Indian J. Applied & Pure Bio. Vol. 39(3), 1414-1442 (2024).

ISSN: 0970-2091

A web of Science Journal

Phenotypic Variability, Heritability and Trait Association of Durum wheat (*T. Turgidum var. durum* L.) Genotypes in Central Ethiopia

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Abstract

The experiment aimed to identify superior durum wheat genotypes for grain yield across various environments and to assess phenotypic variability, heritability, and trait associations within and among populations in central Ethiopia. Analysis of variance (ANOVA) conducted for each site revealed significant differences ($P < 0.05$) among genotypes for all traits at Debre Zeit and Minjar, except for grain filling period and number of tillers. Combined ANOVA indicated significant differences among tested genotypes for all measured traits, highlighting substantial variability. The location x genotype interaction was significant ($P < 0.01$) for days to 90% maturity, grain filling period, grain yield, biomass yield, harvest, and grain filling period. Notably, DWNE9 (4054 kg/ha), Fetan (3873 kg/ha), Werer (3784 kg/ha), Denbi (3766 kg/ha), and Mangudo (3723 kg/ha) emerged as top high-yielding genotypes across the two locations. Grain yield exhibited strong positive associations with number of grains/spikes, 1000 kernel weight, hectolitre weight, biomass yield, and harvest index, both at genotypic and phenotypic levels. Conversely, significant negative correlations were observed between grain yield and date of heading, plant height, number of tillers, spike length, number of spikelet/spikes, and grain protein content at both genotypic and phenotypic levels. High estimates of heritability (greater than 70%) coupled with substantial genetic advance as a percent of the mean (greater than 20%) were noted for plant height, spike length, number of grains per spike, grain yield, and harvest index, indicating potential for selecting the top 5% of the base population to significantly enhance mean values. Cluster analysis categorized the 49 durum wheat genotypes into three clusters, with most advanced and released varieties grouped together, exhibiting superior grain yields. The study emphasizes ample phenotypic variations among durum wheat genotypes, highlighting their potential for multi-environment evaluation and genotype-environment interaction studies to assess grain yield stability. Moreover, the populations represent valuable breeding resources for durum wheat improvement initiatives.

Key words : Clusters, Genetic Advance, Genetic Distance, Heritability, Phenotypic Variability.

Wheat, belonging to the grass family Poaceae and the tribe Triticeae, encompasses various species within the genus Triticum, including diploid, tetraploid, and hexaploidy varieties, showcasing the evolutionary significance of polyploidy in wheat. The closely related genus Aegilops has been merged with Triticum, underscoring the intricate genetic relationships within the wheat family[8]. Among the wheat species, Triticum aestivum L. and Triticum durum L. stand out as the most important cereal crops globally, covering vast agricultural lands and contributing significantly to food security. Durum wheat, with its distinct tetraploid genome (2n = 4x = 28, genomes AB), dominates approximately 48% of global wheat cultivation, with key production regions in the Mediterranean basin, North America, and Mexico, alongside emerging importance in other countries such as Australia, Russia, Kazakhstan, India, Ethiopia, and Argentina[5].

Ethiopia, recognized as a secondary centre of durum wheat, boasts diverse environmental conditions suitable for wheat cultivation, with small-scale farmers predominantly growing durum wheat under rain-fed conditions[28]. Despite its adaptability, durum wheat faces challenges from both abiotic and biotic factors, resulting in suboptimal productivity. Soil acidity, nutrient fixation, aluminium toxicity, and various diseases like stem rust, yellow rust, and fusarium head blight pose significant threats to durum wheat production[17,20].

In the global context, wheat ranks as the most widely cultivated crop, contributing substantially to human nutrition and food security. Africa, including Sub-Saharan Africa (SSA), plays a crucial role in wheat production, with countries like Ethiopia, South Africa, and Sudan among the leading producers[14]. Despite its importance, wheat production in Ethiopia falls short of meeting domestic demand, necessitating a deeper understanding of genetic variability and traits associated with yield and disease resistance[6].

Genetic variability studies are pivotal for crop improvement programs, enabling breeders to identify traits with high heritability and genetic advances for targeted selection. Traits such as grain yield, harvest index, biomass yield, and thousand seed weight exhibit significant genetic variability, offering promising avenues for enhancing productivity[3]. Heritability estimates, coupled with genetic advances, provide valuable insights into the potential for trait transmission and breeding value. Traits like days to maturity, grain filling period, and plant height demonstrate high heritability, indicating their suitability for selection and improvement through breeding programs[16].

Path analysis elucidates the relationships between yield components, guiding indirect selection strategies for promising genotypes. Phenotypic and genotypic correlations between grain yield and related traits, such as harvest index, biomass yield, and thousand seed weight, inform breeding efforts aimed at improving overall productivity[2]. Given the importance of durum wheat in Ethiopia and the need to enhance its productivity, understanding the associations among yield-related traits is crucial. The present study aims to fill these knowledge gaps and provide valuable insights for further crop improvement efforts in durum wheat cultivation in Central Ethiopia.

The trial confined a total of 49 durum wheat genotypes, comprising 17 released varieties, 16 advanced lines, and 16 landraces. It was conducted during the main cropping season of 2020/2021 at two distinct locations: the Debre Zeit Research Centre and the Minjar testing site. These locations were carefully selected to represent the diverse agro-ecologies found in central Ethiopia, ensuring a comprehensive assessment of the genotypes' performance under varying environmental conditions. The experimental design was a 7x7 simple lattice incomplete block design, strategically chosen to optimize space and resource utilization while maintaining experimental integrity. Each genotype was sown at a seed rate of 120 kg/ha, in accordance with recommended fertilizer application practices of 100 kg of NPS and 92 kg of N per hectare[12]. These fertilizer rates were selected with the goal of maximizing plant growth and yield potential across the diverse soil and climatic conditions present in the study areas. The locations selected for the trial differed significantly in climate and altitude, influencing the growth and development of the durum wheat genotypes. Monthly temperature fluctuations, including maximum and minimum temperatures (°C), as well as monthly rainfall (mm), were carefully monitored throughout the growing periods to assess their impact on crop performance. For a comprehensive understanding of the test accessions, detailed descriptions are provided in Table-2.

Data collection :

All agronomic, yield and yield-related data were recorded on the middle four rows of each experimental unit. These data along with their details are mentioned below:

Days to heading (DTH, days): The number of days from planting to when 50% of the plants in the plot give heading.

Days to 90% maturity (DTM, days): The number of days from sowing to when 90% of the plants in the plot mature.

Days to grain filling period (GFP, days): The number of days from 50% heading to 90% maturity.

Table-1. Description of the experimental site

Site	Temperature		annual R.F	Altitude	Latitude	Longitude
	Min.	Max.	(mm)	(masl)		
Debre Zeit	8.9^{0}C	28.3^{0}C	851	1900	08^{0} 44'N	38^{0} 58'E
Minjar	10^{0}C	28^{0}C	867	1810	08^{0} 55'N	39^{0} 45'E

Table-2. The list of the genotypes tested at both locations

SN	Genotype	Pedigree	Origin	Status
1	DWNL2	C F4 20 S/4/YAZI-1/AKAKI-4//SOMAT-	CIMMYT	ADL
2	Yerer	CHEN/TEZONTLE/3/GUILLEMOT//CANDEAL-II	CIMMYT	RV
3	DWNL 39	C0RDEIR0/9/GUAYACAN INIA/GUANY/8/GEDIZ FG0//GTA/3/SRN-1/4/TOTUS/5/ENTE/MEXI-2//ï¿½	CIMMYT	ADL
4	DWLRC 25	DWLR	Ethiopia	LR
5	DWNL4	AG 1-22/2*ACO89//2*UC1113/3/5*KOF	CIMMYT	ADL
6	DWLRC 34	2019/20DW/Landrace cluster plot # 34	Ethiopia	LR
7	Ude	CHEN/ALTAR-84//JORI	CIMMYT	RV
8	DWLRC28	DWLR	Ethiopia	LR
9	DWNE9	Mangudo/Mekuye/DZ 2013 meh DW F1 P#20/DZ 2014 meh DW F2	Ethiopia	ADL
10	Mekuye	STJ3//BICRE/LOUKOS-4/3/TER3	ICARDA	RV
11	DWLRC 39	DWLR	Ethiopia	LR
12	Mangudo	MRF1/STJ2|/3/1718/BT//KARIM, TUN	ICARDA	RV
13	DWNE11	CMH83.2578/4/D88059//WARD/YAV79/3/AC089/5/2*S00TY-	CIMMYT	ADL
14	Hitosa	CHEN/ALTAR-84	CIMMYT	RV
15	DWLRC60	2019/20DW/Landrace cluster plot # 60	Ethiopia	LR
16	Tesfaye	ARMENT//SRN-NIGRIS-4/3/CANED-9.1/4/TOSKA-26RASCON-37//SNITSN/5/PLAYERO	CIMMYT	RV
17	DWNL10	MINIMUS/COMB DUCK-2//CHAM-/3/FICHE-	CIMMYT	ADL
18	Denbi	AJAIA/BAUSHEN [3589]	CIMMYT	RV
19	DWNE10	KR0N0S/10/K0FA/9/USDA595/3/D67.3/RABI//CRA/4/AL0/5/HUI/YAV- 1/6/ARDENT/7/HUI/ï¿½	CIMMYT	ADL
20	DWLRC 48	DWLR	Ethiopia	LR
21	DWNL18	JUPARE C 2001* 2/RBC/5/MOHAWK/3/GUANAY //TILD-1LDTUS-	CIMMYT	ADL
22	Werer	1346/LAHN//BICRE/LOUKOS-4	ICARDA	RV
23	DWLRC 16	DWLR	Ethiopia	LR
24	Utuba	(=Icajihan42) Omruf1/Stojocri2/3/1718/BeadWheat24 //Karim½	ICARDA	RV
25	DWNL9	Mangudo/Mekuye/DZ 2013 meh DW F1 P#20/DZ 2014 meh DW F2 P#19-1	Ethiopia	ADL
26	Alemtena	Icasyr-1/3/Gcn//Sti/Mrb3	CIMMYT	RV
27	DWNE8	Mangudo/Bekelcha/DZ 2013 meh DW F1 P#19/DZ 2014 meh DW F2 P#18-6	Ethiopia	ADL

28	Fetan	ARMENT//2*SOOTY-9/RASCON-37/4/CNDO/PRIMADUR//HAI-OU-17/3/SNITAN	CIMMYT	RV
29	DWLRC20	DWLR	Ethiopia	LR
30	DWNL11	CMH83.2578/4/D88059//WARD/YAV79/3/AC089/5/2*S00TY-9/RASC0N-37/6/1A.1D5+1-06/ï¿½	CIMMYT	ADL
31	D-18	CGS	Italy	RV
32	DWLRC 94	DWLR	Ethiopia	LR
33	Gerardo	VZ 466/61-130xGII' 's", CM9605	Ethiopia	RV
34	DWNE13	otb4/3/HFN94N-8/Mrb5//Zna-1/4/5+j3//Dra2/Bcr/3/Ter-3	ICARDA	ADL
35	Cocorit	RAE/4*TC60//STW63/3/	Mexico	RV
36	DWLRC96	DWLR	Ethiopia	LR
37	Bekelcha	980SNGedirfa/Gwerou #15 patho	CIMMYT	RV
38	DWNE7	Yere/Mova/DZ2013mehF1 P#9/DZ 2014mehF2P#9-2	Ethiopia	ADL
39	Toltu	4/B/R9096#21001(980SN Patho)	CIMMYT	RV
40	DWLRC92	DWLR	Ethiopia	LR
41	DWLRC79	DWLR	Ethiopia	LR
42	DWNE8	Mangudo/Bekelcha/DZ 2013 meh DW F1 P#19/DZ 2014 meh DW F2 P#18-6	Ethiopia	ADL
43	DWLRC84	DWLR	Ethiopia	LR
44	DWLRC85	DWLR	Ethiopia	LR
45	DWNL12	CMH83.2578/4/D88059//WARD/YAV 79/3/ACO89/5/2*SOOTY.9/RASCON-37/6/1A.1D 5+1-6/ï¿½	CIMMYT	ADL
46	DWLRC 88	DWLR	Ethiopia	LR
47	DWLRC89	DWLR	Ethiopia	LR
48	DWNL19	YAVA 79/9/ USDA 595/3/D67.3/RABI//CRA/4/ALO/5/HUI/YAV-1/6/ARDENTE /7/HUI/YAV 79/8/T1/2	CIMMYT	ADL
49	Filakit	EN-25	CIMMYT	RV

Where, ADL- is advanced line, LR- is landrace, and RV- is released variety.

Plant height (PHT) (cm): It was measured from the soil surface to the tip of a spike (awns excluded) for 10 randomly selected plants from the net plot area at physiological maturity and finally averaged over 10 plants.

Number of tillers per plant (NTP, No): The average number of tillers per plant was counted for 10 randomly selected plants from the net plot area.

Number of spikelets per spike (NSP, No): The average number of spikelets per spike was counted for 10 randomly selected plants in the net plot area.

Spike Length (SPL, cm): It was measured from the base to the tip of the spike excluding the awns for the averaged 10 randomly selected plants from the net plot area.

Number of grains per spike (NGS, No): The number of grains of the main tillers of each of the ten randomly taken plants for each experimental unit was recorded and the averages of the ten plants were used for analysis.

Thousand kernel weight (TKW, g): the weight of one thousand grains for each experimental unit.

Hectoliter weight (HLW, kg/h L): The grain weight of a one-liter volume (random sample) was estimated for each experimental unit by standard procedure (AACC, 2000) and the result was converted to g/hL.

Grain yield (GY, kg/ha): Grain yield was measured from net plot area (g/plot) and converted to kg/ha.

Biomass yield (BY, kg/ha): The weight of total above-ground biomass yield in kg/ plot and finally converted to kg/ha.

Harvest index (HI, %): It was computed as the ratio of grain yield to total biological yield and multiplied by 100.

Grain protein content (GP, %): The grain protein content of the harvested varieties was determined via near-infrared reflectance (NIR) spectroscopy.

Statistical Analysis

All measured parameters were subjected to analysis of variance (ANOVA) using R software. The homogeneity of error mean squares between the two locations were tested by the F test on variance ratio and combined analyses of variance are performed for the traits whose error mean squares are homogenous using R Software (R3.5.2, 2018). Mean separation was carried out using Duncan's Multiple Range Test (DMRT) at 5% probability levels.

General linear model for single location:

$$Yijl = \mu + G_i + R_j + B_k(R_j) + E_{ijl}$$

Where μ= General mean, G_i= genotype i effect, R_j= replication j effect, $B_k(R_j)$ = Block l with in replication j effect, E_{ijk}= random error associated to genotype i, replication j and block k.

General linear model of over location (combined):

$$Yijlk = \mu + G_i + B_j + L_k. + G_iL_k + B_j(R_m) + E_{ijkm}$$

Where μ= General mean, Gi= effect of treatment i, Bj= effect of block j, Lm = effect location m, $G_i \times L_m$ = interaction effect of genotype i in location m, $B_j(R_m)$= effect of block j in replication m; E_{ijkm} = error variance.

Table-3. Analysis of variance for simple lattice design

Source of variation	DF	SS	MS
Replication (adj.)	(r-1)	SSR	
Treatments	(t-1)	SSt	
Blocks(adj.)	r(q-1)	SSB	Eb
Intra block error	(q-1) (rq-q-1)	SSE	Ee
Total	rq-1	Total SS	

DF= degree of freedom, MS = Mean square, q= Number of plots in a block, r = Number of replications, SS = Sum of square, t= Number of treatments.

Computation of Variance Components :

1. The genotypic coefficient of variation and genetic advance were calculated using as follows equations: Genotypic variances (GV) = (MSG/rl-MSE)
   Where, GV is genetic variance; MSG-Mean square for genotypes; MSE-Mean square for error; r- is replication; and l-is location
2. Phenotypic variance (PV) = GV+MSE
3. Genotypic coefficient of variation (GCV) = (√GV / X) 100
   Where, GV is as defined in above; X is the mean of the population.
4. Phenotype coefficient variation (PCV) $=(\sqrt{PV}/X)\ 100$
5. Broad sense heritability (H^2) = GV/PV was calculated according to Allard.[4].
6. Genetic advance (GA) $=KH^2\sqrt{PV}$
   Where the selection intensity which is 2.06 at 5 % selection intensity;
7. Genetic advance as percent of the mean (GAM) = (GA/X) 100

Computation of Correlation Coefficients :

Phenotypic and genotypic correlation coefficients were tested using the standard procedure suggested by Miller *et al.*,[18] from corresponding variance and covariance components as:

Phenotypic correlation coefficient

$$(rp_{xy}) = \frac{\sigma_{p\,xy}}{\left(\sqrt{\sigma^2 p_x * \sigma^2 p_y}\right)}$$

Genotypic correlation coefficient

$$(\mathbf{r}g_{xy}) = \frac{\sigma_{g\,xy}}{\left(\sqrt{\sigma^2 g_x * \sigma^2 g_y}\right)}$$

Where, $\mathbf{r}p_{xy}$= phenotypic correlation coefficient between character x and y.
rg_{xy} = genotypic correlation coefficients between character x and y. Significance of phenotypic correlation coefficients were tested using the formula given by Sharma[25].

Genotypic correlation coefficient was tested with the follows formula as suggested by Robertson,[23].

$$t = \frac{rg_{xy}}{SErg_{xy}}$$

$$\text{Where, } SErg_{xy} = \sqrt{\frac{1 - r^2 g_{xy}}{2h^2{}_x * h^2{}_y}}$$

$SErg_{xy}$=Standard error of genotypic correlation coefficient between character X and Y; h^2x = heritability for character X; h^2y = heritability for character y.

The calculated absolute t values were tested against the tabulated t- value at g-2 degree of freedom for both phenotypic and genotypic correlations.

Genetic Distance Analysis :

The genetic distance of 49 durum wheat germplasm was estimated using Euclidean distance (ED) calculated from quantitative traits after standardization (subtracting the mean value and dividing it by the standard deviation) as established by Sneath and Sokal.[27] as follow:

$$EDik = \sqrt{\sum_{i=1}^{n}(Xij - Xik)^2}$$

Where, EDjk = distance between genotypes j and k; xij and xik = phenotype traits values of the i^{th} character for genotypes j and k, respectively; and n = number of phenotype traits used to calculate the distance. The distance matrix from phenotype traits was used to construct a dendrogram based on the unweight Pair-group Method with Arithmetic Means (UPGMA). The results of cluster analysis were presented in the form of a dendrogram. In addition, mean ED was calculated for each genotype by averaging a particular genotype to the other 49 germplasm. The calculated average distance (ED) was used to estimate which germplasm(s) (genotype) is closest or distant to others.

Analysis of Variance :

Single Location's Analysis of Variance :

The results of the analysis of variance conducted for each location across 14 traits are presented in Appendix Table-1. At both the Debre Zeit and Minjar locations, significant differences ($P<0.01$) were observed among the genotypes for all traits considered. Additionally, significance was noted for NSP ($P<0.05$) at the Minjar location, while differences for GFP and NTP at Minjar were non-significant ($P>0.05$). These significant variations among genotypes across locations underscore the abundant diversity present, which holds promise for durum wheat breeding. This aligns with findings from previous studies, where significant differences in agronomic traits among different durum wheat populations were reported by Dejene *et al.*,[11]; Alemu *et al.*,[3].

Combined Analysis of Variance :

The combined analysis of variance revealed highly significant differences ($P<0.01$) among genotypes due to location effects for DTM, GFP, PHT, NTP, NSP, SPL, NGS, TKW, and GPC. Days to 50% heading, harvest index, and hectoliter weight also exhibited significant differences ($P<0.05$). However, for grain yield and biomass yield, no significant differences among genotypes were observed due to location effects (Table- 4). Among all traits, differences among genotypes were highly significant ($P<0.01$) except for GFP, which showed significance at ($P<0.05$). Notably, the interaction between location and genotype was highly significant ($P<0.01$) for DTM, GFP, GY, BY, HI, and GPC, and significant ($P<0.05$) for PHT among genotypes. This suggests varying performance of genotypes across the two locations. These findings in line with previous research indicating wide genetic variability among durum wheat genotypes for the traits considered in this study[11].

Mean and Range Values for Different Traits:

Table-5 and Appendix tables 1, 2, and 3 present the combined mean and range values for 13 traits across 49 durum wheat genotypes. Days to 50% heading ranged from 57.5 days (Filakit and DWNL10) to 71 days (DWLRC89), with an average of 63 days. Approximately 39% of the genotypes exhibited late heading, indicating potential for breeding programs targeting heading traits. Longer heading duration allows sufficient floral development, crucial for high grain yield[7]. Days to 90% maturity ranged from 85.5 days (DWNL10) to 105 days (Werer), with an average of 95 days. Around 38% of the genotypes displayed

Table-4. Combined ANOVA (Mean squares) for 14 traits of durum wheat genotypes tested at Debre Zeit and Minjar

S N	Traits	Environ-ment (df=1)	Rep (environ-ment), Df=2	Block (rep), df=12	Geno-type (df=48)	Genotype x Environ-ment (df=48)	Error (df=84)	CV (%)	Mean	MSD
1	DTH	36.00*	0.16^{ns}	40.20**	48.87**	3.14 ^{ns}	3.75	3.09	62.71	5.67
2	DTM	2317.73**	10.05^{ns}	85.97**	80.36**	27.23**	10.37	3.22	94.53	9.42
3	GFP	1776.02**	11.19^{ns}	40.52*	18.64*	31.63**	11.42	10.62	31.82	9.89
4	PHT(cm)	1554.61**	52.66*	260.58**	506.91**	27.60*	16.22	4.76	84.62	11.79
5	NTP	83.59**	2.61*	0.97*	1.30**	0.73^{ns}	0.51	19.51	3.65	2.09
6	NSP	149.19**	39.76**	5.81*	5.36**	1.29^{ns}	1.67	7.52	17.21	3.79
7	SPL (cm)	1.98**	5.12**	2.60**	5.39**	0.23^{ns}	0.28	8.71	6.11	1.56
8	NGS	569.16**	22.37^{ns}	541.59**	300.07**	26.93^{ns}	24.81	11.52	43.26	14.58
9	BY (kg/ha)	475971.90^{ns}	672986.40^{ns}	2966483.20**	2758708.6**	865275.20**	270407.90	6.07	8566.36	1522.10
10	GY (kg/ha)	153496.05^{ns}	98372.58^{ns}	1338167.56**	1282351.33**	292690.06**	73849.17	9.01	3014.80	795.46
11	HI (%)	51.94*	2.05^{ns}	65.35**	79.92**	18.72**	9.34	8.76	34.91	8.95
12	HLW (kg/hl)	17.88*	0.18^{ns}	43.37**	45.55**	3.21^{ns}	4.43	2.76	76.12	6.16
13	TKW (g)	293.88**	32.37*	67.00**	76.29**	10.21^{ns}	10.29	9.48	33.82	9.39
14	GPC (%)	3.34**	1.98**	1.54**	1.23**	0.91**	0.31	4.50	12.41	1.64

Where, ** = highly significant ($P<0.01$); * = significant ($P<0.05$); and ns= non-significant ($P>0.05$), BY= Biomass yield, CV= Coefficient of variance, DTH=Days to 50% heading; DTM= Days to 90% maturity; GFP= Grain filling period; GPC= Grain protein content, GY=Grain yield; HI=Harvest index; HLW= Hectoliter weight, MSD =Minimum standard difference, NGS= Number of grains per spike; NSP= Number of spikelet per spike; NTP=Number of tillers per plant; PHT= Plant height; SPL= Spike length; TKW= Thousand kernel weight.

late maturity compared to the overall mean. Grain filling period ranged from 24.80 (DWLRC92) to 37.80 days (DWLRC92), averaging 32 days. Plant height ranged from 69.80 cm (DWNL19) to 111.50 cm (DWNL16), with an average of 84.60 cm. About 39% of the population exhibited taller plant height than the overall mean, particularly among landrace genotypes known for their longer stature and susceptibility to lodging[21].

Spike length, tillers per plant, spikelets per spike, and grains per spike displayed ranges from 4.5 cm (DWNE13) to 9.10 cm (DWLR85), 2.80 (DWNE10) to 5.50 (DWLRC94), 15.0 (DWNE13) to 20 (DWLRC16), and 24.0 (DWLRC89) to 63.0 (DWNL18), respectively. Notably, spikelet per spike and grains per spike exhibited wider ranges than spike length and tiller number per plant. Thousand kernel weight ranged from 25.0 g (DWLRC79 and DWLRC88) to 42.0 g (Utuba), with an average of 34 g. Around 47% of the genotypes shown higher seed size than the overall mean, indicating potential for selecting genotypes with larger seed sizes, though influenced by environmental factors. Hectoliter weight ranged from 64.0 kg/hl (DWLRC88) to 80.40 kg/hl (Fetan), averaging 76.0 kg/hl. Approximately 59% of the genotypes exhibited higher values than the general mean, with values above 68 kg/hl considered acceptable for breeding purposes[19].

Biomass yield ranged from 4968.6 kg/ha (DWLRC88) to 9389.50 kg/ha (Gerardo), with an average of 8566 kg/ha. About 69% of the population exhibited higher values than the general mean. Harvest index ranged from 28.0% (DWLRC88 and DWLRC28) to 43.60% (DWNE9), with a mean of 35.0%. Approximately 51% of the genotypes displayed values higher than the population mean. Grain filling period ranged from 11.40% (DWNE9) to 14.10% (DWLRC20), with a mean of 12.40% around 43% of the genotypes exhibited values higher than the population mean. The results indicate significant differences in phenological, yield, and yield-related traits among durum wheat genotypes[22]. Grain yield ranged from 1392.0 kg/ha (DWLRC88) to 4053.80 kg/ha (DWNE9), averaging 3014.82 kg/ha approximately 57% of the genotypes exhibited higher mean values than the general mean, indicating potential for breeding programs. Across locations, a yield difference of 2986 kg/ha at Debre Zeit and 1432.5 kg/ha at Minjar was observed between the highest and lowest yielding genotypes. However, overall means were similar across locations, suggesting consistent performance of genotypes. High yielding genotypes included DWNL39 (3701 kg/ha), Mangudo (3723 kg/ha), Denbi (3766 kg/ha), Werer (3784 kg/ha), Fetan (3873 kg/ha), and DWNE9 (4054 kg/ha), primarily released varieties. These genotypes align with the acceptable potential grain yield threshold of above 3.0 tons per hectare[19].

Genotypic and Phenotypic Coefficients of Variation :

The genotypic and phenotypic coefficients of variation (GCV and PCV) serve as crucial indicators of variability within a population[9]. In our study, GCV ranged from 3.86% for grain protein content to 19.18% for the number of grains per spike, while PCV ranged from 5.04% for hectoliter weight to 23.04% for the number of tillers per plant (Table- **7**). Based on established criteria, PCV values were categorized as high (>20%) for traits like the number of tillers per plant and

Table-5. Combined mean for the phonological and yield related traits in 49 durum wheat genotypes tested at Debre Zeit and Minjar in 2020/21 main cropping season

SN	Genotypes	DTH	DTM	GFP	PHT (cm)	NTP	SPL (cm)	NSP	NGS	TKW (g)	HLW (kg/hl)	BY (kg/ha)	HI (g)	GPC (%)
1	DWNL2	68.3^{abc}	99bcde	30.8d-k	78i-m	3.0^{fg}	5.0n-r	18b-g	57a-d	34g-l	78.8a-d	8822.5a-f	41.2a-e	13.0c-h
2	Yerer	69.3^{ab}	103ab	33.8a-g	72nop	3.3efg	7.1def	18b-g	51c-g	39a-e	79.2abc	8810.0a-f	34.7j-o	12.8c-i
3	DWNL39	60.8^{g-l}	91.5i-o	30.8d-k	71op	3.5d-g	5.0l-r	16ghi	44h-k	38b-g	80.0ab	9224.7abc	40.3a-f	11.4p
4	DWLRC25	63.3^{e-h}	93.5f-l	30.3e-k	102b-e	4.8ab	5.8h-k	18b-f	33m-q	30l-o	73.5g-k	8847.3a-e	31.9n-s	12.2h-o
5	DWNL4	60.8^{g-l}	90.5k-p	29.8f-k	78.8i-l	3.5d-g	6.4f-i	19a-d	54b-e	33i-n	78.2a-d	8153.6e-i	35.8g-n	13.1b-f
6	DWLRC34	63.0^{f-i}	93.5f-l	30.5d-k	99.3def	4.0b-e	6.6fg	18b-g	32m-q	33h-m	72.9ijk	9056.0abc	29.5qrs	12.0j-p
7	Ude	58.5^{lm}	89.3l-q	30.8d-k	79.8i-l	3.0fg	5.6j-p	17e-i	51c-f	41abc	78.1a-d	8522.3d-i	38.8b-j	12.3fo
8	DWLRC28	65.0^{def}	96e-i	31.0d-k	105.8b	4.0b-e	8.7ab	19abc	31m-r	34g-l	73.9g-j	8239.9d-i	28.0s	12.1i-p
9	DWNE9	63.5^{efg}	97.8c-g	34.3a-f	82.5ij	4.0b-e	5.7i-n	17c-h	61ab	41abc	77.9a-e	9302.3a	43.6a	12.2h-o
10	Mekuye	59.3^{lm}	91.3j-p	32.0c-k	77j-n	3.3efg	4.9o-r	15i	36lmn	40a-d	77.0b-f	8719.0a-g	36.8e-m	12.5d-n
11	DWLRC39	61.0g-l	90.5k-p	29.5f-l	100c-f	3.5d-g	8.5ab	19a-d	29n-s	29m-p	69.2lm	8224.1d-i	28.6s	12.5d-n
12	Mangudo	59.3lm	92.8h-m	33.5a-h	79.5i-l	3.3efg	5.3j-r	18b-g	52c-f	41abc	80.0ab	8917.0a-d	41.8abc	12.2k-p
13	DWNE11	60.5h-l	93h-l	32.5b-j	71.8nop	3.0fg	5.4j-q	18b-g	59ab	37c-i	78.5a-d	9289.7ab	37.2d-m	12.3g-o
14	Hitosa	58.8lm	91.5i-o	32.8b-i	78.5i-l	3.5d-g	5.5j-p	18b-g	51c-h	33h-m	80.2a	9216.0abc	38.3b-k	12.0j-p
15	DWLRC 60	66.8bcd	97d-h	30.3e-k	101.3b-f	4.3bcd	8.6ab	19ab	35l-p	31k-o	74.0f-j	8165.0e-i	29.2rs	12.0j-p
16	Tesfaye	60.3i-m	91.8i-n	31.5c-k	77j-n	3.3efg	5.0m-r	16ghi	57abc	27opq	74.9e-i	8894.9a-d	35.8g-n	12.8c-i
17	DWNL10	57.5m	85.3q	27.8jkl	72.8m-p	3.3efg	5.0l-r	15i	41i-l	34f-l	76.3c-g	8565.5b-g	34.9h-o	11.7op
18	Denbi	59.3lm	90.8k-p	31.5c-k	78.5i-l	3.5d-g	5.8h-l	18b-f	54b-e	31k-o	79.9ab	9241.8abc	40.7a-f	12.0j-p
19	DWNE10	62.3f-k	95.8-j	33.5a-h	70.8op	2.8g	4.7qr	15i	50d-h	32k-n	78.2a-d	8928.3a-d	33.7m-q	12.6d-m
20	DWLRC48	58.5lm	86.8pq	28.3ijkl	105.5bc	4.5bc	7.7cd	18b-g	36l-o	33h-m	72.7ijk	9038.1abc	31.0o-s	13.0b-g
21	DWNL18	63.5efg	95e-k	31.5c-k	76k-o	3.8c-f	5.7i-n	19a-e	63a	27opq	76.1d-h	8924.8a-d	34.0k-p	12.7d-l
22	Werer	68.3abc	104.5a	36.3abc	78i-m	3.5d-g	5.4j-q	17e-i	46f-j	41ab	79.5ab	9017.5abc	42.0ab	11.6op
23	DWLRC6	70.3a	100.8a-d	30.5d-k	111.5a	4.0b-e	7.6cde	20a	38klm	32j-n	72.5ijk	7999.6ghi	28.4s	12.0k-p
24	Utuba	62.3f-k	92.8h-m	30.5d-k	83.5i	3.3efg	5.0n-r	17e-i	48e-j	42a	80.2a	9170.2abc	39.7a-g	12.0j-p
25	DWNL9	62.8f-j	97d-h	34.3a-f	80.8ijk	3.0fg	5.6j-p	17f-i	49e-h	38a-f	78.8a-d	9360.0a	33.9l-p	11.9l-p
26	Alemtena	59.3lm	91.8i-n	32.5b-j	74.8l-p	3.5d-g	5.3j-q	17e-i	49e-h	35e-k	79.2abc	9240.1abc	37.7c-m	11.9l-p

27	DWNE8	59.0lm	88.3m-q	29.3g-l	78.3i-m	3.0fg	5.6j-o	17f-i	52c-f	38a-f	78.2a-d	9347.1a	37.6c-m	11.9l-p
28	Fetan	62.8f-j	91.5i-o	28.8h-l	78.3i-m	2.8g	5.5j-q	17f-i	48e-j	32k-n	80.4a	9118.0abc	42.5ab	11.8nop
29	DWLRC20	62.3f-k	87opq	24.8lp-s	99.8def	4.0b-e	8.1bc	18b-f	29o-s	26pq	73.3g-k	7241.9jk	30.1m-q	14.1a
30	DWNL11	59.3lm	91.8i-n	32.5b-j	78i-m	3.5d-g	5.4j-q	16ghi	42i-l	41abc	78.3a-d	8931.5a-d	39.1b-i	12.4e-o
31	D-18	61.0g-l	92.8h-m	31.8c-k	70p	3.3efg	6.5fgh	17c-h	49e-h	37b-h	79.0a-d	9032.1abc	39.6a-g	12.0j-p
32	DWLRC94	64.8def	97d-h	32.3c-j	96fgh	5.5a	7.6cde	18b-f	28p-s	27opq	70.6kl	7171.9jk	28.4s	14.1a
33	Gerardo	69.0ab	104a	35.0a-e	80.5ijk	3.3efg	7.1def	18b-f	44h-k	41ab	77.8a-e	9389.5a	33.3m-r	12.3f-o
34	DWNE13	63.5efg	100.8a-d	37.3ab	77.3j-n	3.3efg	4.5r	15i	50d-h	35e-k	78.5a-d	8729.3a-f	39.6a-g	12.3f-o
35	Cocorit	63.3e-h	94f-k	30.8d-k	78.3i-m	4.5bc	5.6j-o	18b-g	46f-j	37b-h	77.1b-e	9120.3abc	37.3d-m	12.1i-p
36	DWLRC96	70.8a	102.3abc	31.5c-k	90.5h	4.8ab	6.9ef	18b-g	30n-s	34f-l	73.3g-k	7723.4ij	28.8s	11.6op
37	Bekelcha	59.5klm	93h-l	33.5a-h	78i-m	3.8cdef	5.8h-m	17f-i	44g-k	39a-e	78.7a-d	9256.6ab	38.1b-l	13.2bcd
38	DWNE7	62.8f-j	98cdef	35.3a-d	97.5ef	3.5defg	4.9pqr	15i	41jkl	36d-j	78.2a-d	8780.8a-f	31.9n-s	11.8nop
39	Toltu	59.8klm	93.3g-l	33.5a-gh	72.8m-p	3.3efg	5.5j-p	17e-i	50d-h	30l-o	79.0a-d	9087.6abc	39.2b-h	12.2g-o
40	DWLRC92	66.0cde	103.8a	37.8a	100.3b-f	4.5bc	5.2k-r	16ghi	27qrs	31l-o	72.3ijk	7761.6ij	29.3rs	13.5abc
41	DWLRC79	70.8a	102.3abc	31.5c-k	91.3gh	3.5d-g	8.5ab	18b-g	25rs	25q	66.8mn	5429.6l	28.5s	12.5d-n
42	DWNL8	60.8g-l	94.8e-k	34.0a-g	80.5ijk	3.5d-g	5.3j-q	17e-i	50d-h	37b-h	79.3abc	8871.7a-e	41.4a-d	11.9m-p
43	DWLRC84	60.0j-m	87.3n-q	27.3kl	96.8efg	4.5bc	7.1def	17c-h	30n-s	30l-o	71.5jkl	7809.1hij	31.4o-s	12.8c-j
44	DWLRC85	64.8def	96.8d-h	32.0c-k	102b-e	4.5bc	9.1a	19ab	32m-r	33h-m	73.1h-k	9345.1a	29.2rs	12.7c-k
45	DWNL12	60.5h-l	93.3g-l	32.8b-i	72nop	2.8g	5.4j-q	16ghi	48e-i	30l-o	76.3c-q	8105.3f-i	34.7i-o	12.7d-l
46	DWLRC88	62.8f-j	92.5h-m	29.8f-k	103.8bcd	4.0b-e	6.7fg	19abc	35l-o	25pq	64.0n	4968.6l	28.0s	13.8ab
47	DWLRC89	71.0a	104a	33.0a-hi	90.5h	4.5bc	6.0g-j	16hi	24s	29n-q	73.5g-k	6923.3k	28.3s	12.8c-j
48	DWNL19	59.8klm	91k-p	31.3d-k	69.8p	3.5d-g	4.9o-r	16ghi	50c-h	29m-p	74.0f-j	9000.0abc	30.8o-s	13.1b-e
49	Filakit	57.5m	91k-p	33.5a-h	78.8ijkl	3.5defg	6.0g-j	17d-i	44h-k	37b-h	78.6a-d	8717.6a-g	36.5f-m	12.2h-o
Mean		62.7	94.6	31.8	84.6	3.7	6.1	17.2	43.3	33.8	76.1	8566.3	34.9	12.4
CV (%)		3.2	3.2	11.0	4.7	17.9	8.9	7.6	11.5	9.3	2.8	6.0	8.8	4.5
MSD		5.67	9.42	9.89	11.79	2.09	1.56	3.79	14.58	9.31	6.16	1522.10	8.95	1.46

Where, Numbers followed by same letter in the column are not significantly different; BY= Biomass yield, CV= Coefficient of variation, DTH=Days to 50% heading; DTM= Days to 90% maturity; GFP= Grain filling period; GPC= Grain protein content, GY=Grain yield; HI=Harvest index; HLW= Hectoliter weight, MSD= Minimum standard difference, NGS= Number of grains per spike; NSP= Number of spikelet per spike; NTP=Number of tillers per plant; PHT= Plant height; SPL= Spike length; TKW= Thousand kernel weight.

Table-6. Combined mean performance for the grain yield (kg/ha) of the 49 durum wheat genotypes tested at Debre Zeit and Minjar during 2020/21 main cropping season

SN	Genotypes	Debre Zeit	Minjar	Mean
1	DWNL2	3532.5e-h	3740.0a-g	3636.25bcd
2	Yerer	2970.0i-l	3125.0h-m	3047.5g-n
3	DWNL39	3977.5a-d	3425.0c-i	3701.25abc
4	DWLRC25	2530.0m-q	3125.0h-m	2827.5j-o
5	DWNL4	2625.0k-q	3265.0g-l	2926.25i-n
6	DWLRC34	2607.0k-q	2735.0j-p	2671.25n-r
7	Ude	3585.0c-g	3017.5i-n	3301.25d-i
8	DWLRC28	2417.5o-s	2187.5p-s	2302.5r-u
9	DWNE9	4002.5abc	4105.0a	4053.75 a
10	Mekuye	3002.5ijk	3417.5d-i	3210e-j
11	DWLRC39	2207.5qrs	2497.5n-s	2352.5q-u
12	Mangudo	3892.5a-e	3552.5a-i	3722.5abc
13	DWNE11	3695.0 a-e	3182.5g-l	3438.75c-g
14	Hitosa	4035.0ab	3047.5i-n	3541.25b-e
15	DWLRC 60	2135.0rs	2657.5l-r	2396.25p-t
16	Tesfaye	2967.5i-l	3380.0d-i	3173.75e-l
17	DWNL10	2690.0k-p	3280.0e-j	2985i-n
18	Denbi	3522.5e-h	4010.0abc	3766.25abc
19	DWNE10	2990.0ijk	3015.0i-n	3002.5i-n
20	DWLRC48	2982.5i-l	2565.0m-r	2773.75m-p
21	DWNL18	2932.5i-m	3127.5h-m	3030 h-n
22	Werer	3715.0a-e	3852.5a-e	3783.75abc
23	DWLRC6	2367.5p-s	2172.5p-s	2270stu
24	Utuba	4082.5a	3212.5g-l	3647.5bcd
25	DWNL9	3125.0hij	3225.0g-l	3175e-l
26	Alemtena	3252.5f-i	3645.0a-h	3448.75c-f
27	DWNE8	3155.0g-j	3847.5a-f	3501.25b-e
28	Fetan	3637.5b-f	4107.5a	3872.5ab
29	DWLRC20	2237qrs	2110.0qrs	2173.75stu
30	DWNL11	3880.0a-e	3120.0h-m	3500 b-e
31	D-18	3562.5d-g	3552.5a-i	3557.5b-e
32	DWLRC94	1990.0st	2085.0rst	2037.5tu
33	Gerardo	2982.5i-l	3215.0g-l	3098.75f-m

34	DWNE13	2930.5i-m	4020.0ab	3475c-f
35	Cocorit	2932.5i-m	3880.0a-d	3406.25c-h
36	DWLRC96	2462.5n-r	1970.0stu	2216.25stu
37	Bekelcha	3922.5a-e	3150.0h-m	3536.25b-e
38	DWNE7	2895.0i-n	2680.0k-q	2787.5l-p
39	Toltu	3862.0a-e	3265.0f-k	3563.75b-e
40	DWLRC92	2432.5o-r	2112.5qrs	2272.5 stu
41	DWLRC79	1590.0tu	1510.0tu	1550v
42	DWNL8	3812.5a-e	3512.5b-i	3662.5a-d
43	DWLRC84	2132.5rs	2775.0j-o	2453.75o-s
44	DWLRC85	2807.5i-o	2647.5l-r	2727.5m-q
45	DWNL12	2172.5rs	3460.0b-i	2816.25k-o
46	DWLRC88	1332.5u	1432.5u	1392.5v
47	DWLRC89	1535.0u	2410.0o-s	1972.5u
48	DWNL19	2550.0l-r	2995.0i-o	2772.5m-p
49	Filakit	3677.5a-f	2712.5j-q	3195e-k
	Mean	2986	3043	3014.82
	CV (%)	7.2	9.5	9.276
	MSD			795.46

Where: - Numbers followed by same letter in the column are not significantly different; CV= coefficient of variation, MSD= Minimum standard difference.

spike length, and medium (10-20%) for others such as grain filling period and biomass yield. Conversely, GCV values were medium for traits like plant height and grain yield, and low for traits such as days to 50% heading and grain protein content. High PCV and GCV values suggest that selection based on these traits could yield significant improvements, as they indicate substantial genotypic variability[26].

Estimates of Heritability and Genetic Advance :

Heritability estimates, ranging from 14% for grain-filling period to 88% for plant height, indicate the degree to which phenotypic variation is attributable to genetic factors (Table-7). Notably, traits like grain yield, plant height, and spike length exhibited very high heritability, suggesting strong genetic control over these traits and the potential for effective selection based on phenotypic performance. Genetic advance, expressed as a percentage of the mean, was high for grain yield, harvest index, plant height, spike length, and number of grains per spike. This suggests that selecting the top 5% of the population could result in significant advances beyond the population mean. Medium genetic advances were observed for traits like biomass yield and 1000

Table 7. Mean, range values and genetic variances, heritability and genetic advance as percent of the mean of 14 traits in 49 durum wheat genotypes

SN	Traits	Mean	Range	δ^2g	δ^2e	δ^2P	GCV	PCV	H^2(%)	GA	GAM
1	Days to 50% heading	62.71	57.50 - 71.0	11.28	3.75	15.03	5.36	6.18	75.0	6.00	9.57
2	Days to 90 % maturity	94.53	85.3 - 104.5	17.50	10.37	27.87	4.43	5.58	63.0	6.84	7.23
3	Grain filling period	31.82	24.8 - 37.8	1.81	11.42	13.23	4.22	11.43	14.0	1.02	3.22
4	Plant height (cm)	84.62	69.80 - 111.50	122.67	16.22	138.89	13.09	13.93	88.0	21.47	25.38
5	Number of tillers plant^{-1}	3.65	2.80 -5.50	0.20	0.51	0.71	12.18	23.04	28.0	0.48	13.27
6	Number of spikelets per spike	17.21	15.0 -20.0	0.92	1.67	2.59	5.58	9.36	36.0	1.18	6.87
7	Spike length (cm)	6.11	4.50 - 9.10	1.28	0.28	1.56	18.50	20.43	82.0	2.11	34.56
8	Number of grains per spike	43.26	24.0 - 63.0	68.82	24.81	93.63	19.18	22.37	74.0	14.67	33.92
9	Biomass yield (kg/ha)	8566.36	4968.6 - 9389.50	622075.18	270407.90	892483.08	9.21	11.03	70.0	1358.45	15.86
10	Grain yield (kg/ha)	3014.80	1392.5 - 4053.8	302125.54	73849.17	375974.71	18.23	20.34	80.0	1016.50	33.72
11	Harvest index (%)	34.91	28.0 - 43.60	17.65	9.34	26.99	12.03	14.88	65.0	7.01	20.07
12	Hectolitre weight (kg/hl)	76.12	64.0 - 80.40	10.28	4.43	14.71	4.21	5.04	70.0	5.53	7.26
13	Thousand kernel weight (g)	33.82	25.0 - 42.0	16.50	10.29	26.79	12.01	15.30	62.0	6.58	19.45
14	Grain protein content (%)	12.41	11.40 - 14.10	0.23	0.31	0.54	3.86	5.92	43.0	0.65	5.20

Where; δ^2e environmental variance; GA= Genetic advance; GAM= Genetic advance as percentage of mean GCV= genotypic coefficient of variation; δ^2**g** –Genetic variance H^2= broad sense heritability; PCV= Phenotypic coefficient of variation, δ^2**p** –phenotypic variance.

kernel weight, while low genetic advances were noted for others such as days to 50% heading and grain protein content. The combination of high heritability and high genetic advance, particularly observed in traits like plant height, spike length, and number of grains per spike, indicates the potential effectiveness of selection in early generations for these traits. These findings align with previous studies Tilahun *et al.*, [29] and underscore the importance of considering both heritability and genetic advance in breeding programs for durum wheat improvement.

Genotypic Correlation Analysis :

Table-8 presents the genotypic correlation coefficient estimates for 14 traits across the 49 durum wheat genotypes. Strong positive associations were observed among DTH, DTM, and GFP, with DTH also positively correlated with PHT, NTP, SPS, and SPL. Conversely, DTH exhibited negative correlations with NGS, HLW, BY, GY, and HI, indicating that late-maturing genotypes may experience reduced yield due to terminal stress. DTM showed significant positive correlations with GFP but negative correlations with GY, HI, and GPC. GFP correlated positively with several traits including TKW, HLW, BY, GY, and HI, while negatively correlated with others like PHT, SPS, SPL, and GPC. Similarly, PHT exhibited positive correlations with NTP, SPL, SPS, and GPC, but negative correlations with NGS, TKW, HLW, BY, GY, and HI. Notably, traits strongly correlated with grain yield could serve as indicators for indirect selection techniques, whereas those negatively correlated, like GPC, justify separate selection strategies.

Phenotypic Correlation Analysis :

Phenotypic correlation coefficients among different traits were computed and presented in Table-8. DTH showed strong positive correlations with DTM, PHT, NTP, SPL, and SPS but negative correlations with NGS, HLW, BY, GY, and HI, suggesting that late-heading genotypes may have reduced yield potential. DTM displayed strong positive correlation with GFP but weaker associations with other traits. PHT correlated positively with NTP, SPL, and SPS but negatively with NGS, HLW, BY, GY, and HI, indicating that longer PHT may lead to reduced yield and yield-contributing traits. Similarly, NTP exhibited positive correlation with SPL, SPS, and GPC but negative correlations with NGS, TKW, BY, GY, HLW, and HI. Strong positive correlations of NGS with TKW, HLW, BY, GY, and HI suggest its utility as an indirect/direct selection criterion for higher grain yield in durum wheat populations. TKW correlated positively with HLW, BY, GY, and HI but negatively with GPC, suggesting the need for separate breeding strategies when aiming for higher TKW and GPC. Overall, these results align with previous findings and underscore the complexity of trait associations in durum wheat breeding[1].

Cluster Analysis :

The 49 durum wheat genotypes were subjected to cluster analysis, resulting in three major clusters based on Euclidean distances (Fig. 2). The dendrogram illustrates the variability among the tested genotypes, with distinct groupings observed. Cluster one predominantly comprised released durum wheat varieties and 16 advanced lines, indicating similarity in their genetic background, likely stemming from common sources such as CIMMYT and ICARDA. Conversely, Table-8. Genotypic (below diagonal) and phenotypic (above diagonal) correlation coefficients among yield and yield related traits of 49 durum wheat genotypes

Traits	DTH	DTM	GFP	PHT	NTP	SPL	NSP	NGS	TKW	HLW	BY	GY	HI	GPC
DTH		0.875**	0.224ns	0.358**	0.321**	0.387**	0.306**	-0.363**	-0.157ns	-0.321**	-0.386**	-0.434**	-0.402**	0.042ns
DTM	0.999**		0.668**	0.138ns	0.174ns	0.105ns	0.060ns	-0.171ns	0.064ns	-0.079ns	-0.186ns	-0.20ns	-0.186ns	-0.04ns
GFP	0.871**	0.999**		-0.272ns	-0.142ns	-0.384**	-0.351**	0.214ns	0.370**	0.333**	0.220ns	0.265ns	0.244ns	-0.15ns
PHT	0.389**	0.121ns	-0.426**		0.681**	0.683**	0.550**	-0.739**	-0.392**	-0.721**	-0.479**	-0.697**	-0.724**	0.260ns
NTP	0.410**	0.499**	0.326*	0.999**		0.495**	0.411**	-0.647**	-0.341**	-0.578**	-0.359**	-0.539**	-0.573**	0.341**
SPL	0.412**	0.096ns	-0.999**	0.712**	0.749**		0.745**	-0.598**	-0.352**	-0.617**	-0.416**	-0.623**	-0.652**	0.250ns
NSP	0.404**	-0.013ns	-0.999**	0.622**	0.741**	0.829**	-	0.174ns	-0.273ns	-0.408**	-0.226ns	-0.350**	-0.376**	0.164ns
NGS	-0.362*	-0.218ns	0.356*	-0.854**	-0.857**	-0.685**	-0.401**		0.377**	0.711**	0.598**	0.767**	0.750**	-0.25ns
TKW	-0.175ns	0.0695ns	0.993**	-0.413**	-0.515**	-0.384**	-0.354**	0.449**		0.693**	0.623**	0.681**	0.609**	-0.51**
HLW	-0.353**	-0.0928ns	0.629**	-0.772**	-0.843**	-0.652**	-0.542**	0.806**	0.719**		0.790**	0.903**	0.832**	-0.51**
BY	-0.468**	-0.264ns	0.604**	-0.618**	-0.613**	-0.470**	-0.289*	0.737**	0.701**	0.906**		0.832**	0.595**	-0.49**
GY	-0.516**	-0.331*	0.723**	-0.818**	-0.833**	-0.680**	-0.454**	0.887**	0.757**	0.976**	0.850**		0.940**	-0.49**
HI	-0.471**	-0.321*	0.727**	-0.842**	-0.889**	-0.723**	-0.508**	0.921**	0.702**	0.937**	0.691**	0.968**		-0.4**
GPC	0.015ns	-0.294*	-0.819**	0.378**	0.839**	0.371**	0.205ns	-0.339**	-0.835**	-0.852**	-0.784**	-0.662**	-0.535**	

Note: ** = highly significant (P<0.01); * = significant (P<0.05); and ns= non-significant (P>0.05). BY= Biomass yield, kg/ha, DTH= date of heading, DTM= Days to 90% maturity; GFP= Grain filling period; GPC= Grain protein content %. GY= Grain yield, kg/ha; HI= Harvest index, %; HLW= hectoliter weight, kg/hl; NGS= Number of grains per spike; NPS= number of spikelets per spike; NTP= Number of tillers per plant; PHT= Plant height, cm; SPL= Spike length, cm; TKW= 1000 kernel weight, g.

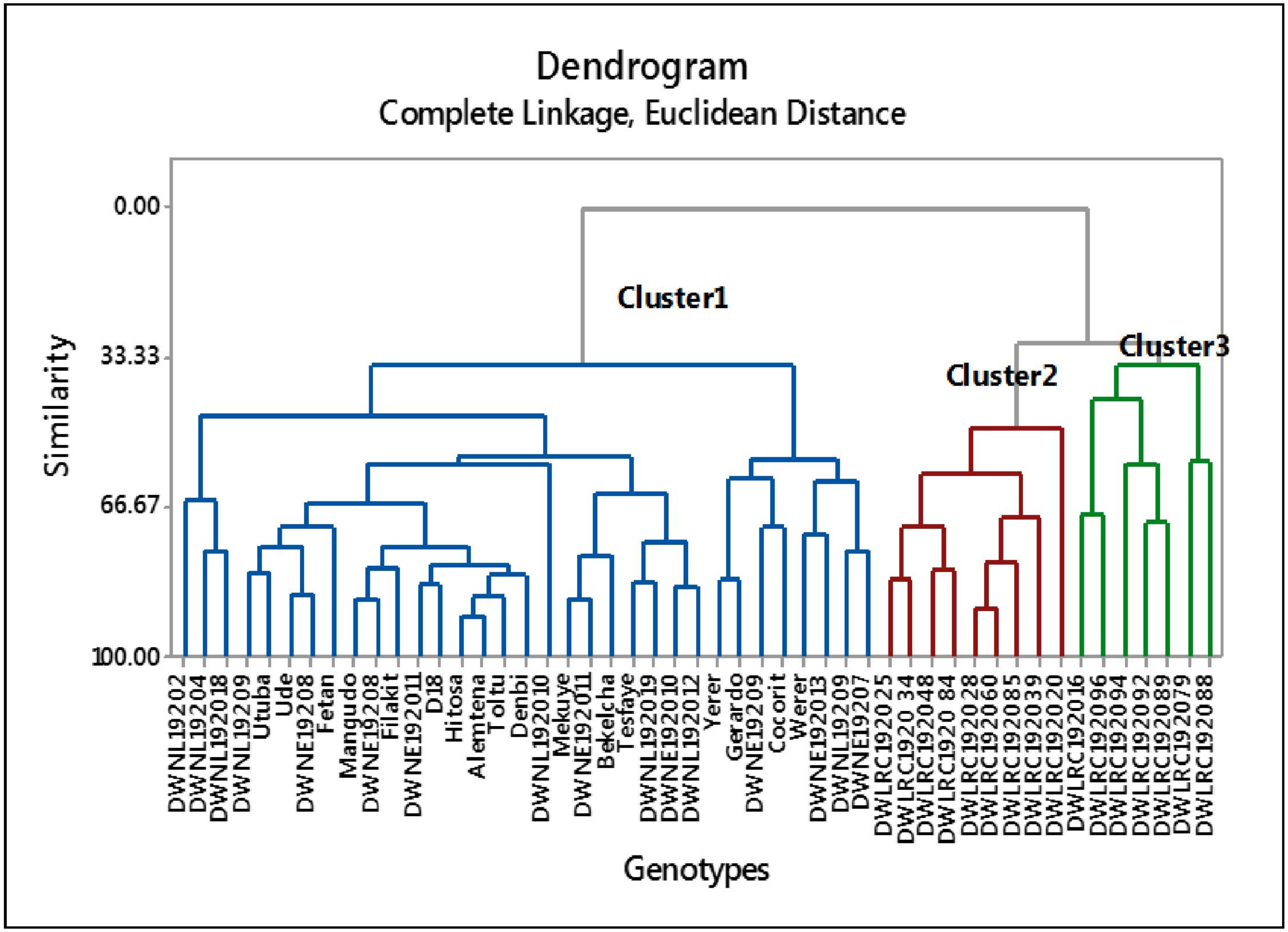

Figure. 1. Dendrogram depicting phenotypic relationships among 49 durum wheat genotypes based on 14 traits.

cluster II consisted of 9 landraces, while cluster three encompassed seven landraces (Table-10). This clustering pattern provides valuable insights for durum wheat breeding programs, facilitating the selection of appropriate genotypes for specific agro-ecologies in Ethiopia[30]. Table-11 shows the intra-cluster and inter-cluster distance values, with cluster 1 containing 33 genotypes exhibiting the highest intra-cluster distance. Particularly, the largest inter-cluster distance was observed between clusters I and III, followed by clusters I and II. This suggests that hybridization between parents from clusters I and III may yield higher heterotic values compared to other combinations. Consequently, selecting parents for hybridization based on large inter-cluster distances could facilitate the isolation of valuable recombinants in segregating generations[13].

Table-9. Cluster analysis based on 14 traits in 49 durum wheat genotypes

Clusters	Genotypes
1	DWNL2, DWNL4, DWNL18, DWNL9, Utuba, Ude, DWNE8, Fetan, Mangudo, DWNL8, Filakit, DWNL11, D-18, Hitosa, Alemtena, Toltu, Denbi, DWNL10, Mekuye, DWNL11, Bekelcha, Tesfaye, DWNL19, DWNE10, DWNL12, Yerer, Gerardo, DWNE9, Cocorit, Werer, DWNE13, DWNL9, DWNE7.
2	DWLR25, DWLR34, DWLR48, DWLR84, DWLR28, DWLR60, DWLR85, DWLR39, DWLR20.
3	DWLR16, DWLR96, DWLR94, DWLR92, DWLR89, DWLR79, DWLR88.

Table-10. Intra (diagonal) and inter cluster distances for the three cluster classes of 14 traits of 49 durum wheat genotypes.

Clusters	I	II	III
I	**3.34**	5.69	7.25
II		**3.35**	5.32
III			**5.18**

Table-12 provides the cluster mean values for the three clusters identified in the analysis. *Cluster I:* This cluster is characterized by high grain yield, a higher number of grains per spike, higher 1000 kernel weight, higher hectoliter weight, higher biomass yield, higher harvest index, and lower protein content. *Cluster II*: In this cluster, traits such as lower grain filling period, longer plant height, higher number of spikelets per spike, and longer spike length are predominant. *Cluster III*: The third cluster, consisting of 7 durum wheat genotypes, is mainly characterized by lower grain yield, longer days to 50% heading, longer days to 90% maturity, a higher number of tillers, lower number of grains per spike, lower 1000 kernel weight, lower hectoliter weight, lower biomass yield, lower harvest index, and higher protein content. These distinct characteristics among the clusters highlight the genetic diversity present within the durum wheat genotypes, providing valuable information for breeding programs aimed at enhancing specific traits such as yield, maturity, and grain quality.

Table-11. Mean values of the three clusters for 14 traits of 49 durum wheat genotypes

Variables	Clusters		
	I	II	III
Days to 50% heading	61.68	62.72	68.04
Days to 90% maturity	94.08	92.03	100.4
Grain filling period	32.39	29.31	32.32
Plant height (cm)	77.29	101.4	97.68
Number of tillers per plant	3.34	4.22	4.54
Spike length (cm)	5.49	7.79	6.9
Number of spikelets per spike	16.79	18.33	17.75
Number of grains per spike	49.27	31.99	29.53
Thousand kernel weight (g)	35.68	31.44	28.79
Hectolitre weight (kg/hl)	78.28	72.64	70.42
Biomass yield (kg/ha)	8963.64	8440.71	6853.93
Grain yield (kg/ha)	3311.79	2542.08	1958.75
Harvest index (%)	37.64	29.87	28.53
Grain protein content (%)	12.26	12.6	12.88

Table-12. Principal components (PCs) for 14 characters of durum wheat genotypes

Characters	PC1	PC2	PC3
Grain yield	0.358	-0.009	0.185
Biomass yield	0.292	-0.006	0.336
Date of heading	-0.183	0.506	0.083
Date of maturity	-0.076	0.641	-0.040
Grain filling period	0.128	0.513	-0.208
Grain protein content	-.0193	-0.143	-0.380
Harvest index	0.341	-0.015	0.057
Hectoliter weight	0.350	0.074	0.137
Number of grains/ spikes	0.306	-0.052	0.012
Number of spikes/spikes	-0.205	-0.049	0.543
Number of tillers	-0.265	0.055	0.157
Plant height	-0.314	0.013	0.247
Spike length	-0.291	-0.026	0.404
1000grain weight	0.258	0.186	0.303
Eigen value	6.952	2.275	1.427
Variability (%)	49.654	16.248	10.190
Cumulative %	49.654	65.902	76.092

Principal component analysis :

The principal component analysis was made to estimate the relative contribution of the different traits studied towards the overall genotypes among the released variety, advanced lines, and landrace of durum wheat. In the present investigation, only the first three principal components showed Eigen values greater than one and cumulatively they explained 76.092% variability (Table-9). The PC1 had 49.654%, PC2 showed 16.248% and PC3 showed 10.190% variability among the genotypes for the characters under study. The first two principal components PC1 and PC2 values contributed more to the total variation. Because the first principal component accounts for maximum variability in the data with respect to succeeding components[15].

In addition to cluster analysis, Principal Component Analysis (PCA) was performed to identify the key traits contributing to phenotypic variability among the durum wheat genotypes. The first principal component (PC1) was primarily influenced by grain yield, harvest index, hectoliter weight, and the number of grains per spike. These traits collectively represent the yield potential and grain quality of the genotypes. The second principal component (PC2) was mainly affected by days to heading, days to maturity, and grain filling period, indicating their role in determining the maturity and phenological characteristics of the genotypes. The third principal component (PC3) was primarily influenced by biomass yield, grain protein content, the number of spikes per spike, spike length, and 1000-grain weight. These traits contribute to biomass production, protein content, and spike morphology. The significant variations observed across these principal components suggest ample opportunities for phenotypic improvement through targeted selection and conservation of genotypes for future breeding programs. By understanding the cumulative effects of multiple traits through PCA, breeders can make informed decisions regarding the selection of parents for hybridization and the design of breeding strategies to enhance specific agronomic traits. Similar approaches utilizing principal component analyses have been reported in previous studies, demonstrating their effectiveness in grouping wheat genotypes and identifying key traits influencing phenotypic variability[10,24].

The study reveals substantial genotypic variability among durum wheat genotypes, with many exhibiting superior traits suitable for direct utilization in breeding and selection programs. These genotypes can serve as valuable genetic resources for enhancing grain yield and quality traits. While grain yield is strongly correlated with various yield-contributing traits, it's negatively associated with grain protein content (GPC). Hence, indirect selection methods or multi-trait selection strategies can be employed to improve grain yield while considering GPC. The findings provide valuable insights for planning crosses and maximizing the utilization of phenotypic variability to develop high-yielding genotypes. Specifically, genotypes such as Utuba, Hitosa, and DWNE9 are recommended for Debre Zeit, while Fetan, DWNE9, DWNE13, and Denbi are suitable for Minjar due to their superior grain yield performance. Particularly, genotype DWNE9 demonstrated high yield potential across both locations. Traits such as grain yield, biomass, harvest index, hectoliter weight, number of grains per spike, and kernel weight are suggested for indirect selection due to their positive and significant associations with grain yield. However, it's essential to recognize that these traits are polygenic and heavily influenced by environmental factors. Therefore, further assessment across multiple seasons and locations is to justify, validate the findings and ensure the strength of future breeding programs. Continued research efforts will contribute to the development of durum wheat varieties with improved agronomic performance and adaptability to diverse environmental conditions.

Data Availability

Data is available in the manuscript.

Conflict of Interest

The authors do not have any possible conflicts of interest.

The authors would like to thank Debre Zeit Agricultural Research Center (DZARC) for extending research facilities to this study.

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APPENDIX

Appendix Table-1. Analysis of variance for agronomic traits in durum wheat genotypes tested at Debrezeit and Minjar.

SN	Traits	Rep (Df=1)		BLK (Rep) (Df=12)		Genotypes (Df=48)		Error (Df=36)		CV (%)		Mean	
		Debre-zeit	Minjar	Debre-zeit	Minjar	Debrezeit	Minjar	Debre-zeit	Minjar	Debre-zeit	Minjar	Debre-zeit	Minjar
1	DTH	0.16	0.16	3.48	3.69	31.95**	19.73**	3.1	5.18	2.78	3.64	63.14	62.28
2	DTM	2.95	17.15	3.84	15.02	43.84**	63.52**	5.46	16.87	2.38	4.51	97.96	91.09
3	GFP	1.72	20.66	7.33	16.73	28.00**	22.51ns	8.33	16.25	8.29	13.99	34.83	28.81
4	PHT, cm	1.23	104.09	27.02	14.34	257.29**	275.85**	11.97	19.56	3.96	5.41	87.44	81.81
5	NTP	2.61	2.61	0.72	0.51	1.62**	0.4ns	0.52	0.34	16.75	19.45	4.31	3.0
6	NSP	79.0	0.5	1.69	3.83	2.45**	4.20*	1.24	2.17	6.17	9.01	18.08	16.34
7	SPL, cm	10.2	0.1	0.35	0.35	2.51**	3.11**	0.24	0.35	7.8	9.89	6.21	6.01
8	NGS	8.0	36.73	75.22	32.12	167.93**	154.25**	15.95	33.55	8.88	13.94	44.96	41.55
9	TKW, g	39.22	25.51	9.61	11.52	44.88**	40.56**	11.43	8.17	10.37	8.16	32.59	35.04
10	HLW, kg/hl	0.18	0.18	2.63	5.2	26.24**	22.76**	2.31	7.1	1.01	3.49	75.82	76.43
11	BY, kg/ha	232728	1113245	181706	327631	2086597.50**	1381928**	264143	265058	5.97	6.04	8615	8517
12	GY, kg/ha	90616	106129	73114	63861	846807**	660158**	45643	83908	7.15	9.52	2987	3043
13	HI, %	3.92	0.17	7.51	17.02	55.98**	39.76**	7.17	11.9	7.79	9.74	34.39	35.42
14	GPC, %	0.003	3.96	0.22	0.5	0.87**	1.17**	0.29	0.32	4.31	4.61	12.54	12.28

Where, ** = significant at (P<0.01), *= significant at (P<0.05; ns= non-significant.; BY= Biomass yield; DTH= Days to 50% heading; DTM= Days to 90% maturity; Df= Degree of freedom; GFP= Grain filling period; NGS= Number of grains per spike; GPC= Grain protein content, GY=Grain yield, HI= Harvest index; HLW= hectoliter weight; NSP= Number of spikelet per spike; NTP= Number of productive tillers per plant; PHT= Plant height; SPL= Spike length; TKW= Thousand kernel weight.

Appendix Table-2. Mean date of heading, days to 90% maturity, grain filling period and plant height of the 49 durum wheat genotypes for tested at two locations

SN	Genotypes	DTH		DTM		GFP		PHT (cm)	
		D/zeit	Minjar	D/zeit	Minjar	D/zeit	Minjar	D/zeit	Minjar
1	DWNL2	69.5a-d	67.0a-d	104.0a-d	94.0c-i	34.5d-i	27.0c-h	82.0h-m	74.0i-o
2	Yerer	70.5abc	68.0abc	105.0a-d	101.0abc	34.5d-i	33.0a-f	72.0pq	72.0j-o
3	DWNL39	61.5h-n	60.0g-k	95.5hij	87.5h-k	34.0e-j	27.5c-h	71.0q	71.0j-o
4	DWLRC25	64.0f-j	62.5d-j	91.0jk	96.0a-g	27.0lm	33.5a-e	103.0bcd	101.0b-e
5	DWNL4	59.0mn	62.5d-j	95.0hij	86.0ijk	36.0a-i	23.5gh	81.0h-n	76.5i-l
6	DWLRC34	64.0f-j	62.0e-j	97.0e-h	90.0f-j	33.0f-k	28.0c-h	103.0bcd	95.5b-g
7	Ude	59.0mn	58.0jk	95.0hij	83.5jk	36.0a-i	25.5e-h	86.0ghi	73.5i-o
8	DWLRC28	66.0d-g	64.0c-h	101.0c-f	91.0e-j	35.0c-i	27.0c-h	109.5ab	102.0bc
9	DWNE9	64.0f-j	63.0d-i	100.5d-g	95.0b-h	36.5a-h	32.0a-f	83.5g-l	81.5hi
10	Mekuye	59.0mn	59.5h-k	95.0hij	87.5h-k	36.0a-i	28.0c-h	78.0k-q	76.0i-m
11	DWLRC39	61.5h-n	60.5f-k	92.0ij	89.0g-j	30.5i-l	28.5c-h	108.0abc	92.0fg
12	Mangudo	59.0mn	59.5h-k	97.5e-h	88.0g-k	38.5a-f	28.5c-h	84.5g-k	74.5i-o
13	DWNE11	61.0i-n	60.0g-k	97.0e-h	89.0g-j	36.0a-i	29.0c-h	76.0m-q	67.5mno
14	Hitosa	58.5n	59.0ijk	96.5f-i	86.5ijk	38.0a-f	27.5c-h	84.0g-l	73.0i-o
15	DWLRC 60	68.0b-e	65.5a-e	96.5f-i	97.5a-f	28.5j-m	32.0a-f	98.5de	104.0b
16	Tesfaye	60.0k-n	60.5f-k	97.0e-h	86.5ijk	37.0a-h	26.0d-h	79.0i-q	75.0i-o
17	DWNL10	58.0n	57.0k	85.5l	85.0jk	27.5klm	28.0c-h	77.0lm-q	68.5l-o
18	Denbi	59.0mn	59.5h-k	96.0ghi	85.5jk	37.0a-h	26.0d-h	79.5i-o	77.5ijk
19	DWNE10	63.0g-l	61.5e-k	104.5a-d	87.0h-k	41.5a	25.5e-h	74.5n-q	67.0no
20	DWLRC48	58.0n	59.0ijk	86.5kl	87.0h-k	28.5j-m	28.0c-h	113.0a	98.0b-f
21	DWNL18	65.0e-h	62.0e-j	101.0c-f	89.0g-j	36.0a-i	27.0c-h	82.0h-m	70.0k-o
22	Werer	71.0ab	65.5a-e	106.0ab	103.0ab	35.0c-i	37.5ab	80.5h-n	75.5i-n
23	DWLRC6	71.0ab	69.5ab	98.0e-h	103.5a	27.0lm	34.0a-d	110.0ab	113.0a
24	Utuba	64.0f-j	60.5f-k	97.0e-h	88.5g-j	33.0f-k	28.0c-h	87.5fgh	79.5hij
25	DWNL9	64.0f-j	61.5e-k	104.5a-d	89.5f-j	40.5abc	28.0c-h	85.5g-j	76.0i-m
26	Alemtena	59.0mn	59.5h-k	96.0ghi	87.5h-k	37.0a-h	28.0c-h	78.5j-q	71.0j-o
27	DWNE8	59.0mn	59.0ijk	96.5f-i	80.0k	37.5a-g	21.0h	84.0g-l	72.5j-o
28	Fetan	64.5e-i	61.0e-k	96.5f-i	86.5ijk	32.0g-l	25.5e-h	84.0g-l	72.5j-o
29	DWLRC20	61.5h-n	63.0d-i	86.0l	88.0g-k	24.5m	25.0fgh	106.5abc	93.0d-g
30	DWNL11	59.0mn	59.5h-k	97.0e-h	86.5ijk	38.0a-f	27.0c-h	79.5i-o	76.0i-m
31	D-18	60.0k-n	62.0e-j	97.5e-h	88.0g-k	37.5a-g	26.0d-h	73.0opq	67.0no
32	DWLRC94	65.0e-h	64.5c-g	98.0e-h	96.0a-g	33.0f-k	31.5a-g	98.0de	94.0c-g

33	Gerardo	70.0abc	68.0abc	106.5a	101.5abc	36.5a-h	33.5a-e	82.5h-m	78.5ijk
34	DWNE13	64.0f-j	63.0d-i	104.0a-d	97.5a-f	40.0a-d	34.5abc	79.5i-o	75.0i-o
35	Cocorit	62.5g-m	64.0c-h	98.0e-h	90.0f-j	35.5b-i	26.0d-h	78.0k-q	78.5ijk
36	DWLRC96	72.0a	69.5ab	105.0a-d	99.5a-d	33.0f-k	30.0a-g	93.5ef	87.5gh
37	Bekelcha	60.5j-n	58.5ijk	97.5e-h	88.5g-j	37.0a-h	30.0a-g	79.0i-q	77.0ijkl
38	DWNE7	64.0f-j	61.5e-k	104.5a-d	91.5d-j	40.5abc	30.0a-g	103.5bcd	91.5fg
39	Toltu	58.5n	61.0e-k	97.5e-h	89.0g-j	39.0a-e	28.0c-h	74.5n-q	71.0j-o
40	DWLRC92	67.0c-f	65.0b-f	104.5a-d	103.0ab	37.5a-g	38.0a	101.5cd	99.0b-f
41	DWLRC79	72.0a	69.5ab	105.5abc	99.0a-e	33.5e-j	29.5b-g	90.0fg	92.5efg
43	DWLRC84	59.5lmn	60.5f-k	86.0l	88.5g-j	26.5lm	28.0c-h	101.0cd	92.5efg
44	DWLRC85	65.5efg	64.0c-h	97.5e-h	96.0a-g	32.0g-l	32.0a-f	102.0cd	102.0bc
45	DWNL12	60.0k-n	61.0e-k	97.5e-h	89.0g-j	37.5a-g	28.0c-h	73.0opq	71.0j-o
46	DWLRC88	63.5f-k	62.0e-j	95.0hij	90.0f-j	31.5h-l	28.0c-h	106.0abc	101.5bcd
47	DWLRC89	72.0a	70.0a	105.5abc	102.5ab	33.5e-j	32.5a-f	86.0ghi	95.0c-g
48	DWNL19	59.0mn	60.5f-k	96.0ghi	86.0ijk	37.0a-h	25.5e-h	73.0opq	66.5o
49	Filakit	58.0n	57.0k	96.5f-i	85.5jk	38.5a-f	28.5c-h	83.0g-m	74.5i-o
	Mean	63.1	63.3	98.0	91.0	34.8	28.8	84.3	81.8
	CV (%)	2.7	3.7	2.4	4.5	8.3	13.9	3.9	5.4

Note: Numbers followed by same letter in the column are not significantly different; CV=coefficient of variation DTH= date of heading; DTM= days to 90% maturity; GFP= Grain filling period; PHT= plant height.

Appendix Table 3. Mean number of tiller per plant, spike length, number of spikelet per spike, number of grain per spike and 1000kernel weight of 49 durum wheat genotype tested at two locations

S. N.	Genotypes	NTP		SPL (cm)		NSP		NGS		TKW (g)	
		D/zeit	Minjar	D/zeit	Minjar	D/zeit	Minjar	D/zeit	Minjar	D/zeit	Minjar
2	Yerer	3.5ef	3ab	7.25d-h	7.0d-h	18.0c-g	17.0b-f	52.0c-i	49.5b-g	38abc	40a-e
3	DWNL39	4def	3ab	4.75r	5.3k-r	16.0g	16.5b-g	45.5h-l	41.5e-n	36a-d	39a-f
4	DWLRC25	5.5bc	4a	5.9j-o	5.75i-p	18.5b-f	18.0a-d	34.0o-st	32.5l-r	28e-h	32g-k
5	DWNL4	3.5ef	3.5ab	6.65f-k	6.2h-m	20.5ab	17.0b-f	59.0abc	49.5b-g	30d-g	35e-i
6	DWLRC34	5cd	3ab	6.8e-j	6.4g-m	18.5b-f	16.5b-g	34.0o-t	30.5n-r	30d-g	36d-h
7	Ude	3.5ef	2.5b	5.85j-p	5.25k-r	17.5d-g	16.0c-h	57.0a-f	45.0d-k	38abc	43ab
8	DWLRC28	5.5bc	2.5b	8.8ab	8.55abc	20.5ab	17.5b-e	33.0p-t	29.5o-r	32c-f	35e-i
9	DWNE9	4def	4a	5.95i-n	5.45k-r	18.0c-g	16.5b-g	63.5a	57.5ab	40ab	41a-d
10	Mekuye	3.5ef	3ab	4.95o-r	4.8pqr	16.5fg	14.0gh	37.0m-r	35.5i-r	36a-d	43ab
11	DWLRC39	4.5cde	2.5b	8.95a	8.0bcde	21.0a	16.5b-g	32.0p-u	26.5pqr	28e-h	30i-l
12	Mangudo	4def	2.5b	5.2n-r	5.3k-r	18.5b-f	16.5b-g	57.5a-e	45.5c-j	38abc	43ab

13	DWNE11	3f	3ab	5.4m-r	5.3k-r	18.5b-f	17.0b-f	61.0ab	57.0abc	36a-d	37c-g
14	Hitosa	4def	3ab	5.8k-q	5.2l-r	19.5a-d	15.5d-h	55.5a-g	45.5c-j	32c-f	34f-j
15	DWLRC 60	5cd	3.5ab	8.55abc	8.65abc	20.0abc	18.5abc	36.0n-s	34.0j-r	30d-g	32g-k
16	Tesfaye	4def	2.5b	5.1n-r	4.9o-r	17.0efg	15.5d-h	57.0a-f	57.5ab	24gh	30i-l
17	DWNL10	3.5ef	3ab	5.35m-r	4.7pqr	16.5fg	14.0gh	45.5h-k	37.0h-q	32c-f	36d-h
19	DWNE10	3f	2.5b	4.9pqr	4.5qr	16.5fg	14.0gh	56.5a-f	43.5d-m	32c-f	31h-l
20	DWLRC48	5cd	4a	7.65cde	7.65b-f	18.5b-f	16.5b-g	38.5l-p	33.5k-r	32c-f	34f-j
21	DWNL18	4.5cde	3ab	5.85j-p	5.55j-q	19.0a-e	18.0a-d	63.5a	62.0a	26fgh	28kl
22	Werer	4def	3ab	5.4m-r	5.4k-r	17.0efg	16.5b-g	44.5i-m	47.0b-i	40ab	42abc
23	DWLRC6	5cd	3ab	7.15d-h	8.05bcd	20.0abc	20.5a	38.0l-q	38.5g-o	30d-g	34f-j
24	Utuba	4def	2.5b	4.8r	5.15m-r	17.5d-g	16.0c-h	49.0f-k	46.0b-i	40ab	44a
25	DWNL9	3.5ef	2.5b	5.65l-r	5.45k-r	17.5d-g	15.5d-h	50.0e-k	48.0b-h	36a-d	40a-e
26	Alemtena	4def	3ab	5.45m-r	5.1m-r	17.5d-g	16.0c-h	50.5d-j	47.5b-h	36a-d	34f-j
27	DWNE8	3.5ef	2.5b	5.8k-q	5.45k-r	18.0c-g	15.0e-h	60.0abc	43.5d-m	36a-d	40a-e
28	Fetan	3f	2.5b	5.85j-p	5.05m-r	18.0c-g	15.0e-h	52.0c-i	44.0d-l	27fgh	36d-h
29	DWLRC20	5cd	3ab	8.1a-d	8.15bcd	19.0a-e	17.5b-e	30.0q-u	28.0o-r	23h	28kl
30	DWNL11	4def	3ab	5.6l-r	5.25k-r	17.5d-g	14.5fgh	44.5i-m	39.0f-o	42a	39a-f
31	D-18	3.5ef	3ab	6.85e-i	6.15h-n	18.5b-f	16.0c-h	53.5b-h	44.5d-k	36a-d	38b-f
32	DWLRC94	7a	4a	7.95bcd	7.15d-h	19.5a-d	17.0b-f	33.0p-t	23.0r	24gh	30i-l
33	Gerardo	3.5ef	3ab	7.45def	6.8e-i	18.5b-f	18.0a-d	42.5j-n	44.5d-k	40ab	42abc
34	DWNE13	4def	2.5b	4.7r	4.3r	16.0g	14.5fgh	48.0g-k	51.0a-e	36a-d	34f-j
35	Cocorit	5.5bc	3.5ab	5.8k-q	5.45k-r	18.5b-f	16.5b-g	44.5i-m	47.0b-i	34b-e	40a-e
36	DWLRC96	6.5ab	3ab	7.3d-g	6.45f-k	18.0c-g	17.5b-e	28.5s-v	31.0n-r	38abc	30i-l
37	Bekelcha	4.5cde	3ab	5.85j-p	5.65i-q	17.0efg	16.0c-h	44.0j-n	44.5d-k	38abc	40a-e
38	DWNE7	4def	3ab	5.15n-r	4.55pqr	17.0efg	13.5h	44.0i-n	38.0g-p	34b-e	38b-f
39	Toltu	3.5ef	3ab	5.35m-r	5.65i-q	16.5fg	17.0b-f	48.0g-k	51.5a-e	28e-h	32g-k
41	DWLRC79	4.5cde	2.5b	8.1a-d	8.8ab	17.5d-g	17.5b-e	21.5v	28.5o-r	27fgh	22m
42	DWNL8	4def	3ab	5.5lm-r	5.15m-r	18.5b-f	15.0e-h	49.0f-k	50.5a-f	36a-d	38b-f
43	DWLRC84	5.5bc	3.5ab	6.65f-k	7.55c-g	17.5d-g	17.0b-f	29.0r-v	31.0n-r	26fgh	34f-j
44	DWLRC85	5.5bc	3.5ab	8.6abc	9.5a	19.5a-d	19.0ab	31.5p-u	32.0m-r	34b-e	32g-k
45	DWNL12	3f	2.5b	5.85j-p	5.0m-r	17.0efg	15.0e-h	52.0c-i	44.5d-k	28e-h	32g-k
46	DWLRC88	4.5cde	3.5ab	6.65f-k	6.75f-j	19.5a-d	18.5abc	34.0o-t	36.5h-q	24gh	26lm
47	DWLRC89	5.5bc	3.5ab	6.45g-l	5.55j-q	16.5fg	14.5fgh	24.5uv	23.0r	28e-h	29jkl
48	DWNL19	4def	3ab	4.85qr	4.95n-r	17.0efg	15.5d-h	56.5a-f	44.0d-l	30d-g	28kl
49	Filakit	4def	3ab	6.3h-m	5.7i-q	18.0c-g	16.0 c-h	42.0k-o	45.0d-k	36a-d	38b-f
	Mean	4.3	3.0	6.2	6.0	18	163	44.9	41.6	32.6	35.0
	CV (%)	16.75	19.45	7.8	9.9	6.2	9.0	8.9	13.9	10.4	8.2

Note: - Figures receiving the same letter within the column is not statistically different; CV=coefficient of variation, NGS= number of grains per spike, NSP= number of spikelets per spike, NTP= number of tillers per plant, SPL= spike length, TKW= 1000kernel weight.

Appendix Table-4. Mean hectoliter weight, biomass yield, harvest index and percent grain protein content of 49 durum wheat genotypes tested at two locations

S	Genotypes	HLW (kg/hl)		BY (kg/ha)		HI (%)		GPC (%)	
N		D/zeit	Minjar	D/zeit	Minjar	D/zeit	Minjar	D/zeit	Minjar
2	Yerer	78.5abc	79.8abc	8865c-i	8755a-i	33.5f-m	35.85c-l	12.65c-l	13.0c-h
3	DWNL39	79.6ab	80.4a	9127.5b-h	9321.9a-d	43.6a	36.95b-i	11.4mn	11.35nop
4	DWLRC25	73.3fgh	73.7f-j	8680.05c-k	9014.5a-g	29.15j-q	34.65e-m	12.0i-n	12.4e-n
5	DWNL4	77.5a-e	78.9a-f	7675.5k-o	8631.75a-j	34.4e-k	37.25b-i	13.05b-i	13.05c-g
6	DWLRC34	72.3gh	73.4g-j	9251a-h	8860.9a-g	28.2m-q	30.75i-m	11.95j-n	12.05g-p
7	Ude	77.2b-e	78.9a-f	8453.4e-l	8591.25b-j	42.4ab	35.15d-m	12.05i-n	12.55d-l
8	DWLRC28	73.6fgh	74.2d-j	8710.25c-k	7769.5i-m	27.8opq	28.2m	12.75c-l	11.45l-p
9	DWNE9	77.7a-d	78.0a-g	9395.25a-e	9209.25a-f	42.6ab	44.65a	11.9k-n	12.5d-m
10	Mekuye	75.0d-g	79.0a-f	8818.75c-j	8619.25b-j	34f-l	39.65a-g	13.2b-g	11.75j-p
11	DWLRC39	69.1ij	69.2jkl	7893.65i-n	8554.5c-j	28n-q	29.2klm	13.2b-g	11.7j-p
12	Mangudo	79.7ab	80.3a	8952.75c-h	8881.25a-g	43.5ab	40a-f	12.3e-n	12.0g-p
13	DWNE11	78.5abc	78.4a-g	9638.6abc	8940.75a-g	38.35a-f	36c-k	11.9k-n	12.60d-k
14	Hitosa	80.3a	80.0abc	9510.9a-d	8921.15a-g	42.4ab	34.2e-m	12.35d-n	11.7j-p
15	DWLRC 60	73.3fgh	74.6c-j	7791.25j-n	8538.75c-j	27.45pq	30.95i-m	12.4c-m	11.6k-p
16	Tesfaye	74.5efg	75.2a-i	8882.75c-i	8907a-g	33.4f-n	38.1a-h	13.2b-g	12.45d-n
17	DWNL10	75.0d-g	77.5a-h	8469d-l	8661.9a-j	31.8h-q	37.95a-h	12.05i-n	11.25op
18	Denbi	79.6ab	80.1ab	8884c-i	9599.5ab	39.65a-e	41.75a-d	12.4c-m	11.6k-p
19	DWNE10	78.2abc	78.1a-g	9111.5b-h	8745a-i	32.8g-p	34.5e-m	12.95c-k	12.25f-p
20	DWLRC48	74.6efg	70.7i-l	10286.25a	7789.9h-m	29k-q	33g-m	13.25b-f	12.75d-j
21	DWNL18	75.0d-g	77.1a-h	8935.5c-i	8914a-g	32.9g-o	35.1d-m	13.4bcd	11.9h-p
23	DWLRC6	70.9hij	74.1e-j	8303g-m	7696.25j-m	28.6l-q	28.2m	11.85lmn	12.05g-p
24	Utuba	80.1ab	80.2ab	9464.65a-e	8875.75a-g	43.15ab	36.15c-k	12.4c-m	11.65j-p
25	DWNL9	79.6ab	77.9a-g	9045c-h	9675a	34.5e-j	33.3f-m	12.45c-m	11.35nop
26	Alemtena	79.2ab	79.2a-e	8920.75c-i	9559.5abc	36.9c-h	38.4a-h	12.1h-n	11.75j-p
27	DWNE8	78.1abc	78.2a-g	9477.5a-e	9216.75a-f	33.4f-n	41.75a-d	12.1h-n	11.7j-p
28	Fetan	80.3a	80.4a	8814c-j	9422abc	41.3abc	43.6ab	12.1h-n	11.4m-p
29	DWLRC20	72.4gh	74.1e-j	7256.25no	7227.5k-n	30.95i-q	29.2klm	13.15b-h	15.05a
30	DWNL11	78.1abc	78.4a-g	9293.5a-g	8569.5b-j	41.75abc	36.35c-j	11.45mn	13.35b-f
31	D-18	79.0abc	79.0a-f	9385abcde	8679.25a-j	38.1b-g	41a-e	12.0i-n	12.0g-p
32	DWLRC94	71.0hij	70.1ijkl	7263.75mno	7080mn	27.4pq	29.45j-m	14.8a	13.35b-f
33	Gerardo	78.1abc	77.4a-h	10140.5ab	8638.5a-j	29.4j-q	37.25b-i	13.0c-j	11.55k-p
34	DWNE13	77.4a-e	79.6a-d	8212.5h-n	9246a-e	35.75d-i	43.5ab	13.0c-j	11.65j-p
35	Cocorit	76.1c-f	78.0ab-g	8766c-i	9474.5abc	33.5f-m	41a-e	11.85lmn	12.4e-n
36	DWLRC96	71.3hi	75.3a-i	8748.75c-j	6698n	28.2m-q	29.4jlm	11.3n	11.95g-p

37	Bekelcha	78.5abc	78.8a-g	9378.25a-f	9135a-f	41.75abc	34.5e-m	12.85c-l	13.55bcd
38	DWNE7	78.4abc	77.9a-g	9378.75a-f	8182.9f-l	30.85i-q	33g-m	12.35d-n	11.2op
39	Toltu	79.2ab	78.8a-g	9350.65a-f	8824.5a-h	41.3abc	37.1b-i	12.2fg-n	12.25f-o
40	DWLRC92	73.8fgh	70.8i-l	8340.7f-l	7182.5lmn	29.15j-q	29.4jlm	12.75c-l	14.25ab
41	DWLRC79	68.0j	65.6l	5541p	5318.25o	28.65l-q	28.4m	13.3b-e	11.65j-p
42	DWNL8	79.3ab	79.3a-e	9493.55a-e	8249.75e-k	40.15abcd	42.6abc	12.1h-n	11.6k-p
43	DWLRC84	72.1ghi	70.9i-l	7570.75l-o	8047.5g-m	28.2m-q	34.5e-m	12.1h-n	13.45b-e
44	DWLRC85	73.9fgh	72.2h-k	9688.75abc	9001.5a-g	29k-q	29.4jlm	12.25e-n	13.20b-f
45	DWNL12	74.6efg	78.0a-g	6743o	9467.5abc	32.75g-p	36.65b-i	12.95c-k	12.4e-n
46	DWLRC88	61.0k	67.0kl	5004.25p	4933o	27q	29lm	13.45bc	14.10abc
47	DWLRC89	72.4gh	74.6c-j	5669.55p	8177f-l	27.05q	29.45j-m	12.9c-l	12.60d-k
48	DWNL19	73.1fgh	74.8b-i	8910.25c-i	9089.75a-g	28.6l-q	32.9g-m	13.3b-e	12.95d-i
49	Filakit	78.6abc	78.6a-g	9102.15b-h	8333d-j	40.4a-d	32.55h-m	11.9k-n	12.5d-m
	Mean	76.4	76.4	8615.6	8517.1	34.4	35.4	12.6	12.3
	CV (%)	2.0	3.5	5.97	6.0	7.79	9.74	4.3	4.6

Note: Means followed by the same letter within the column are not significantly different at P≤0.05; BY= biomass yield, CV=coefficient of variation, GPC= grain protein content, HI= harvest index, HLW= hectoliter weight.