Achievements and tendencies in the breeding of triticale (×*Triticosecale* Wittm.) in Bulgaria

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Abstract
Breeding of triticale (×*Triticosecale* Wittm.) in Bulgaria has a history of more than 50 years. As a result of the experience in the breeding of this crop, the hexaploid secondary winter triticale forms are primarily used in Bulgaria. During the last decade, 11 cultivars were registered, which were distributed according to the specific soil and climatic conditions of the country. With the aim to determine their specific response to the growing conditions, their development during nine economic years was followed in a competitive varietal trial. The parameters days to heading, plant height, number of productive tillers per square meter, absolute and relative yield, number of grains per spike, weight of grains per spike, 1000 kernel weight and test weight were studied. Based on the obtained results, the main tendencies demonstrated by the investigated parameters were formulated. The eleven studied cultivars had later heading in comparison to the average standard (formed by the values of cultivars Vihren and Rakita) and followed a tendency toward lower plant height. In contrast to the standard cultivar Lasko and cultivar Presto, the yield from cultivars Kolorit, Akord, Respekt, Bumerang, Irnik, Dobrudzhanets, Doni 52 and Blagovest was formed mainly by the greater number of grains per spike and the 1000 kernel weight, while the number of productive tillers was of secondary importance. Cultivars Atila, Lovchanets and Borislav were exceptions from this tendency. During the investigated 9-year period, all cultivars exceeded the average standard and Lasko by yield with 9-20%, and Presto – with 5-13%. These results make triticale breeding in Bulgaria very promising, with a tendency toward an on-going increase of the productivity potential of this crop.

Keywords: competitive varietal trial; Bulgarian triticale cultivars; triticale breeding

INTRODUCTION

The cereal crops occupy the greatest share of the plant raw materials market, their purpose being use as food and forage (OECD/FAO, 2016). Therefore, the constantly increasing world population, the economic development and the peculiarities of the market economy are the reason their breeding to be characterized as the most complex and dynamic (Araus et al., 2008). In such crops as wheat, rice, barley and triticale, a constant improvement of various parameters related to the yield and the tolerance to biotic and abiotic stress is being observed (Khush & Virk, 2000; El-Hashash & El-Absy, 2019; Mergoum et al., 2019; Mourad et al., 2019; Rao et al., 2019). These peculiarities form clear breeding tendencies toward yield increase, stability and plasticity of the new developed varieties (Randhawa et al., 2015; Mergoum et al., 2019).

Triticale is the first cereal crop developed by man through the methods of distant hybridization (Mergoum et al., 2019). Although its share in production is comparatively lower than that of wheat, the improvement work on this crop is gaining certain achievements (Randhawa et al., 2015; Mergoum et al., 2019). Tsvetkov (1989) noted that as early as 1976 triticale was not already a plant for purely genetic investigations but a regular crop in production. This fast progress in the early years of the breeding of the crop was a result from the work of Borlaug,

Zielinsky, Kiss, Wolski, Shoulyndin etc. (Tsvetkov, 1989; Mergoum et al., 2003; Randhawa et al., 2015).

Being a typical cereal crop, triticale also demonstrates certain tendencies with regard to breeding. In the 80's and 90's of the 20th century, due to improvements in the breeding process, the developed triticale genotypes exceeded wheat and rye by yield (Tsvetkov, 1989). At the same time, the mean productivity of the tested lines rapidly increased (Mergoum et al., 2003). The increase of grain yield from triticale during 1985 – 2002 according to Salmon et al. (2003) was with more than 0,01 t/ha per year, observing in parallel with this a constant increase of the areas planted with this crop. Mergoum et al. (2003) pointed out that test weight also followed the tendency towards increase after the Mexican triticale variety Armadillo was developed. In parallel with this, higher 1000 kernel weight is observed in this crop as well. Randhawa et al. (2015), too, reported a permanent yield increase in new triticale cultivars included in the International Triticale Yield Nursery. These data and the results obtained by a large number of researchers within multiple breeding programs (Benbelkacem, 2003; Cooper et al., 2003; Salmon, 2003; Bona, 2003; Arseniuk & Oleksiak, 2003; Bespalova et al., 2012; Borovik, 2016; Grabovets & Krohmal, 2019; Kirchev, 2019) are a proof of the great achievements in triticale for a comparatively short time.

Breeding of triticale in Bulgaria, similar to other pioneering countries, has been carried out for more than 50 years now (Baychev & Stoyanov, 2019). During this period, over 15 cultivars were developed, 11 of them after 2000. The new generation of triticale cultivars expressly follow a tendency towards increase of the yield and the values of its components. (Stoyanov et al., 2017). The data provided by Baychev (2006, 2009, 2012, 2013[b], 2014), Baychev & Petrova (2009, 2011), Baychev & Stoyanov (2019), Stoyanov et al. (2022[a], 20022[b]) showed that during the period of their release and distribution good results were achieved, making them suitable for growing under the soil and climatic conditions of Bulgaria. Regardless of the achievements of the Bulgarian breeding, the constantly changing environment sets a challenge to the productivity potential even of the genotypes with high plasticity and stability. Therefore, in order to maintain the tendency the new triticale cultivars to give higher yields than the preceding ones, it is necessary to clearly determine both the tendencies themselves and the specificity of the cultivars already developed within the context of contrasting conditions of the environment. Thus, those achievements of Bulgarian breeding will be identified, which would be the basis for upgrading the components of yield.

The aim of this investigation was to present the achievements of Bulgarian breeding of triticale, outlining the tendencies with regard to yield and its components.

MATERIALS AND METHODS

Plant material

The investigation involved 11 Bulgarian triticale cultivars, bred in Dobrudzha Agricultural Institute – General Toshevo (Table 1). Besides them, the Bulgarian standard varieties AD-7291, Vihren and Rakita were also included, as well as the Polish cultivars Lasko and Presto. The investigated triticale genotypes were grown as a whole area crop in 10 m^2 experimental plots, in four replications according to a standard block design within a competitive varietal trial. The trial was carried out for nine successive harvest years, 2006 – 2015. Sowing was mechanized, within the standard dates for triticale (10th – 15th October) at sowing density 550 seeds/m^2. The plots were harvested at full maturity, reading the yield from each of them separately.

Biometrical analysis

The number of productive tillers per m^2 was determined from each experimental plot using a 0.25 m^2 sampling frame. Plant height (cm), absolute yield (t/ha) and relative yield (RY, %), test weight (kg/100 L) and 1000 kernel weight (g) were also determined. The days to heading (number of days from 1st January), the number and weight of grains in spike (calculated according to a formula based on the number of productive tillers, 1000 kernel weight and yield, Stoyanov, 2018) were determined for each cultivar.

Statistical analysis

The results obtained from the cultivars in the field experiment were averaged and summarized by cultivar, year and studied parameters. The least significant differences were determined over years between the investigated genotypes based on the

Table 1. Triticale cultivars used in the 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

performed ANOVA. The evaluation of the cultivars was done according to parameters based on comparison to the standard triticale varieties – AD-7291, Vihren and Rakita, and to the Polish cultivars Lasko and Presto. The stability of the yield from the studied genotypes was assessed through the parameters variance of Shukla (Shukla, 1972) and ecovalence (Wricke, 1962). The tendencies in the yield, its components and the stability parameters were established on the basis of the comparative evaluation with the standard varieties, and also chronologically, based on the order of developing the cultivars. The studied cultivars were grouped according to their productivity after performing a cluster analysis. MS Office Excel, 2003 and 2013 was used for summarizing the data and for variation analysis, while for ANOVA and cluster analysis IBM SPSS Statistics 19 was involved.

RESULTS

Heading

Averaged for the 9-year period of testing, the cultivars reached heading stage for 125-132 days, the average value of the set being 129 days. Cultivars AD-7291, Vihren and Kolorit were with the earliest date to heading, while Lasko, Atila, Respekt, Lovchanets, Doni 52 and Blagovest – with the latest. The results obtained on heading indicated that the greater part of the studied genotypes fall within the group of the medium early cultivars. Only Respekt was significantly later. Sechnyak & Sulima (1984) pointed out that one of the serious shortcomings of the first triticale forms was their late maturation. This imposed the necessity to direct the parameter to earlier forms in order to avoid unfavorable phenomena. Therefore, a great part of the breeding programs directed the breeding process toward the earlier forms, as supported by data from Ittu & Saulescu (1998), Medvedev et al. (2012), Urazaliev & Aynebekova (2012) and Yurchenko et al. (2012). The results we obtained (Table 2) showed that the main tendency was the triticale varieties being with days to heading close to the average. In this respect, it is a significant breeding achievement that all investigated genotypes had days to heading earlier than the world standard Lasko.

Plant height

This parameter varied within 106-139 cm, and the average height of the investigated set of cultivars was 127 cm. The data for the 9-year period of study showed that shortest were cultivars Lovchanets, Doni 52, Blagovest and Borislav, and highest – the world standard Lasko, cultivars Presto, Kolorit, Atila and Bumerang. A tendency was observed the new developed varieties (Lovchanets, Doni 52, Blagovest and Borislav) to be shorter than the pre-

Table 2. Results for the investigated Bulgarian triticale cultivars during 2006 – 2015 by parameters

Accession	DH	PH, cm	NPT, psc/m^2	Y, t/ha	RY, %	M1000, g	NGS, psc	WGS, g	TW, kg/100L
AS = (V+R)/2	128	123	704	6.78	100.0	44.6	21.9	0.98	70.4
AD-7291	125	114	689	6.51	96.1	43.6	21.9	0.96	69.8
Vihren (V)	126	118	685	6.72	99.1	48.0	20.4	0.99	71.3
Rakita (R)	129	128	724	6.84	100.9	41.3	23.4	0.98	69.6
Lasko	130	139	745	6.77	99.9	42.1	21.7	0.92	72.5
Presto/Alamo	129	137	758	7.18	105.9	43.2	22.4	0.98	72.9
Kolorit	126	134	677	7.51	110.8	44.9	25.6	1.17	70.8
Atila	130	134	733	7.42	109.4	48.5	21.5	1.06	71.6
Akord	129	132	677	7.53	111.1	45.7	24.5	1.13	73.2
Respekt	132	129	738	7.41	109.2	43.3	23.4	1.02	73.1
Bumerang	129	135	694	7.72	113.8	45.1	24.9	1.12	73.1
Irnik	129	133	664	8.06	118.9	43.7	27.9	1.23	71.7
Dobrudzhanets	129	127	754	8.12	119.8	43.6	25.0	1.10	72.0
Lovchanets	130	121	878	8.00	118.0	41.5	21.9	0.91	70.7
Doni 52	130	123	709	7.85	115.8	44.5	25.2	1.13	73.9
Blagovest	130	106	746	7.69	113.5	42.5	24.3	1.04	73.0
Borislav	129	122	729	7.99	117.8	50.4	21.7	1.11	71.0
Average	129	127	725	7.46	110.0	44.5	23.5	1.05	71.9
LSD 5%	*0.9*	*4.5*	*24.9*	*0.254*	*3.75*	*1.26*	*0.97*	*0.046*	*0.63*
LSD 1%	*1.1*	*5.9*	*32.8*	*0.334*	*4.93*	*1.66*	*1.28*	*0.060*	*0.83*
LSD 0.1%	*1.5*	*7.5*	*41.9*	*0.427*	*6.29*	*2.12*	*1.63*	*0.076*	*1.06*

DH – days to heading, PH – plant height, NPT – number of productive tillers, Y – yield; RY – relative yield, M1000 – thousand kernels weight, TW – test weight, WGS – weight of grains in spike, NGS – number of grains in spike; AS – average standard.

ceding ones (Atila, Respekt and Bumerang). Data similar to ours have also been reported by Baychev (2013[a]). None of the investigated cultivars exceeded the world standard Lasko (139 cm), which can be considered a significant achievement. Such a tendency towards decrease in plant height has been registered in different breeding programs and has been observed in varied researches on the crop (Fossati et al., 1996; Ittu & Saulescu, 1996; Iñiguez & Pfeiffer, 1996; Salmon et al., 1996[a]; Salmon et al., 1996[b]; Mergoum et al., 1998; Ittu & Saulescu, 1998; Baychev, 1998; Kociuba, 2002; Dogan et al., 2009; Goyal et al., 2011; Cifci et al., 2010; Akinina et al., 2012; Kalmysh et al., 2012; Mut & Köse, 2018). Kroupin et al. (2019) pointed out that the decrease of plant height in triticale is the best way to solve the problem with lodging in this crop. Although lower height is often related to lower yield, Wolsky & Gryka (1996) reported that even in forms shorter than 100 cm, yields could be within the range 0,780 – 0,800 t/ha. Pfeiffer (1996), as early as 1992-1993 registered plant height within 119 – 145 cm in 1500 lines, corresponding to the data from the research on our cultivars.

Number of productive tillers

In contrast to the previous two parameters, the number of productive tillers varied within a much wider range – 664-878 tillers/m^2. The two standard varieties AD-7291 and Vihren were with the lowest values, and cultivar Lovchanets – with the highest. Cultivars Kolorit, Akord, Bumerang and Irnik

were close to the low values, while Lasko and Dobrudzhanets were close to the high ones, at a high level of statistical significance of the differences. At the level of the standard variety with better tillering - Rakita were cultuvars Atila, Respect, Doni 52, Blagovest and Borislav by their number of productive tillers. Significantly higher values of the parameter were observed in Presto, Dobrudzhanets and Lovchanets, cultivar Lovchents being with the highest significance. Under contrasting conditions of the environment and clearly expressed drought, Baychev (2013[a]) reported decrease in the values of this parameter. Oettler (1996), in a study on 36 genotypes, reported very low values of the parameter (202-444 tillers/m^2) at two different locations. The results from various breeding programs in this crop (Mergoum et al., 1998; Ittu & Saulescu, 1998; Laur et al., 2002; Cifci et al., 2010; Melnikova et al., 2012; Mut & Köse, 2018) show that the world tendency is toward increase of the parameter's values. Such a tendency was observed in the cultivars we investigated (Table 2). At the same time, a considerable breeding achievement is cultivar Lovchanets, the number of tillers of which exceed significantly the results from the other cultivars and the results obtained by other researchers, averaged for the investigated period (878 tillers/m^2).

Grain yield

Highest yield, averaged for the research period, was obtained from cultivars Irnik (8.06 t/ha), Dobrudzhanets (8.12 t/ha), Lovchanets (8.00 t/ha) and Borislav (7.99 t/ha), and lowest – from the standard varieties AD-7291 (6.51 t/ha), Vihren (6.72 t/ha), Rakita (6.84 t/ha), Lasko (6.77 t/ha) and Presto (7.18 t/ha). The best performing cultivar Dobrudzhanets significantly exceeded the average standard and the world standard Lasko with 19.8%, averaged for the 9-year period of study. The exceeding of the better standard was respectively with 18.7%, and of cultivar Kolorit – with 9%, which was significant at high levels ($p<0.001$). Ten out of the sixteen investigated cultivars (Atila, Akord, Respekt, Bumerang, Irnik, Dobrudzhanets, Lovchanets, Doni 52, Blagovest and Borislav) exceeded the average standard and cultivar Lasko by yield at all levels of significance of the differences. The researches of Baychev (2005), Baychev (2009), Baychev & Petrova (2009), Baychev & Petrova (2011), Baychev (2012), Baychev (2013[a]), Baychev (2013[b]), Vasileva et al. (2005), Stoyanov (2018), Baychev & Stoyanov (2019), Muhova & Kirchev (2020), Stoyanov et al. (2022[a]), Stoyanov et al. (2022[b]) confirm the tendency with regard of the yield from the studied cultivars. Pfeiffer (1996) reported that in testing of 1500 triticale lines, yields from 5.00 and 8.40 t/ha were obtained, the average value being 6.90 t/ha. Data from contemporary researches and results from triticale breeding programs (Barnett et al., 2006; Dogan et al., 2009; Goyal et al., 2011; Cifci et al., 2010; Dogan et al., 2011; Beres et al., 2012; Aydiev, 2012; Akinina et al., 2012; Bespalova et al., 2012; Goryanina & Goryanin, 2012; Kalmysh et al., 2012; Medvedev et al., 2012; Melnikova et al., 2012; Ponomarev, 2012; Shakirzyanov et al., 2012; Shishlova et al., 2012; McLeod et al., 2012; Borovik, 2016; Ramazani et al., 2016; Mut & Köse, 2018; Dimitrov et al., 2018; Bezabih et al., 2019; Grabovets & Krohmal, 2019; Neuweiler et al., 2019; Abdelkawi et al., 2020; Derejko et al., 2020; Schillinger & Archer, 2020; Feledyn-Szewczyk et al., 2020; Zenkina, 2020; Gorinoiu & Suhai, 2020; Bielski et al., 2020) demonstrated that the new developed varieties varied within 2.10 – 11.49 t/ha. The obtained averaged data on the studied cultivars show that these cultivars are ahead of the contemporary world tendencies. Similar data on older cultivars and lines have been obtained by Fossati et al. (1996), Bagulho et al. (1996), Haesaert & De Baets (1996a), Ittu & Saulescu (1996), de Carvalho (1996), Baychev (1998), Butnaru et al. (1998), Coutinho et al. (1998), Grib (1998), Tsvetkov (1998), Vajeika (1998), Yoshihira et al. (2002), Laur et al. (2002); Dhindsa et al. (2002), Grabovets (2002), Green (2002), Kronberga (2002), Tsvetkov & Vassileva (2002), Banaszak & Marciniak (2002), Ittu & Saulescu (2002) and Haesaert & De Baets (1996b). Nevertheless, since breeding of triticale is characterized by high dynamics (Stoyanov et al., 2017), and the yield is in practice the most important and complex parameter, its increasing is a permanent task. Results over 8.00 t/ha were observed in some new varieties (Bespalova et al., 2012; Kalmysh et al., 2012; Melnikova et al., 2012; Borovik, 2016; Grabovets & Krohmal, 2019). Regardless of this, cultivars like Bumerang, Doni 52 and Borislav are characterized by exceptionally high productivity, exceeding 9.00 t/ha in some harvest years. These cultivars possess high productivity potential, which can be considered and achievement of modern breeding.

1000 kernel weight

Under the conditions of the experiment carried out, the cultivars involved in the investigation formed M1000 in the range 41.3 – 50.4 g. Cultivars Borislav and Atila were with the highest values of the parameter, while Rakita and Lovchanets were with the lowest. Lasko, Lovchanets and Blagovest were equal to the standard Rakita. Values significantly higher than that of Rakita were observed in cultivars Kolorit, Atila, Akord, Respekt, Bumerang, Irnik, Dobrudzhanets, Doni 52 and Borislav. The exceeding in cultivar Borislav was with the highest level of significance. High values of this parameter were observed also in the standard Vihren. Similar data were obtained in other researches from previous years as well (Stoyanov & Baychev, 2018). Varughese et al. (1987) pointed out that the early forms of triticale were characterized by very low values of the parameter due to their shriveled grains. After cultivar Armadillo was introduced in the breeding programs, this parameter was improved considerably. The results from various studies (Pfeiffer, 1996; Ittu & Saulescu, 1996; Iñiguez & Pfeiffer, 1996; de Carvalho, 1996; Gogas et al., 1996; Salmon et al., 1996[a]; Salmon et al., 1996[b]; Ittu & Saulescu, 1998; Bakhshi et al., 1998; Kraska & Tarkowski, 1998; Baychev, 1998; Wolsky & Gryka, 1998; Laur et al., 2002; Dhindsa et al., 2002; Kociuba, 2002) showed that 1000 kernel weight in older triticale lines and cultivars was within 23.80 – 56.00 g (42.8-59.2 g according to Kociuba (2002)). In the newer genotypes, values within the range 33.0 – 57.3 g were observed (Dogan et al., 2009; Goyal et al., 2011; Cifci et al., 2010; Aydiev, 2012; Akinina et al., 2012; Vysotskaya et al., 2012; Medvedev et al., 2012; Ponomarev, 2012; Shishlova et al., 2012; Mut & Köse, 2018; Kızılgeçi, 2019; Neuweiler et al., 2019). In this respect, our results completely follow the world tendencies, only cultivar Borislav differing considerably. A peculiarity of this genotype is that 1000 kernel weight is a main component of its yield, and the main reason for its high yield.

Weight of grains in spike

In our study, the lowest values of these parameters were formed in cultivars AD-7291, Vihren, Rakita, Lasko, Presto and Lovchanets, and highest - in Kolorit, Akord, Bumerang, Irnik, Dobrudzhanets, Doni 52 and Borislav. Similar data have been obtained from other researches as well in different economic years (Baychev, 2013[a]). Cultivar Respekt was at the level of the average standard. Cultivars Kolorit, Akord, Bumerang, Irnik, Dobrudzhanets, Doni 52 and Borislav significantly exceeded the average standard by this parameter. Cultivars Lasko and Lovchanets were with significantly lower values than the average standard. The two used standards of wheat type AD-7291 and Vihren were also with low values, 0.96 g and 0.99 g, respectively. The tendency observed in the obtained results showed that the new developed cultivars had higher values, but were tending towards the average of the investigated set of cultivars. In fact, this parameter is rather complex and its enhancing is related to considerable difficulties. Data from various researches (Kraska & Tarkowski, 1998; Kociuba, 2002; Dogan et al., 2009; Medvedev et al., 2012; Melnikova et al., 2012; Ponomarev, 2012) demonstrated that the parameter varied within the range 1.7 – 3.8 g. Under the conditions of our experiment, significant values were read in cultivars Kolorit (1.17 g) and Irnik (1.23 g), which is a serious achievement according to the studied standards and the world standard Lasko. It should be emphasized, however, that this parameter is strongly influenced at high levels of abiotic stress, especially under drought (Stoyanov, 2018). Giunta et al. (1992) and Erekul & Köhn (2006), confirm this thesis.

Number of grains in spike

Similar to the previous parameter, number of grains in spike varied within a rather wide range: from 20.4 to 27.9. Cultivars Atila, Lovchanets and Borislav were with the lowest values, and cultivars Kolorit and Irnik – with the highest. Close to the low values were the two standards AD-7291 and Vihren, and the world standard Lasko, and to the high ones – the standard Rakita. Cultivars Presto and Respekt were at the level of the standard with the better seed set (Rakita). Significantly higher values of the parameter were observed in cultivars Kolorit, Irnik and Doni 52, at the highest level of significance, while cultivars Lasko, Atila, Lovchanets and Borislav were with significantly lower values. Quite impressive were cultivars Kolorit and Irnik, which had spikes with high number of seeds. The tendency determined on the basis of the obtained results revealed that the breeding of the new cultivars was directed towards higher values of the parameter number of grains in spike. In this respect, out

of the sixteen investigated cultivars, nine were with higher number of grains in spike in comparison to the world standard Lasko, and this can be considered an excellent achievement of triticale breeding in Bulgaria. The data of a large number of researchers (Ittu & Saulescu, 1996; Iñiguez & Pfeiffer, 1996; Ittu & Saulescu, 1998; Laur et al., 2002; Dhindsa et al., 2002; Kociuba, 2002; Dogan et al., 2009; Cifci et al., 2010; Vysotskaya et al., 2012; Ponomarev, 2012) also point towards a tendency of higher values of this parameter.

Test weight

For test weight, serious differences were not observed and the variation was significantly lower under the conditions of the experiment carried out. The cultivars with the highest test weight were Akord (73.2 kg/100 L), Respekt (73.1 kg/100 L), Bumerang (73.1 kg/100 L) and Doni 52 (73.9 kg/100 L), and those with lowest - Kolorit (70.8 kg/100 L) and Lovchanets (70.7 kg/100 L). These two cultivars did not form a significant difference according to the average standard; they also were with a significant lower test weight than the better standard (Vihren). Cultivars Atila, Akord, Respekt, Bumerang, Irnik, Dobrudzhanets, Doni 52 and Blagovest exceeded the average standard at the highest level of significance of the differences. Cultivars Akord, Respekt, Bumerang, Doni 52 and Blagovest were above the better standard (Vihren) at the highest level of statistical significance (α=0.001). However, the cultivars exceeding the world standard Lasko by this parameter were only two – Akord and Doni 52. This confirmed the high degree of conservatism of test weight. Different researches determined cultivar Presto as characterized by very high values (Kucerova, 2007). Cultivar Doni 52, for the 9-year period of growing, significantly exceeded the results obtained on Presto. This is an exceptional achievement of the Bulgarian triticale breeding program demonstrating that test weight could also be considerably improved. The rest of the cultivars tended towards the average value of the investigated set. In different researches on this crop (Pfeiffer, 1996; Fossati et al., 1996; Baier, 1996; Salmon et al., 1996[a]; Salmon et al., 1996[b]; de Carvalho, 1996; Ittu & Saulescu, 1998; Bakhshi et al., 1998; Baychev, 1998; Wolsky & Gryka, 1998; Abdelkawi et al., 2020), typical values of this parameter were observed – between 66 and 81 kg/100 L, which confirmed the tendency for the greater part of the cultivars we investigated.

DISCUSSION

Varughese et al. (1996) pointed out that if the breeding tendency remained the same until 1997, triticale would reach the productivity potential of wheat. Tsvetkov (1989) concluded that as early as the International Symposium on triticale in 1976, the conviction was confirmed that triticale had passed the barrier of a plant grown for purely genetic investigations and already was a regular production crop in many countries worldwide. Mergoum et al. (2009) determined that the productivity potential of the developed triticale lines exceeded 10 t/ha. Randhawa et al. (2015) confirmed that the productivity potential of triticale was considerably higher than that of the other cereals. These authors pointed out that to increase the yields from this crop, it was necessary to realize multiple goals, the first of which was decreasing the production risks and expenses, while increasing the economic rate of return per unit area. The conclusions of these authors showed that triticale follows a tendency towards increasing its productivity, while at the same time there remain significant problems to be solved. Stoyanov (2018) pointed out that at the International Symposium on Triticale carried out in Szeged, Hungary, the conviction was formed, that at the current stage the problems related to triticale were three: the increasing susceptibility to yellow rust, the insufficient genetic variability and the low tolerance to abiotic stress.

The high productivity potential of the Bulgarian triticale cultivars, averaged for a 9-year period of study, show that they are adapted to a wide range of environmental conditions. Particularly impressive are cultivars Akord, Dobrudzhanets and Doni 52. Besides their high productivity, these cultivars are also medium early, with optimal plant height, values of 1000 kernel weight and number of grains in spike close to the average, with high test weight. Such values demonstrated that the investigated cultivars responded well to a variety of abiotic stress factors. In this respect, Baychev (2013[a]) observed some variation in contrasting periods of growing, without the productivity potential of the crop being considerably reduced. This thesis was also confirmed by the data obtained on the stability parameters of the studied

cultivars (Table 3). A clear tendency was observed the new varieties having higher yield stability, as determined by the Shukla variance and the ecovalence data. The use of other approaches for investigation on the stability (Stoyanov & Baychev, 2016[a]; Stoyanov & Baychev, 2016[b]; Stoyanov et al., 2017; Stoyanov, 2018) confirmed our results with regard to the studied cultivars.

The results on the stability of the yield, however, according to Stoyanov & Baychev (2016[b]), did not follow the tendencies in the stability of its components. The authors pointed out that the studied cultivars differed by the stability of the separate components. Thus, for example, the number of grains in spike was a more stable parameter in cultivars Respect, Lovchanets and Borislav, while in the rest of the cultivars a significantly more stable component was 1000 kernel weight. According to the authors, such data are related to a different way of formation of productivity. The data we obtained clearly showed that in cultivars such as Borislav, 1000 kernel weight was a determining component. On the other hand, in Kolorit and Irnik the high productivity was related to a very high seed set. Markedly different were cultivars Lasko and Lovchanets, in which the number of productive tillers per m^2 had a leading role for the formation of productivity. On the other hand, yet another tendency was observed in the cultivars with the highest stability of productivity such as Akord, Doni 52 and Blagovest, in which no particular yield component stood out. This demonstrated that the genotypes possessed balanced productivity allowing lower response to unfavorable conditions of the environment. Regardless of the above data, a tendency was observed in the investigated cultivars toward a positive change of both the yield and its components.

Table 3. Productivity and stability of the studied Bulgarian triticale cultivars

Cultivar	Average yield	W_i^2	S_i^2
AD-7291	6,51	9,81	1,37
Vihren	6,72	7,21	1,00
Rakita	6,84	5,62	0,77
Lasko	6,77	5,85	0,81
Presto	7,18	3,39	0,46
Kolorit	7,51	1,99	0,26
Atila	7,42	1,84	0,23
Akord	7,53	0,46	0,04
Respekt	7,41	3,53	0,48
Bumerang	7,72	0,98	0,11
Irnik	8,06	0,62	0,06
Dobrudzhanets	8,12	1,75	0,22
Lovchanets	8,00	3,05	0,41
Doni 52	7,85	0,18	0,00
Blagovest	7,69	0,31	0,02
Borislav	7,99	0,87	0,10

W_i^2 – Wricke's ecovalence; S_i^2 – Shukla's variance.

The tendencies in the productivity can also be followed in the grouping of the cultivars through cluster analysis (Figure 1). The standard cultivars AD-7291, Vihren and Rakita and the world standard Lasko were grouped in a common cluster. They possessed lower productivity and considerably less favorable combination of the yield components. The new cultivars Kolorit, Atila, Akord, Respekt, Bumerang, Doni 52 and Blagovest formed a separate cluster, indicating that their productivity was rather different from that of the standards. They were characterized with a balanced combination of heading, plant height, number of productive tillers, 1000 kernel weight and number of grains in spike tending towards the average values for the crop. On the other hand, Borislav, Lovchanets, Dobrudzhanets and Irnik fell within a separate group related to the fact that during the 9-year period of research these cultivars demonstrated the highest yields regardless of the differences both in the formation of their productivity and of yield stability. In these cultivars, a specific component of yield stood out, considerably differentiating them from the rest of the cultivars.

The results obtained from this investigation revealed the high efficiency of the breeding process of triticale in Bulgaria. The results of a large number of researchers (Barnett et al., 2006; Dogan et al., 2009; Goyal et al., 2011; Cifci et al., 2010; Dogan et al., 2011; Beres et al., 2012; Aydiev, 2012; Akinina et al., 2012; Bespalova et al., 2012; Goryanina & Goryanin, 2012; Kalmysh et al., 2012; Medvedev et al., 2012; Melnikova et al., 2012; Ponomarev, 2012; Shakirzyanov et al., 2012; Shishlova et al., 2012; McLeod et al., 2012; Borovik. 2016; Rama-

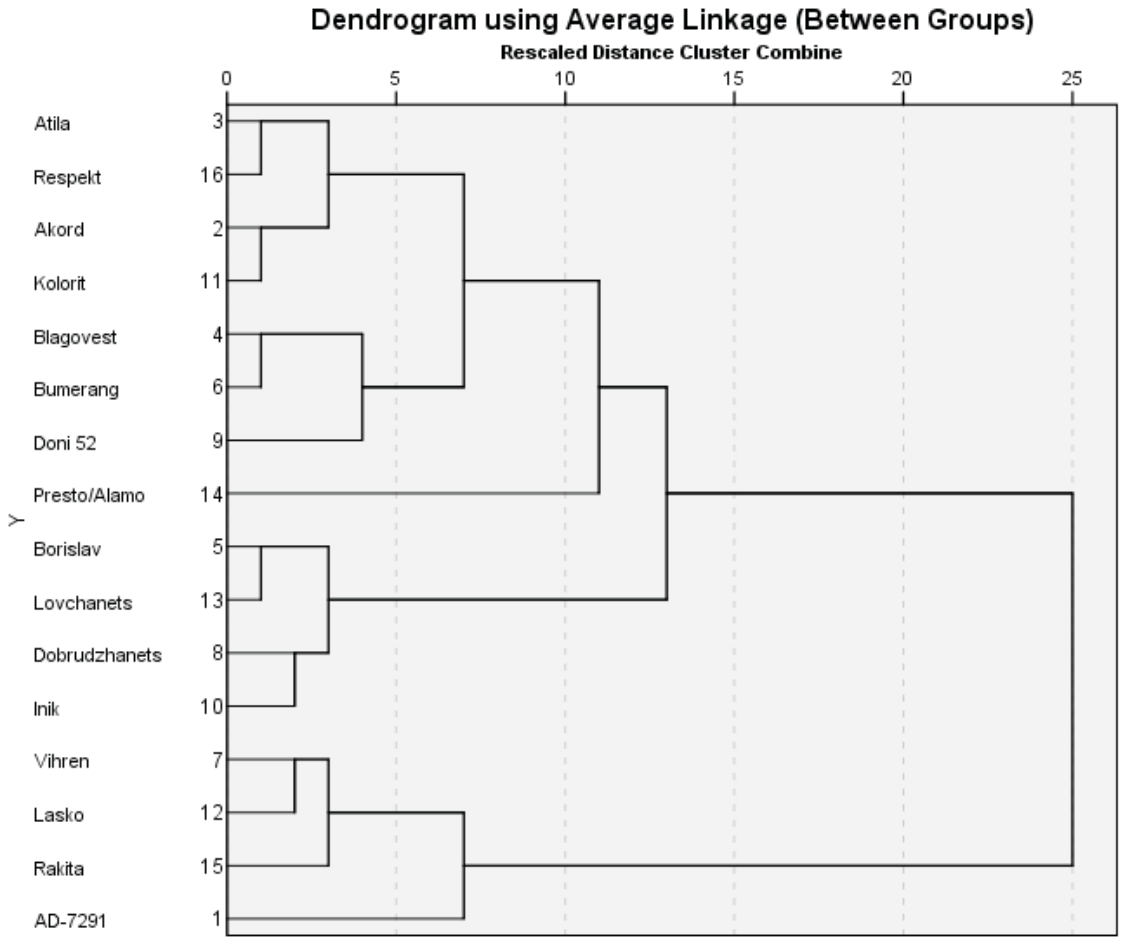

Figure 1. Dendrogram of cluster analysis on the yield of the studied triticale cultivars

zani et al., 2016; Mut & Köse, 2018; Dimitrov et al., 2018; Bezabih et al., 2019; Grabovets & Krohmal, 2019; Neuweiler et al., 2020; Abdelkawi et al., 2020; Derejko et al., 2020), compared to our data, expressly emphasize the fact that Bulgarian breeding follows and in certain aspects overtakes the world tendencies in the different directions related to the productivity of the crop.At the same time, the investigations of Stoyanov (2018) and Stoyanov et al. (2017) showed that the crop, besides being highly productive, also combines high levels of cold resistance and good tolerance to drought. The data of Stanoeva & Stoyanov (2020) demonstrated that triticale possessed resistance to different pathogens as well. Such results demonstrate that the Bulgarian triticale cultivars are a balanced combination of high productivity and stability and can be efficiently grown under the variable soil and climatic conditions of the country.

CONCLUSIONS

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

The eleven studied cultivars had later date to heading in comparison to the average standard (formed by the values of the cultivars Vihren and Rakita) and followed a tendency toward lower plant height. In contrast to the standard cultivar Lasko and cultivar Presto, the yield from cultivars Kolorit, Akord, Respekt, Bumerang, Irnik, Dobrudzhanets, Doni 52 and Blagovest was formed mainly by the greater number of grains per spike and the 1000 kernel weight, while the number of productive tillers was of secondary importance. Cultivars Atila, Lovchanets and Borislav were exceptions from this tendency. During the investigated 9-year period, all cultivars exceeded the average standard and Lasko by yield with 9-20%, and Presto – with 5-13%.

These results make triticale breeding in Bulgaria very promising, with a tendency toward an on-going increase of the productivity potential of this crop.

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