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Evaluation of durum wheat (*Triticum turgdium* var *durum*) genotypes for drought tolerance using morpho-agronomic traits

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Identification of durum wheat variety adapted to drought environment is required to expand durum wheat cultivation to lowland areas in order to meet the growing demand of the crop for industrialization. The objective of the study was to evaluate and identify durum wheat genotypes tolerant to terminal drought, using morpho-agronomic traits. One hundred and forty four durum wheat (*Triticum turgidium* var *durum*) genotypes were grown in lattice design replicated twice under non-drought and drought stressed conditions, induced at anthesis stage at Debre-Zeit experimental station in 2017 during dry season. Analysis of variance showed that significant differences for all the traits, except days to heading and anthesis and between normal and stress conditions and also among studied genotypes as well as interaction effects of moisture environment and genotypes. Drought significantly affected reduction of all traits, except number of days to heading and spikelet number. In average, drought reduced grain yield (48.3%), grain filling period (41.7%), grain yield per spike (29.6%) and 1000 grain weight (18.3%) and number of kernels per spike (16.3%). LRPL-31, MCD-1-21 and ICA# showed superior performance under drought environment whereas Ude, the cultivated variety found the best under non-drought condition. Six genotypes, namely, 55, 30, 31, 91 15 and 58 were found among the top 10% high yielding genotypes and showed superior performance in both stress and non-stress conditions.

Key words: Anthesis, drought tolerance, drought stress, grain yield, *Triticum turgdium*.

INTRODUCTION

Wheat is the major important cereal crop after maize, tef and sorghum in terms of area coverage and production in Ethiopia. Both bread and durum wheats are extensively cultivated, in different agro-ecology and proportion in the country. Wheat is cultivated on over 1.69 million hectares with annual production of about 4.6 million tons (CSA, 2019). Although the crop is among the major food security crops and covers large cultivation area, its national productivity is about 2.74 tones ha^{-1} (CSA, 2019) which is below the world average (3.2 tons/ha).

Agricultural system in Ethiopia is rain fed and characterized by uneven distribution and uncertainty during reproductive stage, leading to terminal drought stress which results in low productivity. Wheat production mainly concentrated in the highlands, where rainfall is high and wheat has disease and quality problems

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besides competing with other crops. Thus, the need of producing addition wheat has become the major critical concern to meet the continuous increasing demand in the country. The expansion of wheat production to lowland environment is limited by lack of tolerant wheat varieties developed for drought in the target area. Drought is one of the most common environmental stresses that limit durum wheat production in much wheat growing environment. Drought usually affects plant growth and development at different growth stages leading to crop losses (Acevedo et al., 2009; Akram, 2011; Arash, 2013). Several studies proved that greater yield reduction occurred during the reproductive stage (Jinmeng et al., 2018) than vegetative stages. Nimai et al. (2019) reported the mean yield advantage of 28 to 37% higher on drought tolerance varieties than drought sensitive wheat during reproductive stages. The reduction of grain growth period from 39 to 33 days after anthesis illustrated by Abdul Karim et al. (2000) also proved that evaluation of wheat genotypes would be better for identification of the right genotypes for drought stress. Genetic variability, correlation on quantitative traits and drought effect on wheat yield and agronomic traits was reported by several authors. Drought affects both grain and biomass yield (Ameer et al., 2009; Garcia et al., 2003; Leilah and Al-Khateeb, 2005; Khan et al., 2010), photosynthesis translocation and partitioning (Muhammad et al., 2014; Wenhui et al., 2020), number of kernels and kernel weight (Simane et al., 1993; Solomon et al., 2003). Furthermore, Campos et al. (2004) illustrated the importance of field evaluation as the best methods for identifying drought tolerance under rain-fed and irrigation condition and would help screen the genotypes uniformly to terminal drought during the reproductive stages.

While wheat germplasm has been developed for drought affected areas in other areas of the globe, very little effort has been directed to develop or adapt wheat to drought in the Ethiopian lowlands by the local breeding programs.

Based on the actual knowledge status it was assumed that deployment of large number of collections from different sources and evaluation for drought stress under field condition to be an effective breeding strategy for the development of tolerant genotypes targeting the lowlands drought prone environment is critical for expanding wheat area and production.

The purpose of the study was undertaken to assess the variation in durum wheat genotypes for terminal drought stress and identify lines to be used in the future breeding program.

MATERIALS AND METHODS

Description of experimental site

The field trial was conducted at Debre-Zeit Agricultural Research Center (DZARC) located at 8° 41’36” latitude and 39° 03’17’ longitude with altitude of 1880 m above sea level (masl). The station categorized as mid highland in sandy clay soil can potentially represent the lowland wheat growing environments of Ethiopia. According to the data obtained from the Agricultural and Nutritional Research Laboratory of DZARC (2018), the soil of the experimental site is characterized by sandy clay texture with pH of 7.3, and organic carbon, total N, electrical conductivity and soil cation exchange capacity of 1%, 0.08%, 0.12 Ds/m and c100 meq/100 g of soil, respectively.

Experimental genotypes

One hundred and forty four durum wheat genotypes were used in the study. Global wheat collections developed for dry environment, landraces collected from different parts of the country and obtained from Ethiopian biodiversity institute, local breeding lines and improved cultivars were included (Table 1). The results for 90 of 144 genotypes tested were presented since some of the genotypes did not adapt to the stress environment during the season.

Experimental design and trial management

The plant materials were grown from January 12 to May 24, 2017 during the dry season. The genotypes were arranged in 12 ×12 simple lattice designs with two replications. Each genotype was grown in two rows of 2.5 m length and 0.20 m width with total plot area of 1 m^2. Seeding rate and planting date were used as per the recommendation. During seeding 50 kg/ha urea (46% N) as N source and 100 kg/ha DAP (46% P_2O_5) as source of phosphorus were applied. At the beginning of tillering, the remaining 50 kg/ha urea (46% N) was applied by top dressing. To reduce the influence of biotic factors under both conditions, weeds were controlled manually as per needed and tilt-250 with rate of 150 ml/ac fungicides were sprayed twice during the season to prevent the genotypes from stem and leaf rust infections.

Moisture treatment

The stress environment was created by growing the genotypes during the dry season when no or very limited rainfall is expected. Seeds were sown on January 12 and harvest was done on May 15 during which small amount of rain were received in very few days. Since drought stress is the only effect examined on genotypes, all the crop management practices followed was the same. Under both drought and non-stressed conditions, furrow conventional irrigation method was supplied every day to the genotypes. Soil moisture depletion was detected using gravimetric methods.

In the drought stress treatment, genotypes were fully irrigated every five days until 50% of genotypes headed and then irrigation was stopped until physiological maturity. The genotypes in non-drought condition were fully watered using furrow irrigation every five days until physiological maturity. Irrigation was applied when the soil moisture depletion was reduced to about 75% field capacity during the growing period.

Data collection

The plants were measured for the following traits: (ii) Days to heading (DH), taken as the number of days from sowing until 50% of the plants in the plot have at least one emerged spike; (ii) Days to maturity, based on number of days from sowing to physiological maturity of at least 90% of the plants in plot; (iii) Grain filling period was computed by subtracting the number of days to heading from the number of days to maturity; (iv) Grain filling rate was determined as the ratio of final grain yield to the days from anthesis to

Table 1. Sources, number of genotypes and names of genotypes tested under drought and non-drought environment at Debre-Zeit sandy clay soil during 2017 off-season.

Source	No. of genotypes	Names
Released cultivars	21	Quamy, Assasa,Ginchi,Ude,Werer,Mangudo,Mukiye,Gerardo, Utuba,Kilinto,Bichena, Yerer , Denbi, Tob-66, Ejersa, Toletu, Flakit, Arendato, Boohai, Hitosa and Cocorit
Global wheat collections	57	ICA -381, ICA-45, ICA -47, ICA- 55, ICA-33, ICA -32, ICA-360, ICA - 77, ICA -378, ICA - 54, ICA-46, ICA-61, ICA-383, ICA-359, ICA- 59, ICA- 353, ICA-26, ICA -50, ICA -60, ICA -23, ICA-56, ICA -13, ICA - 382, ICA -39, ICA-357, ICA- 346, ICA-358, ICA- 48, ICA - 29, ICA -58, ICA-32, ICA-34, ICA-24, ICA-355, ICA -65, ICA-74, ICA- 51, ICA -44, ICA -53, ICA -73, ICA-57, ICA-20, ICA-64, ICA-41, ICA -354, ICA - 25, ICA- 49, ICA-384, ICA-38, ICA-356, ICA -28, ICA -43, ICA -30, ICA -62 and ICA-37
Breeding lines from DZARC nurseries	27	Bl-1,Bl-2,Bl-3,Bl-4,Bl-5,Bl-6,Bl-7,Bl-8,Bl-9,Bl-10,Bl-11,Bl-12,Bl-13, Bl-14,Bl-15,Bl-16,Bl-17,Bl-18,Bl-19,Bl-20,Bl-21,Bl-22,Bl-23,Bl-24,Bl-25, Bl-26,and Bl-27
Landraces from EBI collections	21	EBI-1,EBI-2,EBI-3,EBI-4,EBI-5,EBI-6,EBI-7,EBI-8,EBI-9,EBI-10,EBI-11,EBI-12,EBI-13,EBI-14,EBI-15,EBI-16, EBI=17,EBI-18,EBI-19,EBI-20, and EBI-21
Landraces from DZARC collections	18	GN-1,GN-2,GN-3,GN-4,GN-5,GN-6,GN-7,GN-8,GN-9,GN-10,GN-11,GN-12,GN-13,GN-14,GN-15,GN-16,GN-17and GN-18
Total	144	

physiological maturity; (v) Plant height was also measured from five randomly selected plants per plot and the average were recorded; (vi) Flag-leaf length (FL), measured at heading on five random samples taken from each genotype; (vii) Number of spikelet per spike and number of grains per spike, from the average grain number in ten spikes taken from random plants in the plots; (ix) Number of spikelet per spike, from the average number of spikelet in ten spikes taken from random plants in the plots; (x) 1000 seed weight, from the average weight of 100 grain samples multiplied by 10; (xi) Grain yield was measured from net plot area of 0.8 m^2, after drying and cleaning of grain and adjusted to approximately to 12.5% moisture content; (xii) Above ground biomass determined by measuring dried above ground biomass from net plot area of 0.8 m^2; (xiii) Straw yield per plot determined by subtracting grain yield from dried above ground biomass; (xiv) Harvest index determined as the proportion of grain yield to the overall aboveground biomass; and (xv) Grain weight per spike was taken from ten randomly selected spikes.

Estimation of traits due to drought stress effect in non-drought and to drought was calculated by percent reduction percentage (%R) using the formula where the means for each genotype under stress and non-stress conditions.

Data analysais

The Statistical Analysis System (SAS) version 9.1 (SAS, 2002) was employed for individual and combined variance and means comparisons. Homogeneity of error variances between drought and non-drought was made before the combined analysis of variance was carried out using F max test according to Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Rainfall and temperature recorded (Figure 1) during the cropping season showed the characteristic of the conditions in which the genotypes were screened. There were no extreme records and large differences in both minimum and maximum mean temperatures during the cropping season indicating that drought was the only effect the genotypes experienced. The total rainfall amount and distribution differed in different crop development stages. The amount of rainfall received and the number of rainy days were only 86.6 mm and 11, respectively. The number of drought days from anthesis to ripening (hard dough stage) was about 42 days. Thus screening for drought stress was managed very well and drought intensity reached about 42% and high enough to disorder the rank of the genotypes under stress and non-stress conditions.

Analysis of variance

The main effect variance analysis for the drought condition revealed significant effect of genotypes for the grain filling rate, plant height, number of kernels per spike, thousand grain weight and grain yield. Under non-drought, there was significant effect for the grain yield

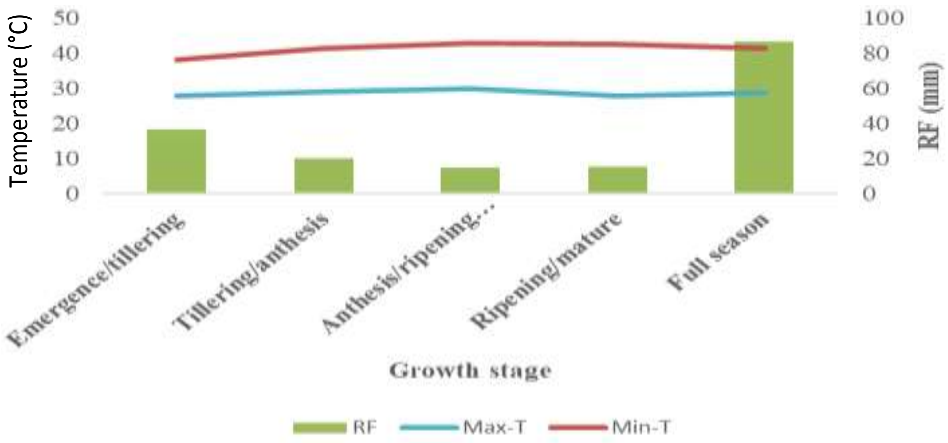

Figure 1. Climatic variables during different crop development stages.

Table 2. Analysis of variance for drought and non-drought conditions.

Trait	Environment	Source of variation	DF	Mean square	Mean	CV (%)
DH	Drought	Genotype	89	60.6^{ns}	68	10.1
		Residue	89	47.4		
	Non-drought	Genotype	89	80.96^{ns}	69	11.4
		Residue	87	20.3		
DAN	Drought	Genotype	89	62.1^{ns}	75	9.1
		Residue	89	46.5		
	Non-drought	Genotype	89	77.7^{ns}	77	9.8
		Residue	89	18.1		
GFR	Drought	Genotype	89	93.4**	10.8	33.4
		Residue	89	80.7		
	Non-drought	Genotype	89	78.1**	18.4	30.3
		Residue	89	27.5		
DM	Drought	Genotype	89	157.5	98	8.5
		Residue	89	41.4		
	Non-drought	Genotype	87	17.1	102	8.5
		Residue	87	6.9		
TGW	Drought	Genotype	89	47.8*	29	22.7
		Residue	89	43.6		
	Non-drought	Genotype	87	73.9*	38.4	18.5
		Residue	87	16.2		
GY	Drought	Genotype	89	11947.9*	214.1	39
		Residue	89	2235.2		
	Non-drought	Genotype	89	24822.6*	439.2	26.1
		Residue	87	7270.2		
PH	Drought	Genotype	89	119.6*	74.9	14.0
		Residue	89	110.4		
	Non-drought	Genotype	89	4534.3*	88.7	20.9
		Residue	87	1852.4		

Table 3. Significance of mean squares for 11 pheno-agronomic traits on 90 durum wheat genotypes and two drought environments (stress and non-stress).

Traits	Environment(E) Df (1)	Genotypes(G) Df (89)	G×E Df (89)	Error Df (156)	CV%
Days to heading	2.2^{ns}	82.4**	13.5**	7.2	4.0
Days to anthesis	6.9^{ns}	84.7**	17.9^{ns}	14.1	5.1
Grain filling period	1269.4**	53.7**	40.1**	18.2	13.0
Days to maturity	1166.4**	45.5**	45.5**	14.1	3.7
Grain filling rate	4853.9**	44.5**	40.7**	15.4	28.3
Grain yield/plot	4184903.9**	22817.9**	10536.9**	2362.7	14.3
Spikelet number/spike	52.9**	4.8**	3.7**	1.3	6.8
Kernel number/spike	3616.3**	93.3**	56.9**	23.7	12.3
Kernel number/spikelet	6.2**	0.39**	0.2**	0.1	13.2
Thousand seed mass	4334.0**	48.1**	46.6**	7.3	8.1
Plant height	64543.8**	57.6**	72.6**	31.7	6.3

Table 4. The 10% highest grain-yielding cultivars under stress.

Genotype	Code	Grain yield (kg/ha)
LRGN-31	31	4290
MCD-1-21	55	4260
ICA#73	30	4115
Ude (Check)	58	3833
IDON-88	97	3780
Acc-226804	119	3740
IDYT-2	1	3563
LMA-1-17	15	3555
IDYT-20	137	3347
Assasa (Check)	91	3325
CV (%)	-	20.3
LSD (0.05)	-	939

thousand seed weight and grain filling rate (Table 2). The combined analysis of variance was conducted based on F max test, which uses the error variance as homogenous when the ratio of the error mean squares is not greater than 7 (Gomes, 2000).

The combined analysis of variance showed significant differences at 0.01% for the environment for all traits studied except days to heading and days to anthesis indicating that drought stress affected the expression of traits. The genotypes effect also was significant for all traits. The results showed that genotypes differed in response of drought treatment. The interaction effects of genotypes and moisture environment for all traits were also detected except for days to anthesis (Table 3).

Response of genotypes to drought

An interaction between durum wheat and drought stress treatment on grain wheat was observed indicating that the existence of genetic variation among the genotypes and water deficit is the limiting factor for the experiment. The genotypes produced different yield across the drought treatments and the analysis was carried out independently for stress and non-stress environments.

Under drought condition, the two top yielding genotypes were the landraces LRPL-31 and MCD-1-21 followed by the exotic genotype ICA#73 but these are not significantly different from the standard check variety Ude (Table 4). These two landraces displayed the highest grain yield and produced about 10.3 and 22.2% mean yield advantages over Ude and Assasa (cultivars for drought stress environment), respectively. This implies that exploring locally existed collection probably have stress related adaptive traits than exotic germplasm.

Similar results were reported by Ayed et al. (2021) in 11 durum wheat evaluated under rain fed and irrigated conditions in Tunisia to determine the extent of drought

Table 5. The 10% highest grain-yielding cultivars under non drought stress.

Genotype	Code	Grain yield (kg/ha)
UDE	58	7509
203762	90	7115
MCD-1-21	55	7193.5
Acc-22321	128	6871
LMA-17	15	6711
ICA-73	30	6706
203882	8	6534
LMA-13	50	6471
ICA-382	74	6045
Arendato	44	6024
CV %	-	19
LSD(0.05)	-	1694

Table 6. Mean, minimum and maximum values and percent reductions for 9 traits on 90 durum wheat genotypes grown under drought and non-drought conditions.

Traits	Average		Minimum		Maximum		Percent reduced
	DS	NS	DS	NS	DS	NS	
Grain filling duration (Days)	31	35	18	20	42	45	11.4
Days to maturity (Days)	98	103	86	96	124	111	4.9
Grain filling rate	10.2	17.5	3.7	7.5	18.5	37.7	41.7
Grain yield (tons/ha)	2.3	4.5	1.1	2.1	4.3	7.5	48.3
Grain yield (gm/spike)	1.1	1.6	0.6	0.9	1.85	2.5	29.6
Kernel /spike (Number)	36	43	24	28	60	59	16.3
Kernel /spikelet (Number)	2.19	2.46	1.5	1.8	3.3	3.8	11.0
Grain weight (gm/1000 seeds)	30.1	37.1	19.1	21.3	40.6	48.6	18.8
Plant height (cm)	75.3	102.1	59.1	97.2	101.2	110.2	26.2

DS=Drought Stress, NS=Non-Stress

tolerance. Similarly, ICA#73, an exotic genotype, developed for dry environment was found high yielding than the cultivated variety (Ude). These genotypes also showed superior performance under irrigated condition indicating that their ability to make use of available water to increase grain yield. Similar findings indicated the existence of genetic variability between durum genotypes for grain yield and yield components on durum wheat (Ayed et al., 2021; Blum et al., 2001; Solomon et al., 2003a; Simane et al., 1993; Bogale and Tesfaye, 2016) and bread wheat (Habtamu et al., 2016; Desalign et al., 2001; Sial et al., 2010).

Grain yield of genotypes under non-stress conditions are shown in Table 5. The best genotypes in non-drought condition were Ude, semi dwarf cultivated varieties followed by 203762 and MCD-1-21. In addition to non-drought condition, these genotypes respond similarly under stress environment and could be used as source of gene for drought stress breeding program.

Effect of drought on yield and agronomic traits

The mean minimum and maximum values and the percentage reduction of traits mean in non-stress and stress condition are shown in Table 6. Drought affected most of the traits studied and showed the highest effect on grain yield, grain filling rate, grain yield per spike, grain weight and kernel number per spike which reduced 48.3, 41.7, 29.6, 18.8 and 16.3%, respectively.

Drought showed an average reduction of grain yield of 2.17 tons/ha (48.3%) compared to non-drought stress condition. Grain yield per spike was between 0.91 and 2.45 g with a mean of 1.59 g for non-stress and from 0.59 to 1.85 g with a mean of 1.12 g for stress. The mean of grain yield per spike was 29.6% higher in the non-stress than the stress environment. Genotype 59 and 13 had the highest and the lowest grain yield per spike, respectively in non-stress, whereas genotype 118 and 128 showed the highest and the least in the stress

Table 7. Correlations coefficient on traits on stress (above diagonal) and on non-stress (below diagonal).

Correlation	GY	DH	DAN	GFD	DM	PH	THSW	FLA	SPKS	KNS	GWPS	BM	STY	HI	GFR	KNSP
GY	**1**	-0.35**	-0.33**	0.05^{ns}	-0.26*	0.09^{ns}	0.25*	0.13^{ns}	-0.16^{ns}	0.22*	0.40**	0.31**	0.04^{ns}	0.52**	0.83**	0.28**
DH	-0.35**	**1**	0.93**	-0.05^{ns}	0.79**	0.29**	-0.26*	0.16^{ns}	0.38**	-0.32**	-0.45**	0.06^{ns}	0.16^{ns}	-0.34**	-0.19^{ns}	-0.47**
DAN	-0.32**	0.93**	1	-0.02^{ns}	0.75**	0.32**	-0.24*	0.09^{ns}	0.39**	-0.36**	-0.44**	0.06^{ns}	0.15^{ns}	-0.32**	-0.07^{ns}	-0.51**
GFD	0.38**	-0.91**	-0.87**	1	0.57**	-0.02^{ns}	0.06^{ns}	0.13^{ns}	-0.14^{ns}	0.18^{ns}	0.21*	-0.10^{ns}	-0.12^{ns}	0.10^{ns}	-0.34**	0.23*
DM	0.20^{ns}	-0.13^{ns}	-0.18^{ns}	0.54**	1	0.22*	-0.17^{ns}	0.21*	0.23^{ns}	-0.15^{ns}	-0.24*	-0.02^{ns}	0.05^{ns}	-0.22*	-0.36**	-0.24*
PH	0.05^{ns}	-0.20**	-0.20^{ns}	0.22*	0.13^{ns}	1	-0.20^{ns}	0.06^{ns}	0.22*	-0.09^{ns}	-0.28**	0.32**	0.31**	-0.25*	0.13^{ns}	-0.18^{ns}
THSW	0.21*	-0.34^{ns}	-0.30**	0.28**	-0.04^{ns}	-0.06^{ns}	1	0.09^{ns}	-0.14^{ns}	0.12^{ns}	0.62**	0.16^{ns}	0.10^{ns}	0.09^{ns}	0.18^{ns}	0.17^{ns}
FLA	0.28**	0.01**	0.05^{ns}	0.06^{ns}	0.17^{ns}	-0.05^{ns}	0.05^{ns}	1	0.24*	0.28*	0.24*	0.35**	0.33**	-0.18^{ns}	-0.01^{ns}	0.14^{ns}
SPKS	0.05^{ns}	0.34^{ns}	0.29**	-0.25*	0.09^{ns}	-0.01^{ns}	-0.32**	0.07^{ns}	1	0.10^{ns}	-0.02^{ns}	0.24**	0.29**	-0.32**	-0.06^{ns}	-0.38^{ns}
KNS	0.32**	-0.17**	-0.16^{ns}	0.21*	0.15^{ns}	0.14^{ns}	0.12^{ns}	0.22*	0.12^{ns}	1	0.75**	0.02^{ns}	-0.04^{ns}	0.21*	-0.01^{ns}	0.88**
GWPS	0.36**	-0.33^{ns}	-0.30**	0.32**	0.08^{ns}	0.05^{ns}	0.72**	0.18^{ns}	-0.11^{ns}	0.77**	1	0.12^{ns}	0.01^{ns}	0.27**	0.16^{ns}	0.69**
BM	0.23*	0.15^{ns}	0.20^{ns}	-0.14^{ns}	-0.03^{ns}	0.06^{ns}	-0.05^{ns}	0.14^{ns}	0.15^{ns}	0.05^{ns}	0.00^{ns}	1	0.96**	-0.58**	0.31**	-0.09^{ns}
STY	-0.09^{ns}	0.26*	0.31**	-0.26*	-0.10^{ns}	0.05^{ns}	-0.12^{ns}	0.05^{ns}	0.14^{ns}	-0.05^{ns}	-0.12^{ns}	0.95**	1	-0.76**	0.09^{ns}	-0.17^{ns}
HI	0.69**	-0.44**	-0.46**	0.46**	0.22*	-0.02^{ns}	0.18^{ns}	0.06^{ns}	-0.10^{ns}	0.23^{ns}	0.28**	-0.47**	-0.70**	1	0.38**	0.34*
GFR	0.41**	0.53**	0.64**	-0.57**	-0.27*	-0.16^{ns}	-0.06^{ns}	0.20^{ns}	0.19^{ns}	0.04^{ns}	-0.01^{ns}	0.35**	0.23^{ns}	0.06^{ns}	1	0.03^{ns}
KNSP	0.28**	-0.33**	-0.31**	0.32**	0.09^{ns}	0.12^{ns}	0.29**	0.14^{ns}	-0.42**	0.85**	0.76**	-0.04^{ns}	-0.13^{ns}	0.28**	-0.06^{ns}	1

GY=Grain yield, DH=Days to heading, DAN=Days to anthesis, GFD=Grain filling duration, PH=Plant height, THSW=Thousand seed mass, FLA=Flag leaf area, SPKS=Spikelet number per spike, KNS=Kernel number per spike. KNS=Kernel number per spike, GWPS=Grain weight per spike, BM=Biomass yield, STY =Straw yield per plot, HI=Harvest index, GFR=Grain filling rate, KNSP=Kernel number per spikelet.

condition in the respective order. The grain yield reduction due to drought was comparable to the works of Darzi-Ramandi et al. (2016) and Sahar et al. (2016) who reported a 49 9 and 42% yield reduction, respectively. The probable reasons for significant effect of severe drought stress on grain yield is associated to photosynthesis, translocation and partitioning of carbohydrate reserves leading to decrease in production. Drought caused 18.8% reduction of 1000 grain weight. Genotype 117 showed the highest 1000 seed weight and genotype 13 the lowest in non-stress condition. Genotype 33 and 43 showed the highest and the lowest 1000 seed weight, respectively in the stress environment.

Grain filling rate was also highly affected by stress with reduction of about 41.7% compared to non-stress. Grain filling period ranged from 3.7 (Genotype 121) to 18.5% (Genotype 30), which was among the highest yielding genotypes under stress. Similarly, the lowest grain filling period was obtained from genotypes 35 and 79 which gave the maximum record under non-drought stress.

The reduction in performance due to drought stress observed was consistent with the previous work in wheat that drought stress induced from anthesis to maturity resulted in remarkable reduction in yield and yield related traits (Solomon et al., 2003; Bogale and Tesfaye, 2016). Terminal drought shortens grain filling duration and grain filling rate compared to non-stress (Table 6). This result is supported by Muhammad et al. (2014) who reported that grain filling rate under drought affected due to reduced photosynthesis, accelerated leaf senescence, and sink limitations. Similarly, Mahpara et al. (2018) emphasized that drought after heading results in reduced grain weight by shortening the time between fertilization and maturity.

Pearson correlation analysis

The Pearson correlation coefficient between grain yield and yield related traits under drought and non-drought are shown in Table 7. Grain yield was negatively correlated with days to heading, anthesis date and days to maturity but it showed a

Table 8. Path coefficients on traits under non-stress.

Correlation	DH	DAN	GFD	TSW	FLA	KNS	GWPS	HI	GFR	KNSP
DH	0.54578	-0.7921	-0.5505	0.06234	0.00056	0.00434	-0.1031	-0.0862	0.51456	0.05434
DAN	0.50757	-0.8517	-0.5263	0.05501	0.00282	0.00408	-0.0938	-0.0901	0.62135	0.05104
GFD	-0.4967	0.741	0.60492	-0.0513	0.00339	-0.0054	0.1	0.09012	-0.5534	-0.0527
TSW	-0.1856	0.25552	0.16938	-0.1834	0.00282	-0.0031	0.225	0.03527	-0.0583	-0.0477
FLA	0.00546	-0.0426	0.0363	-0.0092	0.05649	-0.0056	0.05625	0.01176	0.19417	-0.0231
KNS	-0.0928	0.13628	0.12703	-0.022	0.01243	-0.0255	0.24063	0.04506	0.03883	-0.14
GWPS	-0.1801	0.25552	0.19357	-0.132	0.01017	-0.0197	0.31251	0.05486	-0.0097	-0.1251
HI	-0.2401	0.39179	0.27826	-0.033	0.00339	-0.0059	0.0875	0.19592	0.05825	-0.0461
GFR	0.28926	-0.5451	-0.3448	0.011	0.0113	-0.001	-0.0031	0.01176	0.97086	0.00988
KNSP	-0.1801	0.26403	0.19357	-0.0532	0.00791	-0.0217	0.2375	0.05486	-0.0583	-0.1647

non-significant and positive association with grain filling duration although the association was weak under moisture stress.

Grain yield showed a positive and significant correlation with plant height under both non-moisture and moisture stress conditions. Thousands kernel weight, kernel number, above ground biomass, harvest index, kernel number per spikelet and grain weight per spike had similar trend and they were positively and significantly correlated with grain yield under both moisture stress and non-moisture stress conditions. These findings were consistent with the Khan and Naqvi (2012) works of previous authors (Solomon et al., 2003; and Simane et al., 1993) suggesting that the supply of metabolites to grain development through dry matter reallocation would be expected under moisture stress.

The correlation of grain filling rate with grain yield was strongly positive and highly significant at 0.01% under stress (0.83) than non-stress (0.41) indicating that indirect selection for improving grain yield through these traits would be effective under terminal stress environment. The result is consistent with the work of Bogale and Tesfaye, (2016). Grain filling rate was significant at 0.01% and had strong positive association with grain yield (0.41) than grain filling period (0.38). Similarly, Dias and Lindon (2009) indicated strong relationship between grain yield and grain filling rate and the relative advantage of grain filling rate than the duration of grain filling period in increasing the rate of photosynthate translocation to grains as one of the mechanisms to confer stress tolerance to wheat. Therefore, it is likely to predict that genotypes 30 and 31 with high grain filling rate performed better than the other genotypes. These results reflected that the two traits probably could be genetically improved separately or indirectly**.** The correlation of thousand seed weight and grain number was significant at 0.05%, with values 0.25 and 0.22, respectively. The moderate response of thousand seed weight of wheat genotypes for genetic and environmental factor was presented by Soares et al. (2021). The negative association between grain yield and these phenological traits found in this study were similarly reported by authors (Gonzalez et al., 2007) indicating the importance of earliness as drought tolerance mechanism. f earliness as drought Spikelet number per spike showed positive but non-significant correlation with grain yield under non-moisture stress while it showed a negative and significant association with grain yield under stressed condition. This could be due to the fact that moisture stress induced after the plants reached its maximum growth probably influence grain number on wheat. Khan and Naqvi (2012) spikelet numbers and grains number may be used as an effective selection criterion for increasing grain yield of wheat under different moisture levels. Similarly, Dorion et al. (1996) reported no or little effect of drought on the number of spikelet per spike.

Path coefficient analysis

The correlations were analyzed further by the path coefficient technique, which partition the correlation coefficient into direct and indirect effects via alternative traits. Grain yield was performed and influenced by different traits. The direct and indirect effects of grain yield traits under non-stress and stress conditions are shown in Tables 8 and 9, respectively. The path coefficient analysis showed that the direct effect of grain filling rate on grain yield under both non-stress and stress condition were very high and positive (0.97) and (0.76) in respective order. The strong and positive correlation of grain filling and grain yield and its importance to be used as good selection trait than duration (Jones et al., 1979). This indicates that there were little or no indirect effects of these traits and the relationship between grain yield and grain filling rate was direct under non-stress and stress environments. Singh and Chaudhary (1979) suggested that if the correlation coefficient between a causal factor and the effect is almost equal to its direct effect, the correlation explains the true relationship and direct

Table 9. Path coefficients on traits under drought stress.

Correlation	DH	DAN	DM	TSW	KNS	GWPS	BM	HI	GFR	KNSP
DH	0.16107	-0.6591	0.39547	0.02087	0.00399	-0.06	0.01847	-0.1169	-0.1444	0.03055
DAN	0.1498	-0.7087	0.37545	0.01926	0.00448	-0.0587	0.01847	-0.11	-0.0532	0.03315
DM	0.12725	-0.5315	0.5006	0.01365	0.00187	-0.032	-0.0062	-0.0756	-0.2736	0.0156
TSW	-0.0419	0.17009	-0.0851	-0.0803	-0.0015	0.08269	0.04926	0.03094	0.13681	-0.011
KNS	-0.0515	0.25514	-0.0751	-0.0096	-0.0125	0.10002	0.00616	0.0722	-0.0076	-0.0572
GWPS	-0.0725	0.31184	-0.1201	-0.0498	-0.0093	0.13336	0.03695	0.09282	0.12161	-0.0448
BM	0.00966	-0.0425	-0.01	-0.0128	-0.0002	0.016	0.30789	-0.1994	0.23562	0.00585
HI	-0.0548	0.22679	-0.1101	-0.0072	-0.0026	0.03601	-0.1786	0.34379	0.28882	-0.0221
GFR	-0.0306	0.04961	-0.1802	-0.0144	0.00012	0.02134	0.09545	0.13064	0.76006	-0.0019
KNSP	-0.0757	0.36145	-0.1201	-0.0136	-0.011	0.09202	-0.0277	0.11689	0.0228	-0.065

selection through this trait is effective. Ashene and Kinde (2016) also obtained similar result on durum wheat suggesting that selection of wheat genotypes based on grain filling rate under non-stress environment would be beneficial for increasing wheat grain yield.

Conclusions

Drought caused significant reduction in yield and its related traits. Grain yield reduction reached about 48.3% due to the effect of drought. Grain filling rate was also highly affected by drought stress. LRPL-31, MCD-1-21 and ICA#73 are potentially useful and could be considered as source of genes to improve drought tolerance in the breeding program whereas the released cultivar Ude would be utilized for irrigated as well as good rainfall environment. Genotypes 55, 30, 31, 91 15 and 58 were identified among the top 10% high yielding genotypes and showed superior performance in both stress and non-stress environments.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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