Int.J.Curr.Res.Aca.Rev.2023; 11(11): 14-23

EXCELLENT PUBLISHERS

International Journal of Current Research and Academic Review

ISSN: 2347-3215 (Online) Volume 11 Number 11 (November-2023)

Journal homepage: http://www.ijcrar.com

doi: https://doi.org/10.20546/ijcrar.2023.1111.003

Performance Evaluation of Sorghum [*Sorghum bicolor* (L.) Moench] Varieties for Grain Yield in Buno Bedele, South West Oromia, Ethiopia

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Abstract

Sorghum plays an important role as a staple food as well as source of feed for livestock in Ethiopia. Its production in Ethiopia is found to be constrained by several biotic and abiotic factors. To this end, this study was conducted with the objective of identifying high yielding, biotic and abiotic stresses resistance or tolerance varieties adaptable to Buno Bedele Zone of Western Oromia. A total of nine sorghum varieties were evaluated in RCBD. AMMI analysis showed that environments, varieties and their interaction effects were significantly different. The stability and high yielding ability of the varieties have been graphically depicted by the AMMI bi-plot. The variation for seed yield among the varieties for each variety was significant at different environments. Varieties such as G3 (Dano) and G4 (Lalo) were widely adapted to high yielding environments. In GGE bi-plot analysis; IPCA1 and IPCA2 explained 69.89% and 30.11% of variation, respectively, of sorghum variety by environment interaction and made a total of 100% of variation. Therefore, Dano (27.73 qtha^{-1}) and Lalo (26.06qt ha^{-1}) were identified as most stable and thus recommended for production in the study area and similar agro-ecologies and Dabo Hana is identified as the ideal environment for sorghum production.

Article Info

Received: 20 September 2023
Accepted: 15 October 2023
Available Online: 20 November 2023

Keywords

Adaptation, AMMI, G x E interaction, Sorghum, global production.

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is the fifth most important cereal crop in the world next to maize, rice, wheat, and barley in terms of both production and harvested area (FAOSTAT, 2019). It is a major food crop for more than 500 million people across Africa, Asia, and Latin America, particularly for those in the semi-arid tropical regions (Ejeta, 2005). Sorghum can be grown in drought-prone areas where several other crops cannot reliably grow. Recent FAOSTAT data on annual global production of sorghum showed that it covered about 40 million ha of land and produced grains of ca 57.9 million metric tons (MMT) (FAOSTAT, 2019). The United States, Nigeria, and Ethiopia are the leading sorghum-producing countries in the world with a total production of 8.6, 6.7, and 5.2 MMT, respectively (Mohan *et al.,* 2010). In Africa, sorghum is the second most widely cultivated cereal crop, only surpassed by maize (FAOSTAT, 2019).

Ethiopia has a diverse wealth of sorghum germplasm adapted to a range of altitudes and rainfall conditions. Of the five morphological races of sorghum (bicolor, guinea, caudatum, durra and kafir), all, except kafir, are grown in Ethiopia. Important traits reported from the

Ethiopian sorghum include cold tolerance, drought resistance, resistance to sorghum shoot fly, disease and pest resistance, grain quality and resistance to grain mould, high sugar content in the stalks, and high lysine and protein content. In Ethiopia sorghum is used for making injera, kitta, kollo and locally made beverages (such as Tela and Areke). Being an indigenous crop, tremendous amount of variability exists in the country. As a result, large number of accessions has been collected by the joint efforts of the Ethiopian Sorghum Improvement Project (ESIP) and the Institute of Biodiversity Conservation (IBC).

Many of these accessions have been evaluated in the country and some were released as commercial cultivars for the highlands. Still others have been used in supplementing the germplasm base of the international and national agricultural systems around the globe. Sorghum grain is as nutritious as other cereal grains; contains about 11% water, 340 k/cal of energy, 11.6% protein, 73% carbohydrate and 3% fat by weight (Hiebsch and O' Hair, 1986).

Globally, sorghum is the most important economic crop in area of production next to wheat (*Triticum spp*.), rice (*Oryza spp*.), maize (*Zea mays*), and barley (*Horedum vulgare*) (FAO, 2014). In sub-Saharan Africa, sorghum remains the third important cereal crop after maize and rice accounting for about 22% of the cereal production area (FAO, 2014). Ethiopia is the sixth largest sorghum producer next to USA, Mexico, Nigeria, Sudan and India (FAO, 2014). During 2014 the highest sorghum productivity was recorded by France (6.33 t ha^{-1}) followed by Egypt (5.42 t ha^{-1})

Ethiopia is considered as one of the centers of origin and diversity of sorghum (De Wet and Harlan, 1971) due to the presence of wild relatives and diversified forms of the crop in the country. In Ethiopia sorghum is the third largest cereal crop in area coverage preceded by tef (*Eragrostis tef*) and maize (*Zea mays*) and fourth in total production preceded by tef, maize and wheat (CSA, 2020).

In the country sorghum is produced by five million smallholder farmers with an estimated total grain production of 5.23 million tons from an estimated area of 1.83 million hectares of land. This provides a national average grain yield of around 2.88 t ha^{-1}. Sorghum covers 14.21% of the total area allocated to grain crop production (cereals, pulses, and oil crops) and 15.71% of the area covered by cereals in Ethiopia.

There is an increasing trend of area allotment for sorghum production in Ethiopia. Besides, its productivity increased during the last 20 years due to considerable use of agricultural inputs. For instance, the area coverage, total production and yield of sorghum increased by 9.37, 13.33 and 3.62%, respectively during 2013 to 2014 (FAO, 2014). The crop is highly valued especially in the drier environments of the country owing to its considerable drought-tolerance. Sorghum is recognized as food security crop in Ethiopia. In recent years, the crop is considered as a strategic food security crop by the government and thus due emphasis is given to the genetic improvement and technology development of the crop to boost its productivity under the small-scale farming systems. However, several constraints are hindering sorghum production and productivity in the country and globally.

In Buno Bedele, sorghum is the primary crop cultivated especially in midland to highland areas next to maize. It contributes to food security at household level. Notwithstanding the immense potential uses of sorghum in Ethiopia in general and in Buno Bedele in particular, several biotic and abiotic factors induce an absolute reduction of grain yield of sorghum, and consequently the gap between demand and supply is still wide. In recent years, in Buno Bedele, despite a preferable, good yielding, late-maturing local landraces producing sorghum has become a risky to achieve a maximum production. Presumably coupled with climatic changes, the rainfall becomes unpredictable. Farmers in the study areas are still growing local landraces which are late maturing that lasts around nine months. In addition to this, anthracnose disease infestation is a major yield-reducing factor of sorghum production in Buno Bedele Zone. Thus, it is indispensable to look for relatively early maturing, moderate to high anthracnose-disease tolerant and better adapting varieties which will give a reasonable yield relative to the pattern and distribution of rainfall. Therefore, this study was initiated to evaluate and select better adapted improved sorghum varieties for yield and yield components for the study areas and other similar agro-ecologies

Materials and Methods

Description of the study area

The experiment was conducted in Chora, Dabo Hana and Gechi districts on different farmers' field during 2020-2021 main cropping seasons. Chora is one of the districts in Buno Bedele Zone, Oromia Regional State, and

Southwest part of Ethiopia. The district is bordered on the south by Setema, on the west by Yayo and Dorani, on the north by Dega, and on the east by Bedele. The administrative center of this district is Kumbabe. The district is located 513 km away from the capital city of the country and 36 km away from Bedele Town, the center of Buno Bedele Zone.

The district is located at an average elevation 1013-2200 masl and located at 08^{0}13'33.7" to 08^{0}33'55.0" N latitude and 035^{0}59'59.7" to 036^{0}15'15.8" E longitude. It is generally characterized by warm climate with mean annual maximum temperature of 25.5°C and a mean annual minimum temperature of 12.5°C. The driest season lasts between December and January, while the coldest month is December.

The annual rainfall ranges from 1500-2200mm. The soil of the area is characterized as Nitisol, Acrisol, Lithosol and Cambisol. The economy of the area is based on mixed cropping system and livestock rearing agricultural production system in which the dominant crops are maize, tef, sorghum and wheat and also horticultural crops.

Gechi District

Gechi is one of the districts in Buno Bedele Zone, Oromia Regional State Southwest part of Ethiopia. The district is bordered on the south by Didessa, on the west by Didessa River, on the north by Bedele, and on the east by Jimma Zone. The administrative center of this district is Gechi. The district is located 465 km away from the capital city of the country and 18 km away from Bedele Town. The district is located at an average elevation 1277-2467m.a.s.l and located at 8°16'60''N latitude and 36°34'00''E longitude. The annual rainfall ranges from 1500-2100mm. The economy of the area is based on coffee production system in which the dominant crops are maize, tef, sorghum and wheat and also horticultural crops.

Dabo Hana District

Dabo Hana is one of the districts in Buno Bedele Zone, Oromia Regional State Southwest part of Ethiopia. The district is bordered on the south by Bedele, on the west by Dega and Mako, on the north by Chewaka and Leka dulecha, on south west by Chora, on the east and north east by Jima Arjo. The administrative center of this district is Dabo Hana. The district is located 521 km away from the capital city of the country and 38 km away from Bedele Town. The district is located at an average elevation of 1190-2323 masl and located at 8°30' 21" to 8°43' 29" N latitude and 36°5'27" to 36°26' 19"E longitude.

It is generally characterized by warm climate with mean annual maximum temperature of 28°C and minimum temperature of 11°C. The annual rainfall ranges from 900-2200mm. The soil of the area is characterized as Nitisol, Acrisol, Lithosol, Cambisol and Vertiso.

Experimental Materials and Design

Nine sorghum varieties collected from Melkassa and Bako Agricultural Research Centers were evaluated for their overall performance in the study areas. These materials were randomly assigned to the experimental block and the experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The spacing between blocks and plots was 1.5m and 0.5m, respectively.

The gross size of each plot was 15m^2 (3.75m x 4m) having five rows with a row-to-row spacing of 75cm and plant to plant spacing of 20cm.The total area of the experimental field was 570m^2 (40m x 14.25m).

Planting was done by drilling seeds in rows with a seed rate of 12kg ha^{-1}. NPS fertilizer was applied at the rate of 100kg ha^{-1} at the time of planting; and Urea was also applied at vegetative stage at the rate of 100 kg ha^{-1}.

Data collected

Data were recorded on plot and single plant basis and taken from the central rows of the plot. Individual plant-based data were taken from five plants in each plot, taken randomly from the central rows of each plot.

Data Collected on Plot Basis

Days to flowering (DH)

The number of days from 50% of the plots showing emergence of seedlings up to the emergence of the tips of the heads from the flag leaf sheath in 50% of the plot stands.

Days to Maturity (DM)

The number of days from 75% of the plots showing emergence of seedlings up to the maturity date

Grain yield (g/plot)

The weight of grain for all the central row plants including tillers harvested at the level of the ground

Data collected on plant basis

Plant Height (cm)

Measured as the distance from the base of the stem of the main tiller to the tip of the heads at maturity

Head Length (cm)

The length from the heads where the first head starts up to the tip of the heads at maturity.

Data Analyses

Genstat 18th edition software was used to analyze all the collected data from individual farmers and the combined data over locations. Mean separations was carried out using Least Significant Difference (LSD) at 5% probability level.

Results and Discussion

The results of the combined analysis of variance across locations revealed that there was highly significant ($P<0.001$) differences among sorghum varieties for grain yield across all testing environments (Table 2).

This result indicated the existence of wide range of genetic variability among sorghum varieties across the testing environments indicating that the ranges of varieties in terms of grain yield trait were significantly affected by environments.

This result was similar with the findings of Sayar *et al.*, (2013); Kendal and Sayar (2016); Kendal *et al.*, (2016) on sorghum genotypes. The explained percentage of sum of square (SS) of grain yield by treatment is 41.27%, for locations it was 8.32% and for the treatment x location interaction it was 27.61% (Table-2).

Treatments significantly explained the largest variation (41.27%) of the total sum of squares. This yield variation, largely explained by varieties, indicated that the varieties responded differently and a major part of variation in grain yield could be due to genetic variability of the varieties. Similar result was reported by Akter *et al.*, (2014) and Mekbib (2006).

Mean values for grain yield and yield related traits are presented in Tables 3 and 4. Highly significant differences were observed among varieties ($P \leq 0.001$) for days to flowering, days to physiological maturity, plant height, head length and grain yield.

The combined analysis of variance showed that varieties and location effects were significant for all parameters. Location*varieties were highly significant for grain yields is the result revealed that some varieties steadily performed best in some locations and some were fluctuating in their performance across location.

The average grain yield ranged from the lowest of 8.30 qtha^{-1} for Adele variety to the highest of 27.73 qtha^{-1} for Dano variety across all locations. This large variation might be due to the genetic potential of the varieties and environmental influences. The difference in yield rank of varieties across the locations exhibited the high crossover type of GxE interaction (Yan and Hunt, 2001; Ayana and Bekele, 2000).

Additive main effects and multiple interaction (AMMI) models

Combined analysis of variance revealed highly significant ($P \leq 0.001$) variations among environments, varieties and varieties x environment interaction, IPCA-1 and IPCA-2 (Table 5). This result indicated that there was differential yield performance among sorghum varieties across testing locations and strong GEI.

Similar result was reported on wheat (Menz *et al.*, 2004), rice (Panwar *et al.*, 2008) and on sorghum (Gebeyehu *et al.*, 2019). The largest portion of GEI effect on the grain yield of sorghum varieties i.e. 41.13% of the variation was due to varieties while 8.33% and 27.60% of the variation were due to the environment and the interactions, respectively. This also indicated by the existence of large degree of deferential response among the varieties to changes in the growing environments and the genetic makeup of the varieties. Considerable level of GxE interaction was explained by IPCA-1 (69.89%) followed by IPCA2 (30.11%) and therefore created a two-dimensional GGE bi-plot. Gauch and Zobel (1996) suggested that the most accurate model for AMMI can be predicted by using the first two PCAs. Moreover, several authors took the first and second IPCA for GGE bi-plot analysis and greater proportion of GEI were explained by the first IPCA for maize (Amelework *et al.*, 2015), bread wheat (Yuksel *et al.*, 2002; Farshadfar, 2008; Worku *et al.*, 2013).

Table.1 Description of Sorghum varieties used for the experiment

Variety Name	**Year of Release**	**Agro-Ecology**	**Releasing center**	**Yield Potential (qt/ha)**		**Seed color**
				Research	Farmers	
Chemeda	2013	Midland	BARC/OARI	32	25	Creamy
Gemedi	2013	Midland	BARC/OARI	33	28	Yellow
Dano	2006	Midland	BARC/OARI	40-50	30-48	Orange
Lalo	2006	Midland	BARC/OARI	40-52	35-48	Red
Adelle	2016	Highland	MARC/EIAR	37-72	30-40	Brown Brown Brown
Dibaba	2015	Highland	MARC/EIAR	37-50	30-40	
Jiru	2016	Highland	MARC/EIAR	33-86	32-44	
Dagim	2011	Midland e	MARC/EIAR	27-54	42	Brown
Geremew	2007	Midland	MARC/EIAR	49	40	Red

BARC= Bako Agricultural Research Center, OARI= Oromia Agricultural Research Institute, EIAR= Ethiopian Institute of Agricultural Research, MARC= Melkassa Agricultural Research Center.

Table.2 The combined ANOVA for grain yield of sorghum varieties over locations

Source of Variation	**Degree of freedom**	**Sum of square**	**Mean of square**	**%Explained of TSS**
Replications	2	29.54	14.77	0.48
Treatments (Trt)	8	2532.78	316.60**	41.27
Locations	2	510.82	255.41**	8.32
Trt*Locations	16	1694.36	105.90**	27.61
Residual	52	1369.76	26.34	22.32
Total	80	6137.28		

Table.3 Combined mean grain yield (qt/ha) of Sorghum varieties tested at Chora, D/Hana and Gechi districts in 2020/21-2021/22

	Chora	**D/Hana**			**Gechi**	
Varieties	1st Year	1st Year	2nd Year	Combined	1st Year	Over all
Chemeda	14.47^{bc}	11.00^{c}	12.64^{bc}	11.55^{b}	8.91^{cde}	11.60^{b}
Gemedi	23.22^{b}	7.33^{c}	14.44^{b}	9.70^{b}	12.98^{abc}	13.06^{b}
Dano	38.44^{a}	31.33^{ab}	21.78^{a}	28.15^{a}	15.78^{ab}	27.73^{a}
Lalo	14.98^{bc}	35.78^{a}	27.56^{a}	33.04^{a}	16.22^{a}	26.06^{a}
Adele	12.89^{bc}	9.00^{c}	4.62^{d}	7.54^{b}	6.00^{e}	8.30^{b}
Dibaba	9.87^{bc}	18.67^{bc}	10.96^{bcd}	16.10^{b}	14.67^{ab}	14.56^{b}
Jiru	18.71^{bc}	14.00^{c}	11.91^{bc}	13.30^{b}	11.33^{bcd}	13.99^{b}
Dagim	19.44^{bc}	9.89^{c}	9.78^{bcd}	9.85^{b}	8.00^{de}	11.40^{b}
Geremew	9.00^{c}	9.22^{c}	7.29^{cd}	8.58^{b}	12.00^{a-d}	9.35^{b}
17.89 **13.96** **36.1** *****	16.24.7	13.44	15.31	11.76.5	15.12	
	12.75	7.05	8.74	4.57	6.54	
	30.4	30.30	35.7	22.4	34.80	
	**	**	*	**	**	

GM= grand mean, LSD=least significant difference, CV= coefficient of variation, *= significant, **= highly significant.

Table.4 Combined mean yield related traits and diseases data of Sorghum varieties at Gechi, D/Hana and Chora districts

Varieties	DF (days)	DM (days)	PH (cm)	HL (cm)	Anthracnose	LR
Chemeda	118.3^{a}	179.0^{ab}	242.6^{bc}	20.67^{a}	10mr	15mr
Gemedi	121.3^{a}	168.2^{ab}	229.4^{bc}	19.11^{abc}	15mr	20ms
Dano	116.7^{a}	157.6^{ab}	248.5^{bc}	14.11^{de}	10mr	10mr
Lalo	123.2^{a}	174.3^{ab}	313.4^{a}	20.17^{ab}	15mr	10mr
Adele	119.5^{a}	159.7^{ab}	222.3^{cd}	11.47^{e}	60s	40ms
Dibaba	117.3^{a}	164.4^{ab}	227.0^{bcd}	16.11^{cd}	10mr	15mr
Jiru	114.2^{a}	201.0^{a}	265.7^{b}	19.83^{ab}	30ms	10mr
Dagim	92.9^{b}	133.8^{b}	186.1^{d}	19.06^{abc}	40ms	20ms
Geremew	95.5^{b}	120^{b}	186.2^{d}	17.33^{bcd}	40ms	30ms
GM	113.21	165.93	235.67	17.54		
LSD (0.05)	9.74	62.31	42.09	3.26		
CV%	11.9	52.0	24.7	16.0		
P-value	*	*	**	**		

DF= days to flowering, DM= days to maturity, PH= plant height, HL= Head length, LR= leaf rust, GM= grand mean, LSD=least significant difference, CV= coefficient of variation, *= significant, **= highly significant.

Fig.1 Map of the study areas (Chora, Dabo Hana and Gechi) districts

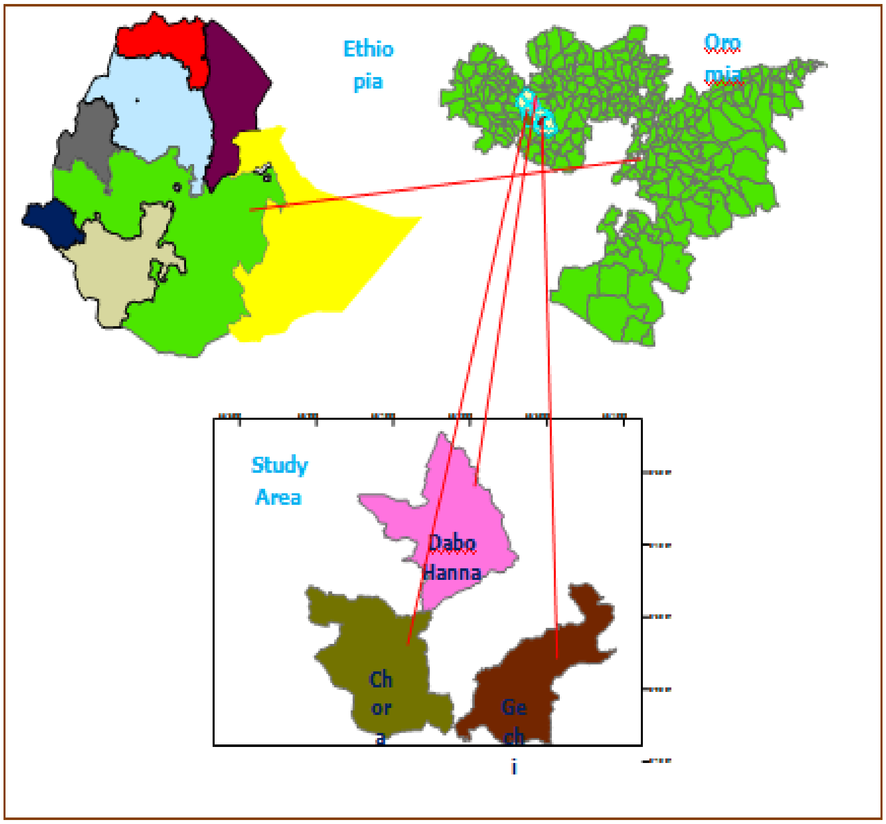


Table.5 Additive main effect and multiplicative interaction analysis of variances (AMMI) for grain yield of sorghum varieties tested

Source of variation	Degree of freedom	Sum of squares	Mean of squares	Ex. % of SS	G*E explained (%)	v.r.	F pr
Total	80	6137	76.7				
Block	6	68	11.3			0.41	0.8703
Genotypes	8	2533	316.6**	41.13		11.41	<0.001
Environments	3	511	255.4**	8.33		22.58	<0.001
Interactions	16	1694	105.9**	27.60		3.82	<0.001
IPCA 1	9	1184	131.6**		69.89	4.74	<0.001
IPCA 2	7	510	72.8*		30.11	2.63	0.0222
Error	48	1331	27.7				

Fig.2 Ranking environments comparatively to ideal environment

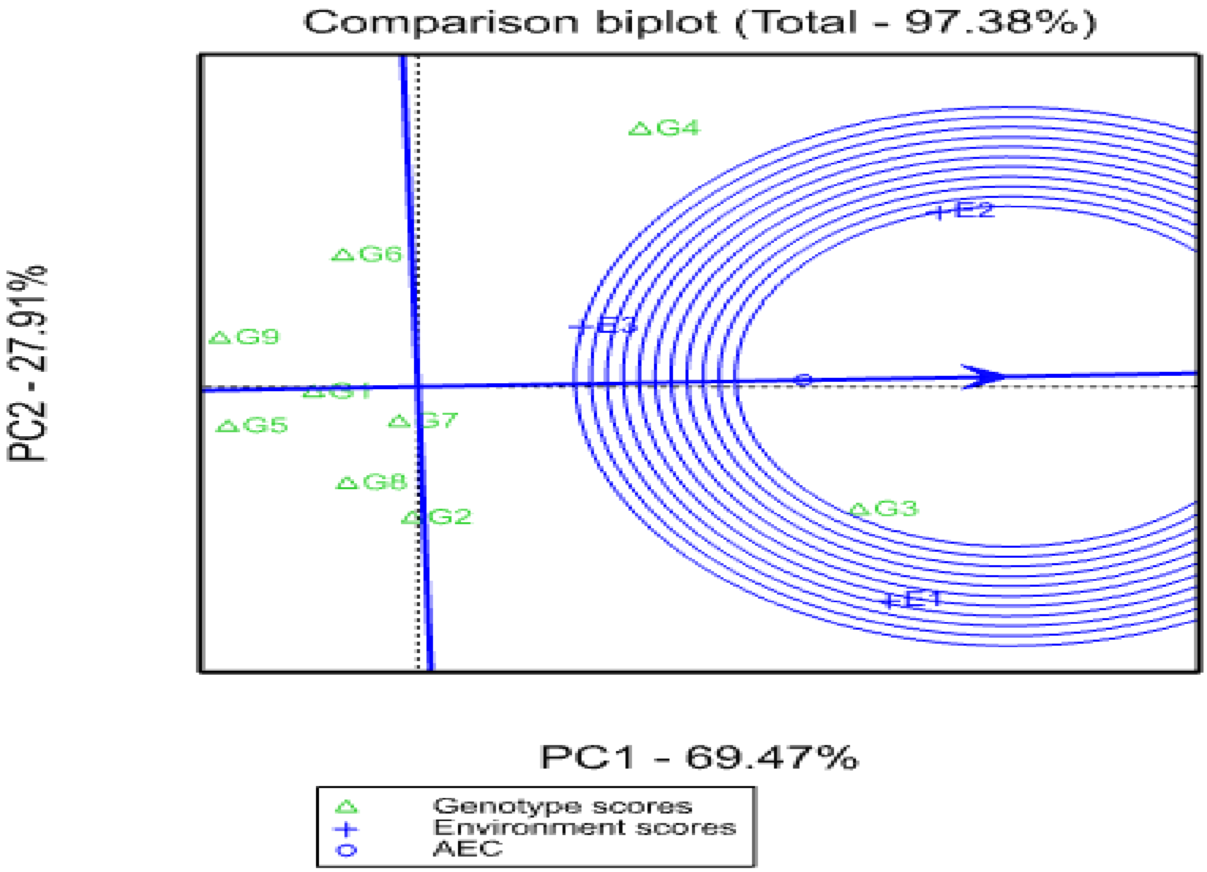
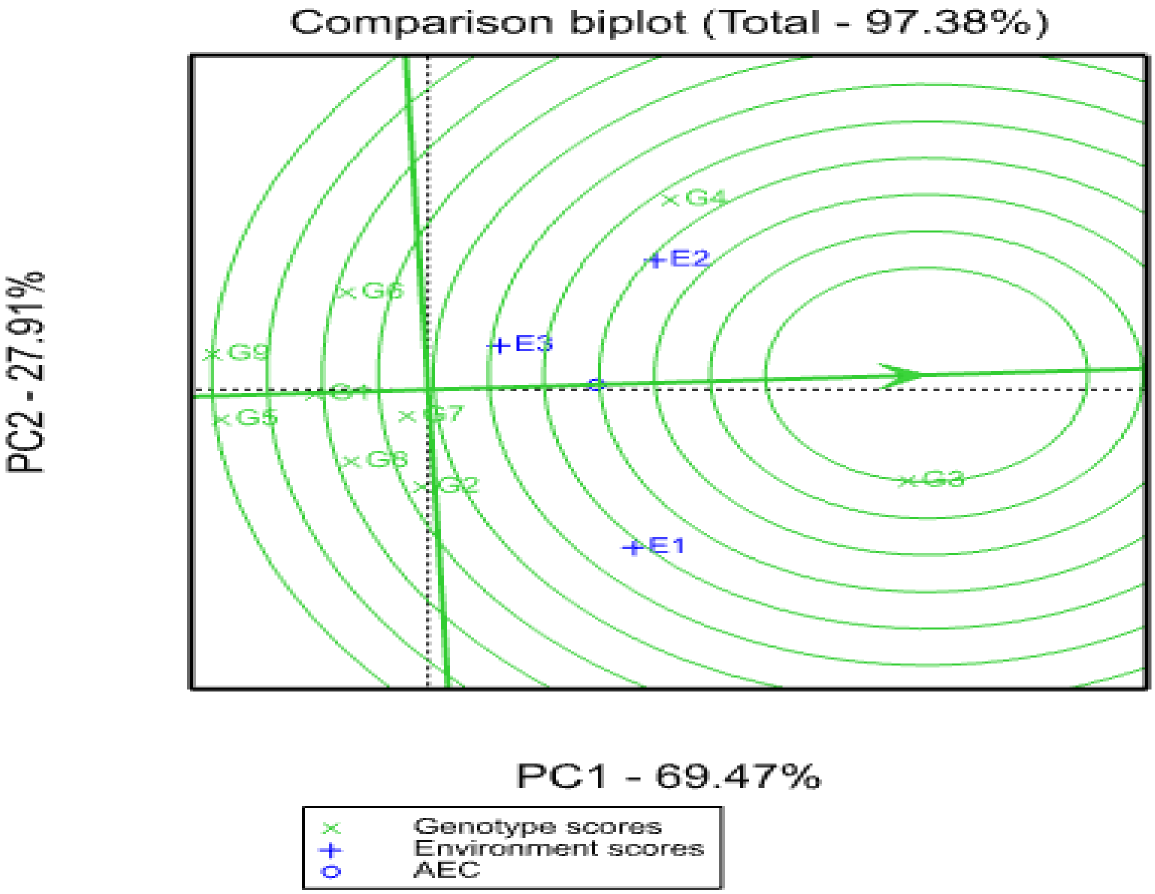


Fig.3 GGE bi-plot based on genotype-focused scaling for comparison of genotypes for their yield potential and stability



Discriminating ability of the test environment and genotype stability

The concentric circles on the bi-plot help to visualize the length of the environment vectors, which are comparative to the standard deviation within the particular environments and are a measure of the discriminating ability of the environments (Worku *et al.*, 2013). Environments as well as genotypes that fall in the central (concentric) circle are considered as an ideal environments and stable genotypes, respectively (Yan and Hunt, 2002). An environment is more desirable and discriminating when located closer to the central circle (Naroui *et al.*, 2013). As a result, in this study, Dabo Hana (E2) was more representative and discriminating environment (Fig.2) Similar study by Odewale *et al.*, (2013) reported that only one environment was stable, representative and discriminating among the nine environments for the performance of five coconut genotypes. Ranking based on the genotype-focused scaling assumed that stability and mean grain yield were equally important (Yan and Hunt, 2002). The best sorghum variety was expected to have high mean grain yield with stable performance across all the tested locations. Consequently, high yielding and comparatively more stable genotypes can be considered as base line for genotype evaluation (Yan and Tinker, 2006). Both environment-focused bi-plot and genotype-focused comparison of genotypes showed that G3 (Dano) and G4 (Lalo) fell in the central circle indicating its high yield potential and comparatively stable to the other genotypes (Fig. 4). Therefore, G3 (Dano), and G4 (Lalo) were the best performing varieties across the locations.

Recommendation

Sorghum is a high-yielding, nutrient-use efficient, and drought tolerant crop that can be cultivated on over 80 per cent of the world’s agricultural land. Its geographic distribution spans temperate to tropical climates, and its rich genetic diversity allows for multiple specialized uses including grain, forage and an increasing number of food applications. Sorghum is one of important cereal crop globally and in Sub-Saharan Africa including Ethiopia. Its production and productivity is affected by both abiotic and biotic constraints. In midland to highland areas of Buno Bedele zone where new improved sorghum varieties are not widely adopted, it's vital to catch immediate action towards setting appropriate way of addressing new technologies. Western Oromia is a potential area for sorghum production. However, farmers are growing the local landraces which are very late maturing that lasting up to nine months as well as low yielder. In such cases, evaluation and adaptation of improved varieties of medium early to medium maturity is a viable approach in facilitating selection and adoption of improved sorghum technologies that can significantly increase yield. In the current study, the analysis of overall location mean values revealed that the highest grain yield was recorded from Dano (27.73 qtha^{-1}) followed by Lalo (26.06 qtha^{-1}) improved sorghum varieties, respectively. However, the lowest seed yield was recorded from Adele (8.30 qtha^{-1}) due to its susceptibility to anthracnose disease. Therefore, the two improved sorghum varieties i.e., Dano and Lalo are selected and recommended for the study areas and other similar areas of Buno Bedele zone.

Acknowledgements

The authors would like to thank Oromia Agricultural Research Institute for funding, and Bedele Agriculture Research Center and cereal crop research case team for data collection and trial management.

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How to cite this article:

Gebeyehu Chala and Gemechu Deso. 2023. Performance Evaluation of Sorghum [*Sorghum bicolor* (L.) Moench] Varieties for Grain Yield in Buno Bedele, South West Oromia, Ethiopia. *Int.J.Curr.Res.Aca.Rev.* 11(11), 14-23.
doi: https://doi.org/10.20546/ijcrar.2023.1111.003