Analysis on test weight of Bulgarian triticale cultivars

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Abstract
Triticale is a typical cereal crop, which possesses high productivity and very good tolerance to abiotic stress factors. Its main purpose is for production of forage since it is characterized with high protein content but low gluten content and low test weight. Such peculiarities do not allow wide usage of triticale for bread making purposes. Test weight is an extremely conservative parameter and its improvement requires considerable breeding work. With the aim to improve this parameter, the test weight of eleven Bulgarian triticale cultivars was analyzed under conditions of five contrasting periods of growing. The stability of the parameter was determined by applying AMMI analysis. The studied cultivars were grouped according to the combination of productivity with test weight. Based on the obtained results, it was found out that this parameter in the investigated Bulgarian cultivars was affected considerably by the environment, and its mean values varied over years from 67.4 kg/100l to 74.9 kg/100l. The highest values of test weight were determined in cultivars Presto, Atila, Akord, Respekt, Bumerang and Doni 52, and a tendency toward high values during the individual years of the investigation was observed in Presto, Atila and Bumerang. Highest stability of test weight was registered in cultivars Vihren, Presto, Akord, Bumerang, Irnik, Dobrudzhanets, Lovchanets and Borislav, and the best combination of high and stable test weight was observed in Akord, Bumerang and Dobrudzhanets. A combination of high and stable yield with high and stable test weight was found only in cultivar Akord. A good combination between productivity, stability and test weight was registered in cultivars Atila, Bumerang and Doni 52. These cultivars are characterized with very good adaptability to contrasting environments, which makes them valuable triticale varieties suitable for growing in practice under variable soil and climatic conditions in Bulgaria.

Key words: AMMI-analysis; yield; triticale; stability; test weight

INTRODUCTION

The diversification of the food raw materials is important from the point of view of cultural plants breeding. By the introduction or development of the specific characteristics in certain plant species or by the development of new species, an opportunity is created to contribute to the nutrition of the global population by using high-yielding plant species that have not been considered food up to now. In cereals, such species are triticale and tritordeum. The initial breeding task was to develop a new type of plant that would combine the properties of its parental components (the productivity of wheat and the stress tolerance of rye and barley). The new contemporary cultivars of triticale and tritordeum, however, are quite different biological species with specific properties. The possibility to include them in the food diversity is due to certain useful characteristics they possess (rich protein content (Tohver et al., 2005; Doneva & Stoyanov, 2019; Abdelkawi et al., 2020), high content of carotenoides (Grabovets et al., 2018), arabinoxylans, higher content of gluten).

The introduction of a completely new plant species as a food crop is a labor- and time- consuming breeding process. The early forms of triticale did not have the potential of a cultural plant since they possessed a large number of shortcomings of both technological and biological nature. Nevertheless, the high importance of triticale has been pointed out by Tsvetkov (1989), who wrote that as early as 1986, at the International Symposium on Triticale, the conviction was reinforced that triticale has passed the barrier of a plant for purely genetic studies and has become a regular production crop in many countries worldwide. The same author also pointed out the possibilities to use triticale as a food crop, however admitting that its gluten content was of poor quality. Varughese et al. (1987) pointed out that the early forms of triticale were characterized also with low test weight (58-72 kg/100l) and strongly shrivelled grains. Such characteristics conditioned the low consumer demand for this crop (Varughese et al., 1987).

The improvement of the test weight in this crop started with the introduction of cultivar Armadillo in the breeding programs (Baychev, 1990; Varughese et al., 1987). In the contemporary triticale cultivars this technological parameter has been significantly improved. Nevertheless, the values of test weight vary according to the used genotypes and the growing environment. Tosun et al. (2003) reported test weight in four triticale cultivars within the range of 63.45 – 73.59 kg/100 l. Aguirre et al. (2002), studying 92 different forms of triticale in two different years, observed test weight within 60.05 – 72.00 kg/100 l without a significant difference between the two periods. Growing 22 different genotypes at four locations during two growing periods in two harvest seasons, Barnett et al. (2006) registered various values of test weight within the range 68.3 – 74.5 kg/100 l. Kendal & Sayar (2016) registered significantly higher values when growing 20 elite lines at 4 locations in Turkey – 65.9 – 78.0 kg/100 l, but the data are from only one growing period. Goyal et al. (2011) demonstrated that even when investigating genotypes with wide adaptability, the variation of test weight was within a wide range: 62 – 80 kg/100 l. Very high values of elite lines and candidate-varieties were reported by Kendal et al. (2016). These authors also pointed out that the parameter was influenced by the late spring cold weather. Kucerova (2007) reported a significant effect of the factors genotype, environment and location on test eight, observing higher values in cultivar Presto. Đekić et al. (2014) noted high effect of the environmental conditions, but a weaker and insignificant reaction caused by the fertilization regime. The data obtained by different researchers on a rich variety of genotypes and growing conditions show that test weight of triticale is a parameter influenced by the conditions of the environment, its improvement being meanwhile a labor-consuming process. Therefore, in order to improve the food properties of the crops, it is necessary to study different genotypes under variable environments.

The aim of this study was to analyze the test weight of Bulgarian triticale varieties during different growing periods and to evaluate the possibility to improve the parameter as a part of the breeding program of this crop.

MATERIAL AND METHODS

To realize the above goal, the following eleven triticale cultivars developed at Dobrudzha Agricultural Institute – General Toshevo were used: Kolorit, Atila, Akord, Respekt, Bumerang, Irnik, Dobrudzhanets, Lovchanets, Doni 52, Blagovest and Borislav. Sowing was done within the standard dates for triticale using mechanized planters, in 10 m^2 plots at sowing norm 550 gs/m^2. The experiment was designed according to a standard block design method with four replications. Testing was carried out during five growing years - 2014/2015, 2015/2016, 2016/2017, 2017/2018, 2018/2019. The crops were harvested at full maturity.

Test weight was measured with a standards test weight measurement kit (Pfeuffer). Readings were done during each period of investigation for each variety and replication after cleaning the grain from mixtures. The results were summarized and averaged over varieties and years. In order to determine the effect of the environmental conditions, the genotype and their interaction, two-way ANOVA was carried out. Duncan test was applied for determining significant differences between the investigated cultivars and the conditions of the environment. The stability of the parameter test weight was evaluated by AMMI-analysis and by determining the separate components of the genotype x environment interaction.

To evaluate the combination of high test weight with high productivity for the same genotypes and periods of investigation, the yield was evaluated by variety and year. The factors, which influenced the variation of the two parameters, were compared. A comparison was also made between the stability of the two parameters. A graphical method was used to group the genotypes by comparing the test weight values, the yield and their stability.

Microsoft Office Excel 2003 was used to summarize and average the data. IBM SPSS Statistics 19 was applied for the ANOVA and the Duncan test, and for the AMMI-analysis - IrriStat 4.0.2.0. Module 3d scatter plot for Excel (Doka, 2013) was used for graphic interpretation of the results.

RESULT AND DISCUSSION

1. Test weight of triticale cultivars under contrasting environments

The meteorological conditions during the five periods of investigation were extremely contrasting (Table 1). Differences were observed both with regard to the average monthly temperatures, and to the monthly precipitation. Growing year 2014/2015 was characterized with favorable temperature conditions and sufficient rainfalls for the development of triticale. The drought in April of 2015 was an exception but such conditions are typical for the region of growing. Lodging and excessively intensive rainfalls were not observed during this period. The weather of harvest year 2015/2016 was rather hot and humid. Especially intensive were the rainfalls during May-June of 2016, which was the reason for poor pollination and grain filling. The period 2016/2017 was characterized with an extremely humid autumn and cold winter and therefore tillering was weaker. In May and June of 2017, there were normal conditions for pollination and grain formation. Growing year 2017/2018 was extremely unfavorable. During this period, there was an accumulation of a considerable number of negative meteorological conditions: rather high air temperatures in May, uneven rainfalls in June and untypical frequent intermittent rainfalls in July. The period 2018/2019 was rather specific with regard to the moisture reserves in soil. The autumn and winter of this period were extremely dry. The rainfalls were insufficient during February – March as well, which significantly retarded the development of the plants. The amount of rainfalls was lowest in May – June of 2019, which impeded the good grain filling. These peculiarities of the weather implied there would be variable values of test weight for each investigated period.

Based on the obtained results, clear differences were observed between the separate periods of investigation, both with regard to the mean values and at genotype level. The differences between the mean values of the separate periods were within 1-8 kg/100 l, which was a considerable range for such a parameter and related to the effect of a serious stress during the unfavorable periods. Growing year 2014/2015 was the most favorable for grain filling since the period May-June was dryer in comparison to the long-term values. Such a tendency was observed also during the same period of harvest year 2016/2017. In this period, as a result from the very good grain filling, test weight was also high. Comparatively low were the values of the parameter during growing year 2015/2016. In that period,

Table 1. Average monthly temperatures and 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 temperatures; TMP – Total monthly precipitations due to the abundant rainfalls in May and the unfavorable development of the plants in June, a significant increase of the action of the stress factors was observed. Therefore, the grain could not form well and the test weight values were lower in all cultivars. Especially low was the level of the parameter during the two periods, 2017/2018 and 2018/2019. In 2017/2018, the harvesting was rather late due to the frequent intermittent rainfalls in July. This considerably deteriorated the grain quality of the grown cultivars. Growing year 2018/2019 was characterized as an extremely dry period. In May and June of 2019, rainfalls were observed, which were significantly lower than the long-term tendency. This caused bad grain nutrition and decrease of both 1000 kernel weight and test weight.

Differences were observed also in the separate cultivars during the different periods of growing. In 2014/2015, cultivar Vihren significantly exceeded the standard Rakita by test weight. Simultaneously, AD-7291 was in an intermediate position between Vihren and Rakita. Cultivars Lasko, Presto, Atila, Akord, Respekt, Bumerang, Dobrudzhanets, Doni 52 and Blagovest realized a significantly higher test weight than the standard Rakita. Cultivar Presto was with the highest test weight (76 kg/100 l). Cultivars Lasko (75.5 kg/100 l) and Accord (75 kg/100 l), Respekt (75 kg/100 l), Bumerang (75 kg/100 l) were also with high values of the parameter. Lowest was the test weight of cultivar Kolorit (72 kg/100 l).

Harvest year 2015/2016 was characterized with significantly lower values. AD-7291 and Vihren had similar values and significantly lower values than the standard Rakita. Cultivars Lasko, Presto, Akord, Respekt, Bumerang, Irnik, Dobruzhanets, Lovchanets and Borislav were with significantly lower values than Rakita. At the level of Rakita were Kolorit and Blagovest. Cultivars Atila and Doni 52 significantly exceeded the standard Rakita. Cultivars Atila (72.5 kg/100 l), Doni 52 (72.5 kg/100 l) and Kolorit (71.5 kg/100 l) were with the highest values. Very low were the test weight values of Lasko (66 kg/100 l), Irnik (67 kg/100 l), Respekt (67.5 kg/100 l) and Borislav (67.5 kg/100 l).

In growing year 2016/2017, the standards AD-7291 and Rakita did not form significant differences

Table 2. Test weight of Bulgarian triticale cultivars over growing periods

Cultivar	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019	Average
AD-7291	72.7	69.5	72.6	66.0	68.3	69.8j
Vihren	74.0	69.5	72.9	67.8	69.3	70.7g
Rakita	72.1	71.0	73.6	65.6	66.3	69.7k
Lasko	74.7	66.0	76.2	68.2	67.8	70.6h
Presto	75.5	69.5	76.6	69.1	69.2	72.0b
Kolorit	72.2	71.5	73.0	66.0	66.4	69.8j
Atila	75.3	72.6	77.8	68.2	69.4	72.7a
Akord	75.2	70.0	77.5	68.3	68.8	72.0b
Respekt	75.6	67.5	75.9	68.5	70.6	71.6c
Bumerang	75.2	69.5	76.5	69.9	66.8	71.6d
Irnik	72.7	67.0	73.5	66.5	66.2	69.2n
Dobrudzhanets	74.4	69.5	75.9	69.0	66.3	71.0f
Lovchanets	72.8	68.5	73.4	68.7	63.1	69.3m
Doni 52	74.2	72.5	74.6	68.8	67.5	71.5e
Blagovest	73.4	70.5	74.7	67.5	66.4	70.5i
Borislav	72.8	67.5	73.6	66.5	66.5	69.4l
Average	73.9b	69.5c	74.9a	67.8d	67.4e	70.7
LSD0.05	0.62	0.92	0.85	0.64	0.89	0.54
LSD0.01	0.81	1.21	1.12	0.84	1.17	0.71
LSD0.001	1.03	1.55	1.42	1.07	1.49	0.90

to the standard Vihren, since AD-7291 had lower values, and Rakita – higher. Cultivars Lasko, Presto, Atila, Akord, Respekt, Bumerang, Dobrudzhanets, Doni 52 and Blagovest significantly exceeded the standard Rakita by test weight. Cultivars Kolorit, Irnik, Lovchanets and Borislav were at the level of Rakita. Cultivar Atila was with the highest values, (78 kg/100 l), followed by Akord (77.5 kg/100 l), Presto (76.5 kg/100 l) and Bumerang (76.5 kg/100 l). Cultivar Kolorit was with the lowest value (73 kg/100 l).

Growing year 2017/2018 was characterized with the highest values in the standard Vihren (68 kg/100 l), which was with significantly higher test weight than the standard Rakita (65,4 kg/100 l). Only cultivars Bumerang (70 kg/100 l) and Dobrudzhanets (69.2 kg/100 l) exceeded significantly the standard Vihren. Very low values were read in cultivars Kolorit (66 kg/100 l), Irnik (66.6 kg/100 l) and Borislav (66.4 kg/100 l). The rest of the cultivars were at the level of Rakita or the standard AD-7291.

In harvest year 2018/2019, the test weight of all cultivars was with significantly lower values. The better standard again was Vihren (69.3 kg/100 l). Standard Rakita differed significantly from both Vihren and AD-7291. Presto (69.2 kg/100 l), Atila (69.4 kg/100 l) and Respekt (70.6 kg/100 l) were with the highest values among the investigated genotypes. Only cultivar Respekt significantly exceeded the standard Vihren. The lowest values were read in cultivars Irnik (66.2 kg/100 l), Dobrudzhanets (66.3 kg/100 l) and Lovchanets (63.1 kg/100 l).

Averaged for the investigated 5-year period, among all standards used, the highest value of test weight was read in Vihren. A tendency toward forming significantly higher test weight was observed in cultivars Presto, Atila and Bumerang.In spite of the highly unfavorable conditions of the environment, the three cultivars were with good grain filling. The two growing years, 2014/2015 and 2016/2017 were characterized with similar results with regard to the values of test weight. In both periods, Lasko, Presto, Atila, Akord, Respekt, Bumerang, Dobrudzhanets, Doni 52 and Blagovest exceeded the standard at a high significance of the differences. In cultivar Kolorit, another tendency was observed: its test weight remained comparatively unchangeable during the first three periods of study as well, although it sharply decreased during 2017/2018 and 2018/2019. Cultivars Irnik, Lovchanets and Borislav, averaged for the 5-year period of growing, demonstrated a low level of test weight. Baychev (2013) and Baychev et al. (2016) reported similar results on the same cultivars. The data obtained by Baychev (2013) clearly showed that in the unfavorable period for the development of the crop, the values of test weight were lower.

Aguirre et al. (2002) reported similar results. These authors pointed out that within a two-year testing of 46 experimental breeding lines, the test weight varied within the range 60.05-71.15 kg/100 l in the first year and within 60.28-72.00 kg/100 l in the second. There is no information if the periods of study were contrasting or differing. Dogan et al. (2009), when investigating old and new triticale lines, reported values between 66.63 and 74.2 kg/100 l. Barnett et al. (2006) found out in a study on 22 triticale genotypes under 9 different types of growing, that test weight varied from 64.3 до 77.7 kg/100 l, without observing any definite model under any of the types of growing conditions. The data obtained by Kucerova (2007) corresponded to the tendency we established of cultivar Presto realizing high test weight values. Đekić et al. (2014), investigating cultivar Favorit during three growing years, observed higher test weight values in the period with the most favorable water regime in May. Cifci et al. (2010) found out significant differences between the 36 triticale lines they investigated, which were grown in three different periods. The data obtained by these authors revealed a specific tendency in the results – in the periods with highest and lowest amounts of rainfalls, values with very low difference were observed for test weight.

The results obtained by different authors, related to a variety of genotypes and growing conditions are definite that the environmental conditions considerably influence the values of test weight. Nevertheless, certain tendencies were observed between some genotypes, which responded in a certain way to the conditions of the environment. The results we obtained also followed a tendency the test weight to be lower under unfavorable conditions of the environment. Simultaneously, the contrasting nature of the five investigated periods and the specific response of the individual genotypes was related to a certain influence of the factor genotype x environment.

The presence of an interaction between the factors environment and genotype is presented in Table 3. The results from the ANOVA showed that 11.35 % of the total variation of test weight was due to the interaction of the two factors. Nevertheless, the effect of the environment on the parameter was considerable – 79.44 %. This was related to high differences observed during the individual periods. Barnett et al. (2006) and Kucerova (2007) also reported significant effect of the interaction genotype x environment on test weight in triticale.

The results Kendal et al. (2016) obtained, on the other hand, point to the absence of such an interaction for the investigated parameter. Under stress related to soil salinity, Salehi & Arzani (2013) also pointed out to the presence of interaction of the two factors in test weight of triticale. Dogan et al. (2009) reported the absence of an interaction between the genotype and the environment, at the lack of effect of the conditions of the environment and very high effect of the factor genotype. In common winter wheat and durum wheat, interaction between the genotype and the environment was also observed with regard to test weight, as reported by different researchers (Bhatt & Derera, 1975; Sakin et al., 2011; Bilgin et al., 2011; Kaya & Akcura, 2014; Rozbicki et al., 2015).

The presence of interaction of the environment implied different stability of the individual cultivars during contrasting periods of growing. Therefore, these cultivars and environmental conditions should be determined, which have the strongest interaction between themselves. This allows grouping the studied cultivars according to their adaptability. After analyzing in detail the genotype x environment interaction by AMMI-analysis, two main components determining 86 % of the variation of interaction were observed. The third component can also be considered significant, though at probability 91.1 %. In triticale, such data concerning test weight have not been reported. Rharrabti et al. (2003) reported the effect of three components on test weight of durum wheat. Aucamp et al. (2006) determined two main components of this parameter in the studied genotypes and conditions of the environment in common winter wheat. Jain et al. (2017) related the interaction of the genotype and the environment in test weight of basmati rice to three main components, which determined 99.8 % of the variation caused by the interaction. The results we obtained and those of other researchers on different cultural plants showed that although the factor genotype x

Table 3. Two-way ANOVA of parameter test weight

Source	Sum of Squares	df	Mean Square	F	Sig.	η^2
Genotype (G)	359.504	15	23.967	10835.078	0.000	9.198
Environment (E)	3104.880	4	776.220	350916.506	0.000	79.439
G * E	443.552	60	7.393	3342.045	0.000	11.348
Error	0.531	240	0.002			
Total	3908.467	319				

Table 4. Analysis of the variance for AMMI-model of test weight

Source	Sum of Squares	df	Mean Square	F	Sig.
Genotype (G)	89.876	15	5.992		
Environment (E)	776.220	4	194.055		
G * E	110.888	60	1.848		
AMMI Component 1	59.578	18	3.309	2.709	0.004
AMMI Component 2	35.376	16	2.211	3.608	0.002
AMMI Component 3	11.508	14	0.822	2.228	0.086
AMMI Component 4	4.4267	12	0.369	********	1.000
Total	976.984	79			

environment determined a smaller part of the total variation in test weight, this parameter was characterized and formed under the effect of complex interactions.

Figure 1 presents the biplot of AMMI1 model. Different interaction reactions were observed based on the distance of the investigated genotypes and years from the center of the graph. Based on the mean values of the studied parameter and IPCA1, the cultivars were grouped according to stability and mean test weight values into four separate groups. First ranked those, which had low values of IPCA1 and were closer to the abscissae, having simultaneously higher test weight. Such genotypes are characterized with good adaptability to all conditions of the environment. Among the investigated cultivars, this group included Presto, Atila, Akord, Bumerang and Dobrudzhanets. The second group included the genotypes with values higher than the average for the parameter, but with high positive or negative IPCA1; therefore they were characterized with adaptability but to the specific conditions of growing. Cultivars Doni 52 and Respekt belonged to this group.The third group included cultivars with values of the parameter lower than the average and with IPCA1 tending towards zero. These genotypes were characterized with very low interactions with the studied conditions of the environment. Cultivars AD-7291, Vihren, Irnik, Lovchanets, Blagovest and Borislav fell into this group of investigated cultivars. A specific feature of cultivar Vihren was that it was in immediate proximity to the cross point of the two abscissae. This was an indication that besides the high stability of its test weight, it was also characterized with values tending towards the average. Such genotypes have the potential to be used as standard cultivars according to the investigated parameter. Cultivars with test weight below the av-

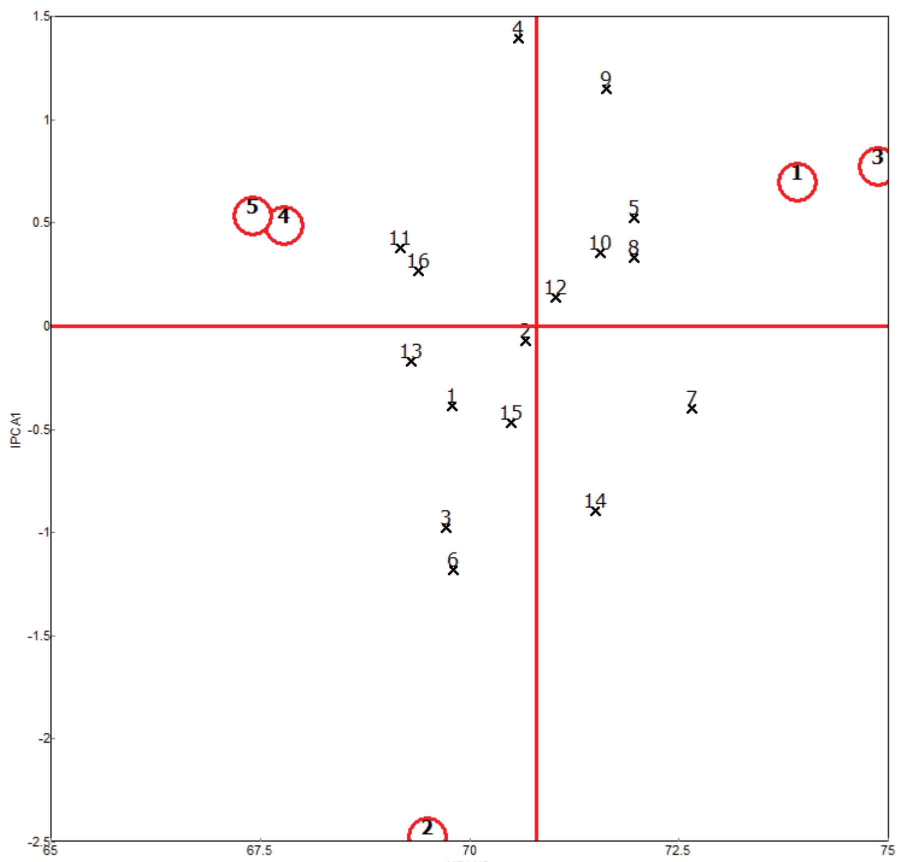

Figure 1. AMMI1-biplot of the parameter test weight

Cultivars: 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

Years (red circles): 1. 2014/2015; 2. 2015/2016; 3. 2016/2017; 4. 2017/2018; 5. 2018/2019 erage and IPCA1 with high values belonged to the fourth group. These genotypes were characterized with low stability and adaptability in general, since they formed high interactions with the environmental conditions. Among the investigated genotypes, Rakita, Lasco and Kolorit fell within this group.

The higher the IPCA values of a given genotype, the stronger its interaction with the environment is. If the values of the genotype and the environment are both with the same sign (plus or minus), their interaction is positive and vice versa – if their values are with different signs, their interaction is negative (Ali et al., 2015). A positive interaction with the two favorable periods (2014/2015 and 2016/2017) was observed in cultivars Presto, Akord, Bumerang and Dobrudzhanets. Such a behavior was related to the possibility these genotypes to realize their potential with regard to test weight in the favorable period. At the same time, positive was the interaction of cultivars Irnik and Borislav with the extremely unfavorable 2017/2018 and 2018/2019. This demonstrated that the two cultivars managed to reach their potential under unfavorable conditions, too, although in principle they were characterized by low values of the parameter test weight. It is noteworthy, that cultivars Doni 52 and Atila formed negative interaction with 2014/2015 and 2016/2017, but positive with 2015/2016. This revealed a compromise formation of test weight, i.e. the cultivar could not reach its optimum potential during the growing period. Cultivars Lasko, Kolorit and Respekt had a very strong interaction with the environment. Kolorit interacted positively with 2015/2016 and negatively with all other periods. Its response was similar to that of Doni 52, but significantly stronger. Such a behavior related to the fact that the cultivar was considerably early and managed to form its grain in 2015/2016 before the occurrence of the unfavorable meteorological conditions. In Lasko and Respekt, the values during the individual periods were rather different and a specific reaction could not be outlined. Cultivar Lovchnets demonstrated considerable stability according to the parameter test weight, but its mean values were very low, regardless of the environment.

In practice, the lowest interaction with the investigated genotypes was observed in the extremely unfavorable 2017/2018 and 2018/2019. This was related to the fact that during these two periods the test weight of all cultivars decreased considerably, which implied low interaction of the environment with the genotypes and strong direct impact of the environment on the parameter. Higher interaction of the environmental conditions with the genotype was registered during 2014/2015 and 2016/2017. Due to the unfavorable conditions of the environment, the individual genotypes had a better opportunity to realize their potential. Opposite was the behavior of the period 2015/2016, when extremely high interaction of the environment with the investigated genotypes was formed, and the values of the parameter were rather variable depending on the genotype.

Figure 2 shows a biplot of AMMI II model, which presents the combined interactions of the environment with the genotype. The conditions of the environment are represented by vectors from the center of the graph. The longer vectors are usually related to a higher level of the interaction (Ali et al., 2015). The length of the vectors during the investigated periods differed considerably. The shortest were for 2014/2015, 2016/2017 and 2017/2018. The vectors for 2015/2016 and 2018/2019 were considerably longer. This indicated extremely contrasting growing conditions.The genotypes and the conditions of the environment, which fell in the same sector, showed positive interaction. Such were the interactions of Lasko, Bumerang and Dobrudzhanets with the conditions of 2014/2015, 2016/2017 and 2017/2018, the interactions of Presto, Akord, Respekt, Irnik and Borislav with the conditions of 2018/2019, and those of AD-7291, Vihren, Rakita, Kolorit and Atila with the conditions of 2015/2016.

It is noteworthy that Lovchanets, Doni 52 and Blagovest were in different sectors in any of the growing periods. This was related to very complex interactions of the genotypes with the growing environment. The same was valid for the cultivars interacting with the growing conditions outside the sector of the graph where they were located. The results from the AMMI-biplot analysis showed variable combinations of test weight with its stability in the studied genotypes. Such a research on triticale under contrasting growing conditions has not been reported yet. Very scarce are the investigations analyzing this parameter by AMMI biplot in other cultural plants as well. Jain et al. (2017) demonstrated similar behavior of the test weight of rice when investigating various genotypes under contrasting environments.

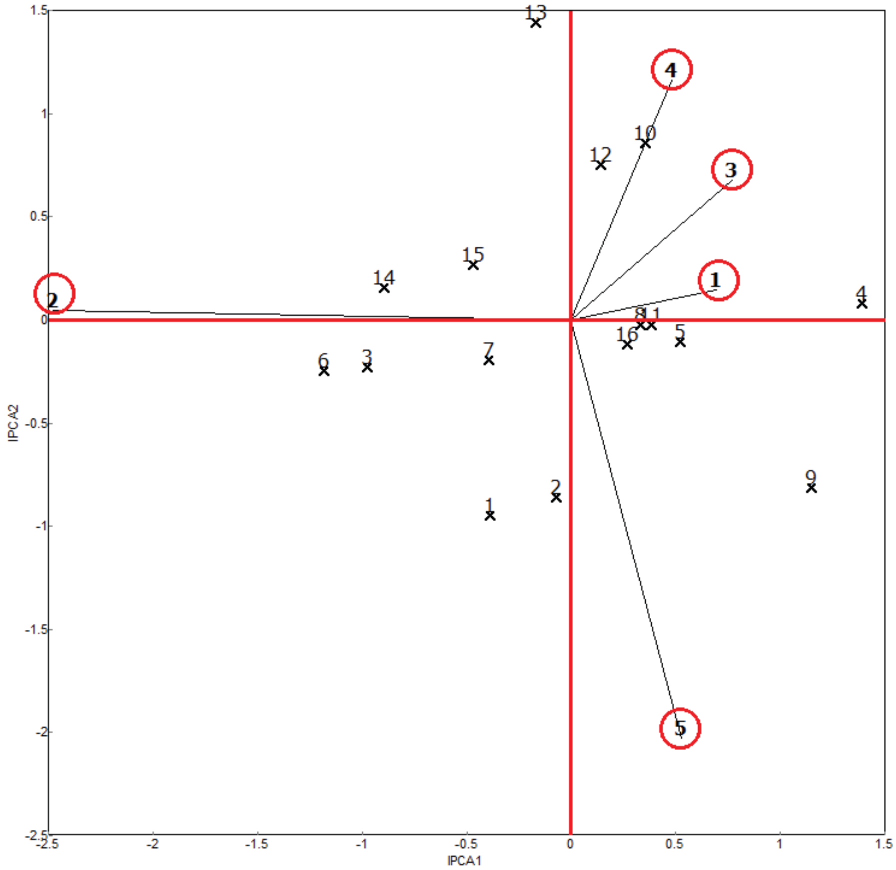

Figure 2. AMMI2-biplot for the parameter test weight

Cultivars: 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

Years (red circles): 1. 2014/2015; 2. 2015/2016; 3. 2016/2017; 4. 2017/2018; 5. 2018/2019

2. Combination of high test weight and yield in Bulgarian triticale cultivars

Test weight in its self is not a sufficient parameter from an economic point of view. Therefore, it is important the cultivars, which possess large and heavy grain to realize higher yields as well. There are different researches on triticale, which observed various correlations of yield with test weight. Đekić et al. (2014) pointed out the absence of a correlation between the two parameters in cultivar Favorit, which they investigated. When studying different triticale genotypes, Goyal et al. (2011) also reported the absence of a correlation between test weight and yield. In a research on old and new lines, Dogan et al. (2009) reported a positive but insignificant correlation. Our results over the separate periods of investigation and for the entire period of study (Table 5) showed that a slight positive correlation was observed between the two parameters, which, however was not significant under highly unfavorable conditions of the environment. This gives grounds to argue that test weight and yield are coded for by different gene systems (Cabral et al., 2018; Houshmand et al., 2008; Wajdzik et al., 2019). At the same time, such data are indicative for the difficult combination of the parameters in the genotypes.

The results, presented in Table 6 are revealing for a different dynamics of yield as compared to test weight. The separate periods, although significantly different by yield, grouped in a different way according to their arrangement by test weight. While the variation of the test weight of the individual varieties was comparatively low, the reaction of their yield placed them in considerably wider groups with smaller differences. Concerning the mean values for the period 2018/2019, which was extremely unfavorable for (the values of) test weight, it was less unfavorable for yield. This was related to the fact that the yield components were considerably more variable and were related to the entire development of the plant during the vegetative growth of the crop, while the effects on test weight could be the result from single and local events in the meteorological parameters, as observed in 2017/2018.

Among the investigated cultivars, Doni 52 (692 kg/da), Borislav (671 kg/da), Bumerang (666 kg/da) and the standard Rakita (663 kg/da) were with the highest yields, averaged for the 5-year period of study. Very low respective yields were determined in cultivars Respekt (534 kg/da) and Lovchanets (523 kg/da). These data completely corresponded to the results for the same cultivars obtained by Stoyanov (2018) in a 3-year testing.

Table 5. Yield from Bulgarian triticale cultivars over growing periods

Year	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019	Average
Pearson Correlation	0.249*	0.442**	0.434**	0.017	-0.194	0.492**

Table 6. Yield (kg/da) from Bulgarian triticale cultivars over growing periods

Cultivar	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019	Average
AD-7291	589	596	602	637	507	586e
Vihren	609	540	631	745	513	607de
Rakita	725	529	735	717	608	663abc
Lasko	765	455	614	631	561	605de
Presto	777	436	681	624	612	626bcde
Kolorit	691	543	609	661	504	602de
Atila	763	632	757	609	476	647bcd
Akord	767	552	692	584	549	629bcde
Respekt	704	320	679	563	406	534f
Bumerang	779	424	776	745	608	666abc
Irnik	793	521	603	634	495	609de
Dobrudzhanets	643	469	770	664	579	625cde
Lovchanets	649	378	489	624	476	523f
Doni 52	803	611	745	700	603	692a
Blagovest	747	543	713	636	532	634bcd
Borislav	839	605	711	602	601	671ab
Average	728a	509e	675b	649c	539d	620
LSD0.05	35.8	43.5	38.5	26.4	29.8	22.5
LSD0.01	47.1	57.1	50.6	34.7	39.1	29.6
LSD0.001	60.2	73.0	64.7	44.4	50.0	37.8

Table 7. Two-way dispersion analysis of parameter yield

Source	Sum of Squares	df	Mean Square	F	Sig.	η^2
Genotype	632733.492	15	42182.233	10.308	0.000	13.373
Environment	2188712.923	4	547178.231	133.712	0.000	46.259
G * E	927825.623	60	15463.760	3.779	0.000	19.609
Error	982131.547	240	4092.215			
Total	4731403.584	319				

The behavior of the yield from the studied cultivars demonstrated significant interaction of the factors genotype and environment. The effect of this interaction on the total variation of the parameter was 19.61 %, considerably higher than in the parameter test weight (Table 7). This was related to the much more variable responses of the separate genotypes to the contrasting conditions of the environment. The ranking of the cultivars and the separate periods by their stability and productivity is presented in AMMI1-biplot in Figure 3. The studied genotypes were considerably more dispersed, and the IPCA1 values were higher than that of test weight. This indicated that yield, being an extremely complex resultant parameter, was characterized with considerably lower stability than test weight.

Cultivars Rakita, Akord, Irnik, Doni 52, Blagovest and Borislav were with the highest stability of yield. Cultivars Doni 52 and Borislav were also characterized with very high productivity. Cultivar Bumerang was with high productivity but rather low stability. Cultivars AD-7291, Vihren, Kolorit and Respekt were with very low yields but also with low yield stability. High stability of yield but low productivity was observed in cultivar Lovchanets. These results did not completely correspond to the stability of test weight shown on Figures 1 and 2. The investigated genotypes responded in a more variable manner according to yield than to test weight. Nevertheless, certain cultivars were observed, which combined both high values and high stability of the two parameters. Figure 4 presents a 4D graph, which gives an idea about the combination of the four investigated values.

The best combination by productivity, test weight and stability of the two parameters was observed in cultivar Akord. Although having high productivity and test weight, cultivar Atila was unstable by

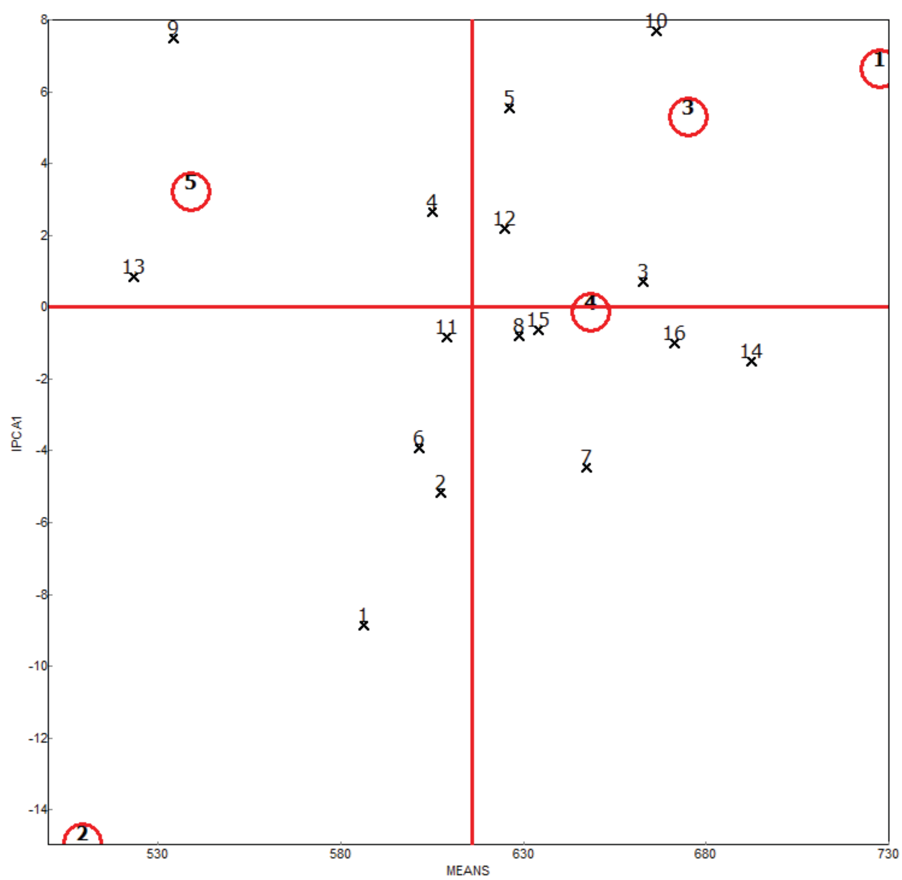

Figure 3. AMMI1-biplot for the parameter yield

Cultivars: 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

Years (red circles): 1. 2014/2015; 2. 2015/2016; 3. 2016/2017; 4. 2017/2018; 5. 2018/2019 both parameters. Similar behavior was observed in Bumerang, but it was characterized also with stable test weight. Similar were the results for cultivar Presto, though at lower values of yield. Cultivar Doni 52 was with high values of yield and test weight and good stability of yield, but the stability of test weight was lower. The data from the graph showed that the greater part of the cultivars combined low test weight, average yields and absence of stability of the two parameters. The most unfavorable combinations were observed in cultivars Respekt and Lovchanets. Respekt combined low and unstable yields with high but unstable test weight. Lovchanets was characterized with low and stable yields and low and stable test weight. Special were the results of the standards Vihren and Rakita. Vihren was characterized with test weight of high stability and values close to the average, but with low and unstable yields. Rakita, on its part, demonstrated yields close to the average and high stability, but low and unstable test weight. These result allowed considering Rakita a standard for productivity, and Vihren – for test weight. Cultivar Kolorit, which is currently a standard for variety testing in Bulgaria, was characterized with low and unstable yields and low and unstable test weight. This was an indication that this cultivar combined the most unsuitable values from a breeding point of view, being at the same time strongly interactive with the conditions of the environment.

The obtained results show that triticale cultivars Akord, Atila, Bumerang and Doni 52 are extremely suitable from a practical point of view since they combine high yield and test weight and have good stability by the two parameters. This allows producing high-quality grain from them that would be applicable in production. At the same time the combination of high and stable test weight in cul-

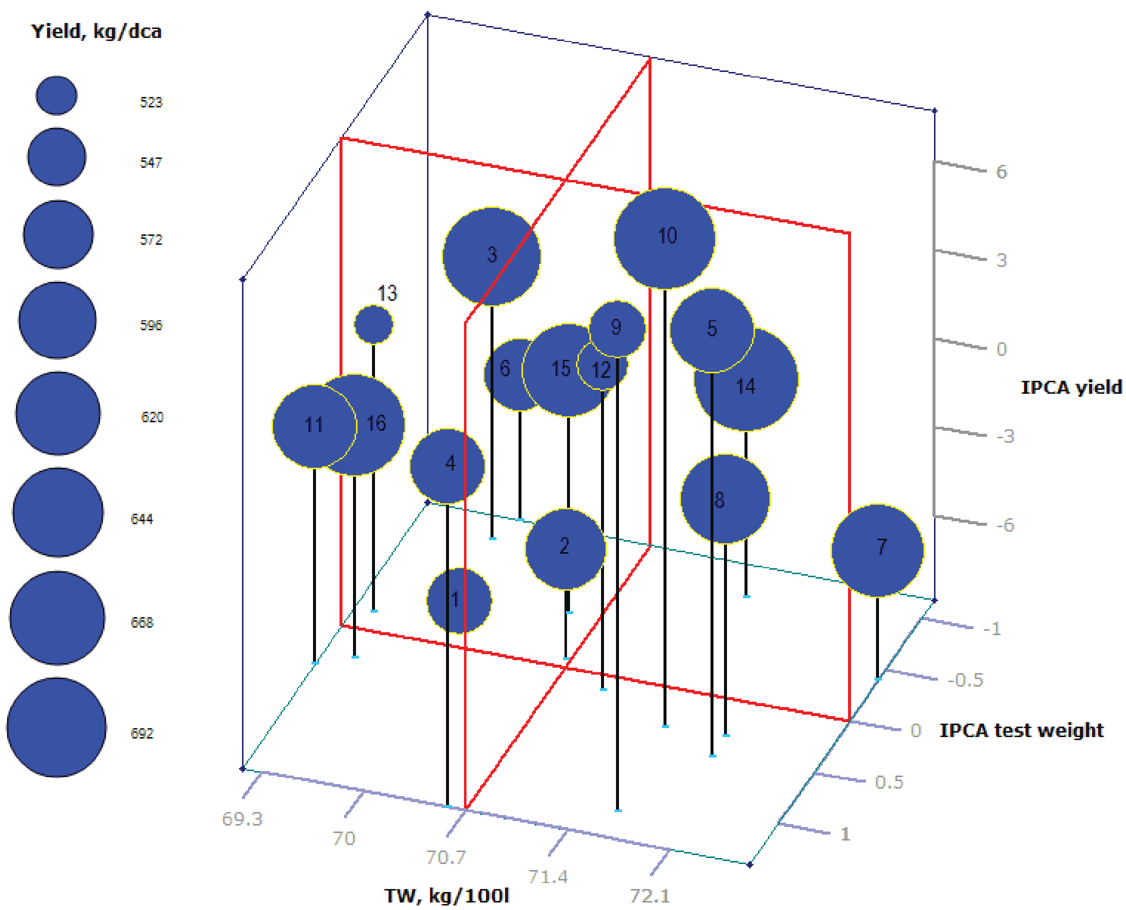

Figure 4. 4D plot combining the values and stability of test weight and yield

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

tivars Akord and Bumerang is a significant breeding achievement. Such results allow using these cultivars as valuable initial material for the triticale breeding program in Bulgaria with the aim to improve the test weight of this crop.

CONCLUSIONS

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

1. The test weight of the investigated Bulgarian triticale cultivars was significantly influenced by the conditions of the environment, its mean values varying within 67.4 – 74.9 depending on the year.

2. The best conditions for formation of high test weight were observed during 2016/2017 and 2014/2015, and the most unfavorable were during growing year 2018/2019, which was characterized as an extremely dry period.

3. The highest values of test weight were registered in cultivars Presto, Atila, Akord, Rspekt, Bumerang and Doni 52 within a 5-year period; in Presto, Atila and Bumerang a tendency towards high values during the separate years was observed.

4. The best stability of test weight was registered in cultivars Vihren, Presto, Akord, Bumerang, Irnik, Dobrudzhanets, Lovchanets and Borislav, and the best combination of high and stable test weight was observed in Akord, Bumerang and Dobrudzhanets.

5. A combination of high and stable yield and high and stable test weight based on the analysis carried out was found only in cultivar Akord. A good combination of productivity, stability and test weight was determined in cultivars Atila, Boomerang and Doni 52.

6. Cultivars Atila, Akord, Bumerang and Doni 52 were characterized with very good adaptability to the contrasting environments, which makes them valuable triticale cultivars suitable for growing under various soil and climatic conditions typical for Bulgaria.

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