate periods compared to the favorable year 2014/2015

Environments compared to the favorable 2014/2015:
1. 2015/2016; 2. 2016/2017; 3. 2017/2018; 4. 2018/2019

en curve of a specific genotype is positioned, the more stable is the realized reaction to the changes of the environment according to the favorable period, and respectively the higher the position of a given curve, the less stable is this genotype to the contrasting environmental conditions. On the other hand, the bigger curves characterize the genotype as having a stronger interaction with the environment, while the curves approximating a straight line have in practice lower interaction with it.

The obtained results place the standard cultivars AD-7291, Vihren and Rakita at the bottom of the graph. This is an indication that these cultivars exhibited the weakest response to contrasting environments, i.e. they are the most stable. At the same time, AD-7291 and Vihren demonstrated very low productivity, which varied little during the individual periods of the study. Cultivar Rakita, on the other hand, always had productivity above the average, which makes it very valuable genotype from a breeding point of view. Similar were the tendencies in the reaction of cultivars Kolorit and Dobrudzhanets. In spite of their varied expressions with regard to productivity, their responses were considerably more stable in comparison to the rest of the investigated cultivars. The reaction of Atila, Bumerang, Lovchanets, Doni 52 and Blagovest with regard to their stability according to the favorable period was extremely similar. These genotypes differed significantly by the way they formed their productivity (Stoyanov & Baychev, 2016b). However, they interacted with the conditions of the environment in a similar way. Cultivar Akord was with a little lower stability and stronger interaction with the conditions of the environment. Lasko and Presto, based on the obtained results, had a significantly similar reaction and interacted with the environment significantly stronger. The tendencies demonstrated in the graph confirm the thesis that cultivars Respekt, Irnik and Borislav had the strongest interaction with the conditions of the environment among all investigated cultivars.

Such ranking of the cultivars by their stability reaction according to a period favorable for the development of the crop allows evaluating the breeding value of these genotypes with regard to their productivity. Although having a weak response to contrasting environments, cultivars such as AD-7291, Vihren and Rakita are characterized with low productivity. On the other hand, cultivars with high productivity potential such as Akord, Respekt, Irnik and Borislav reacted very strongly to sharp changes in the conditions of the environment, which impeded the proper realization of this potential.

The cultivars positions in the middle of the graph – Atila, Bumerang, Lovchanets, Doni 52 and Blagovest – demonstrated a moderate reaction to the environment, simultaneously (with the exception of Lovchanets) being characterized also by high productivity. This makes them considerably valuable both from a breeding point of view and from a production aspect. Therefore, these cultivars possess high potential for use in the agricultural practice in Bulgaria.

CONCLUSIONS

Based on the results presented above, the following conclusions can be drawn:

1. A method was developed and applied for evaluation of the tendencies in the responses of the yield according to a chosen basic (favorable) period for growing of the crop.

2. Based on the data obtained from the applied model under actual contrasting conditions for growing of Bulgarian triticale cultivars, it was found out that the stability according to the period favorable for growing may vary significantly depending on the specificity of the actual contrasting period.

3. The model used allowed ranking the investigated cultivars according to their yield reaction to contrasting environments.

4. It was found that the cultivars characterized by lower productivity such as AD-9291, Vihren and Rakita also had a weaker reaction to the conditions of the environment according to the favorable period, and were more stable, respectively.

5. The cultivars with very high productivity potential were characterized by very low stability based on the applied model and this was related to their stronger response according to the favorable period.

6. In cultivars Atila, Bumerang, Doni 52 and Blagovest, a moderate combination of high productivity and stability of response was observed, which makes them valuable from a breeding point of view and suitable for growing under variable soil and climatic conditions in Bulgaria.

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