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Productivity of modern Bulgarian and Polish winter triticale varieties in three locations in Bulgaria

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Abstract. A comparative four-year field trial of triticale productivity was conducted in two climatic regions of Bulgaria. The work was carried out on the experimental fields of the scientific institutes in Sadovo, Chirpan and General Toshevo at the Agricultural Academy (Bulgaria). Ten triticale varieties - Bulgarian and Polish selections, were studied. Sowing for each variety was carried out on an area of 10 m² in 3 repetitions, after a predecessor of sunflower without applying fertilizers. Environmental conditions were assessed using the De Marton Index. Grain yield, the influence of the variety, the conditions of the year and the location were analysed, and the highest-yielding varieties for each agrometeorological region were identified. The significant differences in the mean values were calculated using the least significant difference (*LSD*) procedure and the significant *F-test*. The results showed that the effects of the variety, location and the total effect of the variety and location are similar and medium in size. The Avocado (5,357.0 kg ha^{-1}), Doni-52 (5,357.0 kg ha^{-1}) and Casino (9,231.0 kg ha^{-1}) varieties are underlined in terms of grain yield in the three regions, Chirpan, Sadovo and General Toshevo, respectively. The highest average yield was achieved in General Toshevo (7,452.0 kg ha^{-1}), followed by Sadovo (5,494.0 kg ha^{-1}) and Chirpan (4,918.0 kg ha^{-1}). 2021 was the most successful in terms of production, which is associated with semi-humid conditions in General Toshevo, Chirpan and Sadovo, according to the De Marton Index.

Key words: agrometeorological contitions, De Marton Index, grain yields.

INTRODUCTION

The main field crops with the largest share of production areas in Bulgaria are cereals. Triticale (×*Triticosecale* Wittmack) is a small-grain cereal product from wheat and rye crossbreeding. The German scientist Rimpau created the first fertile triticale plants in 1888 (Franke & Meinel, 1990). The crop has gained importance in the world economy due to low costs of grain production with a high level of profitability, high resistance to viral and fungal diseases, and ecological plasticity, which allows it to be grown in more extreme conditions compared to other crops, and an increased protein concentration of the essential amino acids (Zhu, 2018; Miedaner et al., 2022; Maksimov et al., 2023).

Triticale is well adapted to temperate environments, and its yield is more stable and less dependent on the weather conditions of the year than that of winter wheat (Derejko et al., 2021). As a foodstuff and fuel, it can be useful only when the growth environment is carefully considered. (Goverin et al., 2011). Modern selection is constantly offering new varieties and heterosis hybrids. However, not all of them are equally suitable for individual countries in the world or production regions (Stoyanov et al., 2024).

Agricultural production requires that crops be grown in an area where the potential of the environment provides the best possible conditions for the growth and development of crops and the possible yield (Stoyanov & Baychev, 2018; Neuweiler et al., 2020; Derejko et al., 2021). One of the conditions for high and stable grain yields is the cultivation of suitable varieties under favourable agroclimatic conditions, using proper agricultural techniques. Each individual region has its own characteristics regarding soil and meteorological factors. Bulgaria distinguishes several climatic regions, resulting in quantitative differences between climatic elements and their impact on field crops. The main field crops with the largest share of production areas in Bulgaria are cereals. According to data from the Ministry of Agriculture of Bulgaria, in 2023 there was an increase in harvested areas, production and average grain yield of 156.0%, 191.2% and 13.7%, respectively compared to 2013 (MZH 2013; MZH, 2024; MZH, 2025). New Bulgarian triticale varieties allow farmers to grow more productive varieties that achieve high and more stable yields (Stoyanov, 2024; Stoyanov, 2025). However, research is needed to determine the productivity of varieties in different regions of the country. Data on the achieved yield and communication of this information to farmers are important.

The aim of the study is to track the grain yield of triticale in three regions of Bulgaria and to differentiate the most productive varieties in each region.

MATERIAL AND METHODS

One-factor field experiments were conducted in the moderately continental region and the transient continental subarea region of Bulgaria (Sabev & Stanev, 1959). The experiments were situated in Chirpan (42.19813°N 25.33043°E), Sadovo (42.13038°N 24.93851°E), and General Toshevo (43.7°N 28.04°E), respectively Institute of Field Crops, Institute of Plant and Genetic Resources and Dobrudzha Agricultural Institute. This sites are located in the administrative regions of Dobrich (09), Stara Zagora (24) and Plovdiv (16) (Fig. 1). The study included four consecutive growing seasons: 2019–2020, 2020–2021, 2021–2022 and 2022–2023. The aim was to test the productivity of eight Bulgarian triticale varieties first registered in the period 2005–2016 (Colorit (Standart), Akord, Borislav, Blagovest, Doni-52, Dobrudzhanets, Irnik and Lovchanets), and two Polish triticale varieties (Avocado and Casino) under contrasting environmental conditions.

The experiments were set up in three replications with a plot size of 10 m². After harvesting the predecessor of the sunflower, appropriate pre-sowing soil treatments were applied in each region. In the hree locations, the soil was cultivated with a disk harrow twice. Sowing was done at a density of 550 seeds m^{-2} with small-sized selection seeder. An adopted technology for growing cereals was applied. Herbicides were applied in the spring to control broadleaf and cereal weeds, and insecticides were used if necessary. No mineral fertilizers were applied. The harvest was done at full maturity, using a small-sized combine harvester, and the yields were weighed from each plot and recalculated to kg ha^{-1}.

Figure 1. Climate zones and administrative organization in Bulgaria.

Note. From *Modelling of the temporal indoor radon variation in Bulgaria*, by K. Ivanova and Z. Stojanovska, 2019, *Radiation and Environmental Biophysics.* https://doi.org/10.1007/s00411-019-00789-y. Copyright 2019 by Springer-Verlag GmbH Germany, part of Springer Nature.

Sowing was late in Chirpan in 2020 and 2021, and in Sadovo in 2021. In General Toshevo in 2019, 2020, 2021 and 2022, due to late rains in thes region (Table 1).

Table 1. Sowing and harvesting dates by year and location

Periods	2019–2020		2020–2021		2021–2022		2022–2023	
Locations	sowing	harvesting	sowing	harvesting	sowinging	harvestingt	sowing	harvesting
Chirpan	23.10	03.07	05.11	13.07	15.11	06.07	18.10	07.07
Sadovo	15.10	30.06	21.10	10.07	09.11	30.06	13.10	07.07
G.Toshevo	03.11	17.07	12.11	20.07	10.11	25.07	08.11	20.07

The soil in Chirpan of the experimental field of the Institute of Field Crops is Pelic Vertisol. In the 0–20 cm layer, humus is of high content (3.8%), and total nitrogen (NO_3 and HN_4) is 0.20%. Phosphorus (P_2O_5) is represented by hardly soluble and poorly accessible to plants mobile phosphates; in the 0–30 cm layer, it is 6.1 mg per 1,000 g soil. Potassium is well supplied at 24.1 mg per 1,000 g. pH =6.5–7.4 (Panayotova, 2004a; Panayotova, 2004b; Panayotova, 2005).

The soil in Sadovo at the Institute of Plant and Genetic Resources is Pelic Vertisol. In the 0–30 layer the total nitrogen is 0.2%, phosphorus (P_2O_5) is 9.0 mg per 100 per g, and potassium content (K_2O) is favourable for plants (23.9 mg per 100 g). pH =6.3 in the 0–30 cm layer (Vasileva, 2007).

The soil in General Toshevo of the experimental field at the Dobrudzha Agricultural Institute is Haplic Chernozems, FAO (2014). In the region they are characterized as heavy sandy-clayey, with good structure, relative density of 2.65–2.70 and bulk density, which varies according to the treatments used (Yankov, 2005). The humus content in the cultivated areas oscillates between 2.92 and 3.57%, pH =6.6–7 (Nankova et al., 2005; Nankova, 2012).

Data were provided from the synoptic station in Chirpan and the meteorological stations in Sadovo and General Toshevo. The assessment of agrometeorological drought during the growing seasons (October-June) was made using the De Martonne index (I_{DM}) (Crespo-Cotrina et al., 2025). This indicator characterizes the humidification conditions of a given territory (Mitkov & Topliyski, 2019). The following formula was applied to calcutated De Marton's Index (I_{DMI}):

$$I_{DMI} = \frac{P}{T+10}, \quad (1)$$

where P is sum of precipitation for the growing period, t – average daily air temperature for the growing period. The following ranges of values for the De Marton Index were assumed: dry $I_{DMI} < 10.0$; semi-dry $10.0 \leq I_{DMI} \leq 20.0$; Mediterranean $20.0 \leq I_{DMI} \leq 24.0$; semi-humid $24.0 \leq I_{DMI} \leq 28.0$; humid $28.0 \leq I_{DMI} \leq 35.0$; exstremely humid (a) $35.0 \leq I_{DMI} \leq 55.0$; extremely humid (b) $I_{DMI} > 55.0$.

The obtained yield results were summarized and averaged by varieties, periods and regions of the study. The data were analyzed by applying ANOVA. Significant differences between individual genotypes, years of cultivation and regions were established. The Biostat software product was applied for the statistical processing of the data (Penchev et al., 1989–1991).

RESULTS AND DISCUSSION

The largest differences, in regard to air temperature in Chirpan, are observed in December and February in all periods, and in January 2023, according to reference values, when the average temperature was remarkably higher. The average temperatures for the period October-June are higher during 2019–2020, 2020–2021 and 2022–2023 than the reference value (9.5 °C), as can be seen in Table 2.

Table 2. Meteorological conditions during the investigated periods in Chirpan and reference period 1931–2000

Months	X	XI	XII	I	II	III	IV	V	VI	$t_{av.}$ (X–VI)
Average daily air temperature (°C)										
2019–2020	15.0	11.2	3.6	1.7	4.0	9.4	11.2	17.2	22.7	10.7
2020–2021	15.2	6.6	5.8	1.4	5.3	8.3	10.5	16.6	20.5	10.0
2021–2022	11.3	7.9	3.9	1.8	4.2	4.2	12.2	17.3	22.0	9.4
2022–2023	14.4	10.1	5.3	5.5	6.6	8.5	11.1	15.3	20.9	10.9
1931–2000	13.2	9.6	1.9	0.8	2.6	7.2	11.7	17.2	21.4	9.5
Sum of precipitation (mm)										(X–VI)
2019–2020	48.2	82.4	21.6	1.5	55.5	67.4	62.2	50.3	62.6	451.7
2020–2021	67.3	7.4	70.4	108.6	25.8	39.1	84.0	34.9	42.8	480.3
2021–2022	150.5	14.2	108.8	21.4	40.1	22.4	26.0	29.4	80.5	493.3
2022–2023	3.5	46.9	44.4	120.0	0.2	34.4	68.2	54.8	69.5	441.9
1931–2000	46.9	40.7	70.0	44.4	38.4	46.3	43.8	57.3	50.8	438.6

Regarding precipitation, excessive amounts were recorded in the autumn-winter period in January 2021, October and December 2022, and January 2023, and their amounts are 64.2, 106.6, 38.8 and 75.6 mm more than the climatic average. In April 2021 and June

2022, they exceeded the average data by 40.2 and 29.7 mm. Precipitation was scarce in January 2020, November 2020, October 2022 and February 2023. According to the data shown, their amounts are 42.9, 33.3, 43.4 and 38.2 mm lower relative to the reference values. According to I_{DM}, the vegetation periods are two Mediterranean (2019–2020 and 2022–2023) and two semi-humid (2020–2021 and 2021–2022) (Table 5), indicating alternating periods of adequate and limited moisture supply. This combination of warmer conditions and uneven rainfall distribution suggests that water availability rather than temperature probably constrained crop performance in this region.

Table 3. Meteorological conditions during the investigated periods in Sadovo and reference period 1931–2000

Months	X	XI	XII	I	II	III	IV	V	VI	t av. (X–VI)
Average daily air temperature (°C)										
2019–2020	14.8	10.7	4.1	2.2	6.1	8.9	11.8	18.2	21.6	10.9
2020–2021	15.1	6.7	5.7	3.3	5.8	5.8	10.9	18.6	22.3	10.5
2021–2022	11.0	7.8	4.0	3.3	5.0	4.9	13.7	18.5	23.0	10.1
2022–2023	13.9	9.6	5.6	5.7	6.0	8.7	12.0	15.7	21.8	11.0
1931–2000	12.6	6.9	2.1	-4.3	2.4	6.3	12.2	17.5	21.2	8.5
Sum of precipitation (mm)										(X–VI)
2019–2020	14.2	81.0	24.9	2.1	49.4	91.5	93.8	40.1	45.9	442.6
2020–2021	72.7	6.3	55.7	96.4	32.8	42.5	78.5	32.7	60.4	478.0
2021–2022	167.9	11.9	96.1	30.3	57.9	22.3	31.0	39.8	159.7	616.9
2022–2023	1.8	49.0	47.6	54.0	1.2	34.8	55.3	80.9	80.2	404.8
1931–2000	37.4	47.1	49.7	39.3	30.9	39.0	42.9	56.8	58.4	401.5

For the Sadovo region, the warmer winter period is noticeable, where the average temperatures in December, January and February during the four seasons were remarkably above the average for the multi-year period (Table 3). The average temperatures for the period October-June were higher than the reference value of 8.5 °C. Increased precipitation was recorded in November, March and April 2019–2020 - 33.6, 52.5 and 50.6 mm, respectively-more than the average. Similarly, in January 2021, October and December 2021, and June 2022, precipitation was abundant. For the indicated months, the amount is higher by 57.1, 130.5, 46.4 and 101.3 mm, respectively. In January and November 2020, October 2022 and February 2023, scanty precipitation was observed compared to the climatic average. According to the calculated drought index (I_{DM}), the periods are two semi-humid (2019–2020 and 2020–2021), one humid (2021–2022), and one semi-dry (2022–2023). (Table 5). Such variability implies that crop growth in this region depended strongly on annual moisture patterns. Warmer winters likely improved plant survival and early development, while the level of precipitation during spring probably determined the extent to which this early advantage translated into higher grain production.

In winter, remarkably higher average temperatures were recorded in General Toshevo (Table 4). In two of the seasons (2021 and 2022), the months of spring are cooler. The average temperatures for the whole growing season are higher than the reference value (10.2 °C). An excess of the amount of precipitation in 2020–2021 and 2021–2022 by 208.0 and 94.1 mm, respectively, is observed, due to an abundance of precipitation in winter and June 2020–2021, as well as in October, December and April 2021–2022. Conditions in 2022–2023 are contrasting, given the lowest amount of precipitation (255.0 mm) compared to the climatic average (388.3 mm). Thus, the periods 2019–2020 and 2022–2023 are characterised as semi-arid, 2020–2021 is Mediterranean, and within 2021–2022, the conditions are semi-humid. Despite this variability, temperatures during the growing seasons were generally favorable and consistently above the long-term averages, indicating that thermal conditions were not a limiting factor. Instead, differences in soil moisture supply, determined primarily by precipitation amount and distribution, likely drove the strong variability in crop performance observed at this site.

Table 4. Meteorological conditions during the investigated periods in General Toshevo, and reference period 1931–2000

Months	X	XI	XII	I	II	III	IV	V	VI	t av. (X–VI)
Average daily air temperature (°C)										
2019–2020	13.4	11.7	5.2	1.8	5.1	8.0	10.0	15.4	19.6	11.9
2020–2021	16.3	6.3	5.3	3.0	4.0	4.2	8.8	15.8	18.9	11.3
2021–2022	10.2	8.3	3.5	1.5	3.9	2.5	10.8	15.6	20.2	10.5
2022–2023	12.9	9.1	4.8	5.3	2.8	6.6	9.5	14.6	20.1	11.6
1931–2000	11.7	6.8	2.1	-0.1	1.3	4.7	9.9	15.2	21.9	10.2
Sum of precipitation (mm)										(X–VI)
2019–2020	27.6	35.4	21.8	2.8	28.1	28.3	5.8	48.0	192.2	390.0
2020–2021	52.9	26.0	74.4	109.7	13.2	22.2	44.6	63.6	162.7	596.3
2021–2022	91.6	42.4	89.2	31.4	30.8	19.0	76.0	25.6	76.4	482.4
2022–2023	6.0	29.4	28.4	29.0	7.4	38.8	79.0	34.2	2.8	255.0
1931–2000	42.5	42.9	42.7	37.3	33.3	35.1	41.1	51.5	61.9	388.3

It should be noted, compared to the climatic average for the three regions, higher average temperatures were observed during most of the growing seasons for the winter period, and redused precipitation during the autumn-winter period. The precipitation showed greater interannual variability, leading to contrasting hydrothermal conditions. During some growing seasons, lower average temperatures were observed in March and April, relative to the reference values. These fluctuations mainly occurred during the sowing and wintering period of the crop, in particular during the grain-filling period and, in Chirpan, also at the time of flowering.

Table 5. De Marton Index by locations and periods

Periods	Chirpan	Sadovo	General Toshevo
2019–2020	22.3	21.2	17.8
2020–2021	24.3	23.3	28.0
2021–2022	26.5	30.7	23.5
2022–2023	21.2	19.3	11.8

Table 6 presents the results by year. Compared to 2020, the average yield was highest in 2021 (27%), followed by 2022 (3.0%). The values in the indicated years are 7,528.0 and 6,105.0 kg ha^{-1}, significant at p =0.1% and p =5.0%. The characteristics by region showed that in 2021 the average yield from the locations was formed under the influence of Mediterranean and semi-humid conditions (Table 5). In addition, the large effect of the studied factors year (29.04***) and year×variety×location (5.04***) is confirmed (Table 12). The lowest yield was in 2023, and the value is statistically significant at $p < 0.001$ – 71.8% to the control. The differences can be explained by the agrometeorological conditions of the regions and the biotic and abiotic stress impacting the plants. In 2022–2023, and according to I_{DM}, semi-arid conditions were established in two of the locations - Sadovo and General Toshevo. These conditions are associated with a total precipitation during the period between 200 and 400 mm. The results therefore confirm the sensitivity of triticale productivity to seasonal variability in rainfall distribution. A study found a strong dependence of the variability of the yield on the availability of water for winter triticale (Wójcik-Gront et al., 2021).

Table 6. Influence of year on grain yield

Year	kg ha^{-1}	%/C
2020 (Contr.)	5,929.0	100.0
2021	7,528.0***	127.0
2022	6,105.0*	103.0
2023	4,255.0°°°	71.8
LSD		
5.0%	156	2.6
1.0%	206	3.5
0.1%	264	4.5

*, *** significance at P =5.0% and P =0.1%, respectively; °°° significance at $P < 0.001$.

The effect of the variety as an independent factor is relatively small (1.33%) (Table 12), but some varieties demonstred consistently high productivity. The relatively small contribution of the varietal factor compared with year and location suggests that environmental conditions played a dominant role in determining yield outcomes. Avocado (6,551.0 kg ha^{-1}), Doni (6,237.0 kg ha^{-1}) and Casino (6,038.0 kg ha^{-1}) are leaders in most years and locations and achieved the highest production, significant at p =1.0% and p =0.1% (Table 7). Avocado maintained high yield in all regions, which indicates good plasticity and stability under contrasting conditions. Doni-52 combined high productivity with stable performance, which makes it particularly suitable for variable climatic conditions. Casino, while also highly productive, appeared to rely more strongly on favorable environments, as shown by its higher yields in optimal conditions but weaker performance in less favorable locations. This support data from other authors (Derejko et al., 2020; Stoyanov, 2023) is according to which varieties with high adaptability can compensate for part of the negative impact of unfavourable climatic factors. For the Lovchanec variety, the lowest yield was recorded (5,774.0 kg ha^{-1}). According to the established coefficient of variation (8.9%), the yield did not differ significantly between the varieties. After a sunflower predecessor, irrigation conditions, without fertilization on reddish preluvosoil, two triticale varieties showed yields of 4,100.0 and 5,500.0 kg ha^{-1} (Dumbravă et al., 2016). A study by Jańczak-Pieniążek (2023) has shown that compared to the average grain yield of

Table 7. Influence of variety on grain yield

Variety	kg ha^{-1}	%/C
Colorit (Contr.)	5,674.0	100.0
Avocado	6,551.0***	115.5
Akord	5,898.0 ns	103.9
Borislav	5,786.0 ns	102.0
Blagovest	5,863.0 ns	103.3
Doni-52	6,237.0***	109.9
Dobrudzhanets	5,871.0 ns	103.5
Irnik	5,882.0 ns	103.7
Casino	6,038.0**	106.4
Lovchanets	5,774.0 ns	101.3
LSD		
5.0%	274	4.8
1.0%	326	5.7
0.1%	418	7.4

, * significance at P =1.0% and P =0.1%, respectively; ns no significance.

8.06 t ha^{-1}, the Avocado variety achieved the lowest average yield among 4 other varieties under an integrated and conventional system.

Depending on the weather conditions for each region, grain yields showed different values (Table 5; Table 8). On average for the period, the highest yield was recorded for G. Toshevo (7,452.0 kg ha^{-1}), which is 51.5% more than the yields in Chirpan, adopted as the control. This advantage is explained by the higher soil fertility - Haplic Chernozems have good structure, a deeper humus horizon and natural fertility, and good aeration contributes to more intensive mineralization of organic matter relatively high humus content (Perfanova et al., 2021), moreover the more balanced precipitation regime during the critical phases of crop development. In 2021–2022, when the agrometeorological conditions in General Toshevo were determined as Mediterranean according to the De Marton Index, the highest yield was achieved (9,573.0 kg ha^{-1}), which confirms the dependence between soil moisture and the realisation of the genetic potential of the variety. Sadovo occupies an intermediate position with a 5,494.0 kg ha^{-1} average yield. Soil conditions with moderate nutrient content and a warmer winter period allow for good overwintering of plants, but annual production is more dependent on the presence of precipitation in the spring months. During the semi-humid year 2020–2021, Sadovo recorded a significant increase in yield (8,027.0 kg ha^{-1}), which emphasizes the role of spring moisture in the region.Chirpan had the lowest average yield (4,918.0 kg ha^{-1}). The region is more sensitive to drought and extreme temperatures, especially during phases of flowering and grain filling. Under the conditions of high summer temperatures and droughts in the Chirpan region, the Pelic Vertisol has impaired aeration, which compromises the root system and the assimilation of soil nitrogen (Dimitrov & Kolev, 1999). This is confirmed by observations in 2022–2023, when scarce precipitation during the autumn-winter period and high temperatures in May-June led to a decrease in yield to 2,981.0 kg ha^{-1}. Similar results proving a high effect of location (25.37%) and variety (1.33%) for eight triticale varieties were reported by Molla et al. (2022). Other authors confirmed a significant effect of agroclimatic conditions at trial locations on triticale grain yield (Biberdžić et al., 2014).

Table 8. Influence of location on grain yield

Location	kg ha^{-1}	%/C
Chirpan (Contr.)	4,918.0	100.0
Sadovo	5,494.0***	111.7
General Toshevo	7,452.0***	151.5
LSD		
5.0%	135	2.8
1.0%	178	3.6
0.1%	229	4.7

*** significance at *P* =0.1%.

The results in Table 9 show different productivity of the varieties, depending on the conditions during the growing season. In 2020, the increase compared to the control was 2.5–34.9%. The Avocado, Doni-52 and Casino varieties are first in yield, and the harvest was 7,057.0; 6,622.0 and 6,186.0 kg ha^{-1}, respectively, or 34.9, 26.7 and 18.2% more than the control variety. These cultivars were able to exploit the available resources more efficiently under moderately favorable conditions. During the second growing season, a greater increase in yield values was recorded, from 28.4% to 50.9%. The Dobrudzhanets, Blagovest and Avocado varieties exceed the control by 50.9%, 49.2% and 48.9%, respectively. The reduced differences between cultivars during this year suggest that favorable hydrothermal conditions allowed most genotypes to express their production potential. Under such conditions, environmental limitations were minimal, and genetic yield potential became the dominant factor determining productivity. In 2022, the obtained yields of the varieties are between 2.6 and 35.9% above the control. The highest yielders were Casino (7,109.0 kg ha^{-1}), Avocado (6,672.0 kg ha^{-1}) and Dobrudzhanets (6,213.0 kg ha^{-1}) varieties. This indicates that these cultivars combine good yield potential with the ability to maintain productivity under moderately favorable conditions.

Table 9. Influence of year × variety on grain yield

Periods	2019–2020	2020–2021	2021–2022	2022–2023
Variety	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}
Colorit (Contr.)	5,232.0	7,168.0***	5,842.0*	4,453.0^{oo}
Avocado	7,057.0***	7,793.0***	6,672.0***	4,698.0^{o}
Akord	5,732.0*	7,546.0***	5,973.0**	4,340.0^{ooo}
Borislav	5,631.0^{ns}	7,618.0***	5,725.0*	4,167.0^{ooo}
Blagovest	5,411.0^{ns}	7,806.0***	5,979.0**	4,257.0^{ooo}
Doni-52	6,622.0***	7,782.0***	6,049.0***	4,469.0^{oo}
Dobrudzhanets	5,913.0**	7,897.0***	6,213.0***	3,460.0^{ooo}
Irnik	6144.0***	7,210.0***	6,119.0***	4,055.0^{ooo}
Casino	6,186.0***	6,717.0***	7,109.0***	4,130.0^{ooo}
Lovchanets	5,364.0^{ns}	7,743.0***	5,370.0^{ns}	4,514.0^{oo}
LSD				
5.0%	494			9.4
1.0%	651			12.4
0.1%	834			15.9

*, **, *** significance at *p* =5.0%, *p* =1.0% and *p* =0.1%, respectively; ^{o}, ^{oo}, ^{ooo} significance at $P < 0.05$, $P < 0.01$ and $P < 0.001$; ^{ns} no significance.

The last period is characterized by significantly lower reported yields for all varieties compared to the control (66.1–89.9%). The results for the Avocado, Lovchanets and Doni-52 varieties were the highest – 4,698.0; 4,514.0 and 4,469.0 kg ha^{-1}, suggesting better tolerance to unfavorable conditions. Conversely, cultivars such as Dobrudzhanets and Casino showed particularly strong reductions, indicating higher sensitivity to environmental stress. The Avocado variety in all years occupies the group of the first three varieties in terms of productivity. The Bulgarian Dobrudzhanets, Doni-52 and Blagovest varieties are distinguished by very good productivity. Recent studies have reported the exceptional productivity and good stability for the Blagovest and Doni-52 varieties (Baychev & Stoyanov, 2019; Stoyanov et al., 2022). Results by Neykov (2024) demonstrated a strong effect of the environment, low for the variety and medium for the environment and variety. In the case of a lack of location factor, there were higher values compared to the data on Table 12.

Different agrometeorological conditions for the three test regions are a prerequisite for a difference in the level of average yield (Table 10). In Chirpan, the maximum yield was obtained in 2020 (6,597.0 kg ha^{-1}), and in the next three years, the favourite was the region of G. Toshevo (9,013.0; 9,573.0 and 4,934.0 kg ha^{-1}). In Sadovo, the highest grain yield was in 2021 (8,027.0 kg ha^{-1}). In support of the results, it was established that the grain yield of the triticale varieties largely depended on the conditions of moisture and heat availability in the growing season (Torikov et al., 2022).

Table 10. Interaction year by location

Year	2020		2021		2022		2023	
Location	kg ha^{-1}	%/C	kg ha^{-1}	%/C	kg ha^{-1}	%/C	kg ha^{-1}	%/C
Chirpan(Contr.)	6,597.0	100.0	5,544.0^{ooo}	84.0	4,549.0^{ooo}	69.0	2,981.0^{ooo}	45.2
Sadovo	4,903.0^{ooo}	74.3	8,027.0***	121.7	4,194.0^{ooo}	63.6	4,581.0^{ooo}	73.5
G.Toshevo	6,287.0^{o}	95.3	9,013.0***	136.6	9,573.0***	145.1	4,934.0^{ooo}	74.9
LSD								
5.0%	271							4.1
1.0%	357							5.4
0.1%	458							6.9

*** significance at P =0.1%; ^{o}, ^{ooo} significance at P < 0.05 and P < 0.001, respectively; ^{ns} no significance.

The combined meteorological evidence therefore (Table 2, Table 3, Table 4) supports the strong effects of year and location detected in the statistical analysis and provides a climatic explanation for the variability in grain yield observed among environments. Therefore, in the absence of nitrogen fertilization, limiting factors for the development and productivity of triticale are soil and weather conditions.

The variety×location interaction (6.50%) shows that some varieties are more suitable for specific areas (Table 11). The Avocado (5,357.0 kg ha^{-1}), Blagovest (5,090.0 kg ha^{-1}) and Casino (5,034.0 kg ha^{-1}) varieties were the most productive in Chirpan. The yield differences among varieties were relatively small and statistically non-significant, indicating that environmental limitations reduced the expression of genetic potential. The narrow yield range among cultivars suggests that moisture stress and less favorable soil conditions in this region restricted crop performance, causing most genotypes to respond similarly. Under such conditions, cultivar choice appears less decisive than environmental management. Doni-52, Irnik and Akord varieties reached 6,282.0; 6,022.0 and 5,978.0 kg ha^{-1} in Sadovo, as mentioned (Table 11).

Table 11. Influence variety × location

Location	Chirpan		Sadovo		General Toshevo	
Variety	kg ha^{-1}	%/C	kg ha^{-1}	%/C	kg ha^{-1}	%/C
Colorit	4,956.0	100.0	5,283.0^{ns}	106.6	6,784.0***	136.9
Avocado	5,357.0^{ns}	108.1	5,630.0**	113.6	8,678.0***	175.1
Akord	4,642.0^{ns}	93.7	5,978.0***	120.6	7,073.0***	142.7
Borislav	4,627.0^{ns}	93.4	5,415.0*	109.3	7,316.0***	147.6
Blagovest	5,090.0^{ns}	102.7	5,174.0^{ns}	104.4	7,326.0***	147.6
Doni-52	5,001.0^{ns}	100.9	6,282.0***	126.8	7,409.0***	149.5
Dobrudzhanets	4934.0^{ns}	99.6	5,758.0***	116.2	6,921.0***	139.6
Irnik	4,562.0^{ns}	92.1	6,022.0***	121.5	7,062.0***	142.5
Casino	5,034.0^{ns}	101.6	3,848.0^{ooo}	77.6	9,231.0***	186.3
Lovchanets	4,977.0^{ns}	100.4	5,548.0**	111.9	6,718.0***	135.6
LSD						
5.0%	428					8.6
1.0%	564					11.4
0.1%	723					14.6

*, **, *** significance at P =5.0%, P =1.0% and P =0.1%, respectively; ^{ns} no significance.

In Sadovo, the results indicate that several Bulgarian cultivars are well adapted to the soil and climatic conditions of this region. The relatively strong performance of these genotypes suggests good utilization of available soil nutrients and moisture. In contrast, Casino performed significantly worse than the control, indicating poor adaptation to this environment and greater sensitivity to local conditions. In General Toshevo, Casino, Avocado and Doni-52 varieties exceeded the control by 86.3%, 75.1% and 49.5%, respectively. General Toshevo demonstrated both the highest yield potential and the clearest differentiation among cultivars. The large yield advantage of these cultivars suggests that they are capable of exploiting the favorable soil fertility and moisture conditions characteristic of this region. The particularly strong performance of Casino indicates that this cultivar has high yield potential under optimal environments but may depend strongly on favorable conditions. Avocado and Doni-52 provides high yield in all areas, which indicates good plasticity and stability under contrasting conditions. These cultivars combined relatively stable yields in the less favorable Chirpan environment with high productivity in the more favorable regions. Casino, on the other hand, displayed a different response pattern, showing exceptional productivity in General Toshevo but weak performance in Sadovo and only moderate results in Chirpan. This suggests that its productivity is strongly environment-dependent. This is in agreement with other authors (Derejko et al., 2020; Stoyanov, 2023), according to whom varieties with high adaptability can compensate for part of the negative impact of unfavourable climatic factors. Other results also showed a large diversity in the ranking of triticale varieties by location (Derejko et al., 2020). In a study, no significance was found for the combination of variety×location, but it was high for location (70.24%) and variety (58.60%) for triticale (Bezabih et al., 2019). The differences in the ranking of varieties can be explained by the environmental conditions and the response of the varieties.

In addition, a seven-year field trial in General Toshevo of the Bulgarian varieties participating in this study showed similar grain yield values (Stoyanov, 2023). This highlights the need for a regional approach to variety selection, especially in conditions of climatic variability.

The most significant contribution to the yield variation has the year (29.04%), which confirms the key role of climatic conditions during the growing season (Table 12). The strong effect of year observed in this study confirms that environmental variability, particularly differences in precipitation patterns and hydrothermal conditions, plays a decisive role in determining triticale productivity under Bulgarian conditions. Location also has a significant effect (25.37%), and the interaction year×location is of similar magnitude (25.96%), which indicates that the influence of year is not uniform in all regions but depends on the specific combination of temperatures, precipitation and soil characteristics in the specific environment. In support of this, studies with triticale lines have also indicated a dominant effect of the environment (45.0%), but higher for the variety (23.4%), under growing conditions in one region (Stoyanov & Baychev, 2023). All possible combinations of factors with the variety show low impacts: Year×variety (2.73%); variety×variety×location (6.50%). According to that, regardless of the agrometeorological and soil conditions in the regions, the variation of yield based on variety is not significant during the studied years. The results support similar studies with triticale. The conditions during the studied years have influenced the obtained yield for triticale grain, according to Jańczak-Pieniążek (2023). The location had a strong influence on yield (38.29%); cultivar main effects have a low influence on triticale yield variation (0.45%); and location×year is 28.67% (Derejko & Studnicki, 2019).

Table 12. Analysis of variance results for grain yield performance of triticale varieties across test locations

Sours of variation	df	SS	η (%)	MS	*F-test*	*P* values
Options	119	1.602E+09	95.96^{***}	1.34E+07	47.591	0.000
A	3	4.848E+08	29.04^{***}	1.61E+08	571.264	0.000
B	9	2.223E+07	1.33^{***}	2470	8.733	0.000
C	2	4.235E+08	25.37^{***}	2.117E+08	748.578	0.000
A×B	27	4.560E+07	2.73^{***}	16891	5.971	0.000
A×C	6	4.333E+08	25.96^{***}	7.222E+07	255.306	0.000
B×C	18	1.084E+08	6.50^{***}	6024534	21.296	0.000
A×B×C	54	8.414E+07	5.04^{***}	1558301	5.508	0.000
Error	238	6.732E+07	4.03	282886.5		

A – year; B – variety; C – location.

Derejko et al. (2020) have found that variety effects on triticale yield range from 8.5 to 5.2%, the effects of year and location depend on environmental management. At moderate and high input levels, year accounts for 11.2 and 37.9% of the total variation, and location accounts for 60.5 and 3.0%, respectively. Climatic variations during the study period had a distinct impact on yield. Increased average winter temperatures, recorded in all locations, probably contributed to better overwintering but at the same time increased evaporation and moisture requirements in spring. Years with lower precipitation during the grain-filling period, especially under semi-arid conditions, led to lower grain yields, even in good soil characteristics.

The obtained data support the need to implement strategies for adaptation to climate change, including selection of varieties with established plasticity and stable yield under different agroclimatic conditions and precise planning of sowing dates so that critical phases of development coincide with optimal moisture and temperature conditions, as well as integration of approaches for soil moisture management through minimal tillage and retention of plant residues. Conducting additional field trials with the inclusion of more varieties and locations will allow a more accurate assessment of yield stability and varietal adaptability.

In conclusion, although variety has a low direct effect on yield compared to year and location, correct variety selection in combination with optimized agrotechnical practices and good adaptability to environmental conditions can significantly increase the production potential of triticale in Bulgaria. The data from the study are a valuable direction for farmers and breeders, emphasizing the importance of combining genetic potential with the specific climatic and soil characteristics of the production region.

CONCLUSIONS

The study presented information on the amount of grain yield of ten modern triticale varieties, grown in three regions of Bulgaria. The applied statistical analysis established a proven influence of the factors year, variety and location, as well as their complex interaction. The conditions of the year, location, year and location have an average effect on grain yield. In the three regions the most productive varieties were determined. The varieties achieved the highest yield in the region of G. Toshevo. The meteorological conditions in 2020–2021 were the most favourable for the growth and development of triticale, and the higher yield can be referred to the agrometeorological assessment of the growing season, which is semi-humid in General Toshevo, Chirpan and Sadovo. In the three regions, Avocado, Casino and Doni-52 varieties are the most productive as regards grain yield.

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