



Genetic diversity of Ethiopian durum wheat (*T. turgidum* subsp. *durum*) landraces under water stressed and non stressed conditions

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ARTICLE INFO

Keywords:

Durum wheat
Diversity studies
Augmented design
Drought tolerance
Grain yield
Landraces

ABSTRACT

Ethiopia, being a major center of origin and diversity for durum wheat, possesses a highly variable genetic pool with diverse agroecological adaptations. Wheat landraces are an important source of genetic variation for breeding programs. This study was conducted to study the genotypic diversity of Ethiopian durum wheat genetic resources under two contrasting environments namely drought-stressed and non-stressed. It was carried out on 100 landraces and 4 local checks using an augmented design. Data were collected on 13 traits comprising yield and yield components, phenology, and canopy condition. The analysis of variance revealed significant differences between landraces for different traits with different sources of variation. Several landraces were found to outyield the checks at both environmental conditions. Intermediate to high estimates of the phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability in a broad sense (h^2_b), and genetic advance in percent of the mean (GAPM) were observed for all the studied traits except for days to flowering at normal, thousands seed weight at stress, and days to maturity, leaf chlorophyll concentration measurement, and canopy temperature measurement at both conditions. The estimation of variability parameters showed that genotypic variation was higher than environmental variation for most traits. The number of tillers, spike length, kernel per spike, and grain yield indicated higher values for h^2_b and GAPM (74.42% and 20.86; 83.2% and 28.24; 70.79% and 28.0; and 89.54% and 74.71) at normal and (97.87% and 98.22; 71.27% and 28.51; 75.52% and 43.9; and 90.04% and 103.68) at the stressed condition, respectively. Spikelets per spike, kernel per spike, and thousands seed weight were positively correlated with grain yield. Grain yield exhibited a weak negative correlation with days to heading and days to maturity. Principal components analysis revealed that six traits were the major loadings on the first two principal components that describe 37.9% and 41.0% of the total morphological variance at normal and stressed conditions, respectively. Cluster analysis grouped the landraces into six clusters, with each cluster showing variation in performance for different traits under normal and stressed conditions. The intracluster distance was maximum in cluster I ($D_2 = 7.68$) and ($D_2 = 8.19$) at normal and stressed conditions respectively and the intercluster distance was found to be maximum between clusters I and IV ($D_2 = 11.02$) and clusters I and II ($D_2 = 10.33$) at normal and stressed conditions respectively. The presence of significant genetic variability among the evaluated durum wheat landraces suggests an opportunity for improvement of grain yield through the hybridization of genotypes from different clusters and subsequent

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<https://doi.org/10.1016/j.heliyon.2023.e18359>

Received 5 October 2022; Received in revised form 13 July 2023; Accepted 14 July 2023

Available online 17 July 2023

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selection. Genotypes with superior agronomic traits that outperform the best checks are identified as potential parents for yield improvement programs for moisture stress.

1. Introduction

Wheat is an important cereal and the main food crop for people over the entire world. According to the Food and Agriculture Organization (FAO) report (2020), wheat in Ethiopia covers 1.78 million hectares of a cooler and intermediate agroecology domain. Predominantly grown by subsistence farmers under rain-fed conditions, wheat is the 4th most important cereal crop in the country, with a production of 5.8 million tons (Central Statistical Agency, 2021). Although Ethiopia is the largest wheat producer, it is still reliant on foreign wheat imports to satisfy its annual domestic demand [1–3].

Wheat is grown in a wide range of agro-climatic environments. However, many of these environments have drought stress as one of the major challenges to their production and productivity. The detrimental effect of periodic drought stress during the growth and development seasons adversely affects production and reduces the yield of wheat [4]. Low water availability and drought stress under the rain-fed-based crop production system of Ethiopia are one of the largest causes of wheat yield reduction. It is estimated that for wheat, a yield loss of 6% per degree of temperature increase due to climate change corresponds to a quarter of all global wheat trade [5].

Drought induces significant alterations in plant physiology and biochemistry. Some plants have a set of physiological adaptations that allow them to tolerate conditions of water stress [6]. The degree of adaptation to the decrease in water potential caused by drought may differ among species (doi.10.3389/fpls.2022.992535). Water stress causes various morphological and biochemical changes in plants. As water stress worsens, functional damage and plant part loss increase [7].

Fundamentals of wheat improvement rely on the study of genetic diversity, as it is a basis for elucidating the genetic structure and improving quantitative traits like drought tolerance. Evaluation of genetic diversity levels among adapted and elite germplasm can provide predictive estimates of genetic variation among segregating progeny for pure-line cultivar development [8–12].

There exists enormous variation among different indigenous accessions of durum wheat in terms of quantitative characteristics that are directly related to yield and yield-related traits which are very important for crop improvement programs through breeding and selection. Grain yield is a complex quantitative trait [13] and is directly and positively influenced by yield-related traits such as the number of tillers, number of grains per spike, thousand grain weight, and spike length [14,15]. Success in crop improvement generally depends on the magnitude of genetic variability [16,17] and the extent to which the desirable characteristics are heritable [18,19]. Several approaches and analyses like those of principal components and cluster distances among and between groups of cultivars studied based on morphological and growth attributes have been suggested by many researchers for the estimation of genetic diversity [20–23]. Correlation coefficient analysis is helpful to select for yield using more than one character [24]. It is the measure of the degree of symmetrical association between two variables or characters which helps us in understanding the nature and magnitude of association among yield and yield components and provides an opportunity for indirect selection [25,26]. Hierarchical cluster analysis has been used to estimate genetic dissimilarity and similarity, and Principal component analysis to determine the factors that contribute to the variation of quantitative characters in durum wheat.

Durum wheat production in Ethiopia experiences a lot of challenges, and various studies have been carried out to tackle different problems. As its production and quality are affected by abiotic and biotic factors [27–29], research has focused mainly on improving grain yield [30,31] and disease resistance [32–37]. As is known, Ethiopian durum wheat landraces are unique sources of useful traits. For example, the study by Negassa, [38] showed that landrace from Gamogofa and Harar were highly resistant to a virulent race of powdery mildew and are used as potential parents for resistant breeding, although collections have not been used to their full potential in breeding programs.

So far, several attempts have been made toward the characterization of Ethiopian durum wheat landraces and released varieties. Molecular characterization and association mapping, which reveals an abundance of high diversity in durum wheat by Refs. [39,40], and [41] was the prominent work. Much effort is also paved on characterization for biotic stress, such as resistance for stem rust, stripe rust, and other quality-related traits. However, studies on the genetic diversity of durum wheat landraces in response to drought tolerance are scant. The selection of drought-tolerant durum wheat genotypes has paramount importance in expanding its production to the untapped potential production areas. Here we report on the diversity of Ethiopian Durum wheat landraces in their response to moisture stress.

2. Materials and methods

2.1. Experimental plant materials

In this study, 104 durum wheat genotypes consisting of 100 landraces and 4 standard checks, namely Alemtena, Fetan, Kuami, and Ude were evaluated. The materials were taken from the Ethiopian Biodiversity Institute (EBI) and the Debrezeit Agricultural Research Center of Ethiopia. Landraces were selected based on the acreage of each seed source region. Thus, more samples were taken from major growing regions (Oromia and Amhara) and fewer samples from minor growing regions with a criterion of addressing all agroecological areas.

2.2. Experimental design and field management

The study was conducted using an Augmented block design [42] at two test sites, namely Debrezeit and Dera 2021/22 cropping season. Debrezeit is located at an altitude of 1920 m above sea level and latitude 8.7° 44' North and 39.0° 58' East. It has a mean annual rainfall of 931.4 mm and average maximum and minimum monthly temperatures of 27.5 °C and 11.4 °c, respectively. Dera is located at an altitude of 1500 m above sea level and latitude 8.3° 20' North and 39.3° 19' East and receives a mean annual rainfall of 816.1 mm and average maximum and minimum monthly temperatures of 29.4 °C and 13.7 °c, respectively [43]. The experiment was laid out in a 24 × 5 augmented block design with an area of 168 m² (24 × 7 m) and the space between rows was 20 cm and the spaces between blocks were 50 cm. The landraces were randomly planted, and the checks were replicated in each block at random. Planting was done by hand drilling using a seed rate of 120 kg/ha for each genotype. Nitrogen and phosphorous fertilizers were applied at the rate of 100 kg/ha urea (applied in the split; half at the seedling stage and the remaining half at the booting) and 100 kg/ha of Di-ammonium phosphate (DAP) at planting respectively. All other management practices were uniformly applied to all plots.

2.3. Data collection

Data were collected on the following traits of wheat according to the IBPGR descriptors for wheat [44]. Days to heading (DTH), number of tillers (TN), Days to 50% flowering (DTF), days to maturity (DTM), spike length (SL), number of kernels per spike (KPS), thousand seed weight (TSW), and grain yield per plot (GY) leaf chlorophyll concentration (LCC) and canopy temperature measurements were taken two times at two different stages of development, i.e., during the pre-heading time and grain-filling time.

2.4. Data analysis

The data were analyzed using SAS 9.3 (SAS, 2011) and R software. Analysis of variance (ANOVA), Pearson’s correlation coefficient (r), and principal component analysis (PCA) were performed. The PCA biplots were plotted. The statistical model used for the augmented design was

$$Y_{ij} = \mu + \beta_i + c_j + \tau_{k(i)} + \varepsilon_{ij}$$

Where μ is the mean, β_i is blocks effect, c_j are checks $\tau_{k(i)}$ is each new entry and ε_{ij} is error

The mean square for the analysis of the variance of the check genotypes is computed by using the below table (Table 1). Standard errors used for computing LSI values are calculated by using

1. Difference between means of two check varieties:

$$\text{Standard error, } S_c = \sqrt{\frac{2MSE}{r}} \tag{1}$$

2. Difference between adjusted yields of two new selections in the same block

$$\text{Standard error, } S_d = \sqrt{2MSE} \tag{2}$$

3. Difference between adjusted yields of two new selections in different blocks:

$$\text{Standard error, } S_v = \sqrt{\frac{2(c+1)MSE}{c}} \tag{3}$$

4. Difference between the adjusted yield of a new selection and a check mean:

Table 1
The mean square formula for the analysis of variance of the check genotypes in the augmented design.

ANOVA			
Source	df	SS	MS
Total	rc-1	$\sum i \sum j x_{ij}^2 - \frac{G^2}{rc}$	
Blocks	r-1	$\frac{1}{c} \sum j R_j^2 - \frac{G^2}{rc}$	
Checks	c-1	$\frac{1}{r} \sum i C_i^2 - \frac{G^2}{rc}$	
Error	(r-1)(c-1)	$SS_{Tot} - SSR - SSC$	$\frac{SSE}{(r-1)(c-1)}$

$$\text{Standard error, Svc} = \sqrt{\frac{(r+1)(c+1)MSE}{rc}} \tag{4}$$

A least significant difference

$$LSD = t_{\alpha} \times Svc \tag{5}$$

The phenotypic, genotypic, and environmental variance ($\sigma_p^2, \sigma_g^2, \sigma_e^2$) are obtained from the ANOVA tables according to the expected value of the mean square described by Federer and Searle and Johnson et al. [45] as follows:

$$\sigma_g^2 = \frac{(GMS - EMS)}{r} \tag{6}$$

$$\sigma_p^2 = \sigma_g^2 + EMS \tag{7}$$

$$\sigma_e^2 = EMS \tag{8}$$

Phenotypic and genotypic coefficients of variation (PCV and GCV) are estimated according to Burton [46] as follows:

$$GCV = \frac{\sigma_g^2}{\sqrt{\bar{x}}} \times 100 \tag{9}$$

$$PCV = \frac{\sigma_p^2}{\sqrt{\bar{x}}} \times 100 \tag{10}$$

Where \bar{x} is the mean

The estimates of PCV and GCV are categorized according to Sivasubramanian and Madhavamenon [47] as follows:

- CV (%) Category
- P(G)CV < 10 Low
- 10 ≤ P(G)CV < 20 Medium
- P(G)CV ≥ 20 High

The broad-sense heritability (h_b^2) is calculated according to the method of Lush [48] as follows:

$$h^2b = \frac{\sigma_g^2}{\sigma_p^2} \tag{11}$$

The estimates of broad-sense heritability (h_b^2) are categorized according to Robinson [49] as follows:

- h_b^2 Category
- $h_b^2 < 30$ Low
- $30 \leq h_b^2 < 60$ Medium
- $h_b^2 \geq 60$ High

Genetic advance (GA) is estimated and categorized according to Johnson et al. [50] as follows:

$$GA = k \times \sigma_g \times \frac{H^2}{100} \tag{12}$$

Where the constant k is the standardized selection differential or selection intensity. The value of k at the 5% proportion selected is 2.063 from the table in Falconer [51].

Genetic advance a percentage of mean (GAPM) is calculated according to the method in Comstock, R. E., and H. F. Robinson [52].

$$GAPM = \frac{\text{Population mean}}{\text{Genetic advance}} \times 100 \tag{13}$$

2.4.1. Principal component analysis (PCA)

The principal components are calculated by finding the eigenvectors of the covariance matrix of the original variables. The eigenvectors are the directions in which the data varies the most, and the eigenvalues are the corresponding variances. The principal components are then ordered by their eigenvalues, with the first principal component accounting for the most variation in the data, the second principal component accounting for the second most variation, and so on [53,54].

2.4.2. Cluster analysis

Cluster analysis was calculated using hierarchical clustering, starting by assigning each object to its cluster, and then iteratively

merging the most similar clusters until there is only one cluster left. Euclidean distance was used to measure the similarity between the two clusters. The Euclidean distance between two clusters is the square root of the sum of the squared differences between the cluster means [55,56].

2.4.3. D² analysis

The genetic distance between two genotypes was measured using D2 analysis. It is based on the Euclidean distance between the genotypes' vector of principal component scores. The formula for D2 analysis is as follows:

$$D^2 = (Y_1 - Y_2)'(Y_1 - Y_2) \tag{14}$$

where:

- D² is the genetic distance between the two genotypes
- Y₁ is the vector of principal component scores for genotype 1
- Y₂ is the vector of principal component scores for genotype 2

The genetic distance between two genotypes is a measure of how different the two genotypes are. The higher the genetic distance, the more different the two genotypes are [57].

3. Results and discussion

3.1. Analysis of variance

The Analysis of variance (Table 2) revealed a significant mean sum of squares for different traits with different sources of variation. There indicates a highly significant difference between landraces eliminating the block effect in all parameters except canopy temperature measurements, and leaf chlorophyll concentration measurements at both normal and stressed conditions. However, the block effects were non-significant for all traits at both conditions except for grain yield at both normal and stressed conditions and thousand seed weights at the stressed conditions. The absence of significant differences between blocks is an indication of the homogeneity of the evaluation blocks. The mean square due to check v/s landraces was significant for all traits indicating the presence of significant differences between landraces and checks.

The overall adjusted mean between the two environmental conditions in the separated ANOVA indicates the presence of differences between genotypes in response to the varying environmental conditions. As indicated in Table 2, at the normal condition, there was a significant difference in the adjusted mean of spike length (8.6), number of spikelets per spike (23.38), and plant height (88.77) than stressed condition (82.83, 6.41, 19.84) respectively. Several researchers also reported the presence of significant differences in major traits in bread and durum wheat genotypes studied under different environmental conditions [58–60]. Highly significant differences in plant height among genotypes under stressed conditions were shown in previous studies [61,62]. The adjusted mean of the number of kernels per spike and thousand seed weight also have a significant difference between normal and stressed conditions. The least significant difference (supplementary data 2, Table 1) was computed to identify the test genotypes that significantly surpassed the best

Table 2

Analysis of variance from augmented block design for the thirteen yield and yield-related traits of 98 durum wheat genotypes at normal and stressed conditions.

Source of variation	Env.	DF	BY	CT	DTF	GY	DTH	PH	
Landraces (EB)	Normal	97	17010.39 *	10.32 ns	61.11 **	1.34 **	54.78 **	147.97 *	
Check genotypes		3	5342.96 ns	14.37 ns	4.6 ns	2.08 **	11.25 ns	65.3 ns	
Landrace vs. Check		1	287.5 ns	73.69 **	990.78 **	17.8 **	417.74 **	578.85 **	
Test treatments		93	16924.1 *	9.71 ns	55.12 *	1.13 **	57.31 **	148.84 *	
Block (ET)		4	21654.7 ns	6.19 ns	2.32 ns	1.73 **	3.58 ns	8.61 ns	
Residuals		12	6861.25	5.45	16.72	0.12	8.87	59.56	
Overall adj. mean				806.99	31.88	74.52	2.62	59.18	84.77
Coeff. Var. (CV)				10.25	7.39	5.56	12.41	5.09	9.02
Landraces (EB)		Stressed	98	45299.36 *	9.51 ns	64.1 **	1.18 **	36.71 **	94.09 **
Check genotypes			3	11776.21 ns	3.33 ns	1.47 ns	0.79 **	9.13 ns	3.26 ns
Landrace vs. Check	1		260547.16 **	95.53 **	1151.21 **	25.31 **	449.46 **	385.19 **	
Test treatments	94		43909.99 *	8.79 ns	53.64 **	0.95 **	33.91 **	93.17 **	
Block (ET)	4		23560.94 ns	4.3 ns	38.05 ns	0.89 **	9 ns	57.93 ns	
Residuals	12		14340.33	5.3	13.22	0.09	7.3	22.91	
Overall adj. mean				605.45	33.23	62.73	1.75	51.46	81.92
Coeff. Var. (CV)				19.29	7	5.89	16.1	5.32	5.8

*, ** Significant at 5% and 1% level of probability, respectively. Env. = Environment, DF = Degree of freedom, BY = Biomass yield, CT = canopy temperature measurement, DTF = days to 50% flowering, GY = grain yield per plot, DTH = days to heading, PH = plant height, KPS = kernels per spike, DTM = Days to maturity, LCC = leaf chlorophyll concentration measurement, SL = spike length, SPS = the number of spikelets per spike, NT = number of tillers, and TSW = thousand seed weight.

Table 3

Adjusted mean values of the 10 best-performing genotypes and five bottom-performing genotypes (based on grain yield under drought-stressed conditions) for the thirteen quantitative traits in normal and stressed conditions.

Treatment	BY		CT		DTF		GY		DTH		PH		KPS	
	Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress
Top ten genotype														
ETDW/15DZ4	1048.02	698.64	26.92	29.72	59.6	56.8	5.73	5.47	45.35	45.8	97.75	78.73	28.84	20.56
ETDW/15DZ23	915.21	257.01	29.62	27.92	76.85	65.55	6.13	4.96	64.6	57.8	88.95	79.48	26.49	29.63
34522	830.16	746.31	26.43	29.98	74.6	52.05	6.08	4.66	61.1	49.8	103.49	86.89	31.09	35.05
34493	726.29	588.34	34.72	33.02	72.85	63.55	5.22	4.54	64.6	53.8	85.67	88.63	26.84	31.39
31831	801.48	283	32.01	32.31	72.35	57.55	4.54	3.62	51.6	50.3	67.25	73.79	48.19	36.86
34217	636.46	360.71	26.97	29.27	82.85	75.55	4.34	3.6	66.6	59.8	104.32	93.01	24.57	17.63
Ude	768.72	740.26	31.95	30.55	66	54.6	4.28	3.22	56.4	45	90.46	85.43	27.6	28.22
Fetan	842.11	720.27	28.88	30.88	67.8	54.6	4	3.25	52.8	46	86.03	86.7	30.64	31.42
ETDW/15DZ010	592.41	795.1	29.12	29.42	73.35	69.55	3.9	3.19	58.6	53.3	87.45	91.79	32.37	22.53
31778	590.16	809.2	28.48	28.78	75.35	59.55	3.7	3.04	56.6	47.3	100.03	88.79	33.79	25.2
Bottom five genotypes														
34295	803.03	681.61	28.72	31.02	74.85	69.55	2.92	0.35	61.6	59.8	93.13	82.63	19.99	28.63
31761	927.36	279.2	28.06	28.36	70.35	62.55	0.93	0.36	55.6	53.3	80.92	88.79	28.12	16.15
MCD1429	994.19	975.76	35.33	36.38	57.6	52.05	0.88	0.38	49.35	45.5	94.21	91.11	21.23	18.19
34451	790.79	661.61	36.42	34.72	66.85	62.55	0.7	0.21	54.6	52.8	68.86	74.54	19.61	14.45
DW-PVT LM8	620.69	357.61	32.43	34.73	62.85	46.55	0.68	0.11	44.6	44.8	76.12	83.55	18.99	14.2
Overall adj. mean	806.99	605.45	31.88	33.23	74.52	62.73	2.62	1.75	59.18	51.5	84.77	81.92	26.12	22.44
Coeff. Var. (CV)	10.25	19.29	7.39	7	5.56	5.89	12.41	16.1	5.09	5.32	9.02	5.8	10.19	13.34
least sign. Inc. (LSI)	180.78	261.35	5.1	5.03	8.93	7.93	0.75	0.68	6.5	5.9	16.84	10.44	5.92	6.83
Treatment	DTM		LCC		SL		SPS		NT		TSW			
	Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress	Normal	Stress		
Top ten genotype														
ETDW/15DZ4	103.5	99.3	41.25	43.03	13.02	9.57	24.59	16.7	17.1	10.8	44.42	39.18		
ETDW/15DZ23	110.25	94.05	45	35.49	13.04	9.59	27.32	21.5	17.51	14.5	46.5	35.78		
34522	114	92.55	38.43	43.1	10.47	8.27	28.68	22	15.17	9.62	41.15	38.16		
34493	99.25	91.05	55.01	48.76	12.79	10.34	23.32	15	23.06	20	47.48	37.53		
31831	109.25	86.8	46.39	47.53	11.88	8.68	23.43	19	19.81	18.3	59.62	41.17		
34217	103.25	99.05	45.7	39.29	11.84	9.39	24.7	18.6	23.23	20.2	48	36.95		
Ude	103.8	92.4	46.64	40.47	8.43	6.13	24.74	20	17.31	15.3	43.92	37.46		
Fetan	101.2	88.6	44.48	38.92	10.65	8.35	24.41	21.2	17.36	15.4	46.3	37.07		
ETDW/15DZ010	109.25	98.8	46.38	50.09	11.68	9.48	23.69	18.9	17.57	16	54.42	32.15		
31778	109.25	95.8	49.14	43.39	11.13	8.93	24.43	19.6	16.42	14.9	49.27	36.23		
Bottom five genotypes														
34295	106.25	94.05	50.53	41.99	10.2	7.75	20.82	18.9	21.48	14.4	42.78	36.25		
31761	103.25	98.8	48.31	38.32	8.44	6.24	13.93	14.4	17.88	16.3	41.99	33.55		
MCD1429	90	85.3	46.84	47.19	7	5.8	15.66	14.7	21.85	16.7	36.55	39.76		
34451	104.25	98.05	48.46	43.69	9.44	6.99	20.44	13.6	20.41	17.4	28.75	36.07		
DW-PVT LM8	103.25	90.05	49.08	42.53	8.14	5.69	19.82	12.6	21.68	18.6	38.28	36.08		
Overall adj. mean	106.31	95.48	46.58	42.45	8.6	6.41	21.38	17.4	19.26	16.3	41.08	38.42		
Coeff. Var. (CV)	2.34	3	5.66	9.38	6.7	10.29	7.28	9.28	6.96	7.12	11.98	5.13		
least sign. increase (LSI)	5.42	6.22	5.74	8.59	1.27	1.46	3.46	3.62	2.89	2.53	10.91	4.28		

check. At both environmental conditions, a total of seven landraces outyielded the checks namely, ETDW/15DZ4, 34493, ETDW/15DZ23, 34522, MCD3-14, 34217, and 31831. From those outyielded landraces ETDW/15DZ23, 34522, ETDW/15DZ4, 34493 at the normal conditions, and ETDW/15DZ4 34493 ETDW/15DZ23 at the stressed conditions surpass all four checks.

3.2. Agronomic performance of durum wheat genotypes

The mean comparison in the separate ANOVA (Table 2) showed the presence of a significant difference between the means of each trait in both environmental conditions. The landraces have significant differences with respect to the checks and each other. For the phenological traits, there is a significant difference between the two environments. The heading, flowering, and maturity days have shown a significant difference between the two environments. The overall mean days for heading, flowering, and maturity at the normal condition were 58.08, 73.89, and 109.27, and for the stressed conditions 51.34, 62.82, and 98.14, respectively. Studies by Marianna V. et al. and Samarah, N.H. indicated that drought can accelerate and shortens the period of flowering and grain maturity it speeds up wheat plant flowering and maturity and caused forced maturity [63,64]. There is an absence of correspondence between days to heading and maturity. Some of the genotypes having early heading did not show early maturity and late maturing was not matched with late days to heading. This is in agreement with a previous study [65,66] that for most of the genotypes, they reported an absence of coincidence with each other.

The full table of the adjusted mean values of the studied genotypes for different agronomic traits in both conditions is given in supplementary data one, Tables 1 and 2 From Table 3 which showed the top 10 and bottom 5 performing landraces, grain yield varies with a range of 0.68 t/h to 6.13 t/h and from 0.11 t/h to 5.47 t/h with an overall adjusted mean grain yield of 2.62 and 1.75 t/h at normal and stressed conditions respectively. The result showed a yield reduction due to drought stress by around 33.2%. The result is in agreement with the reports of other authors where drought stress resulted in a significant reduction of grain yield. The studies by Amare et al. [67] and Habtamu et al. [68] indicated the performance of grain yield under normal conditions to be higher than the stressed condition by around 30.6%, which is an indication of a significant reduction of yield due to stress. Also, Qaseem et al. [69] reported a greater loss (around 63.0%) of yield in durum wheat due to drought stress.

The genotypes also showed variation in the adjusted mean of canopy temperature and leaf chlorophyll concentration measurement across the two environmental conditions and within the genotypes too. The mean canopy temperature at normal and stressed conditions was 33.23 and 31.88 °C respectively. Canopy temperature readings depend on the environment in which the measurements were taken and there are as many responses in CT as there are environments. Studies indicated the mean CT at the normal condition was cooler than that of the stressed condition, which indicates that they adjust their physiology and minimize the loss of water via the

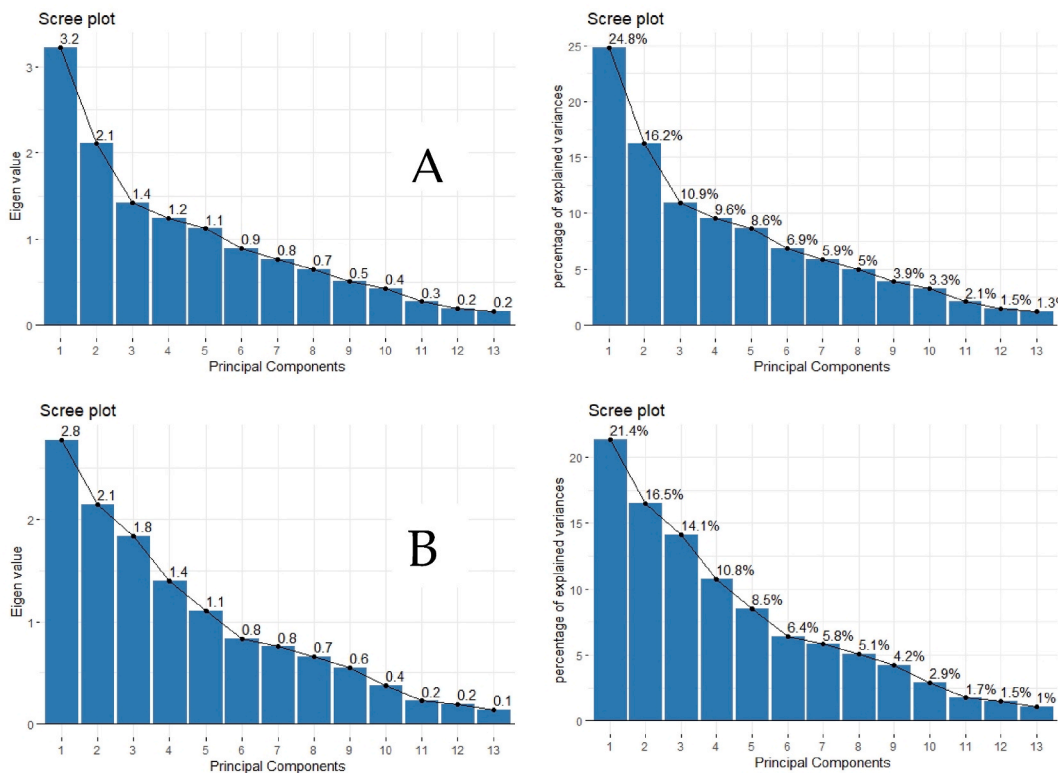


Fig. 1. Eigenvalues of different principal components and their contribution to the total explained variance for the phenotypic diversity of durum wheat landraces grown at normal (A) and stressed conditions (B).

stomata [70,71]. The leaf chlorophyll concentration measurement indicates a high mean value (46.58) in the normal condition than that in stressed (42.45). As indicated in Refs. [72,73], Changes in the structure of chloroplast such as the change in the shape of chloroplasts, swelling of stromal lamellae, clumpy vacuoles, antenna-depleted PS II, and degradation of chlorophyll molecules during stress results in the reduction in chlorophyll content [74]. The mean performance of genotypes at the normal conditions for the number of spikelets per spike, spike length, and thousand seed weight showed a significant increment from that of stressed condition as studies reported that drought stress reduced the number of spikes and grains per plant [63,75].

3.3. Principal component analysis

In Fig. 1, the PCA revealed that at both locations five of the thirteen principal components were significant with eigenvalue >1 and contributed to 70.1% and 71.3 of the variance at the normal and stressed conditions respectively. PC1 accounted for the highest variance (24.8%) followed by PC2 which accounted for 16.2% at normal conditions (Fig. 1A) and PC1 (21.4%) followed by PC2 which accounted for 16.5% at the stressed condition (Fig. 1B). PC3, PC4, and PC5 accounted for 10.9%, 9.6, and 8.6% variance at normal and, 14.1, 10.8, and 8.5 at stressed conditions respectively.

The magnitude and direction of the contribution of different traits in the different principal components are shown in Fig. 2A and B for normal and stressed conditions respectively. The characters coming together in different principal components explaining the variability show the tendency to remain together and must be taken into consideration during the exploitation of these characters in the breeding program [76].

Results from the heatmap of the PCA in Fig. 3A shows that the first principal component was contributed positively by grain yield, number of kernels per spike, spike length, spikelets per spike, and thousand seed weight at the normal condition. The heat map clearly showed that in this condition the PC1 included parameters that were mainly related to grain yield, yield attributes, and grain characteristics. For the stressed condition, in Fig. 3B, the PC1 contributed positively by grain yield, numbers of kernels per spike, spike length, and spikelets per spike, and negatively contributed by tiller number. In both conditions, most of the traits positively contributed to PC1 and PC2.

3.4. Cluster analysis

The landraces were grouped into six clusters as listed in Table 4. Under the normal condition, cluster IV was the largest cluster which included 26 landraces, whereas cluster VI with 24 landraces at the stressed condition followed by cluster II which included 21 and 22 landraces at normal and stressed conditions respectively. At normal conditions clusters, I, III, and V had equal 15 landraces and

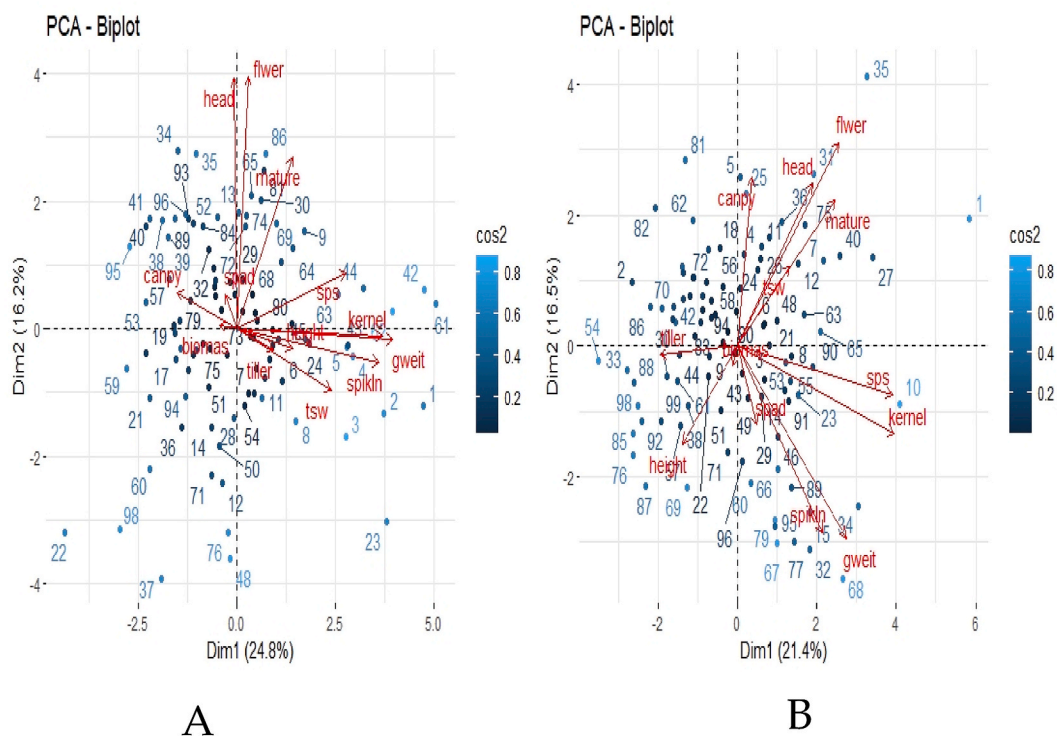


Fig. 2. The biplot of durum wheat landraces for PC1 and PC2 at normal (A) and stressed (B) conditions. The arrows show the contribution (magnitude and direction) of the trait in PC1 and PC2.

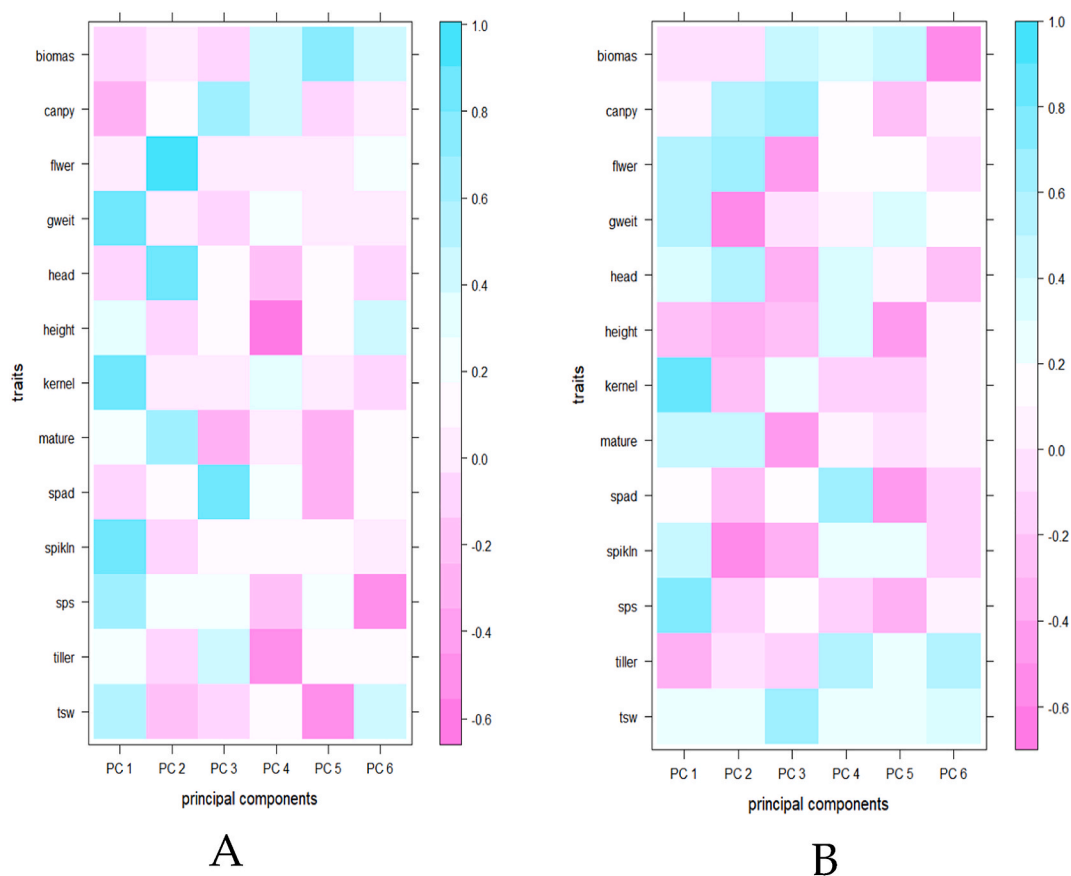


Fig. 3. Contribution of each trait for the principal component at normal (A) and stressed (B) conditions.

the VI cluster contain the minimum number of landraces, which is six. At stress conditions, III, V, IV, and I take the next rank with 19, 14, 13, and 7 landraces respectively.

Cluster I comprised 15 accessions, which represented 15.31% of the total accessions (Table 4) in the normal condition and 7 accessions (7.07%) in the stressed condition. In Table 5 the data on the mean performance of the traits in each cluster indicated a wide range of mean values among the characters. At the normal condition, the mean value of grain yield (4.42 t/h), plant height (91.33 cm), number of kernels per spike (33.89), spike length (11.24 cm), spikelets per spike (24.80) and thousand seed weight (48.27g) was found to be maximum. Genotypes with the highest grain yield were included in this cluster. But at the stressed condition, only a thousand seed weight (45.27g) was the maximum. Cluster II accounts for 21.43% and 22.22% of the population and includes 21 and 22 accessions at the normal and stressed conditions respectively. In this cluster, the mean values of characters such as canopy temperature (30.07), days to 50% heading (55.46) at the normal condition, and biomass weight (700g) at the stressed condition were found to be maximum. Cluster III represents 15.31% of the total 98 accessions and comprised 15 accessions at the normal condition. At stressed conditions, 19.19% of the total 99 accessions comprised 19 accessions. The accessions from this cluster could be picked up for high leaf chlorophyll concentration measurement (50.63) and shortest days to 50% flowering (73.38) at the normal condition while at the stressed condition for the higher number of spikelets per spike (20.30), number of kernels per spike (28.48), and leaf chlorophyll concentration measurement (46.71).

Cluster IV comprised 26 accessions that contributed 26.53% of the total accession at the normal condition and 13 accessions contributed 13.3% of the total accession at the stressed condition. At the normal condition, most of the accession in this cluster have a medium value except days to maturity which take 111.63 which is the maximum. For the stressed condition, this cluster comprised of the cooler canopy (30.21), maximum yield (3.64 t/h), shortest days to 50% flowering (50.21 days), and high spike length (8.32 cm). At the stressed condition, this cluster comprises those with the highest grain yield. Cluster V represents 15.31% of the total 98 accessions and comprised 15 accessions at the normal condition as clusters I and III. Those genotypes with low grain yield at the normal condition were incorporated into this cluster. At stressed conditions, 14.14% of the total 99 accessions comprised 14 accessions. The shortest days to maturity (98.48) at the normal condition and the highest number of tillers (16.45) at the stressed condition were observed in this cluster. Also, the lowest yield (1.56, 0.78) and biomass (762.48, 433.97) were observed in both conditions, normal and stressed respectively. The sixth cluster accounts for 6.12% and 24.24% of the population and includes 6 and 24 accessions at normal and stressed conditions respectively. At the normal condition biomass yield have the maximum value in this cluster while shorter days for

Table 4
Grouping of the studied durum wheat genotypes based on six clusters for various traits for normal and stressed conditions.

	cluster	No. of landraces	% of landraces	Name of landraces
Normal	I	15	15.31	31831, Ude, Fetan, ETDW/15DZ010, 31778, ETDW/15DZ038, ETDW/15DZ4, 34217, ETDW/15DZ23, 34493, 34415, 34522, MCD3-14, 34560, DZDW170204
	II	21	21.43	31794, 31806, Alemtena, Kuami, MCD3-15, ETDW/15DZ 006, ETDW/15DZ 003, 31789, 31761, MCD12-30, 33235, DW-NVT LM 5, DZDW17002, 33239, 33306, 34295, MCD2-17, 34219, MCD1-32, DZDW17010,8, 34596
	III	15	15.31	31797, ETDW/15DZ 057, 31696, 31755, 31759, 33403, ETDW/15DZ 049, MCD12-2, 34520, 34641, 34625, 34607, DW-NVT LM 6, 34622, 34602
	IV	26	26.53	MCD15-49, MCD4-41, 33405, 33241, ETDW/15DZ #39, 33254, 33205, DW-NVT LM 4, MCD13-42, 34452, DW-NVT LM 11, 34545, 34573, 34510, 34516, ETDW/15DZ #35, 34571, MCD2-29, MCD15-7, MCD4-4, ETDW/15DZ 073, 34500, ETDW/15DZ 043, ETDW/15DZ 014, 34613, 34600
	V	15	15.31	31698, MCD4-15, 34423, 34418, MCD10-11, 34484, 34451, DW-PVT LM 8, ETDW/15DZ 012, 34496, 34620, 34611, 34594, 34632, MCD14-29
	VI	6	6.12	33230, 33300, DZDW17004, 33244, 34481, MCD3-27
Stressed	I	7	7.07	34566, 34573, 34580, 33405, 34571, 34607, 34622
	II	22	22.22	MCD4-15, DW-NVT LM 5, 33300, ETDW/15DZ 049, MCD12-30, 33235, 34500, DZDW17002, 34510, 34481, ETDW/15DZ #35, ETDW/15DZ 073, MCD4-41, ETDW/15DZ #39, 33205, 34613, 31759, MCD4-4, MCD15-49, 33254, 34520, ETDW/15DZ 014
	III	19	19.19	DZDW1702,04, 33230, MCD2-29, ETDW/15DZ 003, MCD3-14, MCD3-27, 34545, DZDW17010,8, MCD1-32, DW-NVT LM 6, 34295, ETDW/15DZ 012, 34596, ETDW/15DZ 006, 33403, 33306, 34641, ETDW/15DZ 038, 34415
	IV	13	13.13	31831, ETDW/15DZ #4, ETDW/15DZ #23, Ude, Kuami, Fetan, 34522, Alemtena, 34493, 31778, ETDW/15DZ 010, 34217, 31797
	V	14	14.14	34452, 33244, 31806, DW-NVT LM 11, 33241, DW-NVT LM 4, 34484, ETDW/15DZ 043, 31761, 34594, 31703, 31755, 34219, MCD13-42
	VI	24	24.24	34451, 34516, 34423, 31789, 34611, MCD10-11, 33239, 34620, DW-PVT LM 8, MCD15-7, 31794, 34625, MCD3-15, 34600, 34560, 34496, 31696, ETDW/15DZ 057, MCD12-2, MCD14-29, MCD2-17, 34632, 34418, 34602

Table 5
Mean performance of genotypes in respective clusters for different traits at normal and stressed conditions.

	BY	CT	DTF	GY	DTH	PH	KPS	DTM	LCC	SL	SPS	NT	TSW	
Normal	c1	758.88	30.57	73.57	4.42	58.87	91.33	33.89	107.63	47.45	11.24	24.80	20.35	48.27
	c2	814.47	30.07	73.54	2.62	55.46	82.16	26.34	107.13	45.42	8.68	19.33	19.67	46.51
	c3	896.81	35.24	73.38	2.62	56.72	90.35	26.07	104.98	50.63	8.14	20.97	17.69	40.28
	c4	766.83	31.20	79.67	2.44	64.29	82.79	24.60	111.63	44.00	7.89	21.62	17.97	39.16
	c5	762.48	32.84	65.82	1.56	53.97	84.11	22.41	98.45	47.28	7.75	20.91	20.81	36.04
	c6	961.86	33.68	82.64	1.58	70.06	73.76	21.92	100.08	47.82	8.14	21.19	20.80	27.08
Stressed	c1	532.88	39.22	72.16	1.94	55.64	81.13	29.63	101.84	44.13	6.15	21.63	13.78	45.27
	c2	700.95	33.90	65.73	1.58	51.68	76.64	20.73	97.23	38.20	6.01	16.00	14.79	39.43
	c3	613.59	32.73	62.85	1.83	52.28	79.88	28.48	96.13	46.71	6.74	20.30	14.76	37.77
	c4	602.41	30.21	59.99	3.64	50.21	86.44	28.23	93.80	41.80	8.32	19.54	15.90	36.93
	c5	433.97	32.38	67.09	0.78	55.64	85.98	15.88	96.76	41.41	5.67	15.16	16.45	35.74
	c6	646.79	33.42	55.85	1.31	47.41	86.69	17.85	91.69	43.45	6.04	15.22	16.52	38.38

50%flowering (55.85), large plant height (86.69), and shorter days of maturity (91.69), were observed at the stressed condition. Also, those genotypes with lower yield potentials were categorized in this cluster.

The intracluster and intercluster distance (D^2) presented in Table 6 indicated that the intracluster distance was maximum in cluster I ($D^2 = 7.68$) and ($D^2 = 8.19$) at normal and stressed conditions respectively, followed by cluster V ($D^2 = 7.74$) at normal and cluster III ($D^2 = 7.06$) at stressed condition. Cluster VI has the smallest intracluster distance with ($D^2 = 5.29$) and ($D^2 = 5.32$) at normal and stressed conditions respectively. The low intracluster distance indicated that the landraces in the clusters were closely related due to the heterogeneous nature of the landrace within a cluster and the presence of less genetic diversity within the cluster [77]. Also, the

Table 6
Intracluster (bold diagonal) and intercluster distance among 6 clusters at the normal condition (right) and stressed condition (left).

	c1	c2	c3	c4	c5	c6	c1	c2	c3	c4	c5	c6
c1	7.687						8.195					
c2	8.679	5.813					10.331	6.952				
c3	9.801	7.826	7.270				8.373	8.512	7.069			
c4	8.734	6.979	8.403	6.936			8.986	8.786	7.736	6.487		
c5	11.026	8.482	9.423	8.726	7.746		8.756	7.660	8.202	8.679	5.771	
c6	9.534	7.454	8.080	7.619	8.032	5.291	10.192	7.595	8.011	8.534	6.994	5.328

Table 7

Genetic Variability Analysis for the thirteen yield and yield-related traits of durum wheat varieties at the normal and stressed conditions in 2021/22.

Env	Trait	Mean	Min	Max	PV	GV	EV	GCV	PCV	ECV	h ² b	GA	GAPM
Normal	DTH	59.18	43.1	77.35	57.31	48.44	8.87	11.76	12.79	5.03	84.52	13.2	22.3
	NT	19.26	11.67	24.53	6.85	5.1	1.75	11.72	13.59	6.87	74.42	4.02	20.86
	PH	84.77	58.93	106.56	148.84	89.27	59.56	11.15	14.39	9.1	59.98	15.1	17.81
	DTM	106.31	67.68	119.5	60.87	54.73	6.14	6.96	7.34	2.33	89.91	14.47	13.61
	SL	8.6	6.1	13.04	2	1.67	0.34	15.01	16.45	6.74	83.2	2.43	28.24
	DTF	74.52	51.6	92.6	55.12	38.39	16.72	8.31	9.96	5.49	69.66	10.67	14.32
	SPS	21.38	10.31	28.68	7.33	4.82	2.51	10.27	12.66	7.41	65.77	3.67	17.18
	TSW	41.08	21.4	59.62	60.59	35.66	24.94	14.54	18.95	12.16	58.85	9.45	23
	KPS	26.12	17.29	48.19	25.09	17.76	7.33	16.13	19.17	10.36	70.79	7.31	28
	BY	806.99	487.44	1092.94	16924.1	10062.85	6861.25	12.43	16.12	10.26	59.46	159.58	19.77
	GY	2.62	0.68	6.13	1.13	1.01	0.12	38.27	40.45	13.08	89.54	1.96	74.71
	LCC	46.58	33.6	59.92	16.52	9.62	6.9	6.66	8.72	5.64	58.22	4.88	10.48
	CT	31.88	26.23	41.38	9.71	4.26	5.45	6.48	9.77	7.32	43.91	2.82	8.86
	Stressed	DTH	51.46	36.75	65.75	33.91	26.61	7.3	10.02	11.32	5.25	78.47	9.43
NT		16.33	6.8	21.05	63.09	61.75	1.34	48.13	48.65	7.1	97.87	16.04	98.22
PH		81.92	65.23	102.45	93.17	70.26	22.91	10.23	11.78	5.84	75.41	15.02	18.33
DTM		95.48	81.55	116.55	34.61	26.49	8.13	5.39	6.16	2.99	76.53	9.29	9.73
SL		6.41	4.48	10.34	1.55	1.1	0.44	16.37	19.39	10.39	71.27	1.83	28.51
DTF		62.73	46.55	85.05	53.64	40.42	13.22	10.14	11.68	5.8	75.36	11.39	18.15
SPS		17.38	9.89	26.36	10.52	7.79	2.73	16.06	18.67	9.52	74.01	4.95	28.5
TSW		38.42	28.14	51.58	11.22	7.39	3.84	7.07	8.72	5.1	65.81	4.55	11.84
KPS		22.44	8.39	39.79	40	30.2	9.79	24.49	28.18	13.94	75.52	9.85	43.9
BY		605.45	194.74	1008.44	43909.99	29569.66	14340.33	28.4	34.61	19.78	67.34	291.11	48.08
GY		1.75	0.11	5.47	0.95	0.85	0.09	52.97	55.82	17.62	90.04	1.81	103.68
LCC		42.45	31.8	53.89	23.06	7.57	15.49	6.48	11.31	9.27	32.84	3.25	7.66
CT		33.23	27.92	44.93	8.79	3.49	5.3	5.62	8.92	6.93	39.73	2.43	7.31

PV = Phenotypic variance, GV = genotypic variance, EV = environmental variance, GCV = coefficient of genotypic variation, PCV = coefficient of phenotypic variation, ECV = coefficient of environmental variation, h²b = heritability in a broad sense, GA = genetic advance and GAPM = genetic advance in percent mean. Env = Environment, DF = Degree of freedom, BY= Biomass yield, CT = canopy temperature measurement, DTF = days to 50% flowering, GY = grain yield per plot, DTH = days to heading, PH = plant height, KPS = kennels per spike, DTM = Days to maturity, LCC = leaf chlorophyll concentration, SL = spike length, SPS = the number of spikelets per spike, NT = number of tillers, and TSW = thousand seed weight.

Table 8

The correlation coefficient between yield component traits and grain yield in durum wheat at the normal condition.

	DTH	TN	PH	DTF	DTM	SL	SPS	KPS	TSW	BY	GYLD	LCC	CT	
Normal	DTH	1												
	TN	0.12	1											
	PH	-0.03	-0.08	1										
	DTF	0.41	-0.68	0.10	1									
	DTM	0.33	-0.55	0.05	0.77	1								
	SL	-0.01	-0.10	0.12	0.08	0.06	1							
	SPS	0.23	-0.05	0.18	0.11	0.17	0.37	1						
	KPS	0.01	-0.23	-0.08	0.21	0.27	0.23	0.25	1					
	TSW	-0.19	-0.20	0.13	0.11	0.15	0.35	0.05	0.26	1				
	BY	-0.02	0.18	-0.05	-0.06	-0.14	-0.01	-0.07	0.07	-0.15	1			
	GYLD	-0.08	-0.24	0.21	0.18	0.23	0.55	0.52	0.43	0.40	0.02	1		
	LCC	0.10	-0.05	-0.02	0.11	-0.04	0.13	0.00	0.00	0.02	-0.08	-0.07	1	
	CT	0.06	0.09	-0.13	-0.03	-0.11	-0.21	-0.16	-0.08	-0.18	0.09	-0.25	0.40	1
	Mean	59.18	20.42	84.77	73.36	106.31	8.6	21.38	26.12	41.08	806.99	2.62	46.58	31.88
	Stdev	7.46	8.82	12.07	10.52	7.75	1.47	3	5.28	8.2	141.87	1.17	4.54	3.44

Table 9

The correlation coefficient between yield component traits and grain yield in durum wheat at the stressed condition.

	DTH	TN	PH	DTF	DTM	SL	SPS	KPS	TSW	BY	GYLD	LCC	canopy	
Stressed	DTH	1												
	TN	0.13	1											
	PH	-0.14	0.12	1										
	DTF	0.68	0.11	-0.01	1									
	DTM	0.26	0.23	0.16	0.55	1								
	SL	0.04	0.03	0.11	0.12	0.06	1							
	SPS	0.09	0.04	0.06	0.10	0.04	0.47	1						
	KPS	0.16	-0.18	0.01	0.19	-0.01	0.46	0.43	1					
	TSW	0.12	0.18	-0.10	0.11	0.07	-0.03	0.06	0.02	1				
	BY	0.02	0.07	-0.07	-0.16	-0.13	0.07	-0.10	-0.08	0.14	1			
	GYLD	-0.02	0.01	0.12	-0.01	-0.03	0.75	0.54	0.53	0.05	0.10	1		
	LCC	0.16	0.06	0.08	-0.02	0.11	0.28	0.21	0.17	0.24	0.12	0.22	1	
	CT	0.02	-0.10	-0.14	0.09	0.03	-0.29	-0.14	-0.12	0.43	0.02	-0.32	0.09	1
	Mean	56.182	15.626	82.799	67.901	103.16	6.421	21.44	20.08	38.37	610.376	72.414	42.441	33.211
	Stddev	6.132	2.764	6.765	7.288	5.979	1.262	2.765	6.099	3.297	211.855	41.938	4.764	2.946

BY= Biomass yield, CT = canopy temperature measurement, DTF = days to 50% flowering, GY = grain yield per plot, DTH = days to heading, PH = plant height, KPS = kennels per spike, DTM = Days to maturity, LCC = leaf chlorophyll concentration measurement, SL = spike length, SPS = the number of spikelets per spike, NT = number of tillers, and TSW = thousand seed weight.

intercluster distance was found to be maximum between clusters I and IV ($D^2 = 11.02$) followed by clusters I and III ($D^2 = 9.80$) at the normal condition, and clusters I and II ($D^2 = 10.33$) followed by cluster I and VI ($D^2 = 10.19$) at stressed condition. The minimum inter-cluster distance was obtained between cluster II and IV ($D^2 = 6.97$) at normal and between cluster II and IV ($D^2 = 6.99$) at the stressed condition which is an indication of the presence of less genetic diversity among this cluster.

3.5. Estimation of variability parameters

The genetic Variability Analysis of each trait in the experiment is shown in Table 7. The partition of genotypic variation is higher than the environmental variation for all traits at normal conditions, except for canopy temperature. At the stressed condition, except for leaf chlorophyll concentration measurements and canopy temperature measurements, there is a higher partition of genotypic variation. An argumentative result reported by Ahmed et al. [78], indicates the presence of high level of the genotypic variance than the environmental variance for most of the traits under the study such as days to heading, day to maturity, spikelets per spike, grains per spike, spike weight, thousand kernel weight, spike length, plant height, and biological yield. In connection to their coefficient of variation, the GCV values were greater than ECV values in all studied traits except canopy temperature at the normal condition and canopy temperature and leaf chlorophyll concentration measurement at the stressed condition. This indicated that the environmental effect was small for the expression of most characters other than the aforesaid characters, which also supports the findings of Kumar, A. et al. [79].

For the genotypic and phenotypic coefficient of variation analysis, there is a low to medium variation except for days to maturity, leaf chlorophyll concentration measurement, and canopy temperature measurement in both conditions and days to flowering at the normal condition and thousands seed weight in the stressed condition. In line with this study [80,81] also observed that moderate (10–20%) genotypic coefficients of variation for the number of grains per spike, number of effective tillers per plant, and thousand seed weight and lower (<10%) genotypic coefficient of variation for days to maturity. Also [82,83] record higher PCV and GCV values for the number of thousand seed weights, kernels per spike, and grain yield.

The traits studied in the present investigation (Table 7) expressed moderate to high heritability in a broad sense (h^2b) estimates ranging from 32.84 to 97.87%. Among the traits evaluated at the normal condition except for plant height (59.98%), biomass yield (59.46%), leaf chlorophyll concentration measurement (58.22%), and canopy temp. measurements (43.91%) which showed moderate h^2b , all others showed h^2b (>60%). Similarly, at the stressed condition except for canopy temp. measurements (32.84%) and leaf chlorophyll concentration measurement (39.73%) which showed moderate h^2b , while all others showed high h^2b (>60%). A similar result was reported on high h^2b estimates for days to heading, thousand seed weights, days to heading, the number of spikelets per spike, days to maturity, spike length, and grain yield [29,82,84],[85]]. It is known that if the h^2b of a character is very high, it is less influenced by the environment than characters that are regulated by additive gene action, and direct selection is expected to show improvement in such traits. The plant breeder, therefore, may make his selection safely based on the phenotypic expression of these traits in the individual plant by adopting simple selection methods [86].

High expected genetic advance in percent of mean (GAPM) estimates was obtained for most of the traits in both normal and stressed conditions. The intermediate to high estimate of h^2b and relatively high estimate of GAPM were observed in days to heading, the number of tillers, spike length, kernels per spike, grain yield at normal conditions, and in the number of tillers, spike length, kernels per spike, spikelets per spike, biomass yield, and grain yield at stressed condition. This result is in line with [80,87] in which high h^2b and GAPM were reported for spikelets per spike, kernels per spike, and grain yield. This suggested most likely that h^2b is due to additive genetic effects and selection could be effective in early segregating generations for these traits and the possibility of improving durum wheat grain yield through direct selection for grain yield-related traits [88–90].

3.6. Correlation coefficients

The correlation coefficient indicated in the below table (Tables 8 and 9) shows a significant positive correlation between days to head with days to flowering (0.41, 0.679) and maturity (0.33, 0.25) in both conditions separated by commas respectively. The number of tillers is negatively correlated with all traits studied except biomass yield, leaf chlorophyll concentration, and canopy temperature in the normal condition but positively correlated with all traits except plant height and grain yield in the stressed condition. Grain yield was significantly and positively correlated with spike length (0.55, 0.74), spikelets per spike (0.51, 0.54), and kernel per spike (0.42, 0.53) at both conditions. Grain yield is moderately correlated with thousand seed weights (0.402) in the normal condition but low correlation (0.053) in the stressed condition. The positive correlation coefficients of grain yield with most of the traits imply that improving one or more of the traits could result in a high grain yield for durum wheat. Days to heading (−0.077, −0.023) in both conditions, tiller number (−0.235) at the normal condition, and days to flowering (−0.011) and maturity (−0.027) at the stressed condition have a negative correlation with grain yield. Demelash, A. et al. and Mecha, B. et al. obtained similar results of a highly significant positive correlation of grain yield with most of the yield-attributed traits but negatively correlated with days to head and days to maturity in bread wheat [81,91]. The negative association of grain yield with days to heading in both conditions and days to flowering and maturity, especially in the water-stressed condition, suggests that early heading and maturing genotypes would give a high grain yield [92].

4. Conclusions and recommendations

The present study finds significant differences between durum wheat landraces for various traits and in response to different

environmental conditions. The analysis of variance revealed significant differences between landraces for different traits with different sources of variation. The overall adjusted mean between the two environmental conditions indicated the presence of differences between genotypes in response to varying environmental conditions. Several landraces were found to outyield the checks at both environmental conditions. a total of seven landraces outyielded the checks namely, ETDW/15DZ4, 34493, ETDW/15DZ23, 34522, MCD3-14, 34217, and 31831. From those outyielded landraces ETDW/15DZ23, 34522, ETDW/15DZ4, 34493 at the normal condition, and ETDW/15DZ4 34493 ETDW/15DZ23 at the stressed condition surpass all four checks. Cluster analysis grouped the landraces into six clusters, with each cluster showing variation in performance for different traits under normal and stressed conditions. The intracluster and intercluster distance indicated variation in genetic diversity within and between clusters. The highest inter-cluster distance was exhibited between Cluster I and IV (11.02) followed by Cluster I and III (9.8) and Cluster I and II (10.33) followed by Cluster I and VI (10.19) at normal and stressed conditions respectively which indicates the presence of wider genetic among the landraces found in these clusters. also, the clusters categorized the top higher performed genotypes in cluster I at the normal condition and cluster IV at the stressed condition. The estimation of variability parameters showed that genotypic variation was higher than environmental variation for most traits. The traits studied in your research expressed moderate to high h^2b estimates and high expected GAPM estimates. The correlation coefficients showed significant positive and negative correlations between various traits. Days to head showed a significant positive correlation with days to flowering and maturity in both conditions. The number of tillers showed a negative correlation with most traits in the normal condition but a positive correlation with most traits in the stressed condition. Grain yield showed a significant positive correlation with spike length, spikelets per spike, and kernel per spike at both conditions. As for recommendations, it may be beneficial to further investigate the landraces that outyielded the checks to determine their potential for use in breeding programs or cultivation in specific environmental conditions. Additionally, further research into the mechanisms underlying the observed differences in response to environmental conditions could provide valuable insights for improving crop performance. The results of the cluster analysis, estimation of variability parameters, h^2b estimates, and correlation coefficients could also be used to guide future research and breeding efforts by identifying key traits and clusters of landraces that show improved performance.

Declarations

Author contribution statement

Bantewalu Hailekidan: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed materials, analysis tools or data; Wrote the paper.

Andargachew, Bizuayehu, and Hewan: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Data availability statement

Data included in article/supplementary material/referenced in article.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Bantewalu Hailekidan Dukamo reports financial support was provided by Norwegian Agency for Development Cooperation.

Acknowledgments

The authors gratefully acknowledge the financial and other logistic support of the institutions and staff members of Debrezeit Agricultural Research Center (DZARC), Ethiopian Biodiversity Institute (EBI), and Hawassa University.

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