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Evaluating the Impact of Pre-Anthesis Water Deficit on Yield and Yield Components in Triticale (X *Triticosecale wittmak*) Genotypes under Controlled Environmental Conditions

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ABSTRACT

The purpose of this study was to measure the impacts of pre-anthesis drought during reproductive stages (GS31 and GS39) on triticale (X *Triticosecale wittmak*) yield and yield components. Four triticale genotypes (2 Local and 2 from the USA) were exposed to pre-anthesis drought stress at both the stem elongation stage (B-treatment) and flag leaf emergence stage (C-treatment). Grain yield was not affected by pre-anthesis stress. Under no stress conditions (A-treatment), a strong correlation was detected between grain yield and the number of grains per plant and plant height. Under B-treatment, yield was negatively correlated with spike length; under C-treatment, yield was positively correlated with the number of grains per plant. Drought stresses did not affect the number of grains per plant, thousand grain weight, and harvest index. This implied that the tested genotypes were drought tolerant since they form many tillers. When subjected to pre-anthesis drought it helps the plants to cover the soil surface and reduce water evaporation. JU and S1 showed fast pre-anthesis growth (early flowering cultivars), which makes them favored for further breeding. In contrast, N1 and N2 had slow pre-anthesis growth (late flowering cultivars), which enabled them to store more photosynthate pre-anthesis, which might compensate for the pre-anthesis drought effect on them.

Keywords: yield, yield component, triticale, drought, pre-anthesis.

INTRODUCTION

The world population is dramatically increasing and is expected to have grown by 34% by the year 2050, with an additional 2.3 billion people according to the United Nations Food and Agriculture Organization forecasts (FAO, 2009). As a global concern, the production of important fundamental crops like wheat, barley, and Triticale needs to be enhanced by an estimated 43%. This is a significant challenge considering water scarcity and the sustainability of resources. In the context of a shifting global climate and emerging agricultural challenges, this increase in cereal production will be crucial. Erratic precipitation and frequent droughts demonstrate that climate change and global warming will further impact water supply and agriculture production

(Al-Ajlouni et al., 2016, 2017; Al-Ghzawi et al., 2018, 2019). Middle Eastern countries, including Jordan, are severely affected by climate change and global warming-associated conditions where future scenarios predict a decrease in rainfall and an increase in temperature (Al-Ghzawi et al., 2019). Such adverse climatic changes and more frequent weather extremes will significantly affect rainfed agricultural systems, including cereal productivity, and hence negatively affect food security.

Jordan is unequivocally the most impacted country in the Middle East, with a harsh, arid climate that features scorching summers and moderate, rainy winters (Al-Ghzawi et al., 2019). The amount of precipitation in Jordan fluctuates significantly within and between years, making it a geographically diverse country (Al-Ghzawi et al., 2018). Nowadays, Jordan is severely affected by climate change and global warming-associated conditions where the future scenarios predict decreasing trends for precipitation (8-20%) and increasing trends for temperature (1.0-2.8°C), especially in the northern and western parts of Jordan according to Jordanian Ministry of Environment Records (2009). To ensure the sustainability of agriculture and the environment, it is crucial to introduce new grain crops that can adapt to the effects of climate change. Triticale is among the most promising crops that can meet this requirement.

Triticale is a man-made crop that resulted from breeding rye (*Secale cereale* L) as the male parent with wheat (*Triticum* spp.) as the female parent. This hybrid crop inherits the desirable traits of both parents, such as high protein content, tolerance to cold temperatures, and strong growth and vigor (Gupta and Priyadarshan, 1982; Mcgoverin et al., 2011). It is also more resistant to diseases, droughts, and salinity as compared to wheat and rye. While Triticale is grown for its grain and forage varieties, it is mainly used as animal feed (Mcgoverin et al., 2011). There is a common misconception that triticale does not contribute to the assurance of having enough food. However, it is mainly used as animal feed, and its utilization as human food remains limited (Mcgoverin et al., 2011). Any cereal's potential yield, including triticale, has a significant influence on how well it responds under slight stress (Mcgoverin et al., 2011). Triticale has endurance in challenging environments and demonstrates diversity in adapting to many environmental circumstances. The combination of rye's resistance and efficient utilization of nutrients with wheat's abundant harvest and nutritional content has been demonstrated by Dennett and Trethowan (2013) and Warechowska et al. (2016). Triticale cultivars that have been enhanced exhibit higher levels of biomass and grain production compared to wheat (Mergoum and Gómez Macpherson, 2004) and are similar in performance to rye (Kavanagh and Hall, 2015). Triticale has excellent potential as a crop in regions with limited nutrients and many challenges from living organisms and environmental factors.

Triticale is cultivated in more than forty countries worldwide but not in Jordan. According to a recent study by Al-Bakri et al. (2021), the anticipated yearly need for fodder in Jordan is around 2.5 million tons. The cultivation of alternative crops such as triticale has the potential to effectively address this dilemma. Evaluating the influence of environmental variables such as temperature, precipitation, soil composition, and elevation on the output and characteristics of triticale and barley cultivations has significant importance in enhancing agricultural practices' efficiency and economic viability in Jordan. As previously stated, water is the scarcest resource restricting cereal production in Jordan and other Middle Eastern countries. Middle Eastern countries will experience more frequent and severe droughts as global precipitation patterns shift. Consequently, increased irrigation water demand will be required to sustain the production of crops. The objective of this research is to investigate the effects of pre-anthesis drought on the growth of triticale under controlled environments, as well as the effects of these drought conditions on the yield and yield components of different triticale genotypes. We believe that triticale could be an excellent substitute for specific rainfed crops in Middle Eastern countries like Jordan due to its ability to withstand unpredictable weather and increasingly challenging soil conditions.

MATERIALS AND METHODS

Plant materials

In this investigation, four triticale genotypes from two different geographical locations were selected (Table 1). Two of them were obtained from the University of Nebraska-Lincoln (UNL), USA and the rest are Jordanian genotypes, "Syria-1"

(S1) was obtained from the National Agricultural Research Center (NARC), Amman, Jordan, and "JU- Triticosecale -1", (JU) was obtained from Jordan University, Amman, Jordan (Table 1).

Greenhouse experiment and stress treatments

The experiment was carried out in a controlled glasshouse at the Jordan University of Science and Technology (JUST) in Ramtha, Irbid, Jordan. Using an automatic ventilation system, glasshouse conditions were maintained to keep the temperature at or below 25/18 ˚C (day/night) and the relative humidity at or below 70% to prevent terminal heat stress conditions. The day length circumstances were not modified and were based on the natural day length conditions outside the greenhouse. On December 19, 2022, seeds of the four different triticale genotypes were planted in pots that were 12 liters in size and contained soil. Soil was obtained from the experimental field of JUST. Before the beginning of the experiment, both soil moisture content and field capacity were measured. The irrigation of the soil was used to evaluate the field capacity until saturation, then the pot was covered with a plastic bag, and the weight of the soil was recorded after two days (Juo, 1978; Ryan et al., 2001). Soil moisture content was measured gravimetrically according to Juo (1978) and Ryan et al. (2001): three soil samples were weighted pre- and soil oven-drying at 105 C° for 24, then this equation was applied to calculate soil moisture content:

$$SMC\left(\frac{g}{g}\right) = \frac{(MOC+ADS(g))-(MOC+ODS\,(G))}{ODS-MOC} \quad (1)$$

where: SMC – soil moisture content, MOC – mass of can, ADS – air dry soil, ODS – oven dry soil.

The percent of soil moisture content was obtained by the following equation:

$$SMC\,\% = SMC \times 100 \quad (2)$$

Starting from seed sowing and until emergence, the seedlings were irrigated with tap water to reach field capacity (FC). After emergence, seedlings were thinned to one seedling per pot. Depending on the weight of pots at field capacity, the required amount of water that should be added to conduct the following treatments was determined. Three irrigation regimes were applied after emergence: control (80–100% FC), the tillering stage (Zadoks scale: Growth stage 20-29), and the stem elongation stage (Zadoks scale: Growth stage 30-39). During both stress treatments, the moisture content of the soil has been determined to be maintained between thirty percent and fifty percent of the maximum retention capacity. Treatments were coded to A-treatment: control, B-treatment: drought started at the tillering stage, and C-treatment: drought started at the stem elongation stage. Soil moisture will not be allowed to be less than 30% to avoid permanent wilting.

Data collection

The study recorded the following traits: days to anthesis (DA) – the number of days from emergence to the appearance of anthers, plant height (PH) – the distance from the ground to the tip of the spike excluding awns, tillers per plant (TPP) – the count of fertile tillers, thousand grain weight (TGW) – the weight of 1000 grains, grain number per spike (GNPS) – the count of grains in each spike, harvest index (HI) – the percentage ratio of grain yield to above-ground plant dry weight, peduncle diameter (PD) – the diameter of the peduncle measured using a digital caliper, straw weight (SW) – the above-ground plant dry weight excluding grains, peduncle length (PL) – the distance from the first node to the base of the spike, spike length (SL) – the length of the spike measured in centimeters using a ruler, grain yield per plant (GY) – the weight of grains per plant, grain number per plant (GNPP) – the count of grains produced by each plant.

Table 1. Name and origin of triticale genotypes used in this study

Triticale genotype/cultivar	Abbreviation	Source
Syria-1	S1	National Agriculture Research Center (NARC)
JU- Triticosecale -1	JU	Dr. Ayed Al-Abdallat The University of Jordan
NE03T416-1	N1	University of Nebraska-Lincoln (UNL)
NT18430	N2	University of Nebraska-Lincoln (UNL)

Statistical analysis

The treatment combinations were arranged in a factorial design, with the factors being the plant genotypes and three different water regimes. The experiment used a Randomized Complete Block Design (RCBD) with five replications. Each replication consisted of one pot containing a single biological material. The statistical program SAS version 9.1 (SAS Institute Inc., Cary, NC, USA) was used to perform an analysis of variance (ANOVA) on yield and yield-component attributes. This analysis aimed to identify any significant differences between the treatments. The mean separation was examined using the least standard error of the differences between means (LSD) test with a significance level of 0.05. The Spearman's coefficients of agronomic traits have been calculated for the four Triticale genotypes across three testing contexts (A-treatment, B-treatment, and C-treatment).

RESULTS

Analysis of variance and correlation analysis

A combined analysis of variance was conducted across all three environments using the following traits: day to anthesis (DA), plant height (PH), spikes per plant (SPP), tiller number per plant (TNPP), thousand grain weight (TGW), grain number per spike (GNPS), harvest index (HI), peduncle diameter (PD), straw weight (SW), peduncle length (PL), spike length (SL), grain yield per plant (GY), and grain number per plant (GNPP) (Table 2). After analyzing variance (ANOVA), it was found that the genotypes exhibited significant differences in most of the variables analyzed during the study. The genotype and environment interaction (GEI) was significant, implying that the genotypes responded differently to the three different environmental conditions evaluated (Table 2). According to the

Table 2. Analysis of variance (ANOVA) for greenhouse agronomic traits.

Source of variation	DF	DA	PH	SPP	TNPP	TGW	GNPS	HI	PD	SW
Rep	4	10.4	254.2	55.45	55.45	60.06	160.14	0.007	0.074	438.81
Treatment	2	2.9**	3.61ns	39.71ns	39.71ns	4.77ns	409.09ns	0.0039ns	0.10ns	196.12ns
Genotype	3	7501.4**	228.1*	233.44**	233.44**	830.22**	4050.49**	0.087**	0.77**	1745.72**
G X E	6	0.69**	60.28ns	18.16ns	18.16ns	26.72ns	375.13ns	0.0076*	0.254**	62.37ns
Error	44	1.5	64.64	17.8	17.8	25.70	264.39	0.003	0.086	192.67
Total	59									
Mean		124.36	119.86	16.83	16.83	48.47	6.81	0.51	3.94	48.88
CV %		0.31	6.70	25.07	25.07	10.45	21.16	11.20	7.44	28.39
R2		0.99	0.42	0.59	0.59	0.72	0.58	0.7	0.53	0.48
Source of variation	DF	PL	SL	GY	GNPP					
Rep	4	41.56	4.96	270.87	260322.0					
Treatment	2	24.79*	15.40**	93.84ns	264305.6ns					
Genotype	3	314.81**	19.53**	581.69ns	110972.0ns					
G X E	6	8.44ns	4.48ns	223.05ns	67929.1ns					
Error	44	7.95	2.68	251.35	149559.1					
Total	59									
Mean		19.39	15.48	51.08	1222.5					
CV %		14.54	10.58	31.03	31.6					
R2		0.77	0.53	0.28	0.25					

Note: The significance level is marked by three different symbols: "**" indicates a significant level at alpha 0.001, "*" indicates a significant level at alpha 0.05, and "ns" indicates a non-significant level. The following abbreviations are used for different traits: DA (day to anthesis), PH (plant height), SPP (spikes per plant), TNPP (tiller number per plant), TGW (thousand grain weight), GNPS (grain number per spike), HI (harvest index), PD (peduncle diameter), SW (straw weight), PL (peduncle length), SL (spike length), GY (grain yield per plant), GNPP (grain number per plant).

analysis of variance, none of the traits examined were affected by the treatments, except for the number of days for anthesis, length of the peduncle, and length of the spike (as shown in Table 2). Significant differences in tolerance of genotypes for all traits except for grain yield and number of grains per plant against stress were also illustrated from ANOVA results (Table 2). Grain yield was positively and significantly correlated with plant height and the number of grains per plant under the non-stress treatment (A-treatment; Table 3a). While under pre-anthesis drought at the tillering stage (B-treatment), grain yield had only a strong negative correlation with spike length (Table 3b). Under pre-anthesis drought at the stem elongation stage (C-treatment), grain yield had only a strong positive correlation with the number of grains per plant. All correlations among traits are shown in Table 3.

Furthermore, under A-treatment (Table 3a), there was no correlation between days to anthesis with all measured traits. Plant height was positively correlated ($P < 0.05$) with thousand grain weight, harvest index, peduncle length, grain yield per plant, and number of grains per plant. Moreover, the number of spikes per plant was positively correlated ($P < 0.05$) with the number of tillers per plant and negatively correlated with the number of grains per spike. A significant positive correlation was detected between the harvest index and each of thousand grain weight (TGW) and Peduncle length. As expected, grain yield per plant showed a positive correlation with the number of grains per plant and a neutral effect with TGW.

Under B-treatment (Table 3b), days to anthesis, plant height, TGW, and peduncle length showed no correlation with all measured traits. Spike per plant was positively correlated ($P < 0.05$) with both the number of tillers per plant and the number of gains per plant and negatively correlated ($P < 0.05$) with each of the number of grains per spike, peduncle diameter, and straw weight. Furthermore, the number of tillers per plant was negatively correlated ($P < 0.05$) with each of the numbers of grains per spike, harvest index, peduncle diameter, and number of grains per plant and positively correlated ($P < 0.05$) with straw weight. Additionally, the number of grains per spike showed a positive correlation ($P < 0.05$) with both the harvest index and peduncle diameter and a negative correlation ($P < 0.05$) with each straw weight and number of grains per plant. Harvest index, in turn, was positively correlated ($P < 0.05$) with both peduncle diameter and number of grains per plant and negatively correlated ($P < 0.05$) with straw weight. A negative correlation ($P < 0.05$) was observed between peduncle diameter and both of straw weight and the number of grains per plant. Furthermore, straw weight was positively correlated ($P < 0.05$) with the number of grains per plant, while spike length was negatively correlated ($P < 0.05$) with grain yield per plant. Under C-treatment (Table 3c), there were no correlations ($P > 0.05$) among all measured traits except for plant height vs. peduncle diameter (negative correlation); the number of spikes per plant vs. each of number of tillers per plant (positive correlation) and peduncle length (negative correlation); peduncle length vs. each of thousand grain weight, number of tillers per plant and straw weight (negative correlation) and both of number of grains per spike and harvest index (positive correlation); the number of grains per spike vs. each of harvest index (positive correlation) and straw weight (negative correlation); grain yield per plant vs. number of grains per plant (positive correlation).

EFFECTS OF TREATMENTS ON TRAITS

Yield traits

Among studied traits, B-treatment had a neutral effect on all measured traits except for spike length. B-treatment had higher reduced effects on spike length as it caused an 11.5% reduction in mean value (Table 4). Moreover, C-treatment had a neutral effect on all measured traits except for number of spikes per plant and peduncle length. C-treatment caused a 12.2% and 3% reduction in the mean value for both of number of spikes per plant and peduncle length, respectively. Comparison among genotypes showed significant differences in the number of grains per spike among the tested genotypes under all treatments. “Syria-1” (S1) produced more grains per spike compared to the rest of the genotypes under all treatments. The highest number of grains per spike was 112.15 for S1 under B-treatment, while the lowest number of grains per spike was 62.2 for N1 genotype under C-treatment. The maximum and minimum thousand grain weights were 57.44 g and 40g for the S1 and N2 genotypes, respectively, under B-treatment. Under all treatments, S1 always produced

Table 3. The correlations between the traits studied. (a) Correlation among traits under non stress treatment; (b) correlation among examined traits during pre-anthesis drought at the tillering stage; and (c) correlation among traits under pre-anthesis drought at the stem elongation stage

A	DA	PH	SPP	TNPP	TGW	GNPS	HI	PD	SW	PL	SL	GY
PH	NS											
SPP	NS	NS										
TNPP	NS	NS	+**									
TKW	NS	-*	NS	NS								
GNPS	NS	NS	+**	-**	NS							
HI	NS	+*	NS	NS	+**	NS						
PD	NS	NS	NS	NS	NS	NS	NS					
SW	NS	NS	+**	+**	NS	-**	NS	NS				
PL	NS	+*	NS	NS	+**	NS	+**	NS	NS			
SL	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
GY	NS	+*	NS	NS	NS	NS	NS	NS	NS	NS	NS	
GNPP	NS	+*	NS	NS	NS	NS	NS	NS	NS	NS	NS	+**
B	DA	PH	SPP	TNPP	TGW	GNPS	HI	PD	SW	PL	SL	GY
PH	NS											
SPP	NS	NS										
TNPP	NS	NS	+**									
TKW	NS	NS	NS	NS								
GNPS	NS	NS	+**	-**	NS							
HI	NS	NS	-**	-**	NS	+**						
PD	NS	NS	-**	-**	NS	NS	+**					
SW	NS	NS	-**	+**	NS	-**	-**	-**				
PL	NS	NS	NS	NS	NS	NS	NS	NS	NS			
SL	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
GY	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-**	
GNPP	NS	NS	N+**	-**	NS	-**	+**	-**	+**	NS	NS	NS
C	DA	PH	SPP	TNPP	TGW	GNPS	HI	PD	SW	PL	SL	GY
PH	NS											
SPP	NS	NS										
TNPP	NS	NS	+**									
TKW	NS	NS	NS	NS								
GNPS	NS	NS	NS	NS	NS							
HI	NS	NS	NS	NS	NS	+**						
PD	NS	-**	NS	NS	NS	NS	NS					
SW	NS	NS	NS	NS	NS	-**	-**	NS				
PL	NS	NS	-*	-*	NS	+*	+*	NS	NS			
SL	NS	NS	NS	NS	-**	NS	NS	NS	NS	NS		
GY	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
GNPP	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	+**

Note: ** significant at alpha 0.001, * significant at alpha 0.05, and ns non-significant. DA – refers to days to anthesis, PH – refers to plant height, SPP – indicates spikes per plant, TNPP – for tiller number per plant, TGW – indicates thousand grain weight, GNPS – represents grain number per spike, HI – stands for harvest index, PD – stands for peduncle diameter, SW – refers to straw weight, PL – refers to peduncle length, SL – represents spike length, GY – represents to grain yield per plant, GNPP – refers to grain number per plant.

the highest thousand grain weight followed by "JU-Triticosecale-1" (JU) while N1 and N2 produced the lowest thousand grain weight (Table 4).

The maximum and the minimum number of tillers per plant was 22.6 for N1 and 10.8 for S1 genotypes under B-treatment. The number of tillers per plant for N2 was significantly higher compared to the rest of the genotypes under A-treatment. No significant differences in tillers number per plant among N1, N2, and JU were noted under B-treatment except for S1 tillers number was significantly lower (Table 4). Under A-treatment, the spike length of the N1 genotype was the biggest compared to the rest three genotypes (Table 4). Under B-treatment, no significant differences were recorded among genotypes regarding spike length while under C-treatment the spikes of both N2 and N1 were significantly bigger compared to S1 and JU (Table 4). The maximum and minimum harvest index was 0.63 for the S1 genotype under the C-treatment and 0.37 for the N2 genotype under A-treatment. Under all treatments, S1 and JU have greater HI compared to N1 and N2 (Table 4).

Phenological traits

Days to anthesis is the only phenological trait studied during the present study. Under B and C stress treatments, days to anthesis were reduced by 0.6%. in general days to anthesis are less affected by pre-anthesis drought compared to the rest of traits. N1 and N2 genotypes need 143 days to reach anthesis under control, B and C treatments compared to both JU and S1 which need a shorter time (40 days) to reach anthesis (Table 4).

Plant architecture-related traits

Four plant architecture-related traits were studied during the present study, and these include plant height, peduncle diameter, peduncle length, and straw weight. Under B-treatment, peduncle length was increased in the mean valve by 8% and 10% compared to both of A-treatment and C-treatment respectively. A, B, and C treatments did not affect the rest of the plant architecture-related traits (Table 4). Under A-treatment, significant differences were observed

Table 4. Mean values of studied traits for the four triticale genotypes in control (A-treatment), pre-anthesis drought at tillering stage (B-treatment) and pre-anthesis drought at stem elongation stage (C-treatment) under greenhouse condition

Type of traits	Traits	A control (80%-100% FC)					B the drought started at the tillering stage					C drought started at the stem elongation stage				
		Genotypes					Genotypes					Genotypes				
		N1	S1	JU	N2	Mean	N1	S1	JU	N2	Mean	N1	S1	JU	N2	Mean
Yield traits	Thousand kernel weight (g)	41.44b	54.0a	55.52a	40.8b	47.9a	42.32b	57.44a	54.56a	40b	48.5a	45.7bc	56.8a	50.56ab	42.56c	47.9a
	Grain yield (g)	56.73a	50.69a	67.33a	35.44a	52.5a	50.14a	52.84a	58.59a	46.85a	52.1a	48.58a	50.99a	48.33a	47.23a	48.5a
	Harvest index %	0.48b	0.57a	0.58a	0.37c	0.50a	0.47c	0.61a	0.56b	0.47c	0.52a	0.43c	0.63a	0.54ab	0.48bc	0.51a
	Spike per plant (n)	19.6ab	12.2b	16ab	21.4a	17.3ab	22.6a	10.8b	18.2a	20.2a	17.9a	22.6a	10.8b	18.2a	20.2a	17.9a
	Spike length (cm)	18.46a	14.47b	16.01b	16.21b	16.2a	14.87a	14.35a	13.89a	15.08a	14.5b	16.64a	13.79b	14.73b	17.34a	15.6a
	Number of grains per plant (n)	1284.5a	992.0a	1345.7a	1194.6a	1204.2a	1475.0a	1169.7a	1346.0a	1391.8a	1345.6a	1183.9a	1192.6a	1106.3a	988.9a	1117.9a
	Number of grains per spike (n)	67.6ab	83.3a	80ab	56.3b	71.7a	65.4b	112.2a	76.9b	67.8b	80.5a	62.2b	104.7a	73.8b	71.8b	78.1a
Phenological traits	Days to anthesis (n)	143.8a	105.8b	105.8b	143.8a	124.8a	143.8a	104.6b	104.6b	143.8a	124.2b	143.6a	104.6b	104.6b	143.6a	124.1b
Plant architecture-related traits	Plant height (cm)	119.9ab	119.9ab	128.2a	111.4b	119.8a	124.4a	116.2a	121.8a	118.8a	120.3a	121.7a	116.3a	122.6a	117.2a	119.4a
	Peduncle diameter (mm)	4.2a	4.2a	3.9ab	3.81b	4.0a	3.6b	4.3a	3.8b	3.7b	3.9a	4.04a	4.2a	3.4b	4.1a	3.8a
	Peduncle length (cm)	15.9b	20.5a	24.6a	14.9b	19.0ab	15.55b	24.12a	25.24a	17.7b	20.6a	14.19b	23.26a	22.28a	14.37b	18.5b
	Strawweight (g)	59.62a	39.06a	51.16a	60.18a	52.5a	56.88a	34.22c	45.48b	51.65ab	47.0a	64.11a	32.26c	41.94bc	50.11b	47.1a

among the four cultivars where JU was the tallest (128.2 cm) while the N2 was the shortest (111.4 cm). Whereas under both of B-treatment and C-treatment, there were no differences among the four genotypes in plant height (Table 4). The peduncle diameter of S1 was significantly higher under all treatments. Under both of A-treatment and B-treatment, S1 produced thicker peduncles followed by N1, JU, and N2. While in the C-treatment, N1, S1, and N2 produced thicker peduncles compared to JU (Table 4). Moreover, S1 and JU produced longer peduncles compared to N1 and N2 under all treatments. The four genotypes produced the same amount of straw under A-treatment ($P > 0.05$). Meanwhile, differences were observed under the two drought treatments where N1 and N2 produced the highest amount of straw while JU and S1 were the lowest (Table 4).

DISCUSSION

Crop agronomic traits, which include things like grain yield, plant height, thousand grain weight, and anthesis date, are the most evaluated traits, but they are also the least understood traits genetically (Campbell et al., 2003). In triticale, however, there is a relatively limited amount of information regarding these traits in comparison to other cereal crops (Goyal et al., 2011). Drought applied at pre-anthesis only decreased days to anthesis, peduncle length, and spike length in the four tested triticale genotypes irrespective of the genotype and the time of stress application. This indicated that the tested genotypes could tolerate drought effects. Yield traits are believed to be essential components for increasing the yield of triticale; an increase in grain production may be accomplished by changing yield traits such as the number of grains per spike, the length of the spike, and the number of spikelets per spike (Qaseem et al., 2019; Frantová et al., 2022). Indeed, the present results showed a strong positive correlation between grain yield and the number of grains per plant. Depending on the severity and duration of stress, a reduction in both yield and yield components can be anticipated. In the current study, pre-anthesis drought did not cause significant reduction in most of the measured traits indicating that the genotypes tested were drought-tolerant and can be used in future breeding programs. It is well known in the scientific literature that drought conditions during early growth stages can reduce the percentage and rate of seed germination. This can have a negative impact on the establishment of seedlings (Dodig et al., 2015). The plants that develop under these conditions will have a limited capacity for tillering, resulting in a reduced number of plants and tillers per unit area, and thus, a lower potential yield. Furthermore, dryness during the period of stem elongation can decrease the number of grains per unit area by negatively affecting the production of florets and fertility seedlings (Dodig et al., 2015).

In the current study, JU and S1 showed fast pre-anthesis growth and can be considered as early flowering cultivars but with longer grain filling periods this makes them favored for further breeding. On the other hand, N1 and N2 had slow pre-anthesis growth and can be considered as late-flowering cultivars. This enables N1 and N2 to store more photos-assimilates in stems and leaf sheath before anthesis, which might compensate for the pre-anthesis drought effect on them. Moreover, JU, N1, and N2 could form a large number of tillers when subjected to pre-anthesis drought at the stem elongation stage (B-treatment) which helps the plant to cover the soil surface and subsequently reduce water evaporation. This trait might make these cultivars able to grow successfully in dry areas (Kazan & Lyons, 2016; Su et al., 2013). In addition, since the temperature remains moderate and there is usually sufficient soil moisture for growth and development, JU and S1 can store more assimilates in their stems through rapid pre-anthesis growth (Al-Ajlouni et al., 2016). Moreover, the earliest anthesis of S1 and JU could be explained because both are stable and local cultivars while N1 and N2 genotypes not adapted to the local conditions and have been developed under Nebraska, United States conditions, these findings coincide with the findings of Al-Sayaydeh et al., (2019) who observed that significant and interesting variations have been identified for all of the variables under investigation among the selected genotypes, environments, and their interaction. The authors reported that the landraces Herawi and Nabawi produced the lowest yields in all conditions, whereas the local cultivar Rum and the Baladi landrace had the highest yield performance. According to the finding of Janušauskaitė (2014), grain yield can be affected by some of its yield components and meteorological conditions of growing seasons. Moreover, Present results showed that under all treatments, S1 always produced the highest TGW followed by JU while N1 and N2 produced the lowest TGW. In every cereal breeding program high and across environments stable grain yield is one of the most important breeding goals (Janušauskaitė, 2014). This could be a sign of excellent stability and adaptability of the tested triticale genotypes. Breeders are interested in finding stable genotypes with broad adaptation possibilities, especially those concerning yield and quality (Goyal et al., 2011). As the loss of the thousand grain weight was lower under stresses, crop productivity would be maintained (Duggan et al., 2000; Shaukat et al., 2023). The non-significant genotype and environment interaction (for most traits except for days to anthesis and peduncle diameter) in the present study correspond to the fact that all genotypes respond similarly to stress treatments. The fact that the tested genotypes in the current study have the potential to tolerate pre-anthesis drought via it is compensation effect is supported by ANOVA analysis (Table 2) where the two main yield components (grains per plant and thousand grain weight) in addition to harvest index were not affected by pre-anthesis drought, Furthermore, these results contradicted the findings of (Qaseem et al., 2019)**)**, who studied 108 wheat genotypes and observed that pre-anthesis drought caused 45%, 37% and 16% reductions in grain yield, harvest index and grains per spike respectively. Regarding characteristics associated with plant architecture, the present study showed a neutral effect of drought on each plant height, peduncle diameter, straw weight and peduncle length when subjected to B-treatment. However, peduncle length was reduced by 3% when plant subjected to C-treatment. This was consistent with Gevrek and Atasoy (2012) who reported a 5% reduction in peduncle length when wheat was subjected to drought stress at the post-anthesis stage. Moreover, the current study detected a genotypic effect for all measured plant architecture-related traits. Plant height was found to be significantly correlated with peduncle length. Plant height is a crucial phenotypic characteristic in cereal since it affects the overall structure of the plant and the final output of grains (Bellucci et al., 2015; Hassan et al., 2019). Meanwhile, Table 3 shows a significant relationship between GY and some other variables. This demonstrated that the associated components have an impact on the total grain yield output and that altering one component may have an influence on other components. The only significant correlation that was observed had been associated with heading time, indicating exactly the opposite of what Gowda et al. (2011) indicated.

CONCLUSION

In conclusion, pre-anthesis drought stress did not reduce yield and its components except for the negative effect of C-treatment on spike per plant and the effect of B-treatment on spike length. Meanwhile, grains per spike and grains per plant were not affected by pre-anthesis drought. The yield of the four tested genotypes was not affected by pre-anthesis drought, indicating that these genotypes can tolerate drought stress and have a compensatory mechanism. This makes these genotypes useful for further screening in future breeding programs.

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