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Estimation of Genetic Variability, Quality and Agronomic Contributing Traits of Durum Wheat (*Triticum turgidum* L.) Landraces in Bale Highlands, Ethiopia

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Abstract

Ethiopia is rich in durum wheat diversity and it is produced in diverse agro ecologies of the country. The national average productivity and quality of durum wheat is low due to lack of strong national research program and different biotic and abiotic constraints prevailing in the country, these calls for development of improved durum wheat varieties. Knowledge on extent of genetic variability and identification of important characters is a prerequisite for the development of high yielding and quality durum variety. The present study was carried out to assess the extent of genetic variability and character association among yield and yield related traits in selected Ethiopian durum wheat landraces. Including three checks 49 durum wheat accessions were studied for 20 traits at Sinana and Selka locations using 7 x 7 simple lattice designs in 2018/19. Combined analysis of variance revealed significant differences among accessions for all studied traits, indicating the presence of considerable variability among genotypes. A significant accession by location interaction effect was observed for most characters, indicating differential performance of genotypes over environments. Protein content varied from 10.7% to 16.7% with the overall mean of 13.5%. Phenotypic Coefficients of Variation (PCV) ranged from 2.93 for HLW to 27.08 for PTL while, Genotypic Coefficients of Variation (GCV) ranged from 0 for WGL to 16.43 for VTR. Low to high heritability was observed for the studied traits. Similarly, genetic advance as percent of mean varied from -0.20 to 31.24. High broad sense heritability and high genetic advance were obtained for GY (86.57 and 31.24) and VTR (75.76 and 29.39) respectively which indicate that, these characters could be improved easily through selection. Overall, the present study revealed that there is sufficient variability existed in Ethiopian durum wheat landraces.

Keywords: Trait performance; Heritability; Genetic advance; Quality; Phenotypic Coefficients of Variation (PCV)

Introduction

Durum wheat (*Triticum turgidum* L.) is among the most cultivated in the Mediterranean basin, where approximately 75% of the world's durum wheat area is still grown, which contributes to 50% of the worldwide production [1]. Globally the most important growing areas are situated in the Mediterranean Basin, North America, North and East Africa and South West Asia [2]. Durum wheat is the oldest traditional crop produced in Ethiopia [3]. In Ethiopia, landraces are characterized by significant phenotypic variability [4]. In Ethiopia, the production and quality of durum wheat is low due to biotic and abiotic stresses. Evidence supports the hypothesis that landraces can provide new alleles for the improvement of commercially valuable traits [5]. Thus, it is crucial for breeders to collect characterize and incorporate landrace in breeding program for the improvement of durum wheat in yield, quality and other stress resistance for sustainable durum wheat production. For effective selection in durum wheat, breeders should increase their efforts to know the genetic variability and heritability of important agronomic traits [6].

Ethiopia is recognized as a major vavilovian gene center of diversity and accounting for about 12% of the national gene bank holdings for durum wheat. Therefore, Ethiopia, being the center of diversity for durum wheat, has tremendous potential for the development of varieties that meet yield, rust resistance as well as quality [7]. However, the potential has not yet been fully exploited. It is well established that genetic variability is a base and pre requisite for plant breeding programme on which selection is practiced to select superior genotype among existing diverse germ plasma. Knowledge on variability, heritability, genetic advance and genetic divergent is very important for building of appropriate breeding program. The presence of genetic variability in breeding materials is essential for a broadening the gene pool and therefore for success of plant breeding programs. However, no such studies on diversity of the existing durum wheat collections were carried out under bale highland condition. Thus, the current study was planned to investigate genetic variability for different important agronomic and quality traits in Ethiopian durum wheat landraces.

Objective: To estimate the genetic variability and quality traits in Ethiopian durum wheat landraces based on morpho agronomic traits.

Materials and Methods

Description of the study areas

The field experiment was conducted at two locations in Southeastern Ethiopia namely, at Sinana with geographical coordinate units of 07°07'N, 40°10'E and Selka with geographical coordinate units of 07°04'28''N, 040°12'18''E during 2018/19 main cropping season. Both experimental sites are characterized by pelvic vertical with a slightly acidic soil and its PH ranges from 6.3 to 6.8. Altitude 2400 m and 2509 m above sea level for both locations representing the potential durum wheat production area in the zone. Sinana Agricultural Research Center (SARC) is located 463 km South-East of Addis Ababa in the highlands of Bale zone, South-Eastern Oromia and at a distance of 33 km in East of Robe town, the capital city of the Zone. Selka site is on the way to Sinana Agricultural Research Center (SARC) 7 km away from the SARC. Both areas are characterized by bi-modal rainfall pattern and receive annual total rainfall ranging from 750 to 1400 mm. The main season receives 270 to 842 mm rainfall, while the short season receives from 250 to 562 mm rainfall annually. Mean annual minimum and maximum temperatures are 9.6 and 20.7°C, respectively [8]. The experiment at both locations was conducted during the main cropping season which extends from August to December.

Experimental materials

The experimental materials comprised of 49 durum wheat germ plasma including three (checks) released durum wheat varieties from Sinana agricultural research center *viz.* Bulala, Dire and Obsa and. These landraces were developed in to pure lines by SARC from collections introduced from Institute of Biodiversity and Conservation (IBC). The details of durum wheat accessions along with checks used in this study are summarized in the following Table 1.

Table 1: Names and origin of 49 durum wheat germ plasm used in the study.

S/N	Name	Form	Origin	Woreda	Locality
1	Acc 5152	Landrace	SNNP	Hula	Hagere
2	Acc 5373	Landrace	Oromia	Ada'a	Filtino
3	Acc 243733	Landrace	Amahra	Gonda	7.8 km
4	Acc 242791	Landrace	Oromia	Gimbic	
5	Acc 5457,	Landrace	Oromia	Ejere	
6	Acc 242787	Landrace	Oromia	Gimbic	
7	Acc 5344	Landrace	Oromia	Akaki	Bole
8	Acc 7576	Landrace	Amhara	Were	Kata on
9	Acc 7010,	Landrace	B/Gumz	Wenber	
10	Acc 5760	Landrace	Oromia	Mana	10 km SE
11	Acc 7580	Landrace	Amahra	Jama	Gibat on
12	Dire	Improved	Oromia	Sinana	SARC
13	Acc 243401,	Landrace	Oromia	Gasara	Jile
14	Acc 5472	Landrace	Amahra	Minjar	Yenigus
15	Acc 230678	Landrace	Oromia	Ginir	01Kabele
16	Bulala	Improved	Oromia	Sinana	SARC
17	Acc 6988	Landrace	Oromia	Merti	Ofa 6 Km

18	Acc 5473,	Landrace	Amhara	Farta	
19	Acc 5149	Landrace	Oromia	Alem	Tefki
20	Acc 222393	Landrace	Oromia	A/Robe	-
21	Acc 7295,	Landrace	Amhara	Debre	
22	Acc 6978	Landrace	Amahra	Enarj	Embeyem
23	Acc 8072	Landrace	Oromia	Ginir	Ginir
24	Acc 5020	Landrace	Oromia	Ada'a	SE slope
25	Acc 5342,	Landrace	Amhara	Macha	
26	Acc 5586,	Landrace	Oromia	Gedo	
27	Acc 5428	Landrace	Oromia	Tiyo	Asela
28	Acc 6933	Landrace	Oromia	Agarfa	Agarfa
29	Obsa	Improved	Oromia	Sinana	SARC
30	Acc 242780	Landrace	Oromia	Lome	25 km
31	Acc 2211,	Landrace	Oromia	Meta	
32	Acc 226879	Landrace	Oromia	Meta	--
33	Acc 5141,	Landrace	Tigray	Endam	
34	Acc 7665	Landrace	Amahra	Enema	Sherar
35	Acc 5354	Landrace	Oromia	Alem	Tefki
36	Acc 7673	Landrace	Amahra	Enema	Yerez
37	Acc 5198	Landrace	Amhara	Dembe	Denbech
38	Acc 243706,	Landrace	Oromia	Mulo	
39	Acc 5510	Landrace	Oromia	Bereh	Kakisa
40	Acc 242783	Landrace	Oromia	Lome	1 km
41	Acc 242782	Landrace	Oromia	Lome	1 km
42	Acc 226694	Landrace	Oromia	--	--
43	Acc 235051	Landrace	Amhara	Legam	110 km
44	Acc 7210	Landrace	Oromia	Ambo	Asgori
45	Acc 7647	Landrace	Amahra	Hulet	Mota
46	Acc 6974	Landrace	Amahra	Enema	22 km
47	Acc 5591	Landrace	Oromia	Akaki	sheno
48	Acc 242790	Landrace	Oromia	Gimbic	Gimbic

49	Acc 243403,	Landrace	Oromia	Gsara	Engoye
Acc: Accession; SNNP: South Nation and Nationalities and People; SARC: Sinana Agricultural Research Center					

Experimental design and trial management

The experiment was laid out in 7 x 7 simple lattice designs with two replications having plot size of four rows of 20 cm spacing and 2.5 m length. Seed and fertilizer rate 150 kg/ha and 69/46 N/P_2O_5 were applied. Urea (N) was applied in split application where 1/3rd was applied at planting and the remaining 2/3rd was applied at tillering stage and all agronomic practices were followed uniformly according to the recommendation for the area [9]. Planting was done by hand drilling; weed was controlled by using hand weeding and as well as by using herbicide called Pallas 45 OD at the recommended rate and time of application.

Data collection

All agronomic, yield and yield related traits and quality traits both on plant and plot basis were recorded from the two middle rows of experimental unit. Plant based data were collected from randomly selected and representative ten plants in the plot while, the plot based data were collected from the whole harvestable plot. Plant Height (PLH) (cm), Spike Length (SPL) (cm), Number of Spikelets/Spike (SPS), Productive Tillers/Plant (PTL), Number of grains/Spike (KPS), Days to Heading (DH), Days to physiological Maturity (DM), Grain Filling Period (GFP), Grain Yield (GY) ($kgha^{-1}$), Biomass Yield (BM) ($kgha^{-1}$), Harvest Index (HI) (%), Thousand Kernel Weight (TKW) (g), Vitreousness (VTR) (%), Hectoliter Weight (HLW) (kg/L), Grain Protein Content (GPT) (%), Grain Gluten Content (GGL) (%), Zeleny Index (ZI) (ml), Wet Gluten content (WGL) (%), Sodium Dodecyl Sulfate (SDS) Sedimentation (ml) and Ash Content (ASC) (%).

Analysis of Variance (ANOVA)

The SAS GLM procedure was employed for the analysis of variance. Fisher's protected Least Significant Difference (LSD) test at 5% level of significance was used for mean comparisons, whenever genotypes differences were significant. The total phenotypic variance of each trait was partitioned into genetic and non-genetic factors using the variance component method based on the combined analyses over the two tested locations [10]. Phenotypic (PCV) and Genotypic (GCV) coefficients of variation were calculated following the method of Burton and Devine. Broad sense heritability (H^2) was calculated as a ratio of genotypic variance to phenotypic variance according to Allard. Genetic Advance (GA) was determined following the procedure elaborated by Johnson, et al.

Results and Discussion

Analysis of variance

Mean squares of the 20 studied characters from Analysis of Variance (ANOVA) at individual location and combined over the two locations are presented in Tables 2 and 3 respectively. At Sinana, highly significant ($P<0.01$) variations were observed among genotypes for PLH, BM, GY (tha^{-1}), KPS, PTL, TKW, HLW, VTR and (SDS) while; significance differences at $p \leq 0.05$ was observed among the tested genotypes for DH and DM, HI, WGL, GFP, SPL, SPS, GPC, ZI, GGL and for ASC (Table 2). At Selka, also highly significance differences ($p \leq 0.01$) among genotypes were recorded for DH and DM, GFP, PLH, GY, SPL, PTL, TKW, VTR, ZI, GGL and WGL while; the remaining traits showed significances at $p \leq 0.05$ [11]. Significance differences among accessions suggesting that the existence of wider genetic variation of durum wheat landraces. Similarly, Alemayehu, et al. reported highly significant differences among genotypes for GY, BM, SPL, DH and GFP while, reported significant variation for GPC and SPS. Again, Mengistu, et al. and Mohammed, et al. also reported considerable genetic variability and significant differences for quantitative and qualitative traits in durum wheat genotypes.

Table 2: Analysis of variance (mean squares) for 20 studied traits of 49 durum wheat accessions studied at Sinana and Selka during 2018/2019.

Locations											
Sinana						Selka					
Traits	Genotypes (df=48)	Error (df=36)	Replication (df=1)	bk x rep (df=12)	CV (%)	Traits	Genotypes (df=48)	Error (df=36)	Replication (df=1)	bk x rep (df=12)	CV (%)
DH	31.96*	8.82	2	3.13	4.72	DH	25.98**	4.38	7.44	6.96	3.2
DM	48.39*	12.15	151.88	9.65	2.97	DM	33.68**	6.93	5.87	4.72	2.2
PLH	177.44**	25.29	35.52	29.04	4.88	PLH	234.31**	44.44	68.61	42.04	6.07
GFP	40.59*	16.33	188.73	15.62	7.41	GFP	41.17**	9.13	26.54	14.76	5.6

BM	22475215.0**	4474178	44381658	3698682	16.64	BM	9370323.0*	4446996	72859694	7431122	15.83
GY	1187036.0**	126021.2	792720.4	283529	8.1	GY	829618.0**	221348.3	2345252	340790	12.22
HI	62.17*	29.88	527.2	42.16	15.2	HI	68.99*	22.5	786.91	28.19	15.86
SPL	2.95*	0.73	1.05	1.7	11.61	SPL	2.68**	0.48	0.9	0.54	9.53
SPS	6.47*	2.3	5.88	2.1	9.18	SPS	7.69*	2.41	4.08	1.01	9.12
KPS	68.02**	18.14	1.47	14.62	13.18	KPS	43.52*	15	11.11	11.45	12.65
PTL	1.27**	0.28	0.09	3.38	18.02	PTL	0.93**	0.24	0.09	0.47	18.78
TKW	37.15**	7.86	19.13	17.76	6.95	TKW	37.11**	3.74	21.78	3.94	4.98
HLW	13.35**	2.04	4.25	2.33	1.8	HLW	7.87*	2.45	1.78	1.83	1.97
VTR	751.94**	110.23	6.9	143.23	11.96	VTR	342.49**	76.43	0.09	90.55	10.25
GPC	4.26*	1.23	0.15	1.42	7.95	GPC	3.06*	1.41	0.74	1.2	9.02
ZI	80.76*	31.02	154.38	34.27	8.49	ZI	180.56**	43.88	330.61	79.23	11.62
GGL	22.79*	5.52	23.51	9.39	6.96	GGL	31.08**	7.52	39.22	22.17	8.21
WGL	9.87*	4.5	20.94	4.66	6.39	WGL	29.76**	4.46	5.12	3.13	6.48
ASC	0.08*	0.02	0.02	0.03	12.99	ASC	0.12*	0.03	0.01	0.03	16.94
SDS	115.93**	18.98	0.01	19.29	9.51	SAD	106.38*	45.36	77.23	46.78	13.53

Where: DF: Degree Freedom; *and **, p<0.05 and 0.01 level of significances, respectively, NS: Non-Significant; CV: Coefficient of Variation; DH: Days to Heading; DM: Days to Mature; PLH: Plant Height; GFP: Grain Filling Period; BM: Biomass; GY: Grain Yield; HI: Harvest Index; SPL: Spike Length; SPL: Spike Length; SPS: Number of Spike per Spike; KPS: Number of Kernel Per Spike; PTL: Productive Tillers; TKW: Thousand Kernel Weight; HLW: Hecto Liter Weight; VTR: Vitrousness; GPC: Grain Protein Content; ZI: Zeleny Index; GGL: Grain Gluten; WGL: Wet Gluten; ASC: Ash Content; SDS: Sodium Dodecyl Sulphate; Bk: Block; Rep: Replication.

The results showed that the error mean squares were homogeneous for all the characters studied in the tested locations since the ratio of the highest error mean square to the smallest error mean square was less than 3.00 according to Gomez and Gomez. Therefore, the data were pooled across locations and analyzed accordingly. The results of analysis of variance for combined over locations data showed that there was significance variation among different durum wheat genotypes for all yield attributes and quality traits considered in this study. Highly (P<0.01) significance differences were observed among studied accessions for all traits.

The test locations had also a pronounced effects ranging from highly significance (P<0.01) on fourteen of the 20 traits to significant on DM and DH, BM and GY, HI, PTL, TKW, GPC, ASC, ZI, PLH, SPS, KPS and SDS. However, location effects did not induce significant variation on the six traits *viz.* GFP, SPL, HLW, WGL and GGL.

Locations x genotypes interaction was also significant (P<0.05) for DM, PLH, HI, GY, SPS and HLW, whereas; it showed highly significant differences (P<0.01) for PTL, BM, WGL and for SDS (Table 3). This implies that the different accessions performed differently based on environmental conditions imposed by location while, the remaining variables were showed non-significance for genotype x location interaction, indicates that the genotypes performance were showed close differences. Generally, the observed significance differences among accessions; for the traits under study indicated the presence of genetic variations among the accessions which in turn suggested that selection of landraces can be effective in improving both yield and quality traits of durum wheat [12]. The same results were reported by Mengistu, et al. regarding genotypes by environment interactions in durum wheat landraces. Kumar, et al. also reported considerable genetic variability for quantitative and qualitative traits in wheat. Besides, such kind of variability among wheat genotypes for yield and yield related traits were also reported by Kumar, et al. and Almaz.

Table 3: Analysis of variance (mean squares) for 20 studied traits of 49 durum wheat accessions studied over locations during 2018/2019.

Traits	Genotypes (df=48)	Error ms (df=85)	Replication (df=1)	Location (df=1)	Loc x Geno (df=48)	Block x rep (df=12)	CV (%)

DH	44.21**	6.57	8.58ns	276.99 **	6.31ns	3.196ns	4
DM	53.23**	9.58	108.75*	161.65**	16.73*	7.86ns	2.62
PLH	275.55**	31.5	101.43	2188.90*	54.71*	57.37ns	5.27
GFP	56.95**	13.24	178.41*	15.43ns	19.21ns	16.08ns	6.71
BM	20189923.5**	4176996	115485727**	17911033.2*	11263324.8**	8452572.3*	15.7
GY	1870930.71**	154103.8	2932485.00**	13763411.01**	63214.460*	591983.36**	9.53
HI	65.81**	25.5	1301.14**	1785.66**	59.77*	47.24ns	15.36
SPL	3.69**	0.72	0.003ns	0.52ns	0.99ns	0.96ns	11.58
SPS	8.19**	2.25	9.88*	11.76*	4.38*	1.32ns	8.94
KPS	74.72**	16.39	2.25ns	142.291*	24.16ns	10.23ns	12.87
PTL	1.23**	0.27	0.18ns	4.59**	0.79**	0.37ns	18.87
TKW	59.20**	6.59	0.05ns	106.827**	5.57ns	13.28*	6.48
HLW	14.55**	2.25	5.76ns	4.72ns	4.90*	1.69ns	1.88
VTR	895.32**	85.12	2.69ns	298.79	86.8ns	191.19*	10.65
GPC	4.29**	1.35	0.77ns	28.17**	1.77ns	1.02ns	8.56
ZI	163.52**	41.37	16.58ns	3625.76**	55.35ns	84.22*	10.48
GGL	35.95**	6.96	1.00ns	6.61ns	9.69ns	26.52**	7.85
WGL	16.97**	4.44	2.68ns	15.72ns	17.34**	5.22ns	6.41
ASC	0.16**	0.03	0.02ns	0.485**	0.027ns	0.04ns	15.03
SDS	115.44**	31.522	121ns	760.18**	91.2**	39.0ns	11.75

Where: DF: Degree Freedom; *and **, p ≤ 0.05 and 0.01 level of significances, respectively, NS: No-Significant; CV: Coefficient of Variation; DH: Days to Heading; DM: Days to Mature; PLH: Plant Height; GFP: Grain Filling Period; BM: Biomass; GY: Grain Yield; HI: Harvest Index; SPL: Spike Length; SPS: Number of Spike Per Spike; KPS: Number of kernel Per Spike; PTL: Productive Tiller; TKW: Thousand Kernel Weight; HLW: Hecto Liter Weight; VTR: Vitrousness; PC: Grain Protein Content; ZI: Zeleny Index; GGL: Grain Gluten; WGL: Wet Gluten; ASC: Ash Content; SDS: Sodium Dodecyl Sulphate; Rep: Replication; Loc: Location; MS: Mean Squares

Range and mean values of traits

Performance of genotypes for phenology and growth traits: Plant Height (PLH) showed highly significance differences among studied accessions at both locations as well as interaction with locations for this trait was significant indicate that, differential performance of genotypes over locations. Obsa was the shortest of all while; Acc7010 was the tallest of all studied accessions at both locations (Appendix 1 and 2). This trait was ranged from 80.3 to 137.6 cm and 76.1 to 142.8 cm with the mean values of 103.1 and 109.7 cm at Sinana and Selka respectively (Appendix 3 and 4). Generally, phenology is a key feature for adaptation of genotypes to climatic condition in which they grow [13]. PLH is a major agronomic trait in wheat breeding because it often affects GY because lodging risk prevents the economic use of sufficient quantities of nitrogen to produce canopies large enough to intercept the majority of available light during yield formation, PTL, KPS and it is obstacle during mechanization. Similarly, Verma, et al., Almaz, et al. and Manel, et al. reported that there is appreciable variability among several durum wheat genotypes for plant height.

The genotypes with location interaction for Grain Filling Period (GFP) was showed non-significant indicated that, the performance of genotypes for this trait was close differences over locations. The combined over locations data showed the variation of this trait was varied from 44.8 to 64.1 days with overall mean value of 32.9 days. Obsa and Acc5141 took the longest and shortest period to GFP respectively (Appendix 5).

Combined over locations data for Days to Heading (DH) was varied from 58.7 to 85.5 with the overall mean value of 64.0 days. The shortest and longest DH was recorded from Acc230678 and Acc7010 respectively (Table 4). Also this trait was varied from a minimum 56.0 to 86.5 days at Sinana while; it ranged from 60.5 to 84.5 days at Selka (Appendix 6 and 7). Variation in length of DH of the genotypes influences directly GY and the genetic basis for this trait would be more worthy according to the given environmental conditions. The interaction of genotypes with location was non-significance for this trait indicates that mean performance of genotypes over locations and the wider adaptation range for this trait among accessions. This may be due to genetic differences and selection can be effective according to the breeding objectives. Similarly, Alemayehu, et al. in the study of 64 durum wheat genotypes and reported the mean for DH were 58 days and the earliest line to heading was 49 days while, the latest line to reach heading was 62 days [14]. Manel, et al. and Mengistu, et al. also, reported that there was wider variability among several durum wheat genotypes for days to heading.

Table 4: Estimate of range, mean, phenotypic (σ^2p), genotypic (σ^2g) and environmental (σ^2e) variances, Phenotypic (PCV) and Genotypic (GCV) coefficient of variability, broad sense Heritability (H^2%), genotypic x location variance, expected Genetic Advance (GA) and Genetic Advance as percent of the mean (GA%) for twenty characters for combined over locations, 2018/19.

Traits	Range	Mean	σ^2gl	σ^2g	σ^2p	σ^2e	GCV	PCV	H^2	GA	GAM
DH	58.7-85.5	64.1	6.3	9.5	14.3	6.6	4.8	5.9	66.4	5.2	8
DM	109.5-137 7.2	118.4	16.7	9.1	19.9	9.6	2.6	3.8	45.9	4.2	3.6
PLH	80.3-137. 6	106.4	54.7	55.2	90.4	31.5	7	8.9	61	11.9	4.3
GFP	44.8-64.1	54.3	19.2	9.4	22.4	13.2	5.7	8.7	42.2	4.1	7.6
BM	8525.0-1 8275.0	13015.1	1126332 5	2231650	8907561	4176996	11.5	22.9	25.1	1537.1	11.8
GY	2191.5-5 565.9	4115.8	63214.5	451929.1	522062.2	154103.8	16.3	17.6	86.6	1286	31.2
HI	17.8-40.9	32.9	59.8	1.5	37.8	25.5	3.7	18.7	4	0.5	1.5
SPL	5.0-9.8	7.3	1	0.7	1.3	0.7	11.2	15.9	50	1.2	16.3
SPS	14.0-22.3	16.8	4.4	1	3.7	2.2	5.8	11.5	25.7	1	6.1
KPS	25.1-46.8	31.5	24.2	12.6	28.8	16.4	11.3	17.1	43.9	4.8	15.4
PTL	1.9-4.8	2.8	0.8	0.1	0.6	0.3	11.9	27.1	19.2	0.3	10.7
TKW	33.7-52.4	39.6	5.6	13.4	17.8	6.6	9.2	10.7	75.2	6.5	16.5
HLW	73.5-84.7	79.4	4.9	2.4	5.4	2.3	2	2.9	44.5	2.1	2.7
VTR	20.8-97.2	86.6	86.8	202.1	266.8	85.1	16.4	18.9	75.8	25.4	29.4
GPC	10.7-16.8	13.6	1.8	0.6	1.9	1.3	5.9	10	34	1	7
ZI	45.1-80.4	61.3	55.4	27	65.1	41.4	8.5	13.2	41.6	6.9	11.2
GGL	24.7-42.5	33.5	9.7	6.6	13.2	7	7.6	10.8	49.9	3.7	11.1
WGL	24.7-36.4	32.9	17.3	-0.1	9.7	4.4	0	9.5	1	-0.1	-0.2
ASC	0.6-1.4	1.13	0.03	0.03	0.05	0.03	16.09	20.52	61.52	0.29	25.9
SDS	34.3-68.8	47.8	91.2	6.1	59.5	31.5	5.1	16.1	10.2	1.6	3.4

Where: DH: Days to Heading; DM: Days to Mature; PLH: Plant Height; GFP: Grain Filling Period; BM: Biomass; GY: Grain Yield; HI: Harvest Index; SPL: Spike Length; SPS: Number of Spike Per Spike; KPS: Number of Kernel Per Spike; PTL: Productive Tiller; TKW: Thousand Kernel Weight; HLW: Hecto Liter Weight; VTR: Vitreousness; PC: Grain Protein Content; ZI: Zeleny Index; GGL: Grain Gluten; WGL: Wet Gluten; ASC: Ash Content; SDS: Sodium Dodecyl Sulphate

The genotype with location interaction for Days to Mature (DM) was significant which indicates that, differential performance of genotypes for this trait under each location. The wider range of variation at both locations were recorded and the mean values of locations showed, relatively studied accessions at Sinana matured earlier (117.4) than at Selka (119.3). At

Sinana, this trait value was varied from 111.0 to 138.5 days while, at Selka it ranged from 108 to 136.0 days (Appendix 8). The latest and earliest was recorded from Acc7010 and Acc5141 respectively at both locations. The same was true for combined data the latest and earliest days to maturity recorded from the same accessions. Generally accessions that took shorter days to heading and maturity calls for exploitation of these accessions in national and international breeding programs to develop early maturing varieties that would be viable under adverse climatic change and for in case of like Bale zone the early heading and maturing varieties have high demand because of, double farming/cropping systems are the main practice in the area as well as in areas where low moisture stress is commonly occurred. Earliness alone is not a desired trait as other traits such as the final grain yield matters for adoption of varieties by farming communities. Early maturing accessions must be give average to higher grain yield for adoption by the farmers [15]. This result also agrees with Mengistu, et al. reported, 18 days difference between the early and the late days to maturity of durum wheat landraces and contradict with Alemayehu, et al. who reported a narrow range 93 to 100 days to maturity in durum wheat genotypes.

Grain yield performance

Genotypes interaction with location showed significance differences for Grain Yield (GY) which indicate that, genotypes had showed differential performance under each location. It varied from 2191.7 to 6023.8 kg/ha at Sinana and most of accessions gave above the grand mean (4380.8 kg/ha). At Selka, also GY varied from 2191.3 to 5309.1 kg/ha and here also most of accessions were yielded above grand mean (3850.80 kg/ha). The differences between maximum and minimum mean values in GY per hector at Sinana and Selka were, 3831.1 kg/ha and 3117.7 kg/ha respectively. The difference among accession was greater at Sinana which, indicated that a wider variation among accessions. At Selka though the range was as wide as that of Sinana but, the grand mean was lower (3850.8 kg/ha) than that of Sinana (4380.8 kg/ha). This may be due to the differences between the two locations in terms of edaphic and weather conditions prevailing in the areas and slightly longer growing period of the crop at Selka compared to Sinana which exposed the crop to frost that may cause lowers the yield in the season especially, at grain filling period of the genotypes [16]. The higher grain yield (6023.8 kg/ha, 5914.4 kg/ha and 5774.1 kg/ha) was recorded from Dire variety (check), Acc242783 and Acc243701 respectively, while lowest grain yield was recorded from Acc7010 (2191.7 kg/ha) at Sinana. Also at Selka the higher grain yield was recorded from Obsa (5309.1 kg/ha) and Dire (5093.8 kg/ha). Again, the lowest yield was recorded from Acc7010 (2191.3 kg/ha) which was the same as Sinana. For combined over locations GY ranged from 2191.5 to 5565.9 kg/ha. Including checks thirty one (63%) of accessions had gave grain yield exceeding the overall mean (4115.8 kg/ha) [17]. Generally, yield is formed throughout the growth of the crops, with the environment and agronomic inputs at different growth stages influencing yield through their impact on specific yield components. Some of genotypes GY are competent with the checks that can be used in durum wheat improvement program for the targeted environments. Similarly, Mengistu, et al. and Kumar, et al. reported a wider genetic variation of grain yield of durum wheat genotypes.

Performance of yield related traits

The mean performance of the tested accessions for yield and yield components are presented in Appendix 1, 3 and 5 for Sinana, Selka and for combined data over locations respectively. Also the range and mean values for the traits studied are shown in Appendix 7 and 8 for Sinana and Selka sites respectively while; for combined over locations data is presented in Table 4.

The diverse performance of the studied accessions was also reflected in the final important trait *i.e.* Biomass (BM). At Sinana, it was varied from 6,750.0 to 20,850.0 kg/ha whereas, at Selka it varied from 8700 to 20, 200.0 kg/ha. The differences between maximum and minimum mean values in BM per hector at both locations were wider which, indicates that a wider variation among studied accessions. The highest overall mean values of BM (13317.35 kg/ha) was recorded at Selka as compared to Sinana (12712.80 kg/ha). This indicates that, the crop performance was much better at Selka than at Sinana due to the differences between the two locations in terms of edaphic and weather conditions prevailing in the areas. Maximum and minimum values of BM were obtained from Acc7010 (20200 kg/ha) and Acc5141 (8700 kg/ha) respectively at Selka whereas, at Sinana, the minimum and maximum values were recorded from Acc7673 and dire respectively. Combined over locations data showed BM ranged from 8525.0 to 18275.0 kg/ha kg/ha. Alemayehu, et al., Mengistu, et al. and Mansouri, et al. reported similar result of wider genetic variation for BM in durum wheat genotypes.

The magnitude of variation for combined over locations data showed wider variation for Spike Length (SPL) among studied accessions and it was ranged from 5.0 cm to 9.75 cm with the overall mean of 7.3 cm. The shortest and the longest SPL were recorded from Acc242790 and Acc7010 respectively.

At Selka and Sinana, Harvest Index (HI) varied from 10.8 to 47.4 and 24.7 to 49.8 with the overall mean of 35.9 and 29.9 respectively. At Selka, Obsa had the highest HI value (47.4) and the Acc7010 (10.85) was recorded the lowest value while; Acc5160 and Acc226694 had the lowest and highest HI values at Sinana. For combined over location data it also varied from 17.8 to 40.9. Basheer-Salimia and Atawnah, reported that improvements in HI associated with reduced height, therefore, account for more than 80% of the improvement in yield potential of wheat varieties within some twentieth century breeding programs [18].

Combined over locations data showed Kernels/Spike (KPS) was varied from 25.1 to 46.7 with the overall mean value of 31.4. The maximum and minimum number was counted from dire and Acc5591 respectively. At individual as well as combined over locations Dire recorded the highest value of all accessions and this indicates the stability of this genotype for this particular trait. At Sinana and Selka KPS also ranged from 23 to 47 and 23 to 46.5 respectively.

Number of Spikelets/Spike (SPS) varied from 11.0 to 22.0 at Sinana while; it ranged from 13.0 to 24.5 at Selka. The mean value at Sinana and Selka were 16.5 and 16.9 respectively. The highest number of SPS was recorded from dire (22.0) and the lowest was recorded from Acc7295 at Sinana while, the highest and lowest was recorded from Acc7580 (24.5) and Acc5457 respectively at Selka. Also for combined over locations data this trait ranged from 14.0 to 22.2. Dreccer, et al. reported that, the mature wheat spike may contain 15 to 18 SPS or more attached on alternating sides of the rachis.

The number of Productive Tillers (PTL) showed moderate variation among studied accession at both locations. This trait varied from 1 to 5 at Sinana and the same was true for Selka that ranged from 1 to 5 with the mean values of 2.9 and 2.6 respectively. The minimum number of PTL was recorded from Acc242790 (1) and the maximum was recorded from Acc7580 (5) at Sinana while; at Selka the minimum and maximum were recorded from Acc7576 (1) and Obsa (5). Generally, the results of this study showed differences in phenology, yield and yield related traits among durum wheat accessions. Tillering capacity depends greatly upon variety and also depends on plant density Gooding, et al. Similarly, Mengistu, et al. reported the existence of wider variation of productive tillers/plant that ranged from 2.0 to 4.3 for durum wheat landraces.

Performance of accessions for quality parameters

Harvested grains from the two locations were used for laboratory analysis which means performance for quality traits are presented in Appendix 2, 4 and 6 for Sinana, Selka and for combined data over locations respectively. Also the range and mean values for the characters studied are shown in Appendix 7 and 8 for Sinana and Selka respectively while, Table 4 for combined data locations. Analysis of combined over locations ANOVA showed significance differences for genotypes interaction with locations for traits such as; HLW, WGL and SDS. However, for traits such as; TKW, VTR, GPC, ZI, GGL and ASC did not show significance differences.

The variability of accessions was also reflected in their Thousand Kernel Weight (TKW), which varied from 33.7 to 52.3 g with overall mean of 39.6 g for combined over locations data. Twenty one accessions (45%) had produced TKW heavier than the grand mean value. Accession (Acc5152) was produced heavier TKW (52.4 g) than checks and most of them showed competent with checks. Also the mean values for this trait was varied from 33.5 to 54.5 g at Sinana whereas, it was varied from 32.25 to 50.3 g at Selka. This result is in agreement with the report of Bemnet, et al., who reported TKW ranged from 33 g to 50 g. Again Mengistu, et al., reported a wider range of TKW in durum wheat landraces.

The grand mean at Sinana, Selka as well as overall mean of combined data for test Weight (HLW) was 79.2, 79.5 and 79.4 kg/hL respectively. But at Sinana the mean value varied from 70.0 to 86.4 kg/hL while, at Selka it ranged from 75.4 to 83.0 kg/L. The highest HLW recorded from Dire at Sinana, Selka as well as for combined data over locations. HLW is a primary factor in commercial grading of durum wheat because it is easy to measure and processing attributes such as semolina yield. This result is in agreement with the result reported by Tesfaye, et al. who reported the overall mean hectoliter weight of 80.06 kg/hL and the range was from 76.10 kg/hL to 83.1 kg/hL.

The results of the Vitreousity (VTR) of studied accessions showed highly significant differences was observed among the tested accessions and it varied from 20.85 to 97.15% for combined over locations data with the overall mean value of 86.5%. The minimum and maximum percent were recorded from Acc5591 and Acc242780 respectively. Most of accessions have more than 75% values which are good quality since it gives higher semolina yield during milling. The current result is in line with the result of Al-Saleh and Brennan who reported significant variation comparable to the present study with the mean value of 69% to 95% for Syrian bread wheat varieties.

Combined over locations data showed that, Protein Content (GPC) varied from 10.7% to 16.7% with the overall mean of 13.5%which was recorded from Acc242787 and Acc7010 respectively. Protein is a fundamental quality test of durum wheat since it forms the basis for payment to farmers and is related to its end product processing potential. The highest GPC was obtained from Acc7010 (17.3%) while, the lowest was recorded from Acc5152 (9.9%) at Sinana whereas; the highest and lowest GPC was recorded from Acc7010 (16.2%) and Acc7647 (10.5%) respectively at Selka. The result is in line with Ozbek, et al. who reported grains contain protein ranging from 8 to 20% and again Konopka reported grain protein content varied from 11.6% to 15.6% and was affected by cultivar and endosperm type. Generally, as different authors indicated that, protein quantity is influenced mainly by environmental factors and management factors whereas; the quality of the protein is largely genetically determine.

Zeleny Index (ZI) value varied from 45.1 mL to 80.4 mL with mean values of 61.3 for combined over locations. The highest value was recorded from Acc7010 while, the lowest value was recorded from Acc5152 and totally about 55% percent of genotypes recorded above 60% ZI indicated that good quality of genotypes for this trait. According to this author zeleny value usually ranges from 0 to 80 mL and below 20 is generally regarded as unsuitable for baking and pasta making.

When the starch and the water soluble proteins are washed out of dough, the residual viscoelastic mass that remains water insoluble protein fractions called gluten that, varied from 23.8 to 35.9% and 19.3% to 37.4% at Sinana and Selka with the mean values of 33.1% and 32.6% respectively. The highest values were recorded from Acc7665 and Acc8072 at Sinana and Selka respectively. Also for combined over locations data, it varied from 24.7% to 36.4%. Those accessions scored high gluten percent allows an important firmness and stability to pasta after cooking, whereas pasta made with weak gluten semolina tends to deteriorate rapidly and become soft. Differences in wheat properties are mainly due to variations in structure, amount and proportion of the different gluten proteins. Similarly, Mohammed, et al. reported WGL content of the genotypes ranged from 25.0% to 33.5% in durum wheat. Again, Rharrabti, et al. reported substantial variability in gluten strength and baking performance among durum wheat varieties.

Combined over locations data showed that Ash Content (ASC) value was ranged from 0.6 to 1.4 g with the grand mean value of 1.1 g and the minimum and maximum values were recorded from Acc5198 and Acc7010 respectively. Also it ranged from 0.7 g to 1.5 g at Sinana while, varied from 0.5 g to 1.5 g at Selka respectively. At Sinana, the overall mean value of ASC was slightly higher than at Selka and this might arouse from the mineral content of the soil which maximize ASC at the site.

The SDS sedimentation volume varied from 32.5 to 67.5 mL, 32.5 to 67.5 mL at Sinana and Selka with the mean values of 45.8 and 49.7 respectively. The Acc7673 at Sinana and Acc6974 at Selka recorded the minimum values whereas; Acc7010 recorded the maximum value of SDS at both locations. Combined over locations data, it varied from 34.3 to 68.8 mL. Totally the gluten strength assessment was done by sedimentation volume of whole grounded grain with protein detergent SDS. Similarly, Yonas, et al. reported wider variability of durum wheat genotypes for this trait. The observed signi icance differences among accessions for this quality trait indicated the presence of huge genetic variations among the tested accessions which in turn suggested that selection of lines with better quality would be possible within this germ plasm.

Variance components and coefficients of variation

The 20 studied characters showed homogenous error variances and quali ied for pooled analysis. All the characters exhibited accessions variance lower than that of the environmental variances. The combined over locations estimates of phenotypic (σ^2p), genotypic (σ^2g) and environmental (σ^2e) variances and Phenotypic (PCV) and Genotypic Coefficients of Variation (GCV) are given in Table 4, while for individual location the analyzed data are presented in Appendix 7 and 8.

The PCV values for traits such as HLW, DH and DM, PLH, GY, GFP, SPL, TKW, VTR and ASC were slightly higher than that of GCV values. The relatively larger differences between PCV and GCV for the rest of the traits suggested that, the high contribution of the environmental variance to the phenotypic variance. For most of traits, the PCV values were slightly higher than GCV values, indicating less in luence of environmental effects on the phenotypic expression. Alemayehu, et al. and Dawit, et al. also observed close difference between GCV and PCV in durum wheat genotypes.

According to Sivasubramanian and Madhavamenon, GCV and PCV categorized as high (>20%), moderate (10%-20%) and low (<10%). Based on these categories, high values of PCV were recorded for characters such as BM (22.9%), PTL (27.0%) and ASC (20.5%). Similar results were also reported by Kumar, et al. for HI and Singh, et al. reported for PTL where high values were computed for both GCV and PCV values. Moderate PCV values were obtained for traits such as GY, HI, SPL, SPS, KPS, TKW, VTR, GPC, ZI, GGL and SDS sedimentation whereas, moderate GCV values were observed for BM and GY, SPL, KPS, PTL, VTR, ASC and TKW. Alemayehu, et al. reported moderate GCV value for GY and BM. Again Bhushan, et al. reported the higher magnitudes of GCV and PCV for GY and BM, PTL and PLH.

Low GCV and PCV values were obtained for traits such as DH and DM, HLW, PLH, GFP and WGL. For WGL, genotype x location interaction of GCV values was negative. These negative numbers suggest the error in the size of sampling. Since the exact estimate of these squared numbers cannot be negative, if they appear they are interpreted as being estimate of variance which is equal to zero. In the current study, higher PCV compared to that of GCV were observed for most traits and this was probably associated to high environmental effect due to genotype interaction with location on the expression of traits. Low GCV and high PCV indicate the larger in luence of environment on the expression of these traits and practically difficult for their improvement *via* direct selection. Early generation selection for such traits based on phenotypic evaluation of single plants and/or in single environments might rarely been effective. Similarly, Graziani, et al. reported low PCV and GCV for PLH; Majumder, et al. for SPS; Bilgin, et al. for HLW and Mohammed, et al. for SDS, DH; Kumar, et al. for DH and DM, SPL and HLW in wheat germplasm. Similarly, Taneva, et al. reported low PCV values for WGL.

Heritability

Heritability estimate for characters under study for combined over locations is presented in Table 4. Dabholkar classified H^2 estimate as high (≥ 60%), moderate (30% to 60%) and low (≤ 30%). So based on this classi ication, DH (66.3%), PLH (61.1%), GY (86.6%), TKW (75.2%), VTR (75.8%) and ASC (61.5%) had high broad sense heritability values and this suggesting that, minor environmental effect, since genotypic variance was almost equal to phenotypic counterpart and characters were governed by additive genes and selection could be effective. Also it indicates the reliability with the genotype is to be recognized by its phenotypic expression. Also moderately high heritability broad sense were recorded for DM (45.9%), GFP (42.2%), SPL (50.0%), KPS (43.9%), HLW (44.5%), GPC (34.0%), ZI (41.6%) and GGL (49.9%) suggests that, these traits are still under genetic control and selection for these traits can be achieved through their phenotypic performance. Similarly, Xiao and He reported that, TKW is more heritable and stable under different environments than other yield components. Also Graziani, et al. Mengistu, et al.; Kumar, et al.; Mansouri, et al. and Zaim, et al. were reported the high heritability of DH, PLH, TKW and GY.

Low heritability was recorded for characters such as SDS, BM, HI, WGL, PTL and SPS suggesting selection for these characters would not be effective due to predominant effects of non-additive genes in this population. SDS sedimentation had low heritability which is in contradiction to the results of Clarke, et al. who reported high heritability for this trait [19]. This might be due to variations of in luences of other characters on SDS trait. Generally, heritability is an indicator for transfer of traits from parents to its progeny. Similar results of low heritability of PTL was reported in durum wheat that were evaluated previously by Dawit, et al. and contradicting result for GY and BM, low heritability that was reported by the same authors. Gonzalez-Ribot, et al. reported low heritability values for SPS and GY and Sa i, et al. reported moderate heritability for GFP, SPS and SPL and also reported low genetic gain for DH, DM, PTL, SPS.

Estimates of expected genetic advance

Expected genetic advance as percent of the mean was estimated based on the results of combined analysis over locations. According to Johansen, et al., Genetic Advances as a percentage of the Mean (GAM) is classified as high (>20%), moderate (10 to 20%) and low (≤ 10%). Considering these ranges, high genetic advance estimates as percent of mean were recorded for GY (31.2%), VTR (29.3%) and ASC (25.9%). Similarly, Dawit, et al. reported high heritability for vitreousness. Genetic advance is the improvement in the mean of selected family over the base population and he showed that high heritability should be accompanied by high genetic advance to arrive at more reliable conclusion for wheat improvement *via* selection. High estimate of these traits indicate that whenever we select the best 5% of genotypes as parent for a given trait, genotypic value of the new population for the traits will be improved highly.

Moderately high genetic advance as a percent of mean was obtained for TKW (16.49%), BM (11.81%), KPS (15.38%), GGL (11.10%), SPL (16.32%), PTL (10.68%), and ZI (11.25%). This suggests that, these traits are primarily under genetic control and selection for these traits can be achieved through their phenotypic performance. However, low estimate of genetic advance as a percent of mean was observed for DH and DM, PLH, HI, GFP, SPS, HLW, GGL, WGL and for SDS suggesting that, these traits are not under genetic control and direct selection for these traits are difficult through their phenotypic performance. Arya, et al. and Safi, et al. found the lowest genetic advance as percent of mean value for days to maturity (9.44%), days to heading and spikelets/spike.

Characters such as GY, VTR, ASC, TKW, SPL, KPS, GGL and ZI showed high to moderate broad sense heritability coupled with high to moderate genetic advance. This indicates that, high heritability coupled with high genetic advance reveals the additive gene effects. The results are in accordance with Singh, et al. who reported high heritability coupled with high genetic advance as percentage of mean for KPS, TKW and GY and Taneva, et al. and Bilgin, et al. reported for GY and TKW.

Lowest heritability coefficient coupled with lowest genetic advance was found for the traits such as SDS and WGL. The influence of non-additive gene actions in inheritance of these traits are prevailing and the effective selection of genotypes by phenotype in early generation will be not possible. Totally, high heritability coupled with high Genetic Advance as percentage of Mean (GAM) are more useful than heritability alone in predicting the resultant effect during selection of best individual genotype. The lowest heritability coefficient coupled with lowest genetic advance was reported by Dawit, et al.

Conclusion

The great wealth of morphological diversity in Ethiopian durum wheat landraces may be attributed to the interacting effects of the wide diversity in natural environments natural cross-fertilization as a result of growing mixed genotypes in the field, and/or differences in agricultural practices of smallholding farmers. This high genetic diversity should be exploited in improvement programs to reduce heavy reliance on exotic materials, which often fail to adapt to the wide agro ecological and climatic variations of Ethiopia. The diversity among landraces for days to maturity and degree of seed shriveling enabled us to select a subset of characterized landraces for further study of behavior under terminal drought, a condition that leads to severe yield loss. Selection from the landraces for immediate access to locally adapted varieties through participatory varietal selection could help farmers adapt their crops to the harsh growing conditions of northern Ethiopia. For breeding purposes and further genetic studies, we have selected 50 diverse landraces, based on investigated traits from different districts of origin and altitude classes, and crossed them to "Asassa", an elite improved durum wheat variety. We are currently growing F6 populations of each cross with more than 130,000 individual variants.

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