iResearch
2026, Vol. 1, No. 1, pp. 47–57
https://doi.org/10.11648/j.ir.20260101.16

Research Article

Morphological Characteristics and Performance Evaluation of Sorghum (Sorghum Bicolor (L.) Moench) Yield and Yield Related Traits in Kurmuk District, North West Ethiopia

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Abstract

Knowledge of genetic variability enables plant breeders to identify superior traits and facilitate gene introgression from diverse germplasm into breeding programs. Accordingly, a field experiment was undertaken at the Fladulife testing site in Kurmuk district, northwestern Ethiopia, during the 2020/21 cropping season. This research assessed the extent of variability among sorghum accessions for key qualitative and quantitative characteristics. The experiment comprised seventeen sorghum accessions arranged in a randomized complete block design with three replications. Vegetative stage observations showed that 70% of accessions had white midribs, 66% elliptical heads, 57% small seeds, 86% lacked awns, and 98% exhibited tanned leaf pigmentation. Reproductive traits also varied, with 73% compact ear heads, 62% dark brown glumes, and 50% pearly white seeds, reflecting significant qualitative diversity across the accessions. Phenological assessment revealed that most accessions matured between 90 and 120 days, placing them within the medium-maturing category. Yield performance analysis identified ADM1, ADM2, ADM5, ADM6, ADM8, ADM10, ADM16, and ADM17 as low-yielding, whereas ADM4, ADM7, and ADM14 produced intermediate grain yields. The highest grain yield was obtained from accession ADM4, followed by ADM14, suggesting their superior agronomic potential for breeding. Agronomic and morphological assessments have provided a more precise estimation of genetic diversity, constituting the fundamental resource for breeding programs and variety development. The variability identified in this study should be emphasized when formulating breeding strategies for grain yield improvement. To this end, the collection, conservation, and strategic utilization of available germplasm across the study area are imperative.

Keywords

Breeder, Cereal, Drought, Ethiopia, Tropical

1. Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is a widely grown cereal staple in the semi-arid tropics of Asia, Africa, and Central America [13, 31]. Ethiopia, recognized as a center of origin and diversity, possesses extensive genetic variation among domesticated and wild sorghum relatives [2]. The crop is a critical food and cash source for smallholder farmers in drought-prone regions with unreliable rainfall, where alterna-

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Received: 14 August 2026; **Accepted:** 31 August 2026; **Published:** 20 September 2026

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tives such as maize are often unsuitable [6]. Ethiopian sorghums are notable for their diversity in traits conferring drought tolerance [2], disease resistance [24, 32], and improved nutritional quality [26]. Moreover, sorghum's lower water requirement compared to most cereals renders it a promising option for augmenting food and feed resources in marginal environments.

Sorghum productivity remains suboptimal, primarily due to the use of low-yielding landrace germplasm, cultivation on inherently infertile soils, and exposure to erratic rainfall and temperature stress. Adoption of improved technologies, including inorganic fertilizers and enhanced seed varieties, remains limited among smallholder farmers [23], while pest and disease infestations further undermine yields [19]. Broad genetic diversity constitutes the foundational gene pool for developing new varieties with essential agronomic traits. Adequate knowledge of genetic variability allows breeders to select desirable traits and introgress genes from distantly related germplasm [18]. Thus, systematic collection, assembly, and comprehensive phenotypic and genotypic characterization are critical steps in any well-designed crop improvement program. Such characterizations are essential prerequisites for the effective utilization of genetic resources through conventional breeding approaches. Reliable estimates of genetic variability, heritability, and genetic advance are prerequisites for successful genetic improvement of quantitative traits. This study was therefore conducted to evaluate sorghum accessions for variability in key qualitative and quantitative characteristics. The findings aim to support the selection of high-yielding accessions and desirable traits for future breeding and variety development.

2. Materials and Methods

2.1. Description of the Study Area

A rain-fed field experiment was carried out at Kurmuk district in the Assosa zone of northwestern Ethiopia over the 2020 and 2021 cropping seasons. Kurmuk is bounded by Sudan in the north and west, Sherkole in the east, Komesha in the southeast, and Assosa in the south. The district lies 757 km from Addis Ababa and 96 km from Assosa, the regional administrative center. The district has a total population of 26,692 (12,666 male; 14,026 female) and 2,525 households, of which 2,158 are male-headed and 357 female-headed; Islam is the predominant faith. The soils are largely sandy-textured, with low fertility and poor water-holding capacity, often resulting in crop failure [8]. The population relies primarily on crop production, traditional gold mining, and livestock rearing for their livelihoods. Maize, sorghum, haricot bean, sesame, noug, millet, and groundnut are the main annual crops, all produced during the Meher season (April-September/October). Other income-generating activities include small-scale gold mining, collection of wild foods-increasingly threatened by deforestation, fire, and settlement and wage labor [21].

2.2. Materials and Experimental Design

The trial comprised seventeen sorghum accessions (ADM1 to ADM17), assembled from Assosa Zone, arranged in a randomized complete block design with three replications. Each genotype was grown in 16.875 m^2 plots (4.5 m width × 3.75 m length) with 75 cm inter-row and 15 cm intra-row spacing, followed by thinning to achieve 15 cm between plants within rows. Standard agronomic practices, including hoeing and weeding, were performed as needed. Visual observations were conducted to monitor disease and insect pest occurrence.

Table 1. *Sorghum (Sorghum bicolor (L.) Moench) accessions and their area of collection.*

No	Accessions	Region	Woreda	District site	Latitude	Longitude
1	ADM1	Benishangul	Bambasi	Mender48	9 °47. 42″ N	34 °47. 32″ E
2	ADM2	Benishangul	Bambasi	Mender49	9 °49. 48″ N	34 °49. 45″ E
3	ADM3	Benishangul	Homesha	Ashula	10 °33.25’’ N	34 °23. 50’’E
4	ADM4	Benishangul	Homesha	Tsore	10 °37.15’’N	34 °26. 50’’E
5	ADM5	Benishangul	Abrahamo	Afa	10 °30.28’’N	34 °22.43’’E
6	ADM6	Benishangul	Abrahamo	Neaba	10 °30.35’’ N	34 °23. 43’’E
7	ADM7	Benishangul	Homesha	Molomengele	10 °35.25’’ N	34 °27. 50’’E
8	ADM8	Benishangul	Menge	Tomedibukarii	10 °39.15’’ N	34 °24. 35’’E
9	ADM9	Benishangul	Menge	Deberona	10 °5.66’’ N	34 °33. 55’’E
10	ADM10	Benishangul	Assosa	Amba7	10 °5.59’’ N	34 °33. 48’’E

No	Accessions	Region	Woreda	District site	Latitude	Longitude
11	ADM11	Benishangul	Assosa	Amba14	10 °39. 59'' N	34 °19. 48''E
12	ADM12	Benishangul	Assosa	Amba8	10 °38. 57'' N	34 °18.41''E
13	ADM13	Benishangul	Ura	Tsansahilu	10 °5. 76'' N	34 °33. 32''E
14	ADM14	Benishangul	Ura	Afeawansho	10 °4. 58'' N	34 °23. 58''E
15	ADM15	Benishangul	Ura	Alugo	10 °5. 43'' N	34 °35.44''E
16	ADM16	Benishangul	Ura	Agusha	10 °5. 67'' N	34 °30. 47''E
17	ADM17	Benishangul	Ura	Bashabuda	10 °4. 54'' N	34 °32. 47''E

2.3. Data Collection and Measurements Data Collection and Measurements

2.3.1. Crop Phenology and Growth Traits

Days to 50% flowering, days to 90% maturity, leaf number per plant, plant height (cm), leaf length (cm), leaf width (cm), head length (cm) and panicle length (cm).

2.3.2. Yield and Yield Component

Data were collected for agronomic traits including seed per panicle, head weight, thousand seed weight (TSW), and grain yield (kg/ha). Morphological characterization encompassed leaf orientation, leaf color, midrib color, ear head shape, seed size, awn presence, leaf pigmentation, ear head compactness, and glum color.

Morphological traits: morphological traits recorded were leaf orientation, leaf color, mid rib color, ear head shape, seed size, presence of awns, leaf pigmentation, ear head compactness and glum color.

2.4. Statistical Analysis

Data were subjected to analysis of variance (ANOVA) appropriate to factorial experiment in RCBD according to the General Linear Model (GLM) of GenStat15th edition (Gen Stat, 2020) and interpretations were made following the procedure described by [14, 15]. Whenever the effects of the treatments were found to be significant, the means were compared using the Least Significant Differences (LSD) test at 5% probability level. The estimation of genetic parameters were done to identify and ascertain the genetic variability among the accessions and to determine the extents of environmental effect on various characters. Variance components due to phenotype $(\sigma 2p)$, genotype $(\sigma 2p)$ and the environment $(\sigma 2e)$ were calculated by adopting the following formula.

$$Genotypic\ \ variance\ \ (\sigma 2g)\ = \frac{MSg-MSe}{r}$$

$$Phenotypic\ \ variance\ \ (\sigma 2p)\ = \sigma 2g\ + \sigma 2e$$

$$Environmental\ \ variance\ \ (\sigma 2e)\ = \ Error\ \ mean\ \ square$$

Where,

$$MSg\ = \ Mean\ \ squares\ \ due\ \ to\ \ genotypes$$

$$MSe\ = \ mean\ \ squares\ \ due\ \ to\ \ error$$

$$r\ = \ Number\ \ of\ \ replications$$

According to Sigh, (2001) the phenotypic genotypic coefficients of variances were expressed as:

$$PCV = \frac{\sqrt{Phenotypic\ \ variance}}{Population\ \ mean\ \ for\ \ trait} or\ \ PCV\ = \frac{\sigma 2P}{X} x\ \ 100$$

Where PCV= phenotypic coefficient of variation

$$GCV = \frac{\sqrt{Genotypic\ \ variance}}{Population\ \ mean\ \ for\ \ trait} or\ \ GCV = \frac{\sigma 2g}{x}\ x\ 100$$

Where GCV= Genotypic coefficient of variation

$$x = the\ \ grand\ \ mean\ \ of\ \ a\ \ character$$

Heritability in broad sense was calculated for each trait by using the formula [3] as:

$$H^2\ (\%) = \frac{\sigma 2g}{\sigma 2p}\ x100$$

Where:- H = Heritability in broad sense, σ^2g = genotypic variance, $\sigma^2{}_p$ = Phenotypic variance

Genetic advance (GA) under selection, assuming the selection intensity of 5% was calculated as proposed by [17] as:

$$GA = K.\sqrt{\sigma 2p}.\frac{\sigma 2g}{\sigma 2p} = K.H^*\sqrt{\sigma 2p}$$

Where, GA = Expected genetic advance, K = the selection differential (K= 2.06 at 5% selection intensity).

Genetic advance as percent of mean was calculated to compare the extent of predicted advances of different traits under selection, using the formula given by [12] as:

$$GAM = \frac{GA}{x} X\ 100$$

GAM = Genetic advance as percent of mean
GA = Genetic advance under selection
X = Mean value

3. Results

3.1. Qualitative Traits

Qualitative characterization revealed notable diversity among the 17 sorghum accessions. Midrib color distribution was 70% white, 20% green, and 10% purple. Ear head shapes comprised 66% elliptical, 20% oblong, 12% ovate, and 3% round. Seed size classes included 57% small, 33% medium, and 10% large. The majority of accessions were awnless (86%), while 14% bore awns. Tanned leaf pigmentation was recorded in 98% of accessions, with only 2% non-tanned. Ear head compactness varied as 73% compact, 15% loose, and 12% semi-compact. Glume color distribution was 62% dark brown, 14% brown, 13% black, and 11% red. Mature seed color comprised 50% pearly white, 29% white, and 21% orange.

***Table 2**. Frequencies of qualitative characters studied in 17 sorghum accessions.*

Character	Variable	Frequencies (%)	Character	Variable	Frequencies (%)
Leaf orientation	Erect	66	Presence of owns	Absent	86
	Drooping	34		Present	14
Leaf color	Dark green	84	Leaf pigmentation	Tan	98
	Light green	16		Non tan	2
Mid rib color	White	70	Ear head compactness	Compact	73
	Green	20		Loose	15
	Purple	10		Semi-compact	12
Ear head shape	Elliptical	66	Glum color	Dark brown	62
	Oblong	20		Brown	14
	Ovate	11		Black	13
	Round	3		Red	11
Seed size	Small	57	Seed color	Pearly	50
	Medium	33		White	29
	Large	10		Orange	21

3.2. Quantitative Traits

Analysis of variance

Analysis of variance for agronomic traits (Table 3) revealed significant mean squares due to sorghum accessions for most traits, except leaf number, leaf width, panicle length, and head weight. This indicates substantial variation among accessions, likely attributable to inherent genetic differences. The presence of significant genetic variability for yield and yield-related traits suggests that the current population holds promising genetic resources for sorghum improvement programs.

Table 3. *Mean squares from analysis of variance for agronomic traits of sorghum accessions.*

Trait	Replication (DF=2)	Accession (DF=16)	Error (DF=32)	CV (%)	Grand mean
Days to flowering	9.43	105.09*	48.24	10.16	68.39
Days to maturity	3.37	109.71*	62.56	6.99	113.20
Leaf number	34.82	14.32NS	10.68	22.22	14.71
Leaf length	19.43	430.46*	125.39	15.43	72.55
Leaf width	1.43	3.74NS	2.07	24.19	5.95
Plant height	1004.49	3873.19*	2142.62	20.06	230.75
Head length	0.32	19.16*	9.13	14.82	20.40
Panicle length	48.70	7.45NS	6.61	12.33	20.85
Seeds per panicle	22883.80	71481.80*	32972.10	8.67	2093.30
Head weight	668.18	697.75NS	610.09	14.10	175.12
Thousand seed weight	2.02	34.03*	14.69	13.58	28.22
Grain yield	209183.00	1145965.00*	559305.00	23.52	3179.70

*= significant at 5% probability level, NS = not significant, DF = degree of freedom
CV= Coefficient of variation

3.3. Crop Phenology and Growth Traits

3.3.1. Days to Flowering and Maturity

Accessions exhibited significant variation in days to flowering (57.0-76.3 days) and maturity (103.0-127.0 days), as shown in Table 4. ADM4, ADM7, and ADM14 were earlier flowering (< 60 days), while all others flowered at ≥ 60 days. None of the accessions qualified as early-maturing (< 90 days). The majority matured within 90-120 days, suggesting medium maturity, whereas ADM1, ADM2, and ADM16 were late-maturing, taking > 120 days to reach physiological maturity.

3.3.2. Leaf Number and Leaf Length

Analysis of variance (Table 4) revealed that sorghum accessions did not differ significantly for leaf number per plant; however, significant differences were observed for leaf length. Leaf length ranged from 60.67 to 99.33 cm across accessions. The longest leaves were recorded for ADM4 (99.33 cm) and ADM14 (95.67 cm), though their difference was not statistically significant, while the shortest leaves were observed in ADM3 (60.67 cm).

3.3.3. Leaf Width and Plant Height

Sorghum accessions were significantly differed for plant height (Table 4). Mean plant height ranged from 176.67 cm (ADM5) to 306.00 cm (ADM14). Three accessions (ADM1, ADM5, ADM16) exhibited short stature (< 200 cm), while the majority had heights between 200 and 300 cm. ADM14 recorded the maximum height (306.00 cm), followed by ADM4 (298.33 cm), whereas ADM5 produced the shortest plants (176.67 cm).

Table 4. Mean performance of sorghum accessions for days to flowering, days to maturity, leaf number, leaf length, and leaf width and plant height.

Accession	Days to flowering	Days to maturity	Leaf number	Leaf length (cm)	Leaf width (cm)	Plant height
ADM1	76.33a	127.00a	12.00	65.00c	4.43	192.00cd
ADM2	75.33a	120.67a-c	13.33	61.67c	5.10	210.00cd
ADM3	65.67a-e	114.00a-e	15.00	60.67c	5.45	255.00a-c
ADM4	57.00e	103.00e	19.00	99.33a	8.33	298.33ab
ADM5	70.33a-d	108.33c-e	13.00	66.00c	6.17	176.67d
ADM6	71.67ab	108.67b-e	13.00	67.00c	5.15	220.00cd
ADM7	59.00de	106.67de	16.67	91.67ab	6.83	264.00a-c
ADM8	67.33a-e	112.67b-e	14.33	75.67bc	5.53	232.00a-d
ADM9	65.35a-e	117.67a-d	17.33	71.33c	7.63	252.67a-d
ADM10	71.67ab	114.00a-e	15.68	71.33c	5.52	226.00b-d
ADM11	71.67a-e	111.67b-e	16.33	76.67bc	5.28	203.67cd
ADM12	69.00a-d	112.00b-e	13.33	71.00c	6.12	240.00a-d
ADM13	70.33a-c	109.67b-e	13.33	70.00c	5.53	204.00cd
ADM14	59.67c-e	107.67c-e	18.67	95.67a	8.00	306.00a
ADM15	65.67b-d	116.00a-e	13.33	63.67c	5.22	238.33a-d
ADM16	75.67a	121.67ab	13.00	64.00c	4.99	199.67cd
ADM17	73.33ab	113.00b-e	12.67	62.67c	5.80	204.33cd
LSD	11.55	13.15	NS	18.62	NS	76.98
CV (%)	10.16	6.99	22.22	15.43	5.95	20.06

Means labeled by different superscript letters in the columns are significantly different according to Turkey's Student Range Test (< 0.05) and TSW; thousand seed weight. LSD= least significant difference, CV=coefficient of variation, NS=not significant

3.3.4. Head Length and Panicle Length

Analysis of variance (Table 5) revealed significant differences among sorghum accessions for head length, which ranged from 16.83 to 25.97 cm. The longest head was recorded for ADM4 (25.97 cm), followed by ADM14 (24.33 cm), while the shortest head (16.83 cm) was observed in ADM16. However, panicle length did not differ significantly among accessions.

3.3.5. Seeds Per Panicle, Head Weight and Thousand Seed Weight

Analysis of variance indicated significant differences among accessions for seeds per panicle and TSW, ranging from 1843 to 2383 seeds and 21.67 to 34.00 g, respectively. ADM7 exhibited the maximum seeds per panicle (2383), while ADM14 produced the highest TSW (34.00 g), followed by ADM4 (2360 seeds; 33.67 g). The lowest values were recorded for ADM16 (seeds per panicle) and ADM2 (TSW). Mean head weight, however, was not significantly affected by accession. (Table 5).

3.3.6. Grain Yield

Analysis of variance revealed significant differences in grain yield among accessions, with mean values ranging from 2098 to 4300 kg/ha (Table 5). ADM1, ADM2, ADM5, ADM6, ADM8, ADM10, ADM16, and ADM17 were low-yielding (< 3000 kg/ha), whereas ADM4, ADM7, and ADM14 were high-yielding (> 4000 kg/ha). The highest grain yield was recorded for ADM4 (4300 kg/ha), followed by ADM14 (4265 kg/ha), while ADM2 yielded the lowest (2098 kg/ha). Comparable reductions in panicle length, panicle weight, and grain yield per panicle have been documented [11, 14, 16, 22].

Table 5. Mean performance of sorghum accessions for yield components and yield.

Accession	Head length (cm)	Panicle length (cm)	Seeds per panicle	Head weight (g)	TSW (g)	Grain yield (kg/ha)
ADM1	17.33d	18.67	1906de	173.67	23.33ef	2307de
ADM2	16.92d	19.95	1900de	167.67	21.67f	2098e
ADM3	20.03b-d	22.67	2117a-e	181.33	28.33a-e	3146a-e
ADM4	25.97a	24.67	2360ab	192.67	33.67ab	4300a
ADM5	19.12cd	19.67	2104a-e	170.67	27.00c-f	2904b-e
ADM6	18.55cd	19.67	2020c-e	172.67	26.67c-f	2749c-e
ADM7	23.50a-c	22.00	2383a	192.00	33.00a-c	4145ab
ADM8	21.45a-d	21.00	2087a-e	178.33	28.00a-f	2957b-e
ADM9	21.25a-d	21.00	2180a-d	180.00	30.33a-d	3571a-c
ADM10	20.28b-d	19.50	2053c-e	176.33	27.33b-f	2801c-e
ADM11	20.33b-d	21.67	2062b-e	177.67	27.00c-f	3226a-e
ADM12	20.42b-d	22.52	2028c-e	187.33	26.67c-f	2976b-e
ADM13	21.84a-d	19.50	2114a-e	180.33	28.33a-e	3225a-e
ADM14	24.33ab	21.00	2299a-c	191.33	34.00a	4265a
ADM15	19.67b-d	21.67	2180a-d	128.00	31.33a-d	3450a-d
ADM16	16.83d	18.42	1843e	159.67	26.67c-f	2983b-e
ADM17	18.92cd	21.00	1950de	167.67	26.33d-f	2953b-e
LSD	5.02	NS	302	NS	6.37	1243
CV (%)	14.10	12.33	8.67	14.10	13.58	23.52

Means labeled by different superscript letters in the columns are significantly different according to Turkey's Student Range Test (< 0.05) and TSW; thousand seed weight. LSD= least significant difference, CV=coefficient of variation, NS=not significant

3.4. Variance Components

3.4.1. Phenotypic and Genotypic Variations

Phenotypic variance (σ^2P) among sorghum accessions ranged from 2.63 (leaf width) to 45,808.67 (seeds per panicle), with higher values (≥ 100) recorded for leaf length, plant height, seeds per panicle, head weight, and grain yield (Table 6). A substantial disparity between genotypic and environmental variances was observed for days to flowering, days to maturity, leaf number, leaf length, plant height, head length, seeds per panicle, head weight, and grain yield. This pronounced environmental influence on trait expression underscores the necessity for genotype × environment interaction analysis in breeding programs aimed at improving morpho-physiological, yield, and yield-associated traits to identify stable genotypes. Similar findings have been reported by [5, 10, 14, 30].

Moderate phenotypic variance (50-100) was observed only for days to flowering and days to maturity, while low phenotypic variance (< 50) was recorded for leaf number, leaf width, head length, panicle length, and TSW. Genotypic variance ranged from 0.28 to 12,836.57, with higher values for leaf number, plant height, seeds per panicle, and grain yield, and no moderate genotypic variance was observed. Low genotypic variance was exhibited by days to flowering, days to maturity, leaf number, leaf width, head length, panicle length, head weight, and TSW.

Phenotypic coefficient of variation (PCV) ranged from 7.82% (days to maturity) to 27.32% (grain yield) (Table 6). According to Siva Subramanian and Madhavamenon (1973), PCV > 20% is considered high, 10-20% moderate, and < 10% low. Based on this classification, leaf number, leaf length, leaf width, plant height, and grain yield exhibited high PCV. Days to flowering, head length, panicle length, head weight, and TSW showed moderate PCV, while days to maturity recorded low PCV (< 10%).

This suggests a strong environmental influence on the expression of these traits. Genotypic coefficient of variation (GCV) ranged from 2.54% to 13.91%, with moderate GCV recorded for leaf length, leaf width, plant height, and grain yield. In contrast, days to flowering, days to maturity, leaf number, head length, panicle length, seeds per panicle, head weight, and TSW exhibited low GCV. Notably, no trait displayed high GCV (Table 6).

3.4.2. Broad Sense Heritability and Genetic Advance

Broad-sense heritability estimates (H^2) ranged from 4.06% (panicle length) to 44.78% (leaf length), as presented in Table 8. Higher values indicate greater selection response, consistent with findings for plant height [13, 25]. Moderate H^2 was observed for leaf length and TSW, likely attributable to environmental effects on polygenic traits. Conversely, low heritability was recorded for days to maturity, leaf number, leaf width, plant height, head length, panicle length, seeds per panicle, head weight, and grain yield, limiting their use in breeding programs. This low heritability suggests that environmental variance predominates over genotypic variance for these traits.

Genetic advance as a percentage of the mean ranged from 0.59% (seeds per panicle) to 19.16% (leaf length), as shown in Table 6. This implies that selecting the top 5% of accessions could result in a gain of 0.59-19.16% over the population mean. Following [28] classification, moderate genetic advance (10-20%) was observed for leaf length, leaf width, TSW, and grain yield. Low genetic advance (< 10%) was recorded for days to flowering, days to maturity, leaf number, plant height, head length, panicle length, seeds per panicle, and head weight.

Table 6. *Phenotypic and genotypic coefficient of variability, heritability and genetic advance for sorghum accessions.*

Trait	σ2p	σ2g	σ2e	PCV (%)	GCV (%)	H^2 (%)	GA	GA (%)
Days to flowering	67.19	18.95	48.24	11.98	6.36	28.20	4.76	6.96
Days to maturity	78.28	15.72	62.56	7.82	3.50	20.08	3.66	3.23
Leaf number	11.89	1.21	10.68	23.44	7.47	10.18	0.72	4.89
Leaf length	227.08	101.69	125.39	20.77	13.89	44.78	13.90	19.16
Leaf width	2.63	0.56	2.07	27.26	12.58	21.29	0.71	11.93
Plant height	2719.48	576.86	2142.62	22.60	10.41	21.21	22.79	9.88
Head length	12.47	3.34	9.13	17.32	8.96	26.78	1.95	9.56
Panicle length	6.89	0.28	6.61	12.59	2.54	4.06	0.22	1.06
Seeds per panicle	45808.67	12836.57	32972.10	10.22	5.41	28.02	12.35	0.59
Head weight	639.31	29.22	610.09	14.44	3.09	4.57	2.38	1.36
TSW	21.14	6.45	14.69	16.29	8.99	30.51	2.89	10.24
Grain yield	7548.30	1955.33	5593.00	27.32	13.91	25.91	46.37	14.60

3.4.3. Correlation of Agronomic Traits

The correlation matrix for agronomic traits (Table 7) showed r values from -0.96 to 0.97. Grain yield exhibited significant positive associations with leaf number (0.80), leaf length (0.82), leaf width (0.83), plant height (0.80), head length (0.89), panicle length (0.63), seeds per panicle (0.90), head weight (0.90), and TSW (0.97), indicating their importance as direct selection criteria in sorghum breeding. Conversely, days to flowering (-0.92) and days to maturity (-0.67) were negatively correlated with yield, serving as indirect selection criteria. Comparable findings were reported by [7] for flowering and maturity, and [33] for maturity, flowering, and plant height under moisture stress.

Table 7. *Correlation of agronomic traits of sorghum accessions.*

Trait	DF	DM	LN	LL	LW	PH	HL	PL	SPP	HW	TSW	GY
Days to flowering (DF)	-	0.69*	-0.80*	-0.81*	-0.83*	-0.88*	-0.92*	-0.75*	-0.96*	-0.42^{NS}	0.59*	-0.92*
Days to maturity (DM)		-	-0.53*	-0.66*	-0.62*	-0.49*	-0.76*	-0.57*	-0.73*	-0.47^{NS}	-0.66*	-0.67*
Leaf number (LN)			-	0.84*	0.83*	0.82*	0.83*	0.60*	0.78*	0.56*	0.76*	0.81*
Leaf length (LL)				-	0.79*	0.76*	0.89*	0.54*	0.80*	0.63*	0.76*	0.82*
Leaf width (LW)					-	0.78*	0.84*	0.59*	0.79*	0.56*	0.78*	0.83*
Plant height (PH)						-	0.81*	0.70*	0.78*	0.44^{NS}	0.81*	0.80*
Head length (HL)							-	0.69*	0.91	0.60*	0.87*	0.89*
Panicle length (PL)								-	0.67*	0.33^{NS}	0.59*	0.63*
Seeds per panicle (SPP)									-	0.41^{NS}	0.91*	0.90*
Head weight (HW)										-	0.31^{NS}	0.90*
TSW											-	0.97*
Grain yield (GY)												-

4. Discussion

Morphological characterization using sorghum descriptors including leaf orientation, leaf color, midrib color, ear head shape, seed size, awn presence, leaf pigmentation, ear head compactness, glume color, and seed color revealed substantial variability among genotypes, consistent with reports by [4, 13, 20]. ANOVA for quantitative traits showed significant differences among accessions for most traits, except leaf number, leaf width, panicle length, and head weight (Table 3), indicating considerable genetic variation attributable to inherent differences. Similar significant differences for days to flowering, days to maturity, plant height, head weight, TSW, and grain yield have been reported by [1, 9, 14, 29].

Except for three late-maturing genotypes, the majority of accessions were medium-maturing, and the observed variability in days to flowering and maturity provides a basis for developing environment-specific cultivars, as similarly reported by [29]. Significant differences in plant height (Table 4) allow for strategic selection: tall genotypes are suited for fodder, fuelwood, and building materials [31], while short genotypes are associated with drought adaptation [27].

The significant differences observed for grain yield and TSW (Table 5) suggest that superior accessions can be directly recommended for cultivation, while others hold potential as parental lines for further improvement. Considerable variation in phenotypic, genotypic, heritability, and genetic advance parameters was evident. These results inform parent selection strategies and introduce novel genetic variability for sorghum enhancement. Hybridization between genetically divergent parents is anticipated to produce transgressive segregants through recombination of beneficial alleles.

5. Conclusion

Sorghum accessions exhibited variability for qualitative and quantitative traits recorded and measured due to their genetic variability. Most of accessions reached their maturity within 90 to 120 days and could possibly be considered as relatively medium maturing genotypes. Accessions with relatively low yielder (< 3000 kg/ha) were ADM1, ADM2, ADM5, ADM6, ADM8, ADM10, ADM16 and ADM17. Likewise, accessions with relatively intermediate yielders were ADM4, ADM7 and ADM14 gave relatively higher (> 4000 kg/ha) grain yield over others. With respect to the overall effect, the highest grain yield (4300 kg/ha) was recorded for accession ADM4 followed by accession ADM14 with mean grain yield of 4265 kg/ha. Agronomic and morphological evaluations have provided more accurate estimation of genetic diversity, the raw material of plant breeding which could be exploited for variety development in breeding program. Conservation and utilization of available sorghum accessions in the collection areas must be given attention. Association of phenotypic variability with genetic analysis will also help for better conclusions. The high performing accessions of sorghum crops screened in this study should further be evaluated under a wide range of environments to find widely adapting accessions.

Abbreviations

ADM	Addiselem And Mesay
ANOVA	Analysis of Variance
GLM	General Linear Model
LSD	Least Significant Differences LSD
RCBD	Randomly Completed Blok Design

Acknowledgments

The authors acknowledge Assosa biodiversity center, especially, the Kurmuk district agricultural office for their valuable support in the data collection.

Author Contributions

Addiselem Yasin: Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Mesay Paulos: Conceptualization, Data curation, Formal Analysis , Investigation, Methodology

Conflicts of Interest

The authors declare no conflicts of interest.

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