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# STABILITY AND ADAPTABILITY OF YIELD AND YIELD RELATED TRAITS IN BULGARIAN TRITICALE (×*Triticosecale* Wittm.) CULTIVARS IN DROUGHT CONDITIONS

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***Abstract***

*To determine the adaptability and stability of yield and its related traits during drought conditions in triticale, eleven contemporary Bulgarian cultivars were studied according to the indices yield, number of productive tillers, 1000 kernel weight and number of grains in spike, applying four parameters: regression coefficient and deviation from regression, ecovalence and stability variance of Shukla. Drought had a significant effect on the yield related traits, which differed considerably according to the different parameters of stability. The best combination of stability and adaptability according to number of productive tillers and 1000 kernel weight was observed in Bumerang and Doni 52. The parameter number of grains in spike behaved in a rather complex manner under conditions of drought and the separate stability parameters related to contradictory results. The widest adaptability according to this parameter was observed in cultivars Rakita, Lasko and Respekt. The stability and adaptability parameters of the separate yield traits was not functionally related to the same parameters of yield, which determined the investigated cultivars as developed according to a complex of traits and being suitable for growing under variable environments.*

***Key words***: *adaptability, drought, stability analysis, triticale, yield related traits.*

## INTRODUCTION

Drought is among the most serious factors, which do not allow the obtaining of normal yields from the cultivated plants. This is particularly valid for the cereal crops, the yields from which may be reduced to extremely high levels as a result from different forms of drought (Karrou & Oweis, 2014). In regions, where the greater part of the vegetative growth of such crops as wheat, barley and triticale occurs under scarce rainfalls, strong winds, or soils with low moister retention capacity drought is a serious obstacle. Regardless of the fact that in the regions with typically dry climate the meteorological conditions follow certain tendencies, the duration and intensity of drought as a process cannot be reliably predicted (Majid et al., 2007). Therefore, it is rather difficult to develop both a technology and a certain type of genotype that would constantly react towards avoidance of unfavorable phenomena and processes.

Triticale is one of the cereal crops with considerably higher adaptability to unfavorable environments (Lozano del Rio et al., 2009; Estrada-Campuzano et al., 2012; Lule et al., 2014; Arseniuk, 2015; Kendal & Sayar, 2016; Kendal et al., 2019). On the whole, this crop is characterized by good tolerance to drought (Akbarian et al., 2011; Kutlu & Kinacı, 2010), especially the genotypes developed for the soil and climatic conditions of Bulgaria (Stoyanov et al., 2017). The high tolerance to drought of this crop has been determined by other researchers, too, most often through various physiological parameters (Grzesiak et al., 2003; Hura et al., 2007; Hura et al., 2009; Lonbani & Arzani, 2011; Hura et al., 2012; Grzesiak et al., 2012). On the other hand, however, the effect of drought on the yield related traits of triticale is comparatively insufficiently studied, especially in the contemporary varieties.

Investigating eleven Bulgarian triticale cultivars under conditions of controlled drought, Stoyanov (2018) found out that the crop suffered significant losses due to growing under insufficient moisture in soil. Nevertheless, some of the studied cultivars demonstrated higher productivity in comparison to common winter wheat cultivars with high tolerance to drought. However, during the period of study, the observed tendencies in the separate yield related traits, which were investigated (days to heading, plant height, number of productive tillers, number of grains in spike, weight of grains in spike, 1000 kernel weight, fertility and compactness of spike), were not identical according to the different growing seasons' conditions, in which the experiment was conducted. This indicated that the drought conditions during the individual periods did not affect the genotypes in the same way. Fayaz and Arzani (2011) found that different triticale genotypes respond differently depending on the drought regime applied. In all traits they investigated (plant height, number of productive tillers, number of grains in spike, weight of grains in spike, 1000 kernel weight, biological yield, grain yield and harvest index), a considerable and significant effect of the genotype x environment (regime of drought) interaction was observed. In common winter wheat grown under various regimes of drought, Mehraban et al. (2019) demonstrated significant effect of the genotype x environment interaction on the traits number of grains in spike and 1000 kernel weight.

Such results justify searching for the answer to the question to what extent a given yield trait is stable under different intensity and duration of drought. This is related to the necessity to explain the complex genotype x environment interaction on the size of the yield. Chai et al. (2011) find out that some of the genotypes which possess specific adaptability to lower environments are more drought tolerant than these with wide adaptability. Tsenov et al. (2013) pointed out that due to the complexity of this interaction it was necessary to investigate the effect of the yield related traits from the point of view of their adaptability. In this respect, Majid et al. (2007) studied the stability of yield and its related traits in a group of wheat genotypes under different conditions of drought. The data of the authors indicated that the traits they studied (yield, number of spikelets in spike, number of grains in spike, 1000 kernel weight) did not follow identical stability and adaptability, neither between themselves, nor in comparison to yield. Therefore, especially in rather complex genotypes as the triticale varieties, in order to properly estimate the effect of the genotype x environment interaction, it is necessary to follow in detail the stability and adaptability not only of the yield but also of its components. The aim of this investigation was to study in detail the stability of yield and yield related traits in contemporary Bulgarian triticale cultivars and to evaluate their adaptability under contrasting environments.

## MATERIALS AND METHODS

### *Plant material*

To realize the above aim, eleven Bulgarian triticale cultivars were used (Kolorit, Atila, Akord, Respekt, Bumerang, Irnik, Dobrudzhanets, Lovchanets, Doni 52, Blagovest and Borislav. These cultivars were grown in trial plots of 10 $m^2$, in four replications according to a standard block design within a competitive varietal trial. Planting was done using mechanical equipment within the standard dates ($10^{th}$-$15^{th}$ October) at sowing density 550 seeds/$m^2$. Apart from the cultivars indicated above, the competitive varietal trial also involved the local check triticale cultivars AD-7291, Vihren and Rakita, as well as the world checks Lasko and Presto.

The number of productive tillers per $m^2$ was determined in each trial plot using a sampling frame of 0.25 $m^2$. Thousand kernel weight (g) was determined according to the Bulgarian State Standard and the number of grains per spike, calculated by a formula based on the number of productive tillers, 1000 kernel weight and yield. Data were summarized by calculating the means for each cultivar and year.

### *Meteorological conditions*

The experiment was carried out in three consecutive harvest seasons - 2017/2018, 2018/2019, 2019/2020. The data on the average monthly temperature and the sum of precipitation (Table 1) clearly showed considerable differences in the meteorological conditions during the studied periods. Clearly outlined were certain meteorological phenomena and processes, which were of single occurrence and were not repeated over periods; they were able to strongly influence the physiological processes in the plant organism.

In meteorological and phenological aspects, 2017/2018 growing season was different from the rest of the periods. During the third decade of March, considerably low and durable negative air temperatures were observed, which against the background of a previous warmer period of renewed vegetative growth, posed a serious risk for the crops. Nevertheless, the low temperatures were combined with sufficient snow cover. The precipitation was a strong disturbing factor for the development of triticale during 2017/2018. During previous periods drought has been favorable for the development of triticale, and such high precipitation levels significantly affect the processes of heading and anthesis. June, however, was characterized as considerably more humid, especially its last decade.

The growing period 2018/2019 was comparatively dry. This relates to both the action of temperatures and to the differences in the water regime resulting from the abnormal rainfalls during the vegetative growth of the plants. March of 2019 was extremely warm but also very dry. Practically, the insufficient rainfalls did not allow the plants to develop properly, although the temperatures were favorable for such development.

Table 1. Meteo data of the studied environmets

| Parameter/Months | | Oct | Nov | Dec | Jan | Feb |
|---|---|---|---|---|---|---|
| AMT, ºC | 2017/2018 | 11.8 | 7.5 | 4.7 | 1.7 | 1.1 |
| | 2018/2019 | 13.3 | 5.4 | 1.2 | 1.0 | 3.5 |
| | 2019/2020 | 13.4 | 11.7 | 5.2 | 1.8 | 5.1 |
| | 2017/2020 | 12.8 | 8.2 | 3.7 | 1.5 | 3.2 |
| | 1960/2020 | 11.7 | 6.8 | 2.0 | -0.2 | 1.2 |
| TMP, mm | 2017/2018 | 69.9 | 50.5 | 57.2 | 55.8 | 75.4 |
| | 2018/2019 | 11.7 | 66.2 | 43.8 | 19.2 | 16.3 |
| | 2019/2020 | 27.6 | 35.4 | 21.8 | 2.8 | 28.1 |
| | 2017/2020 | 36.4 | 50.7 | 40.9 | 25.9 | 39.9 |
| | 1960/2020 | 42.1 | 43.4 | 41.7 | 36.4 | 34.2 |
| Parameter/Months | | Mar | Apr | May | Jun | Jul |
| AMT, ºC | 2017/2018 | 4.6 | 13.4 | 17.7 | 20.4 | 22.2 |
| | 2018/2019 | 8.2 | 9.0 | 16.0 | 22.3 | 22 |
| | 2019/2020 | 8.0 | 10.0 | 15.4 | 19.6 | 22.3 |
| | 2017/2020 | 6.9 | 10.8 | 16.4 | 20.8 | 22.2 |
| | 1960/2020 | 4.7 | 9.9 | 15.2 | 22 | 21.4 |
| TMP, mm | 2017/2018 | 48.8 | 4.9 | 30.9 | 90.8 | 59.6 |
| | 2018/2019 | 16.1 | 49.4 | 31.7 | 37.5 | 54.0 |
| | 2019/2020 | 28.3 | 5.8 | 48.0 | 192.2 | 2.7 |
| | 2017/2020 | 31.1 | 20.0 | 36.9 | 106.8 | 38.8 |
| | 1960/2020 | 35.5 | 39.9 | 52.0 | 60.9 | 51.3 |

The severe drought in March considerably retarded growth, and in combination with the cooler April, delayed the heading of plants. Lower and rather uneven rainfalls were registered also in May of the same year. This caused conditions of stress during the grain formation and grain filling processes.

Growing period 2019/2020 differed most significantly from the other two periods. The entire winter period was rather warm and the plants did not fall into dormant state. On the whole, serious soil drought was observed during January - April, and the insufficient soil moisture reserves were the reason for strong disturbance in the development of the plants. There were rainfalls in May, which, however, were with 4 mm lower than the long-term norm. Such rainfalls could not compensate for the absence of good moisture reserves. June was considerably more humid, especially during the second decade. The rainfalls, however, were not significant for triticale since grain was formed and most of the leaf mass died out.

***Stability analysis***

Stability parameters based on the dynamic concept were calculated: regression coefficient ($b_i$) and deviation from regression ($S^2_{di}$) according to Eberhart and Russell (1966), ecovalence ($W_i$) according to Wricke (1962), stability variance ($S^2_i$) according to Shukla (1972). Each of these parameters was applied to the values of the yield and yield related traits. To determine the stability of each trait in order to compare them, the data were referred to the mean value of the entire investigated set, which were then estimated logarithmically and evaluated for stability.

Microsoft Excel 2003 and IBM SPSS Statistics 19 were used for data processing and analysis of stability.

## RESULTS AND DISCUSSIONS

The conditions of the environment during each of the three growing periods undoubtedly define whole the period of growing as extremely dry. This allowed assuming that the genotypes characterized with higher stability and wide adaptability can be successfully grown in regions, where drought is not unusual but is a permanent tendency. At the same time, the drought during the three separate periods was not of the same intensity and duration. Such contrasting condtions of growing were the reason to look for a strong effect of the genotype x environment interaction with respect to both yield and its related traits. It should be emphasized that the stability and adaptability of yield did not follow the tendency of any of the studied traits as evidenced by our previous researches (Stoyanov & Baychev, 2016), and by the data and researches of other authors (Dhindsa et al., 2002; Dimitrievic et al., 2011).

Table 2. Stability and adaptability parameters of yield and yield components

| Cultivar | $b_i$ | $S^2_{di}$ | $W_i$ | $S^2_i$ | $b_i$ | $S^2_{di}$ | $W_i$ | $S^2_i$ |
|---|---|---|---|---|---|---|---|---|
| | Yield, kg/dca | | | | NPT, psc/m$^2$ | | | |
| AD-7291 | 1.31 | 302.01 | 1129.53 | 521.15 | 1.33 | 199.58 | 2420.32 | 970.19 |
| Vihren | 2.31 | 751.13 | 14213.05 | 7997.44 | 0.24 | 3081.48 | 14383.82 | 7806.47 |
| Rakita | 1.18 | 774.75 | 1092.39 | 499.92 | 1.13 | 8274.71 | 8714.32 | 4566.76 |
| Lasko | 0.71 | 80.91 | 772.87 | 317.34 | 0.38 | 31784.65 | 39205.82 | 21990.47 |
| Presto | 0.18 | 128.83 | 5304.32 | 2906.74 | 1.17 | 4762.41 | 5439.41 | 2695.38 |
| Kolorit | 1.33 | 210.20 | 1146.33 | 530.74 | 1.22 | 46938.03 | 47958.99 | 26992.28 |
| Atila | 0.84 | 3614.76 | 3871.88 | 2088.20 | 0.73 | 157.49 | 1630.91 | 519.09 |
| Akord | 0.24 | 144.85 | 4621.38 | 2516.49 | 0.83 | 3798.75 | 4452.07 | 2131.19 |
| Respekt | 1.14 | 2286.84 | 2497.25 | 1302.70 | 1.12 | 2730.55 | 3103.16 | 1360.38 |
| Bumerang | 1.17 | 133.77 | 415.39 | 113.07 | 0.62 | 240.66 | 3112.82 | 1365.90 |
| Irnik | 1.02 | 1627.28 | 1689.88 | 841.34 | 1.49 | 1679.97 | 6510.07 | 3307.19 |
| Dobrudzhanets | 1.28 | 6426.13 | 7133.40 | 3951.93 | 0.89 | 3691.95 | 4006.07 | 1876.33 |
| Lovchanets | 1.31 | -13.79 | 798.08 | 331.74 | 1.47 | 19478.99 | 23978.57 | 13289.19 |
| Doni 52 | 1.03 | 442.80 | 506.31 | 165.02 | 1.35 | 117.75 | 2609.07 | 1078.04 |
| Blagovest | 0.81 | 497.17 | 830.76 | 350.42 | 1.18 | 4177.45 | 4928.32 | 2403.33 |
| Borislav | 0.14 | 416.22 | 6183.63 | 3409.20 | 0.84 | 405.50 | 945.07 | 127.19 |
| | M1000, g | | | | NGS, psc | | | |
| AD-7291 | 1.96 | 14.93 | 30.16 | 16.84 | 2.20 | -7.12 | 41.40 | 22.98 |
| Vihren | 0.01 | -0.09 | 11.08 | 5.94 | -0.38 | 21.28 | 78.90 | 44.41 |
| Rakita | 0.27 | 3.51 | 10.95 | 5.86 | 0.88 | -1.32 | 2.07 | 0.51 |
| Lasko | 0.81 | 27.21 | 29.50 | 16.46 | 0.90 | 41.75 | 47.11 | 26.25 |
| Presto | 0.26 | 16.07 | 23.21 | 12.87 | 0.63 | 3.44 | 9.69 | 4.87 |
| Kolorit | 0.95 | 8.68 | 11.43 | 6.13 | 0.74 | 21.06 | 26.40 | 14.41 |
| Atila | 1.24 | -2.50 | 0.70 | 0.00 | 1.21 | -3.79 | 1.44 | 0.15 |
| Akord | 0.84 | -0.49 | 1.66 | 0.55 | 1.36 | -4.40 | 3.69 | 1.44 |
| Respekt | 1.87 | 13.81 | 26.78 | 14.91 | 1.11 | 5.47 | 9.90 | 4.98 |
| Bumerang | 1.19 | -1.07 | 1.87 | 0.67 | 0.77 | -1.45 | 2.69 | 0.87 |
| Irnik | 0.63 | 3.13 | 6.56 | 3.35 | 1.62 | 0.15 | 16.65 | 8.84 |
| Dobrudzhanets | 1.27 | -2.56 | 0.87 | 0.10 | 0.22 | 0.32 | 18.82 | 10.08 |
| Lovchanets | 1.39 | -2.52 | 2.01 | 0.75 | 1.39 | 0.81 | 9.90 | 4.98 |
| Doni 52 | 0.97 | -1.87 | 0.13 | -0.32 | 1.25 | -3.96 | 1.90 | 0.41 |
| Blagovest | 0.92 | 4.25 | 6.79 | 3.48 | 1.33 | -0.72 | 6.82 | 3.22 |
| Borislav | 1.43 | -2.90 | 2.12 | 0.82 | 0.78 | 0.71 | 4.94 | 2.15 |

Among the studied genotypes, cultivars Rakita, Respekt, Bumerang, Irnik and Doni 52 were with the widest adaptability of yield, according to the values of parameter $b_i$, under conditions of drought. Respectively, with specific adaptability to the more favorable conditions of the environment were cultivars AD-7291, Vihren, Kolorit, Dobrudzhanets and Lovchanets, and cultivars Lasko, Presto, Atila, Akord, Blagovest and Borislav were with adaptability to the unfavorable conditions. With $b_i$ values almost equal to 1.00 were cultivars Irnik and Doni 52. According to Eberhart and Russell (1966), cultivars with values of $b_i$ equal to 1.00 are considered ideal genotypes regardless of the conditions of the environment. At the same time, Hildebrand (according to Scapim et al., 2000) pointed out that the genotypes with regression coefficient close to 1.00 gave considerably lower results under unfavorable environments than the genotypes with regression coefficient higher than 1.00. This tendency was valid for triticale, too, in the lines we investigated during 2015-2020 (Stoyanov % Baychev, 2021). The line, characterized by high stability and low regression coefficient, was the only one, which under the conditions of the intensive drought of 2019/2020 achieved results higher than the results of all other lines. This tendency was also valid for cultivars as Rakita, Respekt and Irnik. In cultivars Bumerang and Doni 52 on the other hand such results were not observed according to the data on their yield during the same periods (Stoyanov, 2021). This was related to their considerably higher stability. With regard to stability, expressed through the three parameters, ($S^2_i$, $W_i$, $S^2_{di}$), Lasko, Bumerang and Doni 52 were with the highest stability. Most unstable with regard to yield were cultivars Atila, Respekt, Dobrudzhanets and Borislav, respectively. It should be emphasized that the three parameters did not follow an altogether identical tendency. According to the values of $S^2_{di}$, cultivars Presto, Kolorit, Akord and Lovchanets also possessed high stability, while Blagovest was with higher stability according to $W_i$ and $S^2_i$. If we compare the data on the stability and adaptability, cultivars Bumerang and Doni 52 are definitely described as having wide adaptability and high stability. On the other hand, these were genotypes characterized with rather high productivity under drought as supported by a number of previous researches (Stoyanov et al., 2017; Stoyanov, 2018; Stoyanov, 2020). The data of Stoyanov and Baychev (2016) determined cultivars Rakita, Akord and Doni 52 as the most widely adaptable and respectively the most stable according to the above parameters. The long-term investigations on these three cultivars actually revealed both their wide adaptability and the high stability of their yield. Under conditions of drought, however, Rakita and Akord significantly changed their response. Although the method of Eberhart and Russell (1966) places Rakita close to the ideal genotype, the methods of Shukla and Wricke do not give the same tendency. On the other hand, under these growing conditions even the regression coefficient of Akord was with values much lower than 1.00. This indicated that drought had a significant effect even on cultivars with high stability of yield.

This thesis is supported by the researches of Khanna-Chopra and Viswanathan (1999), who pointed out that the most high-yielding cultivars they studied were characterized by the lowest stability under conditions of drought. Testing different conditions of irrigation and drought stress, Mehraban et al. (2019) found out that it was possible to combine high values of yield with good stability. Using the GGE Biplot method, the authors pointed out two out of the ten studied common winter wheat varieties as combining optimal levels of yield and stability. Majid et al. (2007) performed an analysis similar to our on four wheat genotypes. The data of the authors demonstrated that, similar to our results, drought had significant impact on the ranking of the cultivars by their adaptability and stability based on the analysis of Eberhart and Russell.

The number of productive tillers in the investigated triticale cultivars showed stability and adaptability different from yield. The values of the regression coefficient were predominantly higher than 1.00, but in contrast to the values of yield, were significantly higher, and the coefficient closest to wide adaptability was 0.89 of cultivar Dobrudzhanets. Other genotypes demonstrating values close to wide adaptability by the trait number of productive tillers were Rakita, Presto, Respekt, Blagovest and Borislav. The cultivars showing specific adaptability to the favorable conditions were AD-7291, Kolorit, Irnik, Lovchanets and Doni 52. Cultivars Vihren, Lasko, Atila and Bumerang, on their part, were with specific adaptability but to unfavorable environments. This indicated that these cultivars would react better in comparison to the other under extreme adverse meteorological conditions during the vegetative growth. Since drought was a major limiting factor during the period of study, it can be assumed that the process of tillering in cultivars Lasko, Atila and Bumerang was less affected than in the other cultivars. Concerning the parameters of stability ($S^2_i$, $W_i$, $S^2_{di}$), the values of the separate genotypes followed a similar tendency. Cultivars AD-7291, Atila, Bumerang, Doni 52 and Borislav were with the most stable number of productive tillers according to all three parameters. The most unfavorable values were found in Lasko, Kolorit and Lovchanets, respectively. When comparing the stability and adaptability for the trait number of productive tillers, cultivars as Bumerang and Doni 52 were again with very good combinations of the values of the studied parameters. According to the concept of Hildebrand (Scapim et al., 2000), the low regression coefficients in combination with high stability turned out to be more efficient than the ideal genotypes of Eberhart and Russell (1966). The results from our previous studies (Stoyanov, 2018) showed that Atila, Bumerang, Dobrudzhanets and Doni 52 were actually with very good response to drought under controlled conditions. Stoyanov (2021), investigating the model effect of drought according to the most favorable and the most typical of six vegetative growth periods, found out that in Bumerang and Doni 52 the reduction of the parameter as a result from drought was not that great. According to this study, the best model values were demonstrated by cultivars Lasko, Presto, Dobrudzhanets, Lovchanets and Doni 52. Mehraban et al. (2019) showed that the interaction between the factors cultivar and irrigation (drought regime) was not significant in the common winter wheat cultivars they studied in comparison to the parameter fertile spikes per $m^2$. Such data were related to the identical stability of the separate genotypes with regard to the number of productive tillers under different levels of drought. Such a response, however, was not observed in the genotypes we studied.

Concerning 1000 kernel weight, adaptability closest to wide was registered in Doni 52. The value of the regression coefficient of this cultivar was 0.97, which brings it closest to the idea of the ideal genotype according to this parameter. Other genotypes with adaptability close to wide were Lasko, Kolorit, Akord, Bumerang and Blagovest. With the exception of Bumerang, they all tended towards adaptability to more unfavorable conditions since their regression coefficients were lower than 1.00. Cultivars AD-7291, Atila, Respekt, Dobrudzhanets, Lovchanets and Borislav tended towards specific adaptability to favorable conditions of the environment according to the studied parameter, while Rakita, Presto and Irnik were with specific adaptability to unfavorable environments. Particularly interesting was the behavior of cultivar Vihren. The value of its regression coefficient was 0.01, which brought it close to 0.00. According to Becker and Leon (1988), such values were due to the zero effect of the environment on the studied trait. This was an indication that during the study period, drought had practically no effect as a limiting factor on the grain filling in cultivar Vihren. The values of the stability parameters were also extremely low proving that 1000 kernel weight in this genotype was also characterized by high stability. Other genotypes demonstrating high stability according to the values of all three studied parameters were Atila, Akord, Bumerang and Doni 52. With respective lowest stability by the parameter 1000 kernel weight were AD-7291, Lasko, Presto and Respect. The results from our previous studies (Stoyanov & Baychev, 2016) showed that in periods without intensive and durable drought, the adaptability and stability of the cultivars was considerably different. The authors pointed out that in the period they investigated cultivars Dobrudzhanets, Lovchanets and Presto were with the highest stability according to this parameter, and Presto, Kolorit and Dobrudzhanets were with the widest adaptability. The tendency of cultivar Respekt towards being with the lowest stability was valid according to the current data, too. Such differences showed that drought was extremely important for the grain filling as a process. Since the periods of intensive drought, especially in 2018/2019 and 2019/2020 occurred exactly in the phenophase of grain filling, it was quite normal that the genotypes were with different stability according to the studied trait in comparison to the above periods, which were characterized as predominantly humid. Khanna-Chopra and Viswanathan (1999) demonstrated in different types of wheat that 1000 kernel weight was highly important for the formation of yield, being considerably affected at the same time by the conditions of drought. The authors determined that this parameter was of higher significance for yield under no stress in hexaploid wheat types, although significant correlations with yield were not observed.

Mehraban et al. (2019) observed significant effect of the interaction between the factors cultivar and irrigation (drought regime) in the common winter wheat cultivars they studied. Such data showed that the stability of this trait could be rather differing according to the individual genotypes. Mehraban et al. (2019) made the observation that the adaptability and stability of the cultivars they studied with regard to 1000 kernel weight was not affected by the conditions of the year only in two out of the four investigated cultivars. Especially big differences were observed in the other two genotypes, their responses to the different conditions when drought occurred being entirely opposite. Such data were also indicative of the results we obtained in this investigation in comparison to our previous researches.

Quite contradictory were the results on the trait number of grains in spike. In practice, none of the cultivars was sufficiently close to the ideal genotype by the values of the regression coefficient according to the model of Eberhart and Russell (1966). Nevertheless, adaptability closest to wide was observed in cultivars Rakita, Lasko and Respekt. Specific adaptability to the favorable conditions of the environment was observed in AD-7291, Atila, Akord, Irnik, Lovchanets, Doni 52 and Blagovest, and to the unfavorable conditions of the environment - in Presto, Kolorit, Bumerang, Dobrudzhanets and Borislav. In contrast to the other yield related traits, number of grains in spike was with stability parameters, which followed identical tendencies. The data on the deviation of the regression showed that most stable were Irnik, Dobrudzhanets, Lovchanets, Blagovest and Borislav. The values of the ecovalence and the variance of Shukla, on their part, determined cultivars Rakita, Atila, Bumerang and Doni 52 as the most stable. In spite of these divergent data, by all three parameters of stability, Vihren, Lasko and Kolorit were characterized as the most unstable genotypes in the investigated set. Such contradictory data were also reported in the research of Stoyanov and Baychev (2016). In the opinion of the authors, cultivars Vihren, Presto and Akord were with the highest stability according to the deviation of the regression, and according to the ecovalence and variance of Shukla - cultivars Lasko, Respekt and Blagovest. The absence of a tendency in two independent studies on these genotypes showed that the formation of the trait was of a rather complex nature. Simultaneously, radically opposite results were observed with regard to the values of the stability parameters. This indicated that the stability of the number of grains in spike was considerably influenced by drought. This was related to the sensitivity of the process of pollination and fertilization in triticale to the high temperature and the insufficient moisture. On the other hand, the process of grain formation was directly related to other parameters such as period to heading, the occurrence of rainfalls during anthesis, the mean diurnal temperatures during fertilization, etc. Due to its high sensitivity to such phenomena, the stability of this parameter should be considered much more thoroughly and for a longer period of time. The use of model values with regard to drought (Stoyanov, 2021) showed that in comparison to the favorable period of development, drought had the lowest effect on the number of grains in cultivars Rakita, Akord and Irnik, and a positive tendency was found also in cultivars Bumerang and Doni 52. Furthermore, the same research demonstrated that the best number of grains in spike was observed in the period with the most clearly expressed drought, and in the periods when some form of drought was registered during anthesis, the mean number of grains was much higher in comparison to the other periods. Such a thesis shows that drought should lead to lower stability of this yield related trait, but in a positive aspect. The more intensive the drought, the higher the grain set was. On the other hand, the droughts were characterized as single events with certain duration, i.e. they would cause higher variation in the grain set, and in combination with varied genotypes - higher effects of the genotype x environment interaction. The effect of this thesis can be determined through the values of $S^2_i$, $W_i$, $S^2_{di}$ in this study, which were significantly higher than the ones reported in Stoyanov and Baychev (2016) for eight of the 16 genotypes investigated. The researches of Khanna-Chopra & Viswanathan (1999) and Mehraban et al. (2019) showed that, in general, the number of grains in spike was highly important for the formation of yield under conditions of drought. However, the stability of the trait was considerably influenced by the environmental conditions and the regime of drought, as can be also observed in the data of Majid et al. (2007) on the wheat genotypes they studied.

In spite of the established correlations with regard to stability and adaptability of the cultivars we investigated, it was not practically possible to determine which of the above yield related traits was more stable and played a leading role in determining the stability and adaptability of yield itself. The data obtained showed that the yield and the separate yield related traits did not follow the same tendency both with regard to stability and adaptability. In order to clarify such a question, the data on the individual cultivars were normalized according to the mean value of the respective growing period, and since the data were relative, they were consecutively logarithmised.

Table 3. Normalized stability and adaptability parameters by mean of the yield componenets

| | Y | NPT | M1000 | NGS | Y | NPT | M1000 | NGS |
|---|---|---|---|---|---|---|---|---|
| | $b_i$ | | | | $S^2_{di}$ | | | |
| AD-7291 | 1.337 | 1.450 | 2.140 | 1.993 | -0.200 | -0.126 | -0.121 | -0.281 |
| Vihren | 2.226 | 0.208 | 0.080 | -0.390 | -0.055 | -0.203 | -0.005 | -0.097 |
| Rakita | 1.126 | 1.141 | 0.282 | 0.815 | -0.160 | -0.100 | -0.034 | -0.108 |
| Lasko | 0.711 | 1.111 | 0.212 | 0.606 | -0.150 | -0.065 | -0.026 | -0.095 |
| Presto | 0.212 | 1.124 | 0.914 | 0.702 | -0.150 | -0.020 | -0.060 | -0.122 |
| Kolorit | 1.332 | 0.389 | 0.834 | 1.081 | -0.077 | -0.123 | -0.045 | -0.150 |
| Atila | 0.872 | 0.725 | 1.232 | 1.289 | -0.100 | -0.095 | -0.059 | -0.193 |
| Akord | 0.241 | 0.865 | 0.864 | 1.343 | -0.124 | -0.026 | -0.044 | -0.194 |
| Respekt | 1.252 | 1.088 | 1.828 | 1.079 | -0.149 | -0.129 | -0.110 | -0.163 |
| Bumerang | 1.096 | 0.627 | 1.168 | 0.758 | -0.088 | -0.093 | -0.058 | -0.102 |
| Irnik | 1.033 | 1.572 | 0.562 | 1.439 | -0.215 | -0.101 | -0.046 | -0.199 |
| Dobrudzhanets | 1.298 | 0.846 | 1.269 | 0.209 | -0.116 | -0.128 | -0.066 | -0.047 |
| Lovchanets | 1.352 | 1.363 | 1.409 | 1.579 | -0.180 | -0.128 | -0.077 | -0.232 |
| Doni 52 | 0.994 | 1.329 | 0.959 | 1.185 | -0.179 | -0.088 | -0.050 | -0.167 |
| Blagovest | 0.811 | 1.145 | 0.947 | 1.241 | -0.157 | -0.077 | -0.060 | -0.177 |
| Borislav | 0.155 | 0.840 | 1.404 | 0.766 | -0.115 | -0.024 | -0.065 | -0.122 |
| AV | 1.003 | 0.989 | 1.006 | 0.981 | -0.138 | -0.096 | -0.058 | -0.153 |
| | $W_i$ | | | | $S^2_i$ | | | |
| AD-7291 | 0.012 | 0.005 | 0.026 | 0.052 | 0.006 | 0.002 | 0.014 | 0.028 |
| Vihren | 0.038 | 0.038 | 0.007 | 0.152 | 0.021 | 0.021 | 0.004 | 0.085 |
| Rakita | 0.020 | 0.003 | 0.007 | 0.007 | 0.011 | 0.001 | 0.004 | 0.003 |
| Lasko | 0.005 | 0.002 | 0.005 | 0.015 | 0.002 | 0.001 | 0.003 | 0.007 |
| Presto | 0.003 | 0.015 | 0.006 | 0.048 | 0.001 | 0.008 | 0.003 | 0.026 |
| Kolorit | 0.030 | 0.004 | 0.002 | 0.095 | 0.017 | 0.002 | 0.001 | 0.053 |
| Atila | 0.004 | 0.014 | 0.000 | 0.008 | 0.002 | 0.008 | 0.000 | 0.003 |
| Akord | 0.009 | 0.013 | 0.001 | 0.007 | 0.005 | 0.007 | 0.000 | 0.003 |
| Respekt | 0.006 | 0.015 | 0.022 | 0.029 | 0.003 | 0.008 | 0.012 | 0.015 |
| Bumerang | 0.007 | 0.001 | 0.001 | 0.007 | 0.003 | 0.000 | 0.000 | 0.003 |
| Irnik | 0.020 | 0.006 | 0.005 | 0.020 | 0.011 | 0.003 | 0.002 | 0.010 |
| Dobrudzhanets | 0.008 | 0.026 | 0.001 | 0.033 | 0.004 | 0.015 | 0.000 | 0.018 |
| Lovchanets | 0.034 | 0.004 | 0.002 | 0.045 | 0.019 | 0.002 | 0.001 | 0.024 |
| Doni 52 | 0.006 | 0.002 | 0.000 | 0.002 | 0.003 | 0.000 | 0.000 | 0.000 |
| Blagovest | 0.009 | 0.003 | 0.004 | 0.012 | 0.005 | 0.001 | 0.002 | 0.005 |
| Borislav | 0.002 | 0.018 | 0.001 | 0.012 | 0.001 | 0.010 | 0.000 | 0.006 |
| AV | 0.013 | 0.010 | 0.006 | 0.034 | 0.007 | 0.006 | 0.003 | 0.018 |

Table 4. Stability and adaptability parameters sequence

| Parameter | Stability sequence | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| $b_i$ | M1000 | NPT | NGS |
| $S^2_{di}$ | M1000 | NPT | NGS |
| $W_i$ | M1000 | NPT | NGS |
| $S^2_i$ | M1000 | NPT | NGS |

The stability and adaptability parameters calculated on the basis of these data allowed analyzing which of the yield related traits was stable both in the individual genotypes and on the whole. The obtained results showed that on the average, regardless of the applied statistical parameter, 1000 kernel weight was with the highest stability and widest adaptability, followed by number of productive tillers and number of grains in spike (Table 4). This tendency, however, was not identical for all investigated genotypes.

With regard to adaptability, only three genotypes (Presto, Atila and Blagovest) followed the average tendency. In cultivars AD-7291, Rakita, Lasko and Borislav, the widest adaptability was registered for the parameter number of productive tillers, followed by number of grains in spike and 1000 kernel weight. In four cultivars (Vihren, Akord, Dobrudzhanets and Lovchanets), the number of productive tillers was again with the widest adaptability, but it was followed by 1000 kernel weight and number of grains in spike. In cultivars Kolorit and Respekt, number of grains in spike was the most adaptable parameter, but in Kolorit 1000 kernel weight followed by number of productive tillers were with more specific adaptability, while in Respect the opposite tendency was observed. In Bumerang, Irnik and Doni 52, the difference to the average tendency was that the number of grains in spike was characterized by wider adaptability than the number of productive tillers.

The deviation from the regression calculated on the basis of the normalized and logarithmised values, revealed that 11 of 16 cultivars followed the average tendency. In Presto, Akord and Borislav, the most stable yield related trait was the number of productive tillers, followed by 1000 kernel weight and the number of grains in spike. In Vihren most stable was 1000 kernel weight, followed by number of grains in spike and number of productive tillers, while in Dobrudzhanets the most stable element was number of grains in spike, followed by 1000 kernel weight and number of productive tillers.

A different tendency was observed in the parameters ecovalence and Shukla's variance. In these parameters, eight out of sixteen cultivars followed the average tendency. In five of them (AD-7291, Rakita, Lasko, Respekt and Blagovest), the most stable parameter was number of productive tillers, followed by 1000 kernel weight and number of grains in spike. In cultivars Atila, Akord and Borislav, the difference to the average tendency was in the stability of number of productive tillers and number of grains in spike.

Summarizing the results on the three parameters, only five genotypes followed the average tendency: Kolorit, Bumerang, Irnik, Lovchanets and Doni 52. None of these five cultivars followed the average tendency of adaptability. Bumerang, Irnik and Doni 52 followed the average tendency of the regression coefficient observed by Stoyanov and Baychev (2016). This indicated their stable nature regardless of the growing conditions.

The above results showed that although certain predominant tendencies were observed, the cultivars did not have similar stability and adaptability of yield and yield traits. This was related to the rather complex polygenous nature of the investigated traits and the presence of a rather differing genotype x environment interaction. The correlation analysis of the studied parameters of yield to the parameters of the yield related traits revealed that none of the three traits (number of productive tillers, 1000 kernel weight and number of grains in spike) could determine the stability and adaptability of yield.

Table 5. Correlation between yield stability and adaptability parameters and yield elements stability and adaptability parameters

| Yield stability and adaptability parameters on direct values | Yield elements stability and adaptability parameters on direct values | | |
|---|---|---|---|
| | NPT | M1000 | NGS |
| bi | -0.131 | -0.095 | -0.316 |
| S2di | -0.258 | -0.271 | -0.184 |
| Wi | -0.167 | -0.105 | 0.530* |
| S2i | -0.167 | -0.104 | 0.530* |
| Yield stability and adaptability parameters on normalized and logarithmic values | Yield elements stability and adaptability parameters on normalized and logarithmic values | | |
| | NPT | M1000 | NGS |
| bi | -0.273 | -0.095 | -0.315 |
| S2di | -0.199 | 0.427 | 0.554* |
| Wi | 0.167 | -0.011 | 0.727** |
| S2i | 0.160 | -0.007 | 0.718** |

The only significant correlations were observed between the stability parameters of yield and these of number of grains in spike. Such a definition has been confirmed many times in our researches since in the studied triticale cultivars it was the number of grains in spike that was the main element of yield. Even extremely high conditions of drought could not change this tendency, which was indicative that the stability of yield in most cultivars was directly related to their ability to form a good grain set under variable conditions of the environment. Therefore, the stability of the number of grains in spike should be considered one of the most important breeding parameters in triticale. Figure 1 presents a biplot, along the abscissa of which the yield values are placed, and along the ordinate – the values of the variance of Shukla calculated on the basis of the normalized data on the number of grains of the studied genotypes. The graph is conditionally divided into four quadrants. The first encompassed the genotypes with yield higher than the average and stability of grain set higher than the average. Cultivars Rakita, Lasko, Bumerang, Doni 52, Blagovest and Borislav fell within this quadrant. The second quadrant included cultivars with higher yields but low stability of the grain set, to which belonged Vihren and Presto. Cultivars AD-7291, Kolorit and Lovchanets were in the third quadrant; they were characterized by yields lower than the average and stability of the grain set lower than the average. Cultivars Atila, Akord, Respect, Irnik and Dobrudzhanets were in the fourth quadrant. They combined good stability of the grain set with yields lower than the average.

The observed combinations showed that cultivars such as Rakita, Bumerang and Doni 52 were characterized by optimal yield and grain set. Within rather contrasting periods with clearly outlined soil drought, such genotypes become highly promising. A large number of our researches confirm the considerable practical value both of the standard cultivar Rakita and of cultivars Bumerang and Doni 52 (Stoyanov and Baychev, 2016; Stoyanov et al., 2017; Stoyanov, 2018; Stoyanov, 2021; Stoyanov & Baychev, 2021). In this respect, the studies of other authors (Dobreva et al., 2018) show that cultivar Bumerang is a highly productive genotype with serious grain set and possibility to be grown under a wide range of soil and climatic conditions.

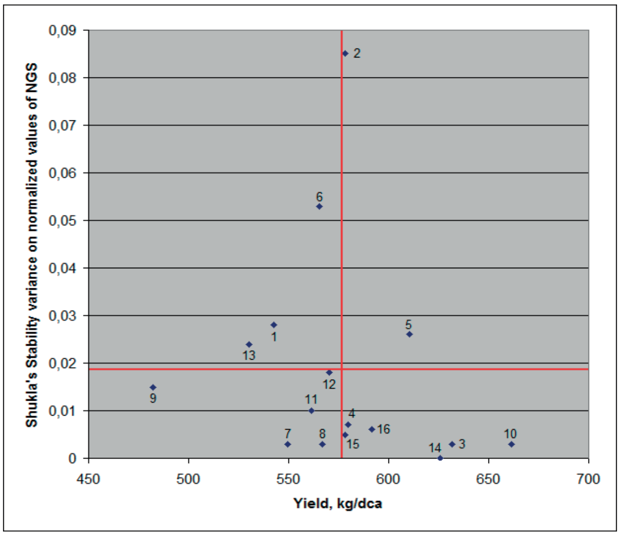


Figure 1. Biplot with combined data on yield and Shukla's variance calculated on normalized data of number of grains in spike of the investigated genotypes
1. AD-7291; 2. Vihren; 3. Rakita; 4. Lasko; 5. Presto; 6. Kolorit; 7. Atila; 8. Akord; 9. Respekt; 10. Bumerang; 11. Irnik; 12. Dobrudzhanets; 13. Lovchanets; 14. Doni 52; 15. Blagovest; 16. Borislav

## CONCLUSIONS

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

The yield related traits - number of productive tillers, 1000 kernel weight, number of grains in spike differed considerably by their stability according to the individual cultivars and the parameters of stability, drought having significant effect on their values.

Cultivars Bumerang and Doni 52 were with the best combination of stability and adaptability by the traits number of productive tillers and 1000 kernel weight.

Trait number of grains in spike was rather complex under drought and the separate stability parameters related to controversial results. The data on the deviation from the regression showed that most stable were Irnik, Dobrudzhanets, Lovchanets, Blagovest and Borislav, while the ecovalence and the variance of Shukla determined cultivars Rakita, Atila, Bumerang and Doni 52 as most stable. According to the three parameters of stability, Vihren, Lasko and Kolorit were the most unstable genotypes.

The widest adaptability according to the trait number of grains in spike was observed in cultivars Rakita, Lasko and Respekt, while specific adaptability to the favorable conditions of the environment was observed in AD-7291, Atila, Akord, Irnik, Lovchanets, Doni 52 and Blagovest, and to unfavorable environments – in Presto, Kolorit, Bumerang, Dobrudzhanets and Borislav.

A general tendency was observed in the investigated set of cultivars showing that most stable and adaptable among the studied parameters was 1000 kernel weight, followed by number of productive tillers; number of grains in spike was with the lowest stability and the most narrow adaptability.

6. A tendency was observed toward the stability of the separate yield components not being functionally related to the stability of yield, which determined the investigated cultivars as developed according to a complex of traits and being suitable for growing under variable environments.

## REFERENCES


Akbarian, A., Arzani, A., Salehi, M. & Salehi, M. (2011). Evaluation of triticale genotypes for terminal drought tolerance using physiological traits. *Indian Journal of Agricultural Sciences*, 81(12), 1110-1115.

Arseniuk, E. (2015). Triticale Abiotic Stresses-An Overview. In: Eudes F. (eds) *Triticale*. Springer, Cham., 69-81.

Becker, H. C. & Leon, J. (1988). Stability Analysis in Plant Breeding. *Plant Breeding*, 101, 1-23.

Chai S.-X., Chang, L., Yang, R.-J., Yang D.-L. & Chen H.-B. (2011). Analysis on Genotype × Environment Interactions and Yield Stability of Triticale. *Journal of Nuclear Agricultural Sciences*, 25(1), 155-161.

Dhindsa, G. S., Dosanjh, A. S., Sohn, V. S., Dhindsa, J. S. & Goyali, J. C. (2002). Genotype x Environment interaction for yield components in hexaploid triticale. *Proceedings of the 5th International Triticale Symposium*, Vol. II, June 30 - July 5, 2002, Radzikow, Poland, 199-200.

Dimitrijevic M., Kneževic, D., Petrovic, S., Zecevic, V., Boškovic, J., Belic, M., Pejic, B. & Banjac, B. (2011). Stability of yield components in wheat (*Triticum aestivum* L.). *Genetika*, 43(1): 29 -39.

Dobreva, S., Kirchev, H. & Muhova, A. (2018). Grain yield of triticale varieties depending on the foliar fertilization in the conditions of increasing norms of fertilization of the soil with nitrogen. *Research Journal of Agricultural Science*, 50(4), 122-126.

Eberhart, S. A. & Russell, W. A. (1966). Stability parameters for comparing varieties. *Crop Sci.*, 6: 36-40.

Estrada-Campuzano, G., Slafer, G. A. & Miralles, D. J. (2012). Differences in yield, biomass and their components between triticale and wheat grown under contrasting water and nitrogen environments. *Field Crops Research*, 128, 167-179.

Fayaz, N. & Arzani, A. (2011). Moisture stress tolerance in reproductive growth stages in triticale (X Triticosecale Wittmack) cultivars under field conditions. Crop Breeding Journal, 1(1), 1-12.

Grzesiak, S., Grzesiak, M. T., Filek, W. & Stabryła, J. (2003). Evaluation of physiological screening tests for breeding drought resistant triticale (x *Triticosecale* Wittmack). *Acta physiologiae plantarum*, 25(1), 29-37.

Grzesiak, M. T., Marcińska, I., Janowiak, F. Andrzej Rzepka & Hura, T. (2012). The relationship between seedling growth and grain yield under drought conditions in maize and triticale genotypes. *Acta Physiol Plant*, 34, 1757-1764. https://doi.org/10.1007/s11738-012-0973-3.

Hura, T., Grzesiak, S., Hura, K., Thiemt, E., Tokarz, K., & Wędzony, M. (2007). Physiological and biochemical tools useful in drought-tolerance detection in genotypes of winter triticale: accumulation of ferulic acid correlates with drought tolerance. *Annals of botany*, 100(4), 767-775.

Hura, T., Hura, K. & Grzesiak, S. (2009). Physiological and biochemical parameters for identification of QTLs controlling the winter triticale drought tolerance at the seedling stage. *Plant Physiology and Biochemistry*, 47(3), 210-214.

Hura, T., Hura, K., Dziurka, K., Ostrowska, A., Bączek-Kwinta, R. & Grzesiak, M. (2012). An increase in the content of cell wall-bound phenolics correlates with the productivity of triticale under soil drought. *Journal of plant physiology*, 169(17), 1728-1736.

Karrou, M. & Oweis, T. (2014). Assessment of the severity and impact of drought spells on rainfed cereals in Morocco. *African Journal of Agricultural Research*, 9(49), 3519-3530.

Kendal, E. & Sayar, M. S. (2016). The stability of some spring triticale genotypes using biplot analysis. *The Journal of Animal & Plant Sciences*, 26(3), 754-756.

Kendal, E., Sayar, M. S., Tekdal, S., Aktas, H. & Karaman, M. (2016). Assessment of the impact of ecological factors on yield and quality parameters in triticale using GGE biplot and AMMI analysis. *Pakistan Journal of Botany*, 48(5), 1903-1913.

Kendal, E., Tekdal, S. & Karaman, M. (2019). Proficiency of biplot methods (AMMI and GGE) for appraise Triticale genotypes across multiple environments. *Applied Ecolgy and Envirnmental Research*, 17(3), 5995-6007.

Khanna-Chopra, R. & Viswanathan, C. (1999). Evaluation of heat stress tolerance in irrigated environment of T. aestivum and related species. I. Stability in yield and yield components. *Euphytica*, 106(2), 169-180.

Kutlu, I., Kinaci, G. (2010). Evaluation of Drought Resistance Indices for Yield and Its Components in Three Triticale Cultivars. *Journal of Tekirdag Agricultural Faculty*, 7(2), 95–103.

Lozano-del Río, A. J., Zamora-Villa, V. M., Ibarra-Jiménez, L., Rodríguez-Herrera, S. A., de la Cruz-Lázaro, E. & de la Rosa-Ibarra, M. (2009). AMMI analysis of genotype-environment interaction and production potential of forage triticale (X *Triticosecale* Wittm.). *Universidad y Ciencia Tropico Humedo*, 25(31): 81-92.

Lule, D., Tesfaye, K. & Mengistu, G. (2014). Genotype by environment interaction and grain yield stability analysis for advanced triticale (x. *Triticosecale* Wittmack) genotypes in Western Oromia, Ethiopia. *Ethiopian Journal of Science*, 37(1), 63-68.

Lonbani, M. & Arzani, A. (2011). Morpho-physiological traits associated with terminal drought-stress tolerance in triticale and wheat. *Agronomy Research*, 9(1-2), 315-329.

Majid, S. A., Asghar, R. & Murtaza, G. (2007). Yield stability analysis conferring adaptation of wheat to pre-and post-anthesis drought conditions. *Pakistan Journal of Botany*, 39(5), 1623-1637.

Mehraban, A., Tobe, A., Gholipouri, A., Amiri, E., Ghafari, A. & Rostaii, M. (2019). The effects of drought stress on yield, yield components, and yield stability at different growth stages in bread wheat cultivar (*Triticum aestivum* L.). *Polish Journal of Environmental Studies*, 28(2), 739-746.

Scapim, C. A., Oliveira, V. R., Braccini, A. D. L., Cruz, C. D., Andrade, C. A. D. B. & Vidigal, M. C. G. (2000). Yield stability in maize (*Zea mays* L.) and correlations among the parameters of the Eberhart and Russell, Lin and Binns and Huehn models. *Genetics and Molecular Biology*, 23, 387-393.

Shukla, G. K. (1972). Some statistical aspects of partitioning genotype-environmental components of variability. *Heredity*, 29: 237-245.

Stoyanov, H. & Baychev, V. (2016). Assessment of yield components stability and plasticity in bulgarian triticale (×*Triticosecale* wittm.) Cultivars. *Scientific works of Institute of Agriculture – Karnobat*, (in press)

Stoyanov, H., Baychev, V., Petrova, T. & Mihova, G. (2017). Triticale cultivars suitable for growing under high level of abiotic stress. *Journal of Mountain Agriculture on the Balkans*, 20(6): 223-242.

Stoyanov, H. & Baychev, V. (2018). Tendencies in the yield and its components of the Bulgarian varieties of triticale, grown under contrasting conditions of the environment. *Rastenievadni nauki*, 55(3), 16-26 (Bg).

Stoyanov, H., (2018). Reacton of Triticale (x*Triticosecale* Wittm.) to Abiotic Stress. PhD Thesis, General Toshevo, Bulgaria (Bg).

Stoyanov, H. (2020). Analysis on test weight of Bulgarian triticale cultivars. *Rastenievadni nauki*, 57(6), 3-16.

Stoyanov, H. (2021). Tendencies in the reaction of the yield of Bulgarian triticale cultivars under contrasting environments. *Rastenievadni nauki*, 58(1), 14-25.

Stoyanov, H. & Baychev, V. (2021). Triticale lines combining high productivity with stability and adaptability under contrasting environments. *Rasteniavadni nauki*, 58(5), 3-15.

Tsenov, N., Atanasova, D. & Gubatov, T. (2013). Genotype x environment effects on the productivity traits of common wheat. I. Nature of interaction. *Scientific Works of Institute of Agriculture – Karnobat*, 3(1): 57-70.

Wricke, G. (1962). Über eine Methode zur Erfassung der ökologischen Streubreite. *Zeitschrift für Pflanzenzüchtung*, 47: 92-96.