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Evaluation of Elite Sorghum (*Sorghum* B*icolor (L) Moench)* Inbred Lines for Yield and Related Traits Under Moisture Stress Areas of Ethiopian

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Abstract

Drought is the major constraint for sorghum production in Ethiopia causing high yield loses every year. However, there were no more sorghum varieties developed and released in Ethiopia that can highly adapt drought stress and perform well in moisture stress areas. Therefore, developing and using drought tolerant or resistant sorghum varieties is one of the available solutions to cope with the effects of drought. The objectives of this study were to evaluate promising sorghum genotypes for drought tolerance and other agronomic traits. A total of 42 sorghum genotypes were evaluated in an alpha-lattice design with two replications in 2019 main cropping season at Mieso and Kobo. The combined analysis of variance revealed that there was a highly significant difference ($p<0.01$) among the genotypes for all the traits. Among the tested genotypes, the top better performing genotypes were 4x14 (6.32 tha^{-1}) followed by genotype 8x15(5.92 tha^{-1}), 1x15 (5.88 tha^{-1}), 13x14 (5.78 tha^{-1}) and 6x15 (5.57 tha^{-1}) with a yield advantage of 32.49%, 24%, 23%, 21% and 16.68% over the check (ESH4) (4.77 tha^{-1}), respectively. The sorghum genotypes showed substantial genetic variation for studied traits under drought stress condition and could be utilized by sorghum breeders to develop new and economically important sorghum varieties. Finally, the study identified the most promising and potential genotypes which could be exploited commercially after critical evaluation for their superiority and yield stability across the locations over years.

Keywords: Sorghum; Drought; Performance; Production constraints; Stability

Introduction

Sorghum [*Sorghum bicolor (L.) Moench*] is the fifth most important cereal grain after maize, rice, wheat and barley in the world (FAOSTAT, 2017). It has been grown as a staple food crop in most of Sub-Saharan Africa and Asia for generations. It can adapt to a wide range of conditions and can withstand high temperatures and drought. It grows in high-radiation environments with inadequate and erratic rainfall, as well as in soils with a weak structure, low fertility, and limited water-holding capacity. Sorghum is an important source of food and feed, especially in dry and semi-arid areas where other cereal crops such as maize and wheat fail to survive. Given recent climate change, sorghum cultivation could help to alleviate anticipated food shortages. More than 500 million people in underdeveloped nations, including Ethiopia, consume sorghum as their primary food source.

Sorghum is a staple grain grown for food and fodder in arid and semi-arid regions of Sub-Saharan Africa (SSA) and South Asia (SA). The most important abiotic factors affecting sorghum production potential in arid and semi-arid regions are drought and high temperatures, resulting in food and nutritional insecurity in SSA and SA. Drought is a long-term shortage of plant-available water caused by insufficient rainfall or precipitation. It can also happen when the evapotranspiration of plants is sped up due to unusually high temperatures and low humidity. Drought is a major environmental factor that affects agricultural growth and productivity around the world. Drought stress threatens several sorghum-producing regions in Africa [1].

Droughts are anticipated to become more common in future climates. Drought consequences and crop production effects, on the other hand, are determined by rainfall distribution patterns rather than total seasonal rainfall. As a result, drought has become a serious issue for crop growth and development, particularly in tropical areas. Drought stress impacts practically all phases of plant development; however, seed germination and early seedling growth phase as well as reproductive stages, especially in sorghum, are highly sensitive and crucial. Drought stress reduces carbon absorption, stomatal conductance, and cell turgor, lowering production and limiting crop growth and development. Wilting of leaves and a loss in leaf area are visible moisture stress signs on crop plants, as are flower production, sink numbers, and overall growth and yield [2].

Variety (using a population improvement strategy) and hybrid sorghum are the two types of products targeted by sorghum breeding programs (using a heterosis breeding approach). The type of product is also determined by the pattern of trait inheritance (additive and non-additive), the growing environment (homogeneous or heterogeneous), and the availability of agricultural inputs such as nutrients and moisture. Drought resistance in sorghum has been a long-term breeding goal for the crop. Because of the changing climate in sorghum-growing countries, breeding for high-temperature tolerance is becoming more popular. As a result, drought tolerance (staying green and yielding even when stressed) is better understood than high-temperature tolerance. However, both genetic and breeding gaps remain in addressing the required tolerance levels in cultivated sorghum varieties or hybrids

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in both stressors. Variability in rainfall patterns and increasing air temperature in semi-arid regions are linked to lower sorghum grain yields. As a result, it's critical to understand the characteristics and mechanisms that are affected directly or indirectly by drought and high temperatures in sorghum [3].

Understanding trait-associated mechanisms will help breeders build drought-resistant or high-temperature sorghum varieties or hybrids that can sustain grain yield. In general, compared to vegetative phases, reproductive stages of sorghum development are more vulnerable to environmental (abiotic) stimuli. The panicle development, flowering and grain filling phases of sorghum are drought stress-sensitive. Various biotic and abiotic factors contribute to the low productivity of sorghum. Among the abiotic factors, drought is the major cause for low productivity of the crop. Worldwide, the annual yield loss due to drought is estimated to be around 10billion US dollar. In Ethiopia it is a major problem leading to food shortages and challenging small-holder farmers in Ethiopia to produce enough sorghum grain when rainfall is low and erratic. The effect of drought on crop yield is dependent on the stage of plant development. Assefa (2010) has reported that water stress occurring during the vegetative stage alone could reduce yield by > 36% and > 55% at the reproductive stage. In Ethiopia, complete yield loss due to drought was recorded in some parts of the country, such as Mehoni area (EIAR, 2014) [4].

However, only a small number of drought tolerant varieties have been developed for enhancing sorghum production and productivity. In many areas where sorghum is produced, farmers continue to use their local varieties with low yield potential. Therefore, there is a need to increase productivity of this crop through development of high yielding varieties with resistance to drought and farmers preferred varieties. Drought tolerance in sorghum is a function of various physiological and morphological traits contributing towards tolerance. Evaluation of root characterized sorghum genotypes under target environments provides an opportunity to identify promising parental which combines desirable drought tolerance traits. However, very limited works have been done to evaluate Ethiopian sorghum germplasm for drought tolerance.

In sorghum, there are two primary types of drought responses including pre-flowering and post-flowering, which are under the control of two different sets of genetic mechanisms. Pre-flowering refers to the stage from panicle differentiation to flowering, while post-flowering refers to the stage between flowerings to grain development (GS-3). Pre-flowering drought tolerance responses of sorghum includes reductions in panicle size, seed number, and grain yield. Post-flowering drought tolerance encompasses rapid premature senescence, which leads to reductions in seed size, yield loss and stalk lodging. Efforts have also been made to develop early maturing sorghum varieties that are adapted to areas where regular moisture scarcity is detrimental to sorghum production. In Ethiopia, more than 51 early maturing sorghum varieties are currently available for use in such environments [5].

Despite, the long-term efforts made to breeding for tolerance to drought in sorghum, advances made in developing improved varieties with adequate levels of drought tolerance using indigenous landraces combined with farmers' and market-preferred grain, and above ground biomass traits have been limited. Farmers still prefer to plant local sorghum landraces rather than introduced varieties because local landraces produce larger volumes of biomass for animal fodder, fuel, and construction material in good cropping seasons. Therefore, sorghum breeding programs should ensure that the new varieties satisfy the preferences of the farmers through developing drought tolerant or resistant to create sustainable adaptation of the released varieties and their production packages [6].

Generally, sorghum genotypes characterized by early flowering and early maturity, small number of leaves per plant, small leaf area, erect leaf type, larger stem diameter, small number of productive tiller, small leaf area, high grain yield per unit area and short plant height are most suitable for lowland areas with a limited rain fall and short growing season. Hence, the development of locally adapted improved sorghum varieties to a particular environment is one solution to overcome the challenges of both local adaptation and local farmers' end user requirements. The objectives of the experiment were to evaluate the performance of elite sorghum genotypes for drought tolerance and identifying promising genotypes for drought prone areas.

Materials and Methods

Location of the experiment

A study was carried out in two different dry lowland sorghum growth environments. These were Mieso and Kobo, where sorghum is the primary crop and drought is a major productivity constraint. These sites represent the country's sorghum-growing regions in the east and north. Mieso is located 302 kilometers east of Addis Ababa, Ethiopia's capital city, in the Oromia regional state. Its elevation is 1470 meters above sea level, and it is located at 8°30 N latitude and 39°21′ E longitudes, with average maximum and minimum temperatures of 14.0°C and 30.01°C, respectively, with an average annual rainfall of 763 millimeters. Vertisols with a p^H of 5.4 are the most common soil type (EIAR, 2014). Kobo is located 437 kilometers north of Addis Ababa, Ethiopia's capital city, in the Amara regional state. It is located at 12°09 N latitude and 39°38′ E longitude and has an elevation of 1479 meters above sea level. With an average annual rainfall of 650mm and average maximum and minimum temperatures of 15.32°C and 30.24°C, respectively. Vertisols with a p^H of 5.8 are the most common soil type (EIAR, 2014) [7].

Genetic Materials Used for the Study

The experiment comprised two male parents and thirteen cytoplasmic male sterile lines as female parents, as well as their 26 hybrids and one control. In this experiment, a total of 42 genotypes were used, including hybrids, their parents, and checks. For the inclusion of desirable genes responsible for improving yield and other key traits, parental inbred lines were developed using pedigree breeding and back-crossing methods. TX-623B, P-9501B, P-9505B, P-9534B, P-851015B, P-850341B, P-9511B, B5, and B6 were introduced from Perdue University as cytoplasmic male sterile lines, which the sorghum improvement program is using for multiple breeding objectives, including hybrid development, whereas MARC1B, MARC2B, MARC3B, MARC6B were developed and released by National Sorghum coordinating center (Melkassa Agricultural Research Center) as cytoplasmic male sterile lines and ESH-4 hybrid was recently released and used as a standard check. Melkam and ICSR-14 are restorer lines for low moisture stress areas produced by Melkassa Agricultural Research Center and ICRISAT (India) respectively [8].

Experimental Design and Trial Management

During the 2019 cropping season, the experiment was designed using an alpha lattice (0, 1) design with two replications at two locations. Each genotype was planted in two 5m long rows with 75cm row spacing, giving a plot area of 7.5m^2. Each block was separated by a distance of one meter. There were seven plots per block and six blocks each replication in this experiment. Seeds were drilled at a rate of 12 $kgha^{-1}$ in each row. The seedlings were thinned to 0.20 m spacing between plants after three weeks after sowing. All of the standard agronomic packages were applied to basal, as well as fertilizer rates of 100 $kgha^{-1}$ DAP and 50 $kgha^{-1}$ urea. Nitrogen (urea) was applied three weeks following planting. All cultural and other management practices were carried out in accordance with the test locations' recommendations [9].

Data Collection

A random sampling technique with descriptors for sorghum was used to collect data on plot and plant bases (IBPGR/ICRISAT, 1993). The following standard procedures were used to collect the important yield and yield-related traits, as well as drought tolerance related traits:

Data collected on the basis of individual plants

Plant height (PH in cm): The height of the plant from the bottom to the tip of the panicle during flowering on 5 randomly tagged plants.

Panicle exertion (PE in cm): Panicle exertion measured between the bases of flag leaf to the bases of panicle from five randomly selected plants.

Panicle length (PL in cm): Distance from the panicle tip to the lowest panicle branch on five randomly tagged plants.

Panicle width (PW in cm): The average width of five randomly selected plants at the middle of the panicle (head).

Leaf length (LL in cm): Average length of the fourth leaf from the flag leaf on five randomly selected plants.

Leaf width (LW in cm): Average width of the fourth leaf from the flag leaf at the widest point of leaves on five randomly selected plants.

Total leaf area (LA in cm^2): Total leaf area computed as length × width of the fourth leaf from the flag leaf × 0.71 of randomly tagged five plants (Krishnamurthy *et al.*, 1974).

Panicle yield (PY in g): The weight of individual panicle measured using one randomly selected representative plant.

Data collected on the basis of plots

Days to flowering (DTF): Number of days from emergence till 50% of the plants in a plot showed flowering halfway down the panicle.

Days to maturity (DTM): The number of days from emergence to the date when 95% of the plants matured physiologically.

Stay green score (1-5): It was measured at maturity stage as a measure of stay green traits (Haussmann *et al.,* 1999).

Grain yield (GY): Grain yield obtained from total harvest of the plot and then converted to tha^{-1} after adjusting to optimum seed moisture content.

Thousands seed weight (TSW in g): The weight of 1000 grains sampled from a plot at 12.5% moisture content recorded in gram.

Analyses of Variances (ANOVA)

For both separate and combined across locations, analyses of variance were performed using the GLM procedure of SAS statistical version 9.4 (SAS, 2018) according to alpha lattice design. Prior to combining the data from the various environments, the error means were tested using Bartlett's test for homogeneity of variance (Steel and Torrie, 1980) and checked using F-test (ratio of the largest mean square error to the smallest mean square error is less than three or four) according to Gomez and Gomez, (1984). The test revealed that the error means were homogeneous for all traits, and the data were combined for further analyses. The least significant difference (LSD) test was used to compare mean genotypes at 1% and 5% levels of significance. Genotypes were used as a fixed component in this study, while locations, replications, and incomplete blocks within replications were used as random factors [10].

Analysis of variance for single location was done using the following model: $Yijl = \mu + \tau i + \gamma j + \rho l (j) + \varepsilon ijl$, Where; μ is the overall (grand) mean, τi is the effect due to the ith treatment, (i=1, 2, 3…, t), γj is the effect due to the j^{th} replication, and, (j=1, 2…, r), ρl (j) is block within replicate effect, εijl is the error term where the error terms, are independent observations from an approximately normal distribution with mean = 0 and constant variance σ^2 ε. Analysis of variance for combined locations was done using the following model:- $Yijkl = \mu + gi + sj + (g \times s) ij + r(s) jk + eijkl$, Where, Yijkl is the observation, μ is the overall mean, gi is the effect of the ith genotype, sj is the effect of the j^{th} site, (g × s) ij is the interaction effect of the i^{th} genotype by the j^{th} site, r(s) jk is the effect of the k^{th} replication within the j^{th} site and eijkl is the residual variance (Table 1).

Results and Discussion

Analyses of variance (ANOVA) for individual locations

The mean squares due to the different sources of variations were estimated as per standard the procedure of analyses of alpha-lattice design for individual location and combined over the two locations. The ANOVA results for individual location indicated that there were very highly significant differences among tested varieties for all traits at both locations (Table 2) indicating the wide genetic variation in all traits. Specifically, the mean squares due to genotypes revealed the existence of highly significant difference ($P < 0.01$) for days to 50% flowering, plant height (cm), panicle length (cm), panicle exertion (cm), panicle yield (g/plant), grain yield ($kgha^{-1}$) and thousand seed weight

Table 1: List of parents and hybrids with their symbolical representation.

Lines (code)	Name of parents and hybrids	Lines (code)	Name of parents and hybrids
1	TX-623	3x15	P-9505xICRA-14
2	P-9501	4x14	P-9534xMelkam
3	P-9505	4x15	P-9534xICRS-14
4	P-9534	5x14	P-851015xMelkam
5	P-851015	5x15	P-85101xICRS-14
6	P-850341	6x14	P-850341xMelkam
7	B5	6x15	P-850341xICRS-14
8	B6	7x14	B5xMelkam
9	Mar-01	7x15	B5xICRS-14
10	Mar-02	8x14	B6xMelkam
11	Mar-03	8x15	B6xICRS-14
12	Mar-06	9x14	MARC1xMelkam
13	P9511	9x15	MARC1xICRS-14
14	Melkam	10x14	MARC2xMelkam
15	ICRS-14	10x15	MARC2xICRS-14
16	ESH-4	11x14	MARC3xMelkam
1x14	TX-623xMelkam	11x15	MARC3xICRS-14
1x15	TX-623xICRS-14	12x14	MARC6xMelkam
2x14	P-9501xMelkam	12x15	MARC6xICRS-14
2x15	P-9501xICRS-14	13x14	P9511xMelkam
3x14	P-9505xMelkam	13x15	P9511xICRS-14

Table 2: Analysis of variance for yield and yield related characters of sorghum of individual location (Mieso and Kobo in 2019)

Traits	Mean squares									
	MS_R (DF=1)		$MSB_{(R)}$ (DF=10)		MS_G (DF=41)		MS_E(DF=31)		CV (%)	
	MI	KB	MI	KB	MI	KB	MI	KB	MI	KB
DTF	4.29	4.29	1.44	3.56	6.40**	12.85*	2.44	2.56	2.29	2.18
DTM	17.19	0.11	4.62	8.78**	9.86*	19.57**	5.69	2.98	2.21	1.52
PTH	2656.68**	120.9	50.21	81.04	2824.32**	5219.57**	69.01	75.61	4.61	4.37
SG	0.01	0.19	0.07	0.19	1.15**	0.51	0.09	0.44	7.36	18.93
PL	5.15	1.05	2.55	3.54	13.16**	17.32**	4.2	1.87	7.49	4.71
PW	28.35**	0.05	2.47**	1.03*	1.55*	3.08**	0.76	0.42	12.76	6.81
LA	24.88	46.74	600.34	2674.69	3486.39**	6771.79	426.1	3970.9	7.41	17.21
TL	21.00**	198.10*	0.72	29.76	6.44**	61.21*	12.29	35.37	30.03	30.05
PE	14.41**	17.01*	0.72	4.02	18.15**	13.75**	1.99	3.84	15.07	20.32
PY	34.2	385.71	27.83	358.19	808.07**	2363.67**	17.64	497.81	7.36	18.93
GY	1951.28*	3918.61	574.55	889.12	1129.39**	5863.35**	0.42	1.38	31.82	17.97
TSW	0.38	3.72	16.49	3.47	25.78**	46.54**	6.17	2.93	14.53	4.25

*, **- significant at 5% and 1% level respectively, MI= Mieso, KB= kobo, DTF = days to flowering, PHT = plant height, DTM = days to maturity, SG = stay green, PL = panicle length, PW = panicle width, LA = leaf area, TL=number of productive tiller, PE = panicle exertion PY = panicle yield, GY = grain yield, TSW = thousand seed weight, L = location CV = coefficient of variation

Table 3: Combined analysis of variance of sorghum genotypes for yield and yield related traits over location at Mieso and Kobo in 2019.

Traits	MS_L(DF=1)	MS_G(DF=41)	MS_{GL}(=41)	MS_E(DF=72)	CV	R^2
Days to flowering	1080.21**	13.23**	5.51**	2.62	2.29	0.91
Days to maturity	1494.05**	15.10**	13.74**	4.67	1.95	0.89
Plant height	14359.70**	7615.51**	332.80**	70.47	4.43	0.98
Stay green	63.14**	0.78**	0.51ns	0.35	22.15	0.83
Panicle length	117.66**	27.08**	3.80ns	2.99	6.13	0.87
Panicle width	308.34**	3.86**	1.10*	0.65	9.85	0.92
Leaf area	439598.44**	5662.39**	3919.83	2812.38	16.84	0.81
Panicle exersion	388.87**	31.36**	7.47ns	5.31	28.33	0.85
Panicle yield	183467.16**	2206.42**	762.70**	352.03	22.12	0.92
Grain yield	858491.96**	5106.56**	1708.55**	869.54	21.75	0.94
Thousand seed weight	7100.60**	60.41**	13.25**	6.02	9.37	0.96

*, **- significant at 5% and 1% level respectively, MI= Mieso, KB= kobo, DTF = days to flowering, PHT = plant height, DTM = days to maturity, SG = stay green, PL = panicle length, PW = panicle width, LA = leaf area, TL=number of productive tiller, PE = panicle exertion PY = panicle yield, GY = grain yield, TSW = thousand seed weight, L = location CV = coefficient of variation

(g) at both Mieso and Kobo testing sites. This implies the presence of sufficient variation to make selection among the tested genotypes.

Combined analysis of variance for yield and yield related traits

Analyses of variance due to different source of variations were computed as per standard the procedure of alpha-lattice design for combined over the two locations. The analyses of variances revealed significantly high differences (P<0.01) among the genotypes for all of quantitative characters (Table 3).The presence of significant difference among sorghum genotypes for the studied traits ensured the presence of large genetic variation to be improved through selection. This indicated the presence of considerable variation in the genetic materials for these traits and improvement of the genotypes with these traits is possible with simple selection. Plant breeding is primarily depended on presence of substantial genetic variation to address the maximum genetic yield potential of the crops and exploitation of this variation through effective selection for further improvement. Hence, the obtained results encourage the availabilities of substantial genetic variation among sorghum genotypes for the studied traits.

The mean squares due to genotype x environmental interaction exhibited significantly high for days to flowering, plant height, days to maturity, panicle length, panicle width, leaf area, number of productive tiller, panicle yield, grain yield and thousand seed weight. This implies the modification of genetic factors by environmental factors, and the role of genetic factors in determining the performance of genotypes in different environments. Genotype x environmental interaction is said to exist when genotype performance differs over environments. The performances of genotype vary greatly across environment because of the effect of environment on trait expression. Selection of superior genotypes in target environments is an important objective of plant breeding programs. In order to identify superior genotypes across multiple environments, plant breeders conduct trials across locations and years, especially during the final stages of cultivar development.

Mean performance of sorghum genotypes for studied traits

The superior sorghum genotypes were identified based on mean performance for different traits as indicated in (Table 4). Interestingly, genotypes listed as 17 (6.32 tha^{-1}), 8 (5.92 tha^{-1}), 1 (5.88 tha^{-1}), 26 (5.78 tha^{-1}) and 6 (5.57 tha^{-1}) were high yielder whereas genotypes listed as number 34(2.05 tha^{-1}), 31(2.13 tha^{-1}), 32(2.25 tha^{-1}), 28(2.34 tha^{-1}), 33(2. 36 tha^{-1}) were low yielder as compared to the other genotypes. Generally, among the tested genotypes, twenty four genotypes gave higher than the average yield (4.29 tha^{-1}). These included almost the hybrids other than lines and testers. The values of average yield performance of the genotypes ranged from 2.05 tha^{-1} to 6.32 tha^{-1}. In addition to yield performance, considering growth and morphological parameters contributing for the yield performance as a selection criterion in the

Table 4: Description of the genotypes included in the experiment at Mieso and Kobo in 2019 cropping season.

S.N	Lines	Pedigree	S.N	Hybrids	Pedigree
1	TX-623B	TX-623B	21	P-851015A x ICSR -14	P-851015A x ICSR-14
2	P-9501B	P-9501B	22	P-850341A x ICSR-14	P-850341A x ICSR-14
3	P-9505B	P-9505B	23	A5 x ICSR-14	A5 x ICSR-14
4	P-9534B	P-9534B	24	A6 x ICSR-14	A6 x ICSR-14
5	P-851015B	P-851015B	25	MARC1A x ICSR-14	MARC1A x ICSR-14
6	P-850341B	P-850341B	26	MARC2A x ICSR-14	MARC2A x ICSR-14
7	B5	B5	27	MARC3A x ICSR-14	MARC3A x ICSR-14
8	B6	B6	28	MARC6A x ICSR-14	MARC6A x ICSR-14
9	MARC1B	MARC1B	29	P9511A x ICSR-14	P9511A x ICSR-14
10	MARC2B	MARC2B	30	TX-623A x Melkam	TX-623A x Melkam
11	MARC3B	MARC3B	31	P-9501A x Melkam	P-9501A x Melkam
12	MARC6B	MARC6B	32	P-9505A x Melkam	P-9505A x Melkam
13	P9511B	P9511B	33	P-9534A x Melkam	P-9534A x Melkam
	Testers		34	P-851015A x Melkam	P-851015A x Melkam
14	Melkam	WSV387	35	P-850341A x Melkam	P-850341A X Melkam
15	ICSR-14	ICSR-14	36	A5 x Melkam	A5 x Melkam
	Check		37	A6 x Melkam	A6 x Melkam
16	ESH-4	PU20AxPU304	38	MARC1A x Melkam	MARC1A x Melkam
	Hybrids		39	MARC2A x Melkam	MARC2A x Melkam
17	TX-623A x ICSR-14	TX-623Ax ICSR-14	40	MARC3A x Melkam	MARC3A x Melkam
18	P-9501A x ICSR-14	P-9501A x ICSR-14	41	MARC6A x Melkam	MARC6A x Melkam
19	P-9505A x ICSR-14	P-9505A x ICSR-14	42	P9511A x Melkam	P9511A x Melkam
20	P-9534A x ICSR-14	P-9534A x ICSR-14			

development of drought tolerance genotypes were suggested.

Days to flowering and maturity are among the most important attributes that need to be considered in selecting genotypes for drought affected areas. In this study, the mean number of days to flowering ranged from 68 days in the early flowered genotype (35) to 77 days in the late flowered genotypes (31). Similarly, mean number of days to maturity ranged from 108 to 114 for the same group of genotypes. Both early and late maturing genotypes had the same grain fill duration, However, variation was detected for grain yield and related yield components among these genotypes, indicating that, the variation in the other attributes might be associated with factors other than duration of grain fill.

The top yielder genotypes (17) required 69 days to flower and 108 days to mature which was close to the average for genotypes, 70 days for flowering and 111 days for maturity. This indicates that, the yielding potential is not necessarily associated with crop phenology provided that genes for high yield potential are incorporated in the genotypes. The global successes in improving sorghum yield by deploying high yielding early maturing hybrids also supports this idea. Meanwhile, delayed flowering for genotypes encountered severe drought condition was reported, which would have considerable effect on the productivity of the crop Similarly, the actual mean values showed variation among genotypes for plant height and leaf area and these appeared to be under strong genetic control, although environment could have marked effect (Table 5).

Mean plant height ranged from 107.50cm to 271cm, and leaf area ranged from (220.36cm^2 to 405.63cm^2).Breeding for shorter plant height was one of the major goals of the sorghum breeding program for dry lowland areas where drought adversely affects the plants which had prolonged vegetative growth and to make commercial genotypes fit to mechanical harvesting. Drought resistance is a complex trait, expression of which depends on action and interaction of different morphological traits (earliness and reduced leaf area). Among the various drought resistance related traits, leaf area is very relevant by narrowing the leaf length and leaf width when the drought becomes severe in order to limit water loss. Generally, genotypes that were best performing in terms of several traits, i.e. high yield, early flowering, early maturity, shorter plant height and narrow leaf at the same time are preferable than genotypes that vary with different traits for instance, high yielder but late maturity and vice versa.

Mean performance comparisons among of parents, hybrids and check for yield and yield related traits

Hybrids gave the highest mean performance for grain yield trait in comparison to the parents and the check. This ensured the superiority of hybrids (39% to 80%) over open pollinated varieties for yield (Quinby J R, 1974). This also indicates the suitability of hybrids in moisture stress areas where other open pollinated varieties lacked the adaptive traits for diverse local environments. The mean grain yield for hybrids ranged from 3.98 tha^{-1} to 6.32 tha^{-1}. The highest yield was obtained from the hybrid cross of 4x14 (6.32 tha^{-1}) followed by the hybrid combinations of 8x15 (5.92 tha^{-1}), 1x15 (5.88 tha^{-1}), 13x14 (5.78 tha^{-1}) and 6x15 (5.57 tha^{-1}). The mean value of hybrid is 5.01 tha^{-1}, which is higher than the grand mean of the genotypes (4.29 tha^{-1}), mean of lines (2.80 tha^{-1}), mean of testers (3.84 tha^{-1}), mean of check (4.47 tha^{-1}). This implied that, the performances of the parents and the check was lower as compared to hybrids and heterosis breeding is effective to improve this trait (Table 6).

The superiority of the hybrids over the check variety in grain yield indicates the potential positive economic advantage of hybrids in the diverse sorghum-growing environments. Hybrid (4 x14) stood first in grain yield and second in early maturity trait among all genotypes which are preferable in moisture stress areas. From the statistical point of view, the hybrids were significantly different from lines, testers and check at ($p<0.05$) level of significance for grain yield traits. There was statistically significant difference between hybrids and testers in terms of days to flowering and days to maturity, indicating earlier maturity of

Table 5: Mean performance of sorghum genotypes for yield and yield related traits over location at Mieso and Kobo in 2019.

Entry	DTF	PHT	DMT	PY	GY	SG	TSW	PL	PW	LN	LL	LW	LA	PE	PAS
1	70	185.9	108.5	107.8	5.88	2.25	30.7	31.4	9.65	11.3	68.3	7.5	353.8	7.95	1.75
2	69.25	183.7	108	106.8	4.78	3.5	27.3	28.8	8.2	11	65.8	7.08	325.9	6.35	2.5
3	69.25	181.8	109	89.6	4.76	2.75	24.1	29.3	7.6	10.8	66.3	7.75	366	12.6	3.13
4	69.25	176.5	108.5	89.25	4.75	2.5	28.6	30.9	8.2	11.4	65.3	6.92	316.3	6.55	2.25
5	71	206.7	110	99.4	4.94	2.5	26.3	29.9	9.1	11.5	68.1	8	378.6	6.35	2.5
6	69.75	198	109.3	83.6	5.57	3	23.6	30.1	9.9	10.9	63.7	7.75	341	13.35	2.5
7	69.5	184.9	109	96.55	4.81	3.25	24.6	31	9	11.3	62.8	7.58	330.5	5.65	2.25
8	71.25	184.8	111	126.3	5.92	2.75	26.4	31.3	9.15	10.8	63.8	7.83	346.9	7.05	2.25
9	70	258	109	106.1	5.37	3	30.9	28.3	8.85	12.3	60.3	7.58	322.9	10.95	2.75
10	71.5	259.9	110.8	101.5	4.47	2.75	31.3	25.8	8.95	12.8	64.2	7.25	326.7	6	3
11	71	237.9	111.5	93.1	3.98	2.5	31.8	26.4	9.3	12.3	59.4	7.83	325	6.7	2.75
12	71	243.5	110.5	115	4.56	2	34.3	27.5	9.4	19.9	68.7	8.5	405.7	6.95	2.25
13	69.5	187.9	110	104.2	5.02	3	27.2	29.5	8.85	11	64.2	8	355.2	8.6	2.5
14	71.75	188.4	111	95.3	5.33	3	25.9	29.2	7.95	12.5	68.4	7	332.5	5.35	2.75
15	70.25	179.8	109	87.95	4.97	3.25	25.6	31.1	8.5	11.2	64.3	7.67	343.2	6.55	2
16	69	174.8	108.8	98.65	4.89	3.5	27.1	29.5	8.65	10.6	64.4	7.67	351.7	7	2.5
17	69	184.3	107.8	119.7	6.32	2.25	30.3	32.5	9.65	11.2	64.4	6.83	303.5	7.45	2.5
18	72.25	200.5	110	79.05	4.2	2.75	23.3	30.7	8.85	11.3	63.3	7.25	319.5	8	2.5
19	71	195.7	111.8	82.85	5.06	2.5	23.3	30.1	8.6	11.3	63.9	7.5	335.7	11.1	2.25
20	70.25	200.9	109	83.35	5.25	3.5	24.3	30.6	8.2	11.3	62.3	6.92	298.5	6.95	2
21	69.5	185.4	109	111.7	4.68	3	26.8	28.4	8.2	11.4	60.5	7.17	306.9	8.15	2.75
22	70	256.6	109	111.9	5.51	2.75	31.6	30.2	9.85	11.8	67.8	7.17	334.1	9.95	2.5
23	73.25	271	113.5	101.5	4.25	2.25	32.5	27.9	10.1	12.9	60.7	6.92	291.5	5.15	2.88
24	70.5	257.7	109.5	111.8	5.14	2.75	30.7	27.1	9.05	12.2	57.5	7.17	289.1	9.15	2.25
25	71.5	259.1	110.8	107.1	4.88	2.75	30.7	26.6	8.45	11.9	64.8	6.67	299.2	7.25	2.5
26	68.75	196.3	107.8	108.9	5.78	2.75	25.8	30.2	8.6	11.5	68.2	7.09	345.1	10.5	2
27	73.75	125.5	113	65.8	2.78	3	22	26.1	6.65	12.2	63.2	6	265.4	5.55	3.25
28	68.5	113.4	112.3	39.8	2.33	2.5	19.4	25.7	7.25	10.5	61.5	6.5	279.5	10.55	4
29	67.75	119.7	111	49.45	2.82	2.5	21.5	27.5	7.1	9.58	66	7.25	333.6	14.05	4
30	71.25	133.3	112.3	55.8	3.02	3	23.5	29.5	6.65	11.3	61	6.33	268.9	5.85	3.75
31	77	149.4	114.5	42.75	2.13	1.75	17.5	26.6	7.6	11.5	52.5	6.08	220.4	7.4	3.75
32	72.25	132.9	113.5	39.45	2.25	2.75	17.7	22.5	6.05	10.5	59.3	6.42	263.8	10.75	4.25
33	71.75	119.7	113.5	40.05	2.36	3	19.1	24.3	6.6	11.3	55	6.42	242.2	5.5	4
34	71.25	107.5	111.3	52.8	2.05	3.5	18.1	23.9	6.35	11.5	55.7	6.67	258.5	5.9	3.75
35	67.75	220.9	109	67.65	3.53	1.25	27.5	24.3	7	9.58	60.4	7.34	305.4	14.4	3
36	70.5	245.9	109.5	67.35	3	2.5	25.8	26.5	7.55	10.9	59.6	6.42	266.6	8.1	4
37	72	245.1	111.8	78.5	3.94	2.5	25.9	24.6	7.45	11.8	58.7	6.34	260.1	11.65	3.25
38	72.25	232.7	112	59.45	3.21	2.5	24.8	22.8	7.35	11.8	60.3	6.92	290.2	9.9	3.5
39	68	133.6	110.8	46.15	3.03	2.25	24.9	29.5	6.75	9.92	65.1	7.25	326.4	10.85	3
40	74	166.1	112.5	87.45	4.12	2.5	31.5	28.5	9.25	12.1	62.8	7.17	309.1	4.25	1.75
41	73.75	137.1	112.8	67.8	3.55	2.75	30.5	25.8	8.05	11.9	65.1	7.58	341.2	0.5	3.75
42	68	131.3	113	83.15	4.78	1.75	25.2	33.5	7.05	11.3	70.1	7.25	350.5	8.8	2
Mean	70.69	189.38	110.6	84.81	4.29	2.68	26.2	28.2	8.23	11.6	63	7.16	314.9	8.13	2.83
Min	67.75	107.5	107.8	39.45	2.05	1.25	17.5	22.5	6.05	9.58	52.5	6	220.4	0.5	1.75
Max	77	271	114.5	126.3	6.32	3.5	34.3	33.5	10.1	19.9	70.1	8.5	405.7	14.4	4.25
LSD (5%)	2.28	11.83	3.04	26.44	1.31	0.83	3.45	2.44	1.14	3.78	7.36	1.2	74.75	3.24	0.93
CV (%)	2.29	4.43	1.95	22.12	21.8	22.15	9.37	6.13	9.85	23.2	8.28	11.93	16.84	28.33	23.54

hybrids compared to testers and the significant difference was revealed between hybrids and check for days to maturity trait.

Summary and Conclusion

Sorghum is a high-yielding, nutrient-efficient, and drought-tolerant crop that can be grown on more than 80% of the world's agriculture. Farmers can satisfy the growing demand for sustainable food, feed and biomass production while lowering the cost of inputs like water due to the special characteristics of grain sorghum. For different traits at individual and combined locations, the mean squares due to genotypes revealed substantially great variation among all genotypes. Since genotypes differ genetically, selection may be an efficient way to improve genotypes for such traits.

For the traits evaluated, the presence of significant differences among sorghum genotypes indicated the presence of substantial genetic variations that may be enhanced through selection. Since the genetic materials had a huge variation, it was possible to improve the genotypes using simple selection for the traits that were being researched. To address the greatest genetic yield potential of crops and harness these variations through effective selection for subsequent

Table 6: Top and bottom performing genotypes based on their mean performance for selected traits over location at Mieso and Kobo in 2019.

Top 10 performing genotypes									
Genotypes	**DTF**	**Genotypes**	**DTM**	**Genotypes**	**PTH**	**Genotypes**	**GY**	**Genotypes**	**LA**
35	67.75^{m}	26	107.75^{j}	34	107.50^{t}	17	6.32^{a}	31	220.36^{l}
29	67.75^{m}	17	107.75^{j}	28	113.40^{ts}	8	5.92^{ba}	33	242.19^{lk}
42	68.00^{ml}	2	108.00^{ji}	29	119.70^{rs}	1	5.88^{ba}	34	258.48^{jlk}
39	68.00^{ml}	4	108.50^{jhi}	33	119.70^{rs}	26	5.78^{bac}	37	260.07^{jlik}
28	68.50^{mlk}	1	108.50^{jhi}	42	125.50^{rq}	6	5.57^{bac}	32	263.75^{jlihk}
26	68.75^{mljk}	16	108.75^{jhig}	27	131.30^{rq}	22	5.51^{bdac}	27	265.36^{jlihk}
17	69.00^{imljk}	35	109.00^{jhigf}	32	132.90^{q}	9	5.37^{ebdac}	36	266.59^{jlihkg}
16	69.00^{imljk}	22	109.00^{jhigf}	30	133.30^{q}	14	5.33^{ebdac}	30	268.89^{jlihkjf}
4	69.25^{imlhjk}	21	109.00^{jhigf}	39	133.60^{q}	20	5.25^{ebdacf}	28	279.45^{ejlihkg}
3	69.25^{imlhjk}	20	109.00^{jhigf}	41	137.10^{q}	24	5.14^{ebdacf}	24	289.11^{ejlidhkg}
Bottom 10 performing genotypes									
14	71.75^{fcebdg}	30	112.25^{ebdac}	11	237.90^{ef}	39	3.03^{kjmil}	15	343.22^{ebdacf}
37	72.00^{fcebd}	28	112.25^{ebdac}	12	243.50^{ef}	30	3.02^{kjmil}	26	345.14^{ebdac}
38	72.25^{cebd}	40	112.50^{bdac}	37	245.10^{ed}	36	3.00^{kjmil}	8	346.86^{ebdac}
32	72.25^{cebd}	41	112.75^{bac}	36	245.90^{ecd}	29	2.82^{kjml}	42	350.46^{ebdac}
18	72.25^{cebd}	42	113.00^{bac}	22	256.60^{bcd}	27	2.78^{kml}	16	351.73^{ebdac}
23	73.25^{cbd}	27	113.00^{bac}	24	257.70^{bc}	33	2.36^{ml}	1	353.84^{ebdac}
41	73.75^{bc}	33	113.50^{ba}	9	258.00^{b}	28	2.34^{ml}	13	355.22^{bdac}
27	73.75^{bc}	32	113.50^{ba}	25	259.10^{b}	32	2.25^{ml}	3	365.97^{bac}
40	74.00^{b}	23	113.50^{ba}	10	259.90^{ba}	31	2.13^{m}	5	3.78.56^{ba}
31	77.00^{a}	31	114.50^{a}	23	271.00^{a}	34	2.05^{m}	12	405.68^{a}
Mean	70		111		189.38		4.29		314.92
Maximum	77		114.5		271		6.32		405.68
Minimum	67.75		107.75		107.5		2.05		220.36
LSD (5%)	2.28		3.04		11.83		1.31		74.75
SD	1.62		2.16		8.39		0.93		53.03
R^2	0.91		0.89		0.98		0.94		0.81

Table 7: Mean Comparison of genotypes, Parents, Hybrids and Check at Mieso and Kobo in 2019).

Statistics	**DTF**	**PHT**	**DTM**	**SG**	**PL**	**PW**	**LL**	**LW**	**LA**	**GY**	**TSW**
Grand Mean	70.69	189.38	110.58	2.68	28.2	8.23	63.03	7.16	314.92	4.29	26.18
Max	77	271	114.5	3.5	33.45	10.1	70.08	8.5	405.68	6.32	34.33
Min	67.75	107.5	107.75	1.25	22.5	6.05	52.5	6	220.36	2.05	17.53
Mean of Hybrid	70.36	209.18	109.67	2.8	29.36	8.85	64.27	7.4	332.39	5.05	27.87
Max of Hybrid	73.02	269.58	112.86	3.58	32.65	9.86	68.6	8.5	405.68	6.32	34.26
Min of Hybrid	68.37	175.02	107.09	2.02	25.68	7.73	57.63	6.68	287.7	3.98	23.23
Mean of Line	71.08	160.42	111.87	2.54	25.65	6.95	59.87	6.61	275.45	2.8	22.13
Max of Line	77	245.9	114.5	3.5	29.5	7.6	66	7.33	333.62	3.94	27.53
Min of Line	67.75	107.5	109	1.25	22.5	6.05	52.5	6	220.36	2.05	17.53
Mean of Tester	73.88	151.6	112.63	2.62	27.13	8.65	63.95	7.38	325.15	3.84	30.99
Max of Tester	74	166.1	112.75	2.75	28.5	9.25	65.08	7.58	341.15	4.12	31.48
Min of Tester	73.75	137.1	112.5	2.5	25.75	8.05	62.83	7.17	309.14	3.55	30.5
Mean of Check	68	125.5	113	1.75	33.45	7.05	70.08	7.25	350.46	4.77	25.2
LSD (5%)	2.28	11.83	3.04	0.83	2.44	1.14	7.36	1.2	74.75	1.31	3.45
SD	1.62	8.39	2.16	0.59	1.73	0.81	5.22	0.85	53.03	9.32	2.45
CV (%)	2.29	4.43	1.95	22.15	6.13	9.85	8.28	11.93	16.84	21.75	9.37

improvement, plant breeding is mainly dependent on the existence of substantial genetic variation. This high genetic variation among genotypes meant that the cultivars were genetically varied, and it was possible that breeder's r will have an excellent chance to choose genotypes for different traits for variety development **(Tabel 7)**.

Overall, the 4x14, 8x15, and 1x15 sorghum genotypes outperformed the other varieties in terms of yield and yield-related characteristics. The better sorghum genotypes were identified as 4x14 (6.32 tha^{-1}), followed by 8x15 (5.92 tha^{-1}), 1x15 (5.88 tha^{-1}), 13x14 (5.78 tha^{-1}), and 6x15 (5.57 tha^{-1}). Generally, plant breeders are primarily concerned with increasing yields in order to reduce the effect of food security problems. The creation of superior genotypes in terms of yield and other many different traits is becoming increasingly important in order to meet the demands of human population growth and climate change. In the absence of plant genetic improvement to raise agricultural production by addressing the problem of yield decrease and its links to pest control and climate change, overcoming these severe challenges would be more difficult. For lowland areas with limited rainfall and short growing seasons, sorghum genotypes with early flowering and early maturity, small number of leaves per plant, small leaf area, erect leaf type (small leaf angle), larger stem diameter, a small number of the productive tiller, small leaf area, stay in greenness, high grain yield per unit area, and short plant height have been identified.

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