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EFFECT OF DROUGHT ON YIELD AND YIELD COMPONENTS OF TRITICALE IN THE CONDITIONS OF SOUTH DOBRUDZHA

Hristo STOYANOV

Dobrudzha Agricultural Institute General Toshevo, 9521, General Toshevo, Dobrich, Bulgaria

Corresponding author email: hpstoyanov@abv.bg

Abstract

In order to determine the effects of drought on triticale under the conditions of South Dobrudzha, eleven cultivars of this crop were studied during six contrasting periods of growing. The following traits were determined: number of tillers, yield, 1000 kernel weight, number of grains in spike. Based on the used indices (DAASDI and DAADPI), moderate to high effect of drought on the growth and development of the crop was determined in comparison to the period favorable for growing of triticale (2014/2015). In some of the studied genotypes, the reduction in yield exceeded 30%. The intensive drought influenced all yield components, the effect being highest on 1000 kernel weight. Comparatively low was the effect on the trait number of productive tillers regardless of the unfavourable conditions during its formation. Cultivars Bumerang and Doni 52 were characterized by the highest drought resistance based on all periods, in which drought was observed. The reduction of yield in these genotypes was moderate, revealing their high tolerance and suitability for growing under the conditions of South Dobrudzha.

Key words*: drought, triticale, yield.*

INTRODUCTION

Drought is among the most serious problems of agriculture worldwide. This is due to the fact that the most important element for the physiological processes in the plant organism is the availability of water (Kadrev, 1985; Bassett, 2013). Therefore, less than the optimal amount of water in the plant organism causes a large number of metabolic disturbances and inability to carry out the normal physiological processes (Kadrev, 1967). The various forms of such type of stress are the reason for different reactions in the cultural plants. Yield, regardless of the crop, as a complex value is affected by drought to the highest degree. In this respect, it is important to distinguish between biological and agronomic drought tolerance. The first type is associated with the ability of the plant to complete its life cycle overcoming the effect of drought, and the second type – with the ability of the plant to realize sufficient production, overcoming the drought. The agronomic drought tolerance is particularly important from a breeding point of view since it allows for selecting those genotypes, which would realize the highest productivity under stress. There are different methods for determining this type of drought tolerance. A set of indices and coefficients, which give varied information about the behavior of a certain group of genotypes, are most often being mentioned in literature (Khavarinejad and Babajanov, 2010; Farshadfar et al., 2012; Parchin et al., 2013; Mursalova et al., 2015). A major point in all indices, however, is that they are formed on the basis of productivity or the components of productivity, as an obligatory ratio between check (irrigated) variant and drought variant (Anwar et al., 2011).

Triticale, in contrast to other cereal plants, is characterized by a very high tolerance to abiotic stress. Since on a global scale droughts are becoming increasingly common, such crops as triticale would endure water deficiency, which significantly affects their productivity (Arseniuk, 2015). Fayaz and Arzani (2011) and Lonbani and Arzani (2011) reported a significant variation in the response among the triticale genotypes they studied. Nevertheless, these authors also pointed out that triticale exceeded bread wheat by drought resistance. Royo et al. (2000) and Zhang et al. (2009) emphasized the serious variability of triticale under conditions of drought, especially with regard to the traits pertaining to growth – plant height, roots, leaf mass. Drought resistance of triticale, according to Giunta et al. (1992), was due to the higher earliness of the studied genotypes, the earlier date to heading and also to the ability of the roots of triticale to extract water from soil. In spite of these data, Arseniuk (2015) stated that the effect of soil moisture on triticale was not sufficiently studied, which imposes the necessity to study in detail the processes of soil drought, which influence the productivity of this crop.

The indices for evaluation of drought resistance ensure a quantitative approach based on the reduction of a given trait under the effect of drought according to normal or controlled conditions of watering (Mitra, 2001). There are few researches in triticale based on specialized indices. Kutlu and Kinaci (2010) determined through indices the wide response of yield and its components in three studied genotypes with regard to drought. Grzesiak et al. (2012) observed that the reaction of the triticale genotypes to drought can be differentiated through the values of the indices, allowing their efficient grouping.

In Bulgaria, indices for evaluation of the drought effects on triticale have been used by Stoyanov (2018) in a controlled field-laboratory experiment. The research determined that the different triticale genotypes responded with considerable reduction of the studied traits in comparison to the irrigated variant. Under natural conditions, the duration and intensity of drought often are not a controlled factor and unlike the field-laboratory experiments, the results from the separate periods cannot be adequately compared and averaged. At the same time, drought can have a negative effect only on a certain element of yield, but the value of yield itself as a whole may not be affected. Therefore, the results from different field experiments should be analyzed on the basis of the degree of drought during a studied period. Besides yield, other traits should also be evaluated in order to obtain adequate information about the behavior of the studied set of genotypes.

The aim of this study was to determine the effects of the natural processes of drought under the conditions of South Dobrudzha in Bulgarian triticale cultivars.

MATERIALS AND METHODS

Plant material and biometric analysis

To implement the above goal, eleven Bulgarian triticale cultivars were used (Kolorit, Atila, Akord, Respekt, Bumerang, Irnik, Dobrudzhanets, Lovchanets, Doni 52, Blagovest, Borislav). The studied cultivars were grown as a whole-surface crop in experimental plots of 10 m^2, in four replicates in a standard block design, within a competitive varietal trial. Sowing was mechanized within the standard dates for triticale, at density 550 seeds per m^2. Besides the above cultivars, the competitive variety trial also involved the triticale check cultivars AD-7291, Vihren and Rakita, as well as the world checks Lasko and Presto. The number of productive tillers per m^2 (NPT) were determined for each experimental plot using a 0.25 m^2 sampling frame. 1000 kernel weight (g) (M1000) and number of grains in spike (NGS) were also determined. The plots were harvested at full maturity, reading the yield (Y) from each of them separately.

Growing conditions

The trial was carried out for six successive harvest years - 2014/2015, 2015/2016, 2016/2017, 2017/2018, 2018/2019, 2019/2020. The data presented on the mean monthly air temperature and the sum of precipitation (Table 1) shows the contrasting nature of the studied periods. The highest differences according to the long-term tendency with regard to temperature were observed during December – March, and with regard to precipitation – in December and May. The differences between these periods are sufficient to consider that the vegetative growth of plants during the separate years occurred in different ways. Certain events and processes in meteorological respects are clearly outlined; they were of single occurrence and were not repeated over periods; they were also able to affect the physiological processes in the plant organism.

Economic years 2018/2019 and 2019/2020 are worth mentioning due to the extreme intensive spring drought. Highly unfavorable for growing of triticale was economic year 2019/2020 due to the rather long-lasting drought during March – April. At the same time, favorable for growing of triticale were the conditions in 2014/2015 and 2016/2017, when a lower number of negative events during the vegetative growth of plants was observed.

Table 1. Mean monthly air temperature and sum of precipitation for the studied period

Parameter	Year	Aug	Sep	Oct	Noe	Dec	Jan
Mean monthly air temperature, °C	2014/2015	22,70	17,50	11,20	5,60	3,10	1,40
	2015/2016	22,80	19,50	10,90	9,30	3,40	-0,80
	2016/2017	22,20	18,10	10,60	6,50	-0,60	-4,10
	2017/2018	22,50	19,00	11,80	7,50	4,70	1,70
	2018/2019	23,60	17,70	13,30	5,40	1,20	1,00
	2019/2020	22,80	17,90	13,40	11,70	5,20	1,80
	1960/2020	21,13	16,88	11,68	6,77	1,97	-0,21
Sum of precipitation, mm	2014/2015	19,30	31,40	57,90	33,20	87,00	33,20
	2015/2016	42,00	20,80	78,30	55,10	0,40	86,30
	2016/2017	5,00	35,80	72,20	43,30	12,50	48,40
	2017/2018	12,40	69,90	50,50	57,20	55,80	75,40
	2018/2019	1,10	54,70	11,70	66,20	43,80	19,20
	2019/2020	7,80	36,70	27,60	35,40	21,80	2,80
	1960/2020	36,95	46,26	42,08	43,41	41,66	36,37
Parameter	Year	Feb	Mar	Apr	May	Jun	Jul
Mean monthly air temperature, °C	2014/2015	2,00	5,00	10,10	16,40	19,40	22,40
	2015/2016	7,30	6,80	13,20	14,70	20,90	22,80
	2016/2017	2,00	7,30	8,70	15,00	20,20	21,80
	2017/2018	1,10	4,60	13,40	17,70	20,40	22,20
	2018/2019	3,50	8,20	9,00	16,00	22,30	22,00
	2019/2020	5,10	8,00	10,00	15,40	19,60	22,30
	1960/2020	1,19	4,71	9,87	15,24	21,99	21,40
Sum of precipitation, mm	2014/2015	79,50	67,70	8,50	12,90	31,30	27,20
	2015/2016	40,70	52,70	20,80	117,10	55,70	2,80
	2016/2017	27,40	48,90	38,40	29,00	87,70	66,30
	2017/2018	48,80	4,90	30,90	90,80	59,60	59,60
	2018/2019	16,30	16,10	49,40	31,70	37,50	54,00
	2019/2020	28,10	28,30	5,80	48,00	51,30	2,70
	1960/2020	34,18	35,46	39,89	52,00	60,93	51,34

Developing a model

According to Stoyanov (2018) number of indices were developed, which provide varied information on how the conditions of drought influence a certain studied trait. In our previous researches (Stoyanov, 2018; Stoyanov et al., 2019), the sensitivity drought index (SDI) developed by Farshadfar and Javadinia (2011) was preferred as an index for evaluation (Formula 1). This index allows evaluating the degree to which the value of a given studied trait decreases under drought.

$$SDI = \frac{x_n - x_s}{x_n} \quad (1)$$

where

x_n – value of the index in the watered check variant

x_s – value of the index in the variant with drought

The indices as SDI, give an idea about the direct effects of drought without being able to evaluate the levels of a given studied trait. Therefore, the genotypes evaluated as highly drought-tolerant turn out to be with low values of yield or of other studied trait. This gave Stoyanov (2018) reasons to develop the specific index DPI (drought parameter index), which combined in its values the effects of both drought and the potentials of a given trait (Formula 2).

$$DPI = \frac{x_n + x_s}{2} . \frac{x_s}{x_n} \quad (2)$$

Thus developed and applied under controlled conditions, the index give valuable information about the behavior of the genotypes according to a certain level of drought. On the other hand the indices could also be applied to two different periods of study, one of which is selected as a basic one (check), while the other is with a clearly expressed drought. Under natural conditions, however, drought is not a controlled process, and its duration and intensity can be rather different during the separate periods of vegetative growth. Therefore, the question arises – is it possible the values of the indices for the separate dry periods, in comparison to the basic favorable periods, to be compared and averaged? Such differing effects require the indices referring to different periods to be corrected based on the intensity and duration of the respective period of drought, and to select a period meeting certain criteria as a basic (check or favorable) one.

One of the most common methods for evaluation the drought duration and intensity is by using the aridity index of De Martonne (I_{DM}) (Formula 3) (Croitoru et al., 2012). In its original form, this index gives an idea about drought during the entire calendar or economic year (12 month-period). It can be calculated for another specific period, too. When evaluating the vegetative growth period from October to July (10 month-period), this index would satisfy Formula 4.

$$I_{DMY} = \frac{P_Y}{T_Y + 10} \quad (3) \qquad I_{DMGP} = \frac{1,2 P_{GP}}{T_{GP} + 10} \quad (4)$$

where

I_{DMY} – De Martonne index for an economic year

P_Y – Sum of precipitation of an economic year

T_Y – Mean air temperature of an economic year

I_{DMGP} – De Martonne index of a vegetative growth period

P_{GP} – Sum of precipitation of a vegetative growth period

T_{GP} – Mean air temperature of a vegetative growth period

Since each period is characterized by different levels of intensity and duration of drought, it is highly important which of these periods will be taken as a basic (check, favorable) one, to which the rest will be compared. The use of the mean long-term data also allows calculating the I_{DM}. As a basic should be preferred the period, which, by its I_{DM} values is closest to the the long-term period I_{DM} values. In this case, the correction of SDI and DPI should be based on the difference between the I_{DM} calculated for the basic period (I_{DMb}) and the index calculated for the drought period (I_{DMi}). The correction of SDI and DPI for each of the compared periods allows calculating the mean value adjusted with the mean long-term effect of drought on a given genotype according to a certain basic period. The difference between I_{DMb} and I_{DMi} should be of relative character. This makes the ratio an immeasurable value allowing for more adequate interpretation of the obtained data. The mathematically corrected long-term mean value of the two indices SDI and DPI can be presented as Formulae 5 and 6.

$$DAASDI = \frac{\sum_{i=1}^{S}\left(SDI_i \cdot \frac{I_{DMb}}{I_{DMi}}\right)}{S} \quad (5)$$

$$DAADPI = \frac{\sum_{i=1}^{S}\left(DPI_i \cdot \frac{I_{DMi}}{I_{DMb}}\right)}{S} \quad (6)$$

where

DAASDI – De Martonne Adjusted Average SDI
DAADPI – De Martonne Adjusted Average DPI
SDI_i – SDI calculated for a given period i
DPI_i – DPI calculated for a given i
I_{DMi} – De Martonne index for period i
I_{DMb} – De Martonne index for the basic check period b
S – number of compared periods according to the favorable period

Thus calculated, the value of DAASDI shows the maximum reduction of the studied trait based on the intensity and duration of drought in each of the compared periods according to the favorable check period. Simultaneously, DAADPI shows the model values of the studied trait, provided that its actual means are adjusted with the maximum intensity of the drought during a given period (according to the definition of Stoyanov (2018) on DPI) but corrected according to the differences of the separate periods in comparison to the basic period. It can be determined from Formulae 5 and 6 that the corrective factor for the two indices is different, the factor for SDI being reciprocal to the factor for DPI. This is necessary because the two indices have opposite meanings with regard to drought – SDI expresses a reduction, which is increasing with the increase of the effects from drought, while DPI exhibit the model value, which decreases with the increase of the drought effects. Simultaneously, it is necessary to determine for what period I_{DM} should be calculated. Although the vegetative growth period, throughout which the plants develop from planting to harvesting is the preferred variant, it should be emphasized, that the meteorological effects are not limited only to this period. The drought effects may have a durable impact on the condition and moisture reserves of soil, which may influence the pre-sowing tilths and thence – the setting of optimal condition for the emergence and initial development of plants. Therefore, I_{DM} should be calculated for the overall vegetative growth period (which is 10 months for triticale, October-July), but also for the economic year, which in cereals begins with the harvesting of the previous crop or with the initial soil tillage after the previous crop (in this experimental setting the period started in August and its duration was 12 months). The use of the two periods would allow for more precise determining of the basic check period and for more efficient evaluation of the studied genotypes under conditions of drought in the separate compared periods.

Application of the model and statistical analyses

The results obtained on yield and the other studied traits of the studied triticale cultivars were summarized and averaged over genotypes and periods. The aridity index of De Martonne was calculated for each studied period separately both based on a 10-month vegetative growth period (October – July), and for a 12-month economic year (August – July). Analysis was carried out on drought over the years and the basic periods were determined. The indices DAASDI and DAADPI were calculated with a correction factor based on a 10-month vegetative growth period ($DAASDI_{GP}$ and $DAADPI_{GP}$) and a respective 12-month economic year ($DAASDI_{Y}$ and $DAADPI_{Y}$) for each studied trait. A close analysis was carried out on the effect of drought on the yield and its elements. A $DDADPI_{GP}$-$DAADPI_{Y}$ biplot was constructed, determining the genotypes, which were most tolerant under the conditions of long-term forms of drought. MS Office Excel, 2003 was used for all analyses.

RESULTS AND DISCUSSIONS

Peculiarities of drought during the period of investigation

The results obtained on I_{DM} (Table 2), which was calculated on the basis of a 10-month vegetative growth period and a 12-month economic year, revealed extreme differences in drought during the studied periods. The I_{DMY} values of economic years 2018/2019 and 2019/2020 showed that the meteorological conditions in these two years were indicative of an arid type of climate (according to Pellicone et al., 2019), which is not typical for the region of South Dobrudzha as a whole. The data for the long-term period (1960/2020) (Table 2) characterize the region where the experiment was carried out as moderately dry (Mediterranean type according to Pellicone et al., 2019). In this respect, by values of I_{DMY}, economic years 2015/2016 and 2016/2017 were closest to the long-term period, the difference with economic year 2016/2017 being lowest. Therefore we chose this economic year as a basic period, ***most typical meteorologically***, according to which to analyze the effects of drought during the rest of the economic years.

Table 2. Index of De Martonne for the studied periods

Year	I_{DMY}	I_{DMGP}
2014/2015	22,86	26,76
2015/2016	25,38	29,35
2016/2017	24,94	30,36
2017/2018	27,72	31,21
2018/2019	18,31	20,56
2019/2020	13,09	14,22
1960/2020	24,73	26,97

A similar tendency with regard to the separate studied periods was observed also for the values of I_{DMGP}. The data on vegetative growth periods 2018/2019 and 2019/2020 emphasized the extreme dry conditions of growing the studied genotypes. The results on the long-term period, however, showed that the period of vegetative growth of the crop was considerably more humid than the whole of the economic year. Such a peculiarity relates to the fact that the months of August and September, when the crop was not sown yet, were extremely dry. Nevertheless, it is worth mentioning the fact that by values of I_{DMPG}, vegetative growth period 2014/2015 was closest to the long-term period (1960/2020). Respectively, periods 2015/2016, 2016/2017 and 2017/2018 were considerably more humid. When comparing the results on yield (Table 3), it becomes clear that the highest yield from the studied triticale cultivars was realized in 2014/2015. This indicated that this vegetative growth period was ***the most favorable*** for growing of the crop and should also be chosen as a basic period for determining the effects of drought.

The above peculiarities allow calculating the model indices DAASDI and DAADPI on the basis of the two basic periods: 2016/2017, which was ***the most typical*** in a meteorological respect, and 2014/2015, which was ***the most favorable*** for growing of the crop. This, on its part, allows to define in detail the effects of drought and to estimate to what degree drought leads to unfavorable consequences for yield and the other studied traits.

Specificity of the studied traits and effect of drought on them

Yield

Yield was highly influenced by the different conditions of drought (Table 3). During the two periods with the most intensive and long-lasting drought (2018/2019 and 2019/2020), the average yields from the studied cultivars were rather low. It is worth mentioning the facts, however, that the lowest yield was registered in economic year 2015/2016. Comparatively low was also the yield in 2017/2018. These two periods were marked by unfavorable rainfalls in June and July with a highly negative effect on grain filling and on 1000 kernel weight and test weight, respectively. This indicated that the periods with intensive drought, as well as the periods with excessive rainfalls, were rather unfavorable for the formation of yield from the studied cultivars. This is also emphasized by the fact that in the most favorable period, as well as in the period with the most typical meteorological conditions, the productivity of the triticale cultivars was highest.

Table 3. Means of studied traits by years

Cultivar	NPT	Y, kg/da	NGS	M1000, g
2014/2015	689	728	24	43,6
2015/2016	828	510	19	32,7
2016/2017	609	682	23	49,2
2017/2018	726	649	21	42,5
2018/2019	699	539	19	39,7
2019/2020	545	542	27	37,8
Average	683	608	22	40,9
LSD 0,05	*78,3*	*71,8*	*2,4*	*4,48*
LSD 0,01	*102,9*	*94,3*	*3,1*	*5,88*
LSD 0,001	*131,4*	*120,5*	*3,9*	*7,51*

NPT – Number of productive tillers; Y – Yield; NGS – Number of grains in spike; M1000 – Thousand kernels weight.

Table 4. Means of studied traits by cultivars

Cultivar	NPT	Y, kg/da	NGS	M1000, g
AD-7291	622	569	24	38,9
Vihren	633	586	21	43,4
Rakita	641	647	25	40,5
Lasko	712	596	21	40,2
Presto	762	621	20	41,4
Kolorit	610	596	24	40,4
Atila	681	633	21	43,9
Akord	632	618	24	41,8
Respekt	655	525	21	37,7
Bumerang	690	660	23	42,6
Irnik	651	600	25	38,3
Dobrudzhanets	724	599	21	40,7
Lovchanets	787	530	19	37,8
Doni 52	719	673	23	40,7
Blagovest	713	623	22	39,6
Borislav	690	655	21	46,5
Average	683	608	22	40,9
LSD 0,05	*25,1*	*20,9*	*0,9*	*1,16*
LSD 0,01	*33,0*	*27,5*	*1,2*	*1,52*
LSD 0,001	*42,2*	*35,1*	*1,5*	*1,94*

NPT – Number of productive tillers; Y – Yield; NGS – Number of grains in spike; M1000 – Thousand kernels weight.

Averaged for the period of study (Table 4), the highest values of yield were registered in the check cultivar Rakita and in cultivars Atila, Bumerang, Doni 52 and Borislav, and the lowest – in Respekt and Lovchanets. The other cultivars were by their productivity close to some of the involved checks or to the mean value of all genotypes. A tendency towards maintaining high productivity under intensive drought in comparison to the favorable period ($DAADPI_{GP}$) was observed in Atila, Bumerang and Doni 52, as well as in the check cultivars AD-7291, Vihren and Rakita (Table 5). In comparison to the most typical growing period ($DAADPI_{Y}$), such a tendency was observed in the check Rakita, the world check Lasko, and in cultivars Bumerang, Irnik, Doni 52 and Borislav.

In both indices, registering a reduction according to drought, averaged for the period of investigation ($DAASDI_{GP}$ and $DAASDI_{Y}$), comparatively high values were observed, indicating that the effects of drought had a considerable influence on yield. The lowest reduction according to the two basic periods was determined in AD-7291 and Kolorit, and the highest – in Respekt.

The results from different experiments (Kutlu and Kinaci, 2010; Villegas et al., 2010; Akbarian et al., 2011; Lonbani and Arzani, 2011; Fayaz and Arzani, 2011; Shchypak et al., 2016; Munjonji, 2017; Shanazai et al., 2018; Ramazani and Izanloo, 2019) under conditions of drought show that the yield of triticale is affected by drought. Blum (2014) found out, investigating 24 hexaploid triticale lines under drought, that triticale gave higher yields than common wheat. When determining the correlations of the yields under stress and without stress, the data are characterized by high variation, which emphasizes that triticale as a crop is capable of responding adequately to stress. Martyniak (2002), on the other hand, related the reaction to drought to the specific stage when stressed occurred.

The differing tendencies with regard to the two model indices ($DAADPI_{GP}$ and $DAADPI_{Y}$) calculated for the two different basic periods showed that there was a considerable difference in the productivity of the cultivars and their ranking by productivity during the favorable period and the period with most typical meteorological conditions. The period favorable for growing was characterized by I_{DM}, lower than the period with most typical conditions. This demonstrated that the lack of rainfalls (drought) during a certain period of the vegetative growth of triticale was a key moment for higher productivity. In this respect, the most typical conditions observed in economic year 2016/2017, although deviating comparatively little from the long-term tendency, were characterized by a higher level of abiotic stress than in 2014/2015, when, during heading and grain filling a short period of drought was observed. Therefore, drought tolerance should be considered not an absolute breeding criteria but a relative corrective. This means that according to the most favorable growing period, drought tolerance should be considered ***agronomic tolerance to drought***, i.e. which are the cultivars maintaining high productivity according to a certain basic period. On the other hand, the drought tolerance according to the period with most typical conditions should be considered ***biological tolerance to drought***, i.e. which are the cultivars reacting to the effects of drought that are different from those in the meteorologically most typical period. Such a concept means that the values of $DAADPI_{GP}$ would show to what degree a given cultivar would maintain its optimal productivity under the effect of drought, and the values of $DAADPI_{Y}$ – to what extent the typical productivity of a given genotype would react under the effect of drought. The differences in these two concepts are presented in Figure 1 through biplot, on which the values of $DAADPI_{GP}$ and $DAADPI_{Y}$ are respectively given.

The cultivars were distributed along the entire graph showing varied combinations of agronomic and biological drought tolerance. A tendency to maintain higher productivity in comparison to the two basic periods was observed in the checks Vihren and Rakita and in cultivars Bumerang, Doni 52 and Borislav. The exact opposite tendency was registered in Respekt and Lovchanets.

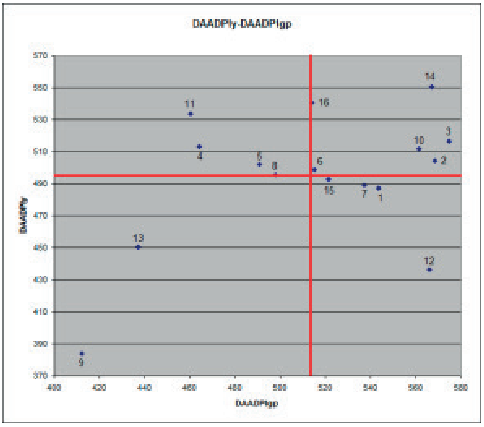

Figure 1. Biplot combining values of $DDADPI_{GP}$ and $DAADPI_{Y}$ on yield

1. AD-7291; 2. Vihren; 3. Rakita; 4. Lasko; 5. Presto; 6. Kolorit; 7. Atila; 8. Akord; 9. Respekt; 10. Bumerang; 11. Irnik; 12. Dobrudzhanets; 13. Lovchanets; 14. Doni 52; 15. Blagovest; 16. Borislav

With low agronomic tolerance to drought but with high biological one were Lasko, Presto, Akord and Irnik, and with high agronomic but low biological tolerance to drought were AD-7291, Atila, Dobrudzhanets and Blagovest. Specific was the behavior of cultivar Kolorit, which was almost at the interception point of the mean values of indices $DAADPI_{GP}$ and $DAADPI_{Y}$. Such a response makes it suitable for using as a check of drought resistance of this crop.

A similar concept can be observed also with regard to the indices showing reduction of yield according to the two basic periods ($DAASDI_{GP}$ and $DAASDI_{Y}$). In this respect, $DAASDI_{GP}$ would show to what degree a given genotype would reduce its optimal productivity under the effect of drought. On the other hand, the values of $DAASDI_{Y}$ would reflect the degree, to which the productivity typical for a genotype under the most typical conditions of the environment would be reduced when influenced by drought. Both groups of indices allow determining the biological and agronomic tolerance to drought of the studied genotypes. However, yield is a rather complex value. Therefore, for a better understanding of the effects of drought, it is necessary to apply the concept of long-term mean effect of drought to the main components of yield, too.

Number of productive tillers

During the period of the most intensive drought (2019/2020), the number of productive tillers, averaged for the studied cultivars, was lowest according to all other periods (Table 3). Respectively, during the two most humid economic years (2015/2016 and 2017/2018), the highest values of the trait were registered. During the other three of the studied periods, the values were considerably close. There were no significant differences between the number of productive tillers averaged for the cultivars during the most favorable and the most typical growing period, their number being lower during the second period. In practice, drought, especially in the early stages of growing, and the insufficient soil moisture in the pre-sowing period were the main reason for the decrease of the number of productive tillers in the studied genotypes.

The highest values of NPT were observed in the world checks Lasko and Presto and in cultivars Dobrudzhanets, Lovchanets, Doni 52 and Blagovest, averaged for the entire period of study (Table 4). Respective low NPT were registered in checks AD-7291 and Vihren and in cultivars Kolorit and Akord.

Concerning the index $DAADPI_{GP}$, a tendency toward maintaining a high NPT according to the favorable period was observed in Presto, Dobrudzhanets and Lovchanets, and a tendency toward lower NPT under the effect of drought was observed in Kolorit and Akord (Table 5). According to the most typical growing period, similar tendencies were registered according to index $DAADPI_{Y}$, but in Bumerang and Borislav it was in a negative direction, while in Akord, the tendency was positive. The lowest reduction caused by drought according to the favorable period ($DAASDI_{GP}$) was observed in the check Rakita and cultivars Irnik and Borislav, and the highest – in Lasko and Akord, Doni 52 and Blagovest. According to the most typical growing period, the lowest reduction ($DAASDI_{Y}$) was observed in Irnik and Blagovest, and the highest – in Bumerang and Borislav. In the greater part of the cultivars, the values of this index were negative indicating that during the typical growing period the number of productive tillers was lower in comparison to the other periods. The results from the calculated indices showed that the different genotypes had a comparatively low response to drought. The agronomic drought tolerance according to this index was comparatively high (only 4.40 % average reduction). In a biological sense, the index responded positively, averaged for the studied periods, because the effect of drought on it was observed only in the period with the longest and most intensive drought (2029/2020). It should be emphasized that the warmer and more humid weather conditioned the higher NPT. On the other hand, in the dryer periods, although being reduced to a certain degree, the number of productive tillers reached moderate values related to the better seed set.

The data obtained by Kirchev et al. (2012); Baychev, (2013); Aggrawal and Sinha (1987); Fayaz and Arzani, (2011) confirm our results. Baychev (2013) observe a very high effect of spring drought on Bulgarian triticale cultivars. The high number of productive tillers resulting from the warmer winter was considerably reduced, especially in cultivar Bumerang. This author also pointed out that the effect of drought was not always identical but was strictly dependent on the conditions of the environment. According to data from our previous research (Stoyanov, 2018), the results on the behavior of the cultivars showed that under controlled conditions this trait was least influenced in cultivars Atila, Bumerang, Dobrudzhanets and Doni 52.

Table 5. Values of the indices applied to the studied triticale cultivars for yield and number of productive tillers

Cultivar	Yield			
	$DAADPI_{GP}$	$DAADPI_{Y}$	$DAASDI_{GP}$	$DAASDI_{Y}$
AD-7291	543,47	487,39	8,39	11,45
Vihren	568,53	504,38	9,86	14,74
Rakita	574,61	516,59	17,12	19,51
Lasko	464,07	513,35	31,52	5,71
Presto	490,84	501,98	27,87	13,04
Kolorit	515,26	498,75	21,60	13,61
Atila	537,04	489,03	26,35	26,43
Akord	497,96	495,63	28,14	16,75
Respekt	412,34	384,04	37,14	34,92
Bumerang	561,40	511,64	22,00	22,58
Irnik	460,18	533,76	34,96	2,74
Dobrudzhanets	565,90	436,29	13,72	35,45
Lovchanets	437,06	450,68	26,74	10,53
Doni 52	567,19	550,34	25,05	16,86
Blagovest	521,28	492,81	24,89	20,31
Borislav	514,20	540,65	31,98	13,42
Average	514,46	494,21	24,21	17,38
Cultivar	Number of productive tillers			
	$DAADPI_{GP}$	$DAADPI_{Y}$	$DAASDI_{GP}$	$DAASDI_{Y}$
AD-7291	637,11	645,66	-0,94	-19,71
Vihren	635,72	570,27	-6,24	-2,50
Rakita	637,14	624,17	5,65	-5,82
Lasko	639,75	844,86	18,81	-49,87
Presto	754,51	820,64	6,20	-25,53
Kolorit	536,32	586,95	12,85	-17,62
Atila	693,75	631,31	-2,25	-1,39
Akord	582,66	712,39	10,15	-45,32
Respekt	622,75	666,16	7,46	-19,96
Bumerang	652,70	563,49	9,85	17,95
Irnik	665,95	616,95	2,24	0,03
Dobrudzhanets	782,19	775,41	-14,80	-30,80
Lovchanets	845,11	887,22	-8,81	-36,59
Doni 52	654,10	735,96	16,93	-18,11
Blagovest	688,68	666,43	10,26	1,09
Borislav	672,65	593,35	3,07	8,77
Average	668,82	683,83	4,40	-15,34

Number of grains in spike

In the dry year 2018/2019, the number of grains in spike was considerably lower (Table 3). In economic year 2019/2020, when drought was much longer and intense, the number of grains in spike was highest in comparison to all years of study. This was related to the fact that in this period lower number of productive tillers were formed in comparison to 2019/2020. This causes the formation of larger spikes and higher number of grains in spike. At the same time, similar to yield during the two most humid economic years, the number of grains in spike was also lower. Such a phenomenon was due to the specific anthesis of triticale, which is strongly influenced by the high air humidity, and to the higher number of productive tillers. The two basic periods were with the optimal value of the trait.

The highest values of this trait (Table 4) were that of the check cultivars AD-7291 and Rakita, and of cultivars Kolorit, Akord and Irnik, and the lowest – of the world check Presto and cultivar Lovchanets. In comparison to the favorable period, under the effect of drought, this tendency was not interrupted according to the values of $DAADPI_{GP}$ (Table 5). Nevertheless, a positive tendency was observed in Bumerang and Doni 52, while a negative one was present in Atila, Respekt and Borislav. According to the most typical period, there was a positive tendency in Kolorit, Bumerang and Irnik, and a negative one in Respekt and Dobrudzhanets.

The lowest reduction of the values of the trait under drought, in comparison to the most favorable period, was observed in Akord, Doni 52 and Blagovest, and the highest – in Atila, Irnik and Borislav. According to the most typical period, the highest reduction was in Akord and Dobrudzhanets, and the lowest in Kolorit and Doni 52. A great part of the cultivars realized negative values of $DAASDI_{Y}$. This was an indication that in the period with the most typical meteorological conditions, a lower number of grains were formed as compared to the periods with expressed drought. This means that for a better seed set, drought (lack of rainfalls) during heading – grain formation is rather a necessity than a stress factor.

The results on the values of the indices emphasized the fact that the number of grains in spike could be influenced largely by the effects of drought. From and agronomic point of view, a reduction of more than 8% was determined, averaged for the studied cultivars, which reached 24% in cultivar Irnik. At the same time, from a biological point of view, the different genotypes responded to drought in accordance with the most typical conditions, but often the lack of rainfalls during anthesis and pollination had a better effect on the values of the trait. This contradicts to some extent the data we obtained under controlled drought (Stoyanov, 2018).

The formation of grain in triticale is related to the considerably more open pollination due to specificity in the biology of the florets. Therefore, drought during anthesis, pollination and fertilization causes severe damages on the pollen and the stigmas of the florets (Barnabas et al., 2008). On the other hand, however, the intensive rainfalls during anthesis and long periods of humid and cool weather impede normal pollination (Stoyanov, 2018). Baychev (2013) emphasized that in periods with stronger drought, the seed set was considerably influenced in cultivars Kolorit and Akord. A large number of researches (Saleem, 2003; Kutlu and Kinaci, 2010; Fayaz and Arzani, 2011) confirmed that the seed set in triticale was highly influenced by the effect of drought but was directly dependent on the specific genotype.

1000 kernel weight

During the two basic periods (favorable and most typical), the highest values of 1000 kernel weight were registered (Table 3). This was due to the fact that during these two vegetative growth periods the most suitable conditions for grain formation and filling were observed. Respectively, under the effect of drought during economic years 2018/2019 and 2019/2020, the values of the trait were lower; significantly lower they were in 2019/2020. On the other hand, the lowest values of this trait were determined in economic year 2015/2016, which was characterized by high precipitation during grain formation and filling. Lower than the basic periods were also the values in economic year 2017/2018 due to the long-lasting rainfalls in July of 2018, which impeded harvesting. These peculiarities show that both drought and excessive rainfalls cause extreme unfavorable effects on grain filling. Therefore, it may be argued that drought is only a part of the complex of stress factors, which have impact on the values of 1000 kernel weight. Averaged for the period, the check cultivar Vihren and cutivars Atila, Bumerang and Borislav were with the highest values of this trait, while Respekt, Irnik and Lovchanets were with the lowest (Table 4). A tendency of maintaining high values of 1000 kernel weight according to the favorable period (Table 6) was observed in the world check Presto and in cultivars Atila and Borislav, and a tendency toward low values – in Respekt, Irnik and Lovchanets. According to the most typical period, the tendency, both in positive and negative directions, remained almost the same, cultivar Bumerang also giving a positive response to drought according to this index. The reduction in the trait based both on the favorable and the most typical periods was however different. This was related to the differing conditions during grain filling in the two basic periods.

Table 6. Values of the indices applied to the studied triticale cultivars for number of grains in spike and 1000 kernel weight

Cultivar	Numer of grains per spike			
	$DAADPI_{GP}$	$DAADPI_{Y}$	$DAASDI_{GP}$	$DAASDI_{Y}$
AD-7291	23,03	18,37	-13,08	10,14
Vihren	19,58	18,61	12,44	6,98
Rakita	22,57	19,33	1,08	11,62
Lasko	18,81	16,55	1,78	8,34
Presto	15,79	16,23	17,25	0,54
Kolorit	22,72	21,53	7,25	1,88
Atila	17,25	16,90	19,27	9,63
Akord	22,31	17,78	3,42	23,01
Respekt	17,86	15,63	11,87	17,94
Bumerang	20,74	21,47	-3,07	-24,75
Irnik	18,13	23,30	24,28	-30,35
Dobrudzhanets	18,02	15,76	17,62	23,46
Lovchanets	14,45	17,25	21,68	-19,38
Doni 52	20,90	19,14	0,21	0,56
Blagovest	18,99	19,52	4,60	-14,54
Borislav	17,38	19,58	11,24	-24,64
Average	19,28	18,56	8,62	0,03
Cultivar	Thousand kernels weight			
	$DAADPI_{GP}$	$DAADPI_{Y}$	$DAASDI_{GP}$	$DAASDI_{Y}$
AD-7291	35,62	31,86	13,28	16,36
Vihren	39,72	35,25	5,82	10,48
Rakita	36,87	32,25	7,60	14,26
Lasko	37,27	28,20	9,01	33,64
Presto	39,61	30,03	4,00	30,01
Kolorit	37,25	31,33	5,89	18,39
Atila	40,22	33,88	10,75	22,26
Akord	37,52	31,18	11,84	24,93
Respekt	33,19	27,28	21,75	34,63
Bumerang	37,34	32,12	16,58	24,78
Irnik	35,55	28,29	7,47	26,74
Dobrudzhanets	38,93	28,86	5,96	33,95
Lovchanets	35,46	27,05	9,62	33,40
Doni 52	38,84	30,08	4,16	27,54
Blagovest	37,08	29,40	6,97	26,76
Borislav	41,30	34,73	16,27	27,24
Average	37,61	30,74	9,81	25,34

During the favorable period, comparatively drier conditions were observed, while during the most typical period the amount of rainfalls was higher and with comparatively even distribution. This was the reason why the values of the reduction were higher in comparison to the most typical period. In contrast to the previous two traits, from an agronomic point of view the reduction of the 1000 kernels weight was significantly lower than the reduction in biological sense. This was due to the fact that the moderate drought, although favorable for optimal values of the number of tillers and a better seed set, restricted the proper grain filling regardless of its duration and intensity.

Thousand kernel weight was characterized by very high variation under the effect of the environmental conditions (Baychev, 2013; Giunta et al., 1993; Villegas et al., 2010). This was related to the long period of formation of the values of the trait and to the sensitivity of the physiological processes of grain filling to a large number of factors of the environment (Moayedi et al., 2009; Dogan et al., 2012). A large number of the researches on triticale (Kutlu and Kinaci, 2010; Fayaz and Arzani, 2011) and other cereals (Dencic et al., 2000; El-Kareem and El-Saydi, 2011) confirm our results that 1000 is influenced considerably by the effects of drought.

The data obtained on yield and its components showed that as a result from the long-term mean effects of drought, under natural conditions the triticale genotypes reacted in a number of different ways depending on their specificity. According to the favorable period, a great part of the cultivars managed to maintain their optimal productivity and moderate levels of productive tillers and number of grains in spike, the reduction of the studied traits not being too high.

From a biological point of view, the studied triticale cultivars reacted significantly stronger; with regard to the NPT and the number of grains in spike a negative correlation was observed. This correlation allowed the separate cultivars to respond adequately to drought, the negative effect in one of the traits being compensated for by the other. Only in periods with severe and long-lasting drought, the effects on both traits could not compensate for the negative ones. In spite of this correlation, in 1000 kernel weight much higher biological effects were observed than agronomic ones. This indicated that grain filling was a highly susceptible period with regard to grain formation, when insufficient moisture and thermal stress were the reason for lower productivity. This thesis was supported by the results of Martyniak (2002), who established that triticale was most influenced by the stages of heading and milk maturity, when the greatest decrease in grain yield was observed. Drought at the initial stages of development affected yield only insignificantly. Stankova and Stankov (2002) pointed out that drought caused significant deviations in traits such as number of grains in spike and weight of grains in spike. Lower is the effect of drought on the same traits during grain filling, without observing effect on the structure of the plants. Dhindsa et al. (1998) found out that under conditions of natural drought on the territory of India, the components of yield, which were least affected, were number of productive tillers per m^2, weight of grains in spike and the harvest index. The presence of compensatory mechanisms between the number of productive tillers and the number of grains in spike and the high sensitivity of 1000 kernel weight indicated high complexity of the effects of drought on the yield from the studied cultivars. In this respect, worth mentioning as genotypes, which reacted adequately both with regard to yield and separate elements of it are Bumerang, Irnik, Dobrudzhnets, Doni 52 and Borislav. The long-term effects of drought, both from agronomic and biological point of view, were less prominent in them, which makes these genotypes suitable for growing under the conditions of South Dobrudzha.

CONCLUSIONS

A model for averaging and comparison of the effects of drought occurring during separate periods under natural conditions was developed. The model was applied on two basic periods – the most favorable for growing of the crop, and the most typical meteorologically. The effects of drought were registered as two separate concepts – agronomic effect and biological response. It was found out that with regard to yield, drought had a significant effect, the agronomic effects being considerably higher. The number of productive tillers was less influenced in comparison to the number of grains in spike. Thousand kernel weight was highly affected by drought, which was essential for the productivity of the crop. Cultivars Bumerang and Doni 52 were with the highest drought tolerance calculated for all periods when drought was observed; this was an indication for their high tolerance to drought and respective suitability for growing under the conditions of South Dobrudzha.

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