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PRODUCTIVITY AND STABILITY OF BULGARIAN TRITICALE CULTIVARS UNDER DIFFERENT LEVELS OF NITROGEN FERTILIZATION AND CONTRASTING ENVIRONMENTS

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Abstract

In order to determine suitable combinations between genotypes and agronomy practices based on productivity, stability and adaptability, four triticale genotypes (Kolorit, Bumerang, Respekt and Atila) were studied in three contrasting growing periods and under four levels of nitrogen fertilization. The productivity, stability and adaptability were determined by using the method of Eberhart and Russell and by AMMI analysis. Cultivar Bumerang was with the highest productivity, in all levels of nitrogen fertilization, while cultivar Respekt was with the lowest yields. A tendency was observed toward higher effect of the genotype, while the effect of the year conditions decreased with the higher nitrogen nutrition; the effect of the genotype x environment remained almost constant. The highest stability, averaged for this experiment, was that of cultivar Bumerang, and the lowest - of cultivar Kolorit. With the exception of the variant without nutrition, both cultivars had a comparatively stable response to the other nitrogen norms, which makes them suitable for growing under the soil and climatic specificity of Bulgaria at varied nutrition regimes.

Key words: *adaptability, nitrogen nutrition, fertilizer norm, triticale, stability.*

INTRODUCTION

Increasing the yields from the crop plants under field conditions is a key task of agricultural production. It arises from the constantly increasing demands for quality food and feed sources worldwide. In this relation, there are two main approaches to increase the productivity of a crop – to choose a more productive genotype or to apply agronomy practices suitable for growing of the respective genotype. With the use of both approaches under conditions of a changing climate, and in a certain geographic region – under conditions of dynamic meteorological parameters, it becomes possible both the genotype and the applied agronomy practice to ensure predictable, i.e. stable yields.

Triticale, being a part of the forage or grain production in an agricultural farm, is characterized by a high production potential with regard to both grain yield and biomass productivity. This is related to its biological an economic properties allowing to grow the crop in a wide area of environmental conditions and under high levels of biotic and abiotic stress. According to data provided by the Ministry of Agriculture and Foods, in 2019 a mean yield from triticale of 2657 kg/ha was registered in Bulgaria. During 2010-2022, the mean annual yields varied from 2.453 t/ha in 2012 to 3.193 t/ha in harvest year 2014, the trend for grain yield being positive. In 2022, seventeen Bulgarian triticale cultivars were included in the official varietal list of Bulgaria (Executive Agency of Variety Testing, Field Inspection and Seed Control, 2022).

One of the ways to increase triticale grain production is to use more efficiently the potential of the crop. Similar to any biological entity, triticale is characterized by a certain susceptibility to some biotic and abiotic factors at genotype level. This determines the different production potential of the developed varieties and lines and is the reason for varied responses of a given genotype to variable conditions of the environment. When conducting Multi Environment Trials (METs), regardless of the crop, the genotypes are ranked differently under different environments. This relates to the effect of the genotype x environment interaction and to the different stability resulting from this interaction. There are various methods for assessment of the stability of a set of genotypes subjected to investigation. According to Becker and Leon (1988), stability can be static and dynamic depending on the point of view: biological (the changes of the environmental conditions are not considered) or agronomic (the changeable environmental conditions are taken into account, as well as the tendency towards change of the average level of productivity of the set of cultivars).

Currently, a large number of parameters have been identified, which can be adequately used for assessment of stability and adaptability (Crossa et al., 1990). According to Tsenov et al. (2022), the use of one method only is not a correct approach since the different approaches reflect to different degrees the yield-stability combination. These authors point out that the adequate solution in this case would be the use of multiple methods, which, however, need to be adequately integrated. Some of the most widely used methods for stability assessment are those of Eberhart and Russell (1966) and the AMMI Stability Model (according to Gauch, 1992). Silveira et al. (2016) emphasized that the use of conventional methods such as the parameters according to Eberhart and Russell (1966) should be complemented with such methods as AMMI. Regardless of this, the methods and approaches for assessment of stability and adaptability are based on the genotype x environment interaction.

In practice, however, it is often necessary to evaluate other interactions, as well: genotype x fertilization, genotype x growing system, genotype x sowing date, etc. Against the background of several periods of conducting this experiment, a tri-factor interaction needed to be assessed. This presented us with a challenge in the interpretation and evaluation of the stability of the genotypes. There are a significant number of researches on triticale, which give assessment on productivity and stability against the background of different growing periods. Scarce are the investigations on stability under different levels and forms of fertilization not only in triticale, but in cereals in general.

The aim of this study was to compare the grain yields from triticale cultivars and to determine their ontogenetic adaptability and stability in the formation of productivity under the agro-ecological conditions of Central South Bulgaria.

MATERIALS AND METHODS

Plant material

During 2014-2017, a three-factor field experiment was carried out at the Institute of Field Crops – Chirpan, Bulgaria. Winter triticale cultivars developed at Dobrudzha Agricultural Institute – General Toshevo were subjected to comparative study. The experiment was designed according to the block method in four replications, the size of the harvest plot being 18 m^2. Sowing was done with 550 germinating seeds after previous crop sunflower.

The following factors and levels were investigated: factor A cultivar – a_1) Kolorit, a_2) Atila, a_3) Bumerang and a_4) Respekt; factor B nitrogen fertilization – b_1) N_0 (without nitrogen fertilization), b_2) N_6 (nutrition with 6 kg/da a.m. N_20), b_3) N_{12} (nutrition with 12 kg/da a.m. N_20) and b_4) N_{18} (nutrition with 18 kg/da a.m. N_20). Cultivar Kolorit has been a standard for Bulgaria since 2015. Nutrition was done manually with ammonium nitrate (NH_4NO_3) at tillering stage in spring. Background phosphorus fertilization with triple superphosphate was used at norm P_2O_5/da, incorporated in autumn in all variants of nitrogen fertilization with a follow-up cultivation. Grain yield was determined as per harvest plot after harvesting and was re-calculated to kg/da. The agronomy practices were according to the standard methodology for growing of cereal crops.

Soil and climate conditions

The soil type was Vertisol with 80-115 cm humus horizon. It was characterized by low to moderate mineral nitrogen reserves, low content of mobile phosphorus and good reserves of available potassium.

The climatic data were obtained from the agro-meteorological station on the territory of the Institute of Field Crops in Chirpan. Agro-climatic assessment was done on the available moisture reserves in soil. The moisturizing coefficients of Ivanov were determined over months for the vegetative growth period. The formula К = Sr/E, where: К – moisturizing coefficient; Sr – monthly sum of precipitation (mm); E – monthly evaporation (mm) was applied. To calculate evaporation (E), the formula used was E = 0.0018 x (t + 25)2 x (100-a), where: t – mean monthly air temperature, (°C); a – mean relative air humidity (%). It was accepted that values of К<0.3 indicated drought, while values of К >2.0 signaled excessive moisture.

The Institute of Field Crops is situated in the transitional continental sub-region (Sabev and Stanev, 1963). Typical for this region are soft winters, hot summers and high variation of temperatures during the vegetative growth period both over years and within the year.

The period 2014/2015 was characterized as warmer and more humid with regard to temperature sums and precipitation, marking it as different from the long-term tendency. Such conditions were a prerequisite for good development of the crop. During the winter period, the mean monthly temperature was higher in December, January and February (Table 1). January was rather warm, with accumulated 79.2ºC more than the long-term mean value (Table 2).

The amount of autumn and winter rainfalls was higher and therefore, according to the hydro-thermal coefficient (HTK), excessive moisture was registered (Table 3). The temperature sum in February was with 184.2ºC more than the climatic mean value, and as a result the mean temperature was also higher. In combination with the snowfall in January, which caused excessive moisture, it led to tillering and early resumed vegetative growth.

The temperatures and precipitation during 2016-2017 were close to the mean data. An exception was the sum in January –160.7ºC below zero, or with 159.3ºC less. Retarded development of the crop was observed and late occurrence of stage 3rd leaf in January. The highest HTK of moisturizing was registered (Table 4).

Statistical analysis

The results obtained on yield were summarized and averaged over genotype, fertilizer norm, year, and in total. A two-way ANOVA over years was carried out according to the model genotype x fertilization and in general according to the model genotype x environment, considering each fertilization norm in each vegetative growth period as representing separate growing conditions. A three-way ANOVA was done according to the model genotype x fertilization norm x year.

To determine the stability and adaptability of the investigated genotypes both under different fertilization norms and for each one individually, the method of Eberhart and Russell (1966) was applied, calculating the regression coefficient (b_i) and the mean square deviation of the regression (s^2_{di}). AMMI Stability Analysis was applied according to Gauch (1992) for each level of fertilization, and for the total of all levels and years of the experiment.

To summarize and average the data, Microsoft Office Excel 2003 was used, IBM SPSS Statistics v.19 was applied for the ANOVA, to calculate the stability parameters – the internet-based platform StabilitySoft (Pour-Aboughadareh et al., 2019), and for AMMI analysis – AMMISoft (Gauch and Moran, 2019).

Table 1. Air temperature (mean diurnal) during the vegetative growth (tº C)

Period	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
2014/15	12.6	7.6	4.4	2.4	3.4	6.2	11.3	18.9	20.3
2015/16	12.7	10.0	3.7	-0.3	8.1	8.8	14.7	16.1	22.7
2016/17	12.4	6.7	0.8	-5.2	1.7	9.3	11.9	16.6	22.1
1928/13	***12.9***	***7.2***	***2.0***	***-0.2***	***2.1***	***6.1***	***11.8***	***16.8***	***20.8***

Table 2. Temperature sums Σ (tº C)

Period	Ocr	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Σ
2014/15	391.9	227.2	138.0	74.8	96.0	192.7	340.4	586.0	608.9	2656.9
2015/16	392.8	299.3	115.1	-8.7	233.6	273.5	439.8	498.0	679.8	2923.2
2016/17	385.0	201.7	26.2	-160.7	45.6	289.2	355.7	513.7	664.2	2321.5
1928/13	***396.7***	***215.9***	***61.1***	***-4.4***	***49.4***	***188.9***	***357.9***	***511.5***	***630.7***	***2407.7***

Table 3. Sum of precipitation (mm)

Period	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Σ
2014/15	135.4	36.9	142.3	50.3	61.7	134.9	15.1	58.8	78.1	713.5
2015/16	76.6	50.2	1.3	73.9	28.3	53.1	26.6	75.0	15.0	400.0
2016/17	12.0	47.7	5.9	69.8	23.8	51.3	22.6	59.5	84.3	376.9
1928/13	***37.5***	***43.3***	***54.0***	***44.3***	***37.7***	***37.0***	***45.2***	***64.1***	***65.4***	***428.5***

Table 4. Hydrothermal coefficient (HTK) of Ivanov

Период	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
2014/15	**4.4**	**2.4**	**10.9**	**1.5**	**2.8**	**5.9**	0.2	0.7	0.8
2015/16	1.7	1.0	*0.1*	**5.1**	0.9	1.3	0.3	1.1	*0.1*
2016/17	*0.2*	1.7	0.3	**9.6**	1.5	1.2	0.3	0.7	0.8

K>2.0 *excessive moisture*

K<0.3 drought

RESULTS AND DISCUSSIONS

Results

The results on the grain yield from the investigated genotypes (Table 5) revealed a tendency towards increase with the higher levels of fertilization during the three harvest years and for all cultivars. At the same time, regardless of the applied fertilization, the most favorable conditions were observed during harvest year 2017, and the highest yield for this period was obtained from cultivar Bumerang, followed by Kolorit. The highest productivity in this growing period was realized by cultivar Respekt. In 2016, the highest values were registered in cultivar Atila – 282.22 kg/da, 417.22 kg/da, 484.72 kg/da and 514. 17 kg/da at levels N_0, N_6, N_{12} and N_{18}, respectively. The lowest productivity was that of cultivar Respekt, regardless of the fertilization used.

In harvest year 2015, an identical tendency in the different cultivars depending on the nitrogen fertilization was not observed. In the variant without using nitrogen fertilizer, cultivars Bumerang (300.69 kg/da) and Respekt (308.19 kg/da) demonstrated high and similar yields; at level N_6 the highest values were registered in cultivar Bumerang (434.25 kg/da), at N_{12} - in cultivars Bumerang (476.36 kg/da) and Atila (460.50 kg/da), and at N_{18} – in Kolorit (554.89 kg/da) and Bumerang (545.36 kg/da). In this economic year, cultivar Atila gave the lowest yield at level N_0, and under all other levels the lowest productivity was observed in cultivar Respekt. These data show that the productivity of the cultivars depended both on the applied mineral fertilization and on the conditions of the environment.

To determine the effect of the year conditions and the cultivar against the background of different nitrogen norms, a two-way ANOVA was carried out (Table 6). Based on the obtained data, it can be assumed that when using certain nitrogen fertilizer doses, the effect of the genotype and the conditions of the environment varied in strength, as well as the effect of their interaction. Under N_0, 79.7% of the total yield variation was due to the conditions of the year. The factor genotype had a statistically significant effect, but of small size – only 3.6%. The effect of the genotype x environment interaction accounted for 10.1%, which was within the normal range for such a crop as triticale. Under N_6, the yield was determined to almost equal degree by the effects of the genotype and of the year conditions, and the effect of their interaction was 7.9%.

Such distribution was not typical for the crop, although the effect of the year conditions was dominant. With the next higher norms of nitrogen fertilization, N_{12} and N_{18}, the effect of the cultivar was dominant for the variation of grain yield, 43.4% and 58.3% from the total variation, respectively. The effect of the environmental conditions determined under N_{12} accounted for 19.3% of the differences in the mean arithmetic value of all cultivars, and under N_{18} – for only 8.4%. A tendency was observed with the higher nitrogen norms towards higher effect of the genotype at the expense of the effect of the conditions of the year. At the same time, the effect of the genotype x environment interaction remained relatively the same for all four variants of fertilization, 10.1%, 7.9%, 8.3%, 13.1%, respectively.

The results from the analysis of the variance for the total of the four variants of fertilization revealed that the factors cultivar and year, as well as the interaction cultivar x year, had significant effects on the yield from the cultivars. The highest influence on the changeability of yield was that of the factor year – 68.1%. The cultivar had a relatively low impact on this parameter – 15.0%, while the genotype x environment interaction was also low – 7.9%. These values were normal for triticale, such results having been reported in previous studies for similar sets of cultivars.

Table 5. Yield over cultivars, levels of fertilization and years (kg/da)

Genotype	2015			
	N_0	N_6	N_{12}	N_{18}
Kolorit	283.56	361.53	431.64	554.89
Bumerang	300.69	434.25	460.50	545.36
Respekt	308.19	336.72	349.61	377.50
Atila	277.83	402.75	476.36	504.08
Genotype	2016			
	N_0	N_6	N_{12}	N_{18}
Kolorit	193.06	382.50	415.83	438.33
Bomerang	216.11	409.44	464.72	511.39
Respekt	197.78	328.06	397.78	419.72
Atila	282.22	417.22	484.72	514.17
Genotype	2017			
	N_0	N_6	N_{12}	N_{18}
Kolorit	486.39	511.39	532.36	555.00
Bomerang	496.11	517.22	546.11	601.81
Respekt	356.67	377.08	399.72	407.22
Atila	442.08	476.39	508.89	531.94

The results given in Table 5 and Table 6 corresponded to those obtained from the three-way ANOVA. The analysis of the factors cultivar, year and fertilization (Table 7) revealed a low but significant effect of the interactions cultivar × year (3.8%), cultivar × fertilization (1.9%) and year × fertilization (8.2%). The values of η on the total variation of the factors (G x Yr x F) explain the low dependence of the differences between the levels of the factors with regard to yield. The highest effect on the value of yield was determined for the factor fertilization – 40.6%. The significant effect of the studied factors and their interaction on the yield from the triticale cultivars allowed the assessment of the parameters related to the stability and adaptability of the genotypes investigated in this research.

Table 6. Two-way ANOVA of the genotype x environment interaction by level of fertilization and in total

Source	SS	df	Mean Square	η(%)	F	Sig.
			N_0			
G	18751.900	3	6250.633***	3.6	6.481	0.001
E	416041.062	2	208020.531***	79.7	215.691	0.000
G * E	52569.664	6	8761.611***	10.1	9.085	0.000
Error	34719.744	36	964.437			
Total	522082.370	47				
			N_6			
G	76382.263	3	25460.754***	37.4	28.479	0.000
E	79742.146	2	39871.073***	39.0	44.598	0.000
G * E	16080.476	6	2680.079*	7.9	2.998	0.018
Error	32184.642	36	894.018			
Total	204389.527	47				
			N_{12}			
G	93339.367	3	31113.122***	43.4	17.892	0.000
E	41518.168	2	20759.084***	19.3	11.938	0.000
G * E	17804.058	6	2967.343ns	8.3	1.706	0.148
Error	62602.275	36	1738.952			
Total	215263.868	47				
			N_{18}			
G	155954.196	3	51984.732***	58.3	35.089	0.000
E	22590.844	2	11295.422**	8.4	7.624	0.002
G * E	35713.053	6	5952.176**	13.1	4.018	0.004
Error	53333.670	36	1481.491			
Total	267591.763	47				
			Total			
G	305848.364	3	101949.455***	15.0	80.293	0.000
E	1385554.807	11	125959.528***	68.1	99.202	0.000
G * E	160746.613	33	4871.109***	7.9	3.836	0.000
Error	182840.330	144	1269.725			
Total	2034990.115	191				

The analysis on the mean yield showed that the maximum value was obtained for cultivar Bumerang (458.64 kg/da), and the lowest – for cultivar Respekt (354.67 kg/da), the average yield of the experiment being 421.35 kg/da. Based on the regression coefficient (b_i) according to Eberhart and Russell (1966), it is possible to estimate the response of the cultivars to the changeable growing conditions. Such a condition in this study was the nitrogen fertilization. Values of b_i close to 1.00 implied wide adaptability of the genotype, while values below or above it indicated narrow adaptability to the favorable growing conditions or narrow adaptability to unfavorable growing conditions. In this research, the adaptability of the cultivars was determined through b_i for each level of the factor fertilization and for each cultivar.

Table 7. Three-way ANOVA according to the investigated factors (cultivar, year and level of fertilization)

Source	SS	df	Mean Square	η (%)	F	Sig.
G	305848.364	3	101949.455***	15.0	80.293	.000
Yr	392383.566	2	196191.783***	19.3	154.515	.000
F	825662.587	3	275220.862***	40.6	216.756	.000
G * Yr	78274.869	6	13045.812***	3.8	10.275	.000
G * F	38579.362	9	4286.596***	1.9	3.376	.001
Yr * F	167508.654	6	27918.109***	8.2	21.988	.000
G * Yr * F	43892.382	18	2438.466*	2.2	1.920	.018
Error	182840.330	144	1269.725			
Total	2034990.115	191				

Table 8 demonstrates several facts. Firstly, with the increase of the levels of fertilization from N_0 to N_{18}, the significance of b_i for cultivar Kolorit also increased. Secondly, the cultivar possessed the narrowest adaptability to favorable environments, but its yield was not the highest, in comparison to the other cultivars. This means that this cultivar was with the highest requirements to the favorable climatic factors and agronomy practices used for its growing. Cultivar Bumerang demonstrated a similar response to the conditions of the environment, with b_i values 1.26, 1.10, 1.33 and 1.71 under N_0, N_6, N_{12} and N_{18}, respectively, in combination with the highest mean yield. The regression coefficient of cultivars Respekt and Atila varied within 0.52-0.65 and 0.35-0.77, respectively. These values determine narrow adaptability to unfavorable conditions of growing and they have low response to change in the growing conditions and the environment as a whole. Under nitrogen deficiency, as was the variant without using synthetic fertilizer (N_0), grain yield from cultivars Respekt and Atila will not demonstrate a significant decrease in comparison to the rest of the cultivars.

Such characteristics of the cultivars regarding their adaptability can also be accepted based on the values of b_i for all levels of fertilization. The coefficient b_i determined for cultivar Respekt under fertilization variant N_{18} was negative (-0.20) and it can be assumed that this cultivar did not interact with the conditions of the environment, i.e. it was not responsive to the high nitrogen norms, regardless of the year conditions. Therefore, the suggestion could be made that under low-productive environment the grain yield from Respekt would be higher than the yields of the other cultivars. Alternatively, under intensive agriculture with the use of higher nitrogen norms, cultivar Bumerang will exceed the yields of the investigated cultivars.

Table 8. Parameters of stability and adaptability over fertilization levels and total for the investigated set of cultivars

Cultivar	Yield (kg/da)	b_i (Plasticity)	s^2_{di} (Stability)
N_0			
Kolorit	321,00	1,32	0,34
Bumerang	337,64	1,26	1,21
Respekt	287,55	0,65	331,73
Atila	334,05	0,77	273,18
N_6			
Kolorit	418,47	1,61	29,08
Bumerang	453,64	***1,10***	45,90
Respekt	347,29	0,52	5,69
Atila	432,12	0,77	14,19
N_{12}			
Kolorit	459,94	1,69	88,38
Bumerang	490,44	1,33	8,44
Respekt	382,37	0,52	131,39
Atila	489,99	0,47	0,71
N_{18}			
Kolorit	516,07	2,14	372,45
Bumerang	552,85	1,71	5,85
Respekt	401,48	-0,20	126,23
Atila	516,73	0,35	31,86
Total			
Kolorit	428,87	1,22	1051,84
Bumerang	458,64	1,22	190,87
Respekt	354,67	0,63	772,14
Atila	443,22	0,93	774,61
Average	421,35		

The stability coefficient s^2_{di} gives an idea of the grain yield expression under different environments. Its mathematical origin is from the deviations of the actual from the theoretical yield values, and statistically speaking, it is the dispersion of variability of the yield values. It is accepted that the higher s^2_{di} value implies lower stability. In this research, stable were considered different cultivars depending on the amount of mineral fertilizer applied. Under N_0, these were cultivars Respekt and Atila, under N_6 – Bumerang, under N_{12} – Respekt, and under N_{18} – Kolorit. At level N_0, cultivar Kolorit demonstrated the highest stability, under N_6 – Respekt, under N_{12} – Atila, and under N_{18} – Bumerang.

Having in mind Table 8, it can be assumed that the productivity of cultivars Kolorit and Bumerang is above the average of the studied triticale genotypes under favorable condition. Based on the regression coefficient b_i = 1.22, cultivar Bumerang was characterized by a narrow adaptability to favorable environments, demonstrating high stability – s^2_{di} = 190.87. At the same time cultivar Kolorit exhibited low stability at significance of s^2_{di} = 1051.84 and identical adaptability – b_i = 1.22. This means that under unfavorable conditions Kolorit will produce comparatively lower and highly variable yields in comparison to the other cultivars, while under good agronomy practices and favorable climatic conditions grain yield will be high but differing and with low predictability relative to the rest of the cultivars. On the other hand, the yields of Bumerang will be high under variable conditions of the environment, and the more favorable they are, the higher the yield will be.

In cultivar Atila, the significance of b_i was close to 1 - 0.93. This implied comparatively wide plasticity under the investigated conditions of the environment and fertilization norms. Its stability, however, was comparatively low suggesting lower yield predictability under changeable meteorological conditions or agronomy practices. In cultivar Respekt, summarized for the study, narrow adaptability to unfavorable conditions of the environment was observed. This showed that the cultivar would respond with higher productivity to unfavorable conditions or to lower levels of nitrogen fertilization. At the same time, however, this cultivar was also characterized by low stability.

The applied AMMI analysis allowed identifying the genotypes, which combined productivity and at the same time were in low interaction with the growing conditions. To visualize the results from the analysis, biplots were constructed for each of the used fertilization norms and in total for the experiment. The genotypes positioned close to the x axis and to the right of the y axis were characterized by lower interaction with the conditions of the environment and were more productive, while those, positioned at a distance from axis x and to the left of axis y, were characterized by higher interaction with the conditions of the environment and were with lower productivity. At level of fertilization N_0 (Figure 1), the lowest interaction with the environmental conditions was that of cultivars Atila, and the interaction of cultivar Respekt was the highest. Opposite but identical reaction was observed in cultivars Kolorit and Bumerang. At the same time, the best combination of productivity with stability was found in cultivars Bumerang and Atila. In Kolorit, the high yield was combined with lower stability, while in Respekt the low yield was in combination with low stability.

Similarly, after using N_6, the highest yield according to the mean (413.0 kg/da) was registered in Bumerang, which was in low interaction with the environment since it was positioned close to the abscissa (Figure 2). Second ranked cultivar Atila, which was characterized by identical but opposite interaction with the conditions of the environments as compared to Bumerang. Under N_0 and N_6, the position of Kolorit (G1) relative to the ordinate remained identical with regard to the mean yield under both levels of fertilization. Additionally, it was positioned at the greatest distance from the abscissa, which determined its lower yield stability. The lowest productivity in combination with the lowest stability was again observed in cultivar Respekt.

Under N_{12}, the tendency of cultivar Kolorit being positioned close to the line determining the mean yield of the cultivars and at distance from the abscissa was also observed (Figure 3). Cultivars Bumerang and Atila were with similar and higher yields than the average under fertilization with N_{12} and had a comparatively lower interaction with the conditions of the environment, the tendency towards simultaneous combination of low productivity and low stability remaining the same. It should be underlined that since the interaction genotype x environment was not significant at level above 95%, the conclusions drawn were valid at level of significance 85%.

Under N_{18}, cultivar Bumerang combined high stability with the highest yield (Figure 4). Its position was closest to the abscissa, and it determined low interaction with the environment. Cultivar Kolorit was in strong interaction with the conditions of the environment and demonstrated the lowest stability. This tendency was valid also for cultivars Atila and Respekt as compared to the other levels of fertilization.

It can be summarized that cultivar Bumerang, under all levels of nitrogen fertilization, demonstrated the highest productivity and low interaction with the conditions of the environment implying very good stability (Figure 5). In cultivar Respekt, the lowest grain yield was accompanied by comparatively low stability as compared to the rest of the cultivars. Concerning cultivar Atila, the observed productivity was lower than the productivity of Bumerang, but close, and in combination with interaction with the environment with opposite values. Cultivar Kolorit, on its part, was characterized by yields close to the mean, averaged for the period of study but at the same time its interaction with the environment was exceptionally high.

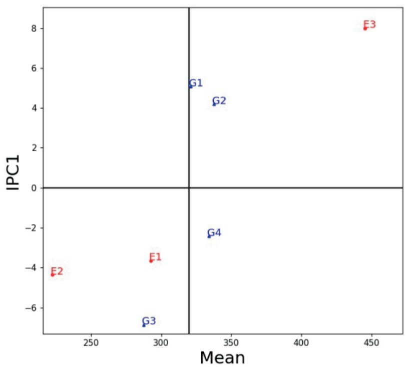

Figure 1. AMMI1 Biplot for fertilization level N_0
(G1-Kolorit; G2-Bumerang; G3-Respekt; G4-Atila; E1-2014/2015; E2-2015/2016; E3-2016/2017)

The results from the AMMI analysis for all four levels of nitrogen nutrition (Figure 5) allow characterizing not only the individual genotypes by their ability to interact with the environment, i.e. to assess in a sense their stability, but also to estimate the degree, to which each combination of year conditions with fertilization relates to the occurrence of genotype interaction.

The highest negative interaction with the genotypes was that of the year conditions during 2014/2015 and 2015/2016 under level N0, and the highest positive – of the year conditions in 2014/2015 and 2016/2017. Respectively, these were the conditions of the environment, under which the lowest and the highest yields were obtained, averaged for the four studied genotypes.

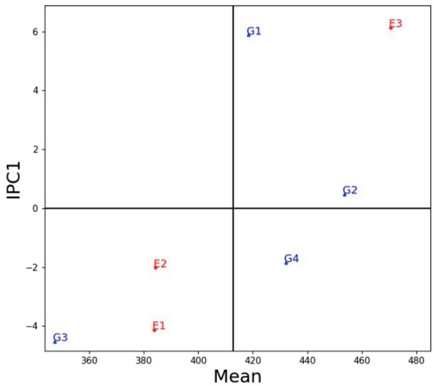

Figure 2. AMMI1 Biplot for fertilization level N_6
(G1-Kolorit; G2-Bumerang; G3-Respekt; G4-Atila; E1-2014/2015; E2-2015/2016; E3-2016/2017)

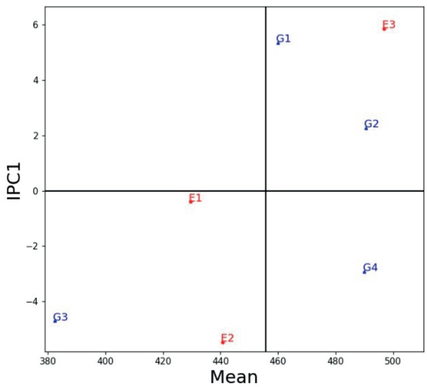

Figure 3. AMMI1 biplot foe reftilization level N_{12}
(G1-Kolorit; G2-Bumerang; G3-Respekt; G4-Atila; E1-2014/2015; E2-2015/2016; E3-2016/2017)

The conditions of 2014/2015 had the lowest interaction with the genotypes under level N12, and to some degree – the conditions of 2014/2015 and 2015/2016 under level N6.

The other combinations of environmental conditions with norms of nitrogen fertilization had comparatively moderate interactions with the genotypes. A tendency was observed of negative to positive change of the interaction with the higher nitrogen norms. A tendency was also observed of cultivar Bumerang having the lowest interaction with the conditions under all levels of nitrogen fertilization in 2016/2017 growing period.

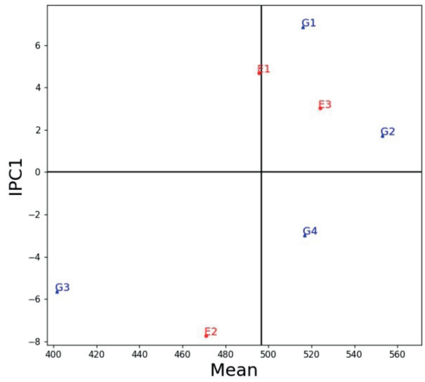

Figure 4. AMMI1 biplot for fertilization level N_{18}
(G1-Kolorit; G2-Bumerang; G3-Respekt; G4-Atila; E1-2014/2015; E2-2015/2016; E3-2016/2017)

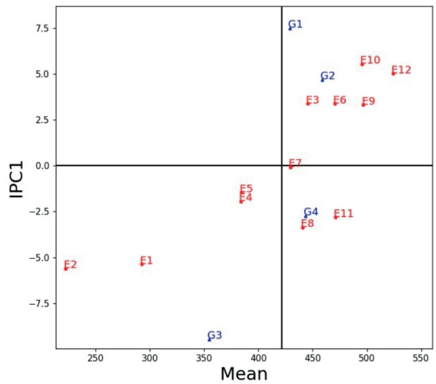

Figure 5. AMMI1 biplot for all levels of fertilization and years
(G1-Kolorit; G2-Bumerang; G3-Респект; G4-Atila; E1-2014/2015, N_0; E2-2015/2016, N_0; E3-2016/2017, N_0; E4-2014/2015, N_6; E5-2015/2016, N_6; E6-2016/2017, N_6; E7-2014/2015, N_{12}; E8-2015/2016, N_{12}; E9-2016/2017, N_{12}; E10-2014/2015, N_{18}; E11-2015/2016, N_{18}; E12-2016/2017, N_{18})

The lowest was the interaction of cultivar Atila with the conditions of 2015/2016 under levels N12 and N18. Kolorit and Respekt were at a significant distance from any combination of year conditions with fertilization norm. This was an indication of their rather low stability and narrow adaptability to the more favorable and more unfavorable environments, respectively. The low response of Bumerang's interaction to multiple specific periods revealed its wider adaptability to the conditions of the year, respectively, and also to the different norms of nitrogen fertilization. Similar was the response of cultivar Atila, but its adaptability was comparatively narrower and tended towards the more unfavorable conditions.

Discussions

The analysis of the cultivars in a series of statistical analyses allowed evaluating their yield and characterizing their adaptability and stability in response to the conditions of the environment. A peculiarity of the parameters for evaluation of the stability and adaptability under differing controlled factors (as a part of the growing conditions) was the possibility to identify tendencies and to determine the genotypes valuable for practice with a view of the needed agronomy practices. The results we obtained undoubtedly showed that the higher norms of nitrogen nutrition increased productivity regardless of the investigated cultivar. At the same time, under all norms and year conditions, the values of the yield from the studied triticale cultivars were within the range normal for this crop. This was also confirmed by the results obtained from our previous researches on the same or similar varieties (Baychev, 2006; Baychev, 2009; Baychev and Petrova, 2011; Baychev, 2012; Stoyanov and Baychev, 2016; Stoyanov et al., 2017; Stoyanov and Baychev, 2018; Stoyanov, 2018; Stoyanov, 2020a; Stoyanov, 2020b, Stoyanov, 2022; Stoyanov and Baychev, 2021; Muhova and Kirchev, 2020; Dobreva et al., 2018), and from foreign studies on other genotypes under different environments (Bespalova et al., 2012; Ponomarev, 2012; Borovik, 2016; Abdelaal et al., 2019; Lalević et al., 2019; Babaitseva et al., 2021). A peculiarity of the four investigated genotypes was their tendency towards maintaining their ranking by mean productivity regardless of the applied norm of nitrogen nutrition. This related to the lower effect of the genotype x environment interaction, although under its definite presence. Stoyanov (2018) and Stoyanov (2022) demonstrated that cultivars Bumerang and Atila were with higher productivity than cultivar Kolorit, while cultivar Respekt was characterized by rather low productivity under variable environments, the ranking of these genotypes being different under contrasting conditions.

The results of Dobreva et al. (2018) confirmed our data on the four cultivars, observing an identical tendency when investigating them under the same fertilizer norms, but in variants with and without leaf fertilization - towards productivity increasing with the higher nitrogen norms. Addy et al. (2020) also confirmed that the yield values increased with the increase of N input. Bielski et al. (2020), too, observed higher grain yields with the higher nitrogen norms. These authors reported that the yield at norm 16 kg N was higher than the yield at fertilization with 12 kg N da, but, similar to the results from our research, the difference was not significant. Usevičiūtė et al. (2022) observed increase of the yield from spring triticale after applying combined NPK fertilizer in comparison to the untreated check variant; they also found that the increased amount of the applied organic charcoal from pines increased the productivity of the genotype they investigated, too.

The results from the above studies undoubtedly support the results we obtained. On the other hand, however, the tendencies of yield change were not identical for the individual cultivars under different levels of fertilization (Figure 6) related to their differing stability.

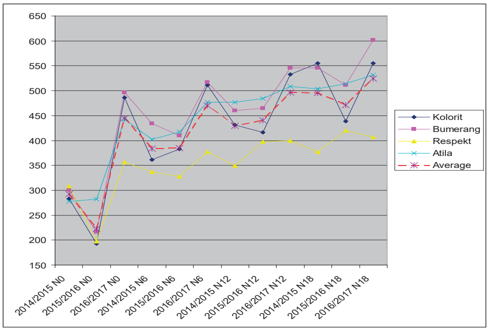

Figure 6. Tendency in the yield of the studied triticale cultivars under different year conditions and norms of nitrogen nutrition

Obtaining high yields from the crop plants is, on the one hand, related to the growing of cultivars, which are adapted to certain soil and climatic conditions (Stoyanov, 2020a). On the other hand, however, certain changes in the technology of growing can destabilize the yields form a given genotype relative to the conditions of the environment.

The results from the dispersion analysis over fertilization levels and in total revealed a definite tendency of lower effect of the year conditions with the higher fertilizer norms. It was also evident that the effect of the cultivar increased with the increase of the fertilization norm. A possible explanation of this tendency is that the genotypes differed in the absorption and utilization of N depending on the environment (Belete et al., 2018). Such a phenomenon is understandable since soil and moisture are important for the nitrogen fertilizer uptake in direct relation to the meteorological conditions. On the other hand, the genotype exercises its influence through its ability to develop under certain conditions, the nutrients uptake being in direct relation to the well-formed roots typical for each variety. Generalized for this study on the variance of yield, the effect of the year conditions was dominant, which was normal for such a crop as triticale. In world literature, a small number of researches on triticale investigated the stability and adaptability of yield and its components under different levels of nitrogen nutrition. While investigating Bulgarian triticale cultivars by the method of Eberhart and Russell, Kirchev et al. (2016) found out that the regression coefficient in the variant without fertilization varied among the cultivars; in two of them (AD-7291 and Zaryad) it tended towards narrow adaptability to the more unfavorable conditions of the environment, in another two (Sadovets and Rozhen), the values showed close to wide adaptability, and in cultivar Rakita narrow adaptability to the favorable conditions was observed.

This tendency was not present under the other levels of fertilization, with the exception of cultivar Rakita. Quite impressive is the fact that with the increase of nitrogen nutrition, the observed regression coefficients also increased, and at the highest level (18 kg/dca), they were close to 1.00 in four of the five studied cultivars. Not all cultivars demonstrated this tendency; the regression coefficients of some of the genotypes became even lower with the higher nitrogen norms. In Kolorit and Bumerang, the regression coefficient increased with the increase of nitrogen nutrition, while in Respekt and Atila it decreased. Such a phenomenon can be explained by the fact that under unfavorable environments the productivity of Atila and Respekt changed to a much lesser extent in comparison to the favorable environments, while in Kolorit and Bumerang the favorable conditions of the environment caused much higher values of the yield (Figure 6).

Concerning stability, the same study (Kirchev et al., 2016) showed that the mean square deviation of the regression increased with the higher nitrogen nutrition.

The results obtained from the AMMI analysis confirmed to some extent the tendencies of values b_i and s^2_{di}. Kolorit was in a strong interaction with the conditions of the environment, with rather variable yields and narrow adaptability to favorable conditions of the environment. On the other hand, Respekt showed similar results, although opposite in direction, related to this cultivar's narrow adaptability under unfavorable environments. This thesis was also confirmed by the fact that in the absence of nitrogen nutrition, cultivar Respekt was characterized by higher productivity, but only under the conditions of harvest year 2015. The results reported by Oral (2018) from an AMMI-analysis on an experiment including two triticale genotypes, two vegetative growth seasons and five norms of fertilization, show that the two genotypes reacted similarly to Respekt and Kolorit, in opposition to each other.

At the same time, a similar tendency was also observed – the IPCA value increased with the higher nitrogen nutrition, when it affected positively the yield. Paderewski et al. (2016), when expanding the AMMI model with the aim to study more complex relationships, demonstrated that the investigation on different agronomy practices led to the division of certain mega-environments, and to the identification of the narrow adaptability of the genotypes to specific regions, way of growing or climatic conditions.

The use of a similar analysis in this study allowed the definite characterization of cultivar Bumerang as comparatively more widely adaptable because of its comparatively low interaction with some fertilizer norms and with certain year conditions. A narrower adaptability was observed in Atila under some of the lower norms. The obtained results clearly demonstrated the excellence of cultivar Bumerang as widely adaptable and comparatively stable, but also high-yielding, relative to the other three studied genotypes. At the same time, regardless of the applied nitrogen nutrition, this genotype was with the best response under more favorable conditions of the environment.

On the other hand, the high productivity of such a genotype as Atila, in combination with similar stability but narrower adaptability to unfavorable growing conditions allowed the cultivar to realize high productivity under meteorological conditions differing form the long-term tendency, but under higher nitrogen nutrition levels. This peculiarity gives good reasons to reintroduce cultivars Atila and Bumerang in mass production and distribute them in the various soil and climatic regions of Bulgaria.

CONCLUSIONS

Based on the above results, the following conclusions can be made:

1. During the investigated economic years, the triticale cultivars differed by their mean productivity, harvest year 2016/2017 being the most favorable for growing of the crop. Cultivar Bumerang was characterized by the highest productivity, averaged for the period of study, while the lowest yields were that of cultivar Respekt.
2. The highest productivity of the cultivars was observed at level of fertilization 18 kg/da nitrogen; this was valid for all cultivars, regardless of the growing conditions, indicating the high potential of the crop for intensive growing.
3. A tendency was observed towards higher effect of the genotype and lower effect of the year conditions with the higher levels of nitrogen fertilization, while the effect of the genotype x environment interaction remained almost constant.
4. The widest adaptability (tending towards narrow under favorable conditions of the environment), regardless of the fertilizer norm, was that of cultivar Bumerang; cultivar Kolorit was with very narrow adaptability to favorable conditions, while Atila and Respekt demonstrated a narrower adaptability to unfavorable environments. A tendency was observed in Kolorit and Bumerang towards higher values of b_i with the higher fertilizer norms, while in Atila and Respekt this value decreased.
5. Cultivar Bumerang was with the highest stability, averaged for the experiment, Kolorit was with the lowest, while Atila and Respekt were with similar results with regard to s^2_{di}. Based on the AMMI carried out, Bumerang and Atila had the lowest interaction with the environment.
6. A tendency was observed in cultivar Bumerang towards lower interaction with the environmental conditions under all levels of nitrogen nutrition in economic year 2016/2017, and in cultivar Atila towards the lowest interaction with the conditions of economic year 2015/2016 at levels N12 and N18. Except for the variant without fertilization, both cultivars had comparatively stable responses to the other fertilizer norms, which makes them suitable for growing under the varied soil and climatic conditions of Bulgaria and under different regimes of nitrogen nutrition.

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