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Original Research Article

Adaptability evaluation of finger millet (*Eleusine coracana* L.) genotypes in moisture-stress areas of Somali Region, Ethiopia

Yohannes Seyoum **Eshetu,** Tesfu Mengistu **Woldemichael,** Walelign Demisie **Bayou**

Department of Plant Sciences, College of Dryland Agriculture, Jigjiga University, Ethiopia

Correspondence to:
Y.S.Eshetu, Department of Plant Sciences, College of Dryland Agriculture, Jigjiga University, Ethiopia,
e-mail: yohannes.seyoum@jju.edu.et

Abstract

Finger millet is a drought-tolerant and nutritious cereal crop grown in semi-arid areas, especially in Africa and Asia. However, due to a lack of improved variety, the grain yield of the crop at the farmer's field is lower than in research centers. Therefore, this field experiment aimed to compare the yield of eleven finger millet varieties in the Kebribeyah and Awbare districts in the Somali Regional State of Ethiopia. The experiment used a randomised complete block design (RCBD) with three replications. The analysis of variance was computed for eight traits for each location, and the result revealed the presence of significant variability among varieties. However, there was no significant interaction between variety and location for most yield and yield-related traits. In both locations, the results of the analysis of variance results revealed that there was a highly significant difference ($p < 0.01$) among varieties for days to flowering, days to maturity, plant height, thousand seed weight, grain yield, and biomass yield, but no significant difference was between the varieties for the number of tillers and traits of the harvest index (not in Awbare). The mean grain yield varied from 1005.0 to 2583.3 kg ha^{-1} and 950.0 to 2266.7 kg ha^{-1} among the tested varieties in Kebribeyah and Awbare, respectively. Meba and Tessema had the highest mean grain yield and related traits in both locations. It showed that these varieties have superior performance and suitability in both locations. Therefore, these varieties are recommended for Kebribeyah and Awebare and areas with similar agro-ecologies.

Keywords: adaptation; finger millet; location; varieties; yield

INTRODUCTION

Finger millet (*Eleusine coracana* L.) is an important drought-tolerant and grain-nutrient-dense food crop grown in semi-arid regions of Africa and Asia (Devi et al., 2014). It can be grown at altitudes ranging from sea level to over 2000 meters above sea level (Gangaiah and Yadav, 2024). Finger millet has been cultivated for centuries (Hilu and de Wet, 1976). It remains an important subsistence crop in small-scale farming systems, particularly in eastern and southern Africa. In addition, it can withstand drought and has high levels of essential amino acids and micronutrients (Reddy et al., 2021)

Finger millet has superior grain nutritional quality with multiple health benefits (Saleh et al., 2013). It serves as an important staple food for rural populations in developing tropical countries where calcium deficiency and anemia are widespread (Srivastava and Arya, 2021). It is rich in protein, iron, and calcium: containing 40 times more calcium than maize and rice, and 10 times more calcium than wheat (Maharajan et al., 2021). On top of that, grains contain special amino acids of high nutritional value, namely tryptophan, cystine, methionine, and total amino acids (Devi et al., 2014). Most of the time, these amino acids are lacking in many other cereals.

The finger millet is also known as the African millet, '*Dagussa*' (Ethiopia), '*Bulo*' (Uganda), '*Wimbi*' (Swahili), '*Telebun' (Sudan)* and '*Ragi*' (India). The world's annual millet production in 2022 is 3 million tons, of which about 1.4 million tons are produced in Africa (FAOSTAT, 2024). In Ethiopia, finger millet is the most important cereal crop with a total area coverage of 0.48 million hectares with 25.04 qt ha^{-1} (CSA, 2021). It plays an important role both as food grain and as animal feed in areas where marginal environments reduce the production of other cereals. As a result of increased drought and soil fertility degradation, a growing number of farmers are resorting to finger millet, and thus the area allocated for this crop has significantly increased over the last ten years (Erenso et al., 2009). It is an important crop in parts of Gojjam, Gonder, Wollega, Illubabur, Gamo-Gofa, Eastern Hararghe, and Tigray. It also becomes an important crop in parts of the Ethiopian central rift valley including Arsi-Negelle, Shashemene and Siraro Woredas (Anchala et al., 2006), and has a great genetic potential in other semi-arid areas of the country like the Somali region.

Finger millet has been used in a wide range in Ethiopia. The flour of finger millet alone or with a mixture of teff (*Eragrostis tef*), maize (*Zea mays*) and barley (*Hordeum vulgare*) is commonly used for making *injera* and *bread*. Traditionally, porridge prepared from finger millet flour is believed to cure diarrhoea and malaria and straw is used for animal feed and thatching roofs (Bezaweletaw et al., 2007). The greatest value of finger millet is that it can be stored for about ten years without weevil damage, which makes it a perfect food grain commodity for areas prone to famine (Erenso et al., 2009; Adugna et al., 2011).

To address the low agricultural production and productivity of dryland areas, such as the Somali region, the National Agricultural Research System (NARS) has been working towards developing drought-tolerant, early maturing, and disease and pest-tolerant crop varieties. In this regard, finger millet, due to its multiple attributes of tolerance to drought and its high food and feed values, was considered a promising crop in drylands in general and the Somali region in particular. However, the efforts exerted so far to introduce improved finger millet varieties in the region are insignificant. Therefore, this study was conducted to evaluate the performance of the millet varieties for their adaptability and to recommend the superior and suitable variety for farmers and agro-pastorals in the Somali region of Ethiopia and areas with similar agro-ecologies.

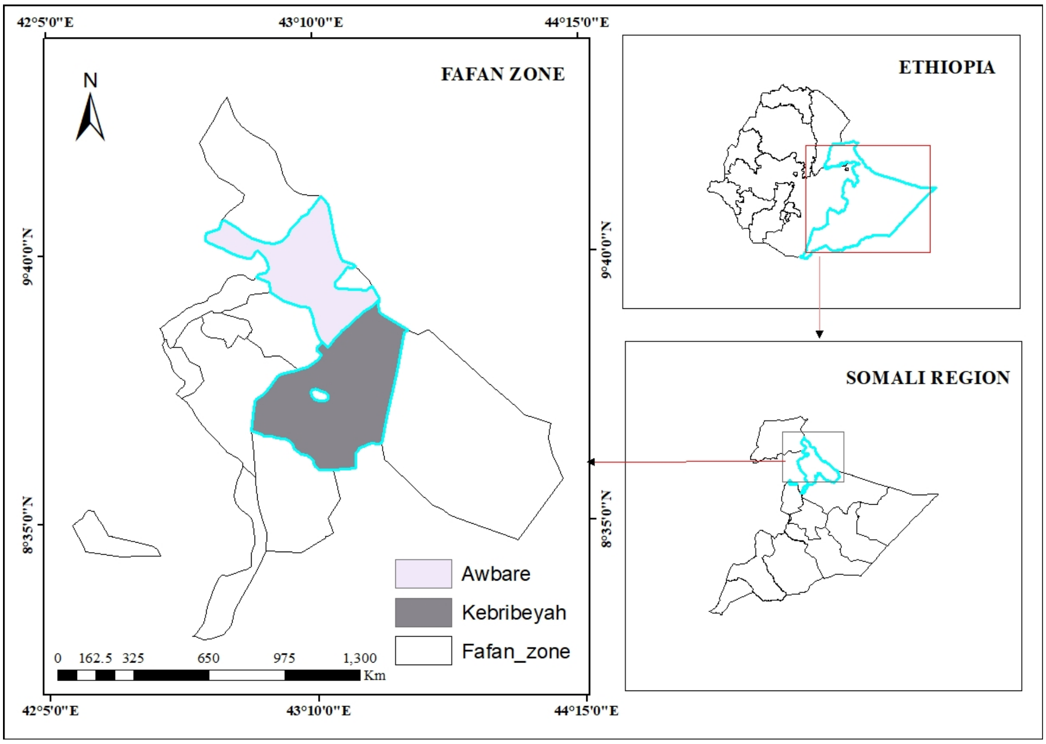

Figure 1. Geographical location of the study areas

MATERIAL AND METHODS

Description of the study area

The experiment was carried out in two locations: Kebribeyah and Awbare districts, Fafen zone of the Somali Region, Ethiopia (Figure 1). Kebribeyah is located at latitude 9°1′24.413″N, longitude 43°1′8.112″E, and an elevation of 1521 m above sea level. Its mean annual rainfall amount is 527 mm and temperatures range from 13 to 31 °C (NASA, 2023). Awbare is located at a latitude of 43°1′55.422″E, a longitude of 9°32′40.232″N, and an elevation of 1704 m a.s.l. Its mean annual rainfall amount is 447 mm and temperatures vary between 11 and 29 °C (NASA, 2023). These study locations' climatic conditions characterised by low rainfall and high-temperature variability are important environmental variations in studying drought-resistant crops. The main crops grown in the districts are sorghum, maize, wheat, barley, millet and beans.

Treatment, design, and field management

Eleven released finger millet varieties were tested in the study locations (see Table 1). Seeds of the varieties under study were acquired from national and regional agricultural research centers as indicated in Table 1. The experiment used a randomised completely block design (RCBD) with three replications.

The gross plot size was 9 m^2 (3 m × 3 m) having four rows, two middle rows were used for data collection. The spacing between rows was 75 cm and planting was carried out by drilling seeds in rows with a seed rate of 15 kg ha^{-1}. NPS fertiliser was applied at 100 kg ha^{-1} at the time of planting and urea was also used in the vegetative stage before booting at 50 kg ha^{-1}. All other agronomic practices were applied uniformly according to the recommendation for finger millet. The same treatments, experimental design, and field management were used for both study locations.

Data collection

Morphological and physiological data were collected from central rows. For data recorded on a single plant base, ten plants were randomly taken and tagged from the net harvested plot and the mean value was used for statistical analysis, it includes plant height (starting from the base of the ground to the tip of the plant); number of tillers (count basal tillers other than mother plant).

Data were recorded on plot bases including days to flowering (days from planting up to the time when 50% of plants have flowered), days to maturity (days from planting up to the time when 95% of plants matured (seed texture becomes hard)), grain yield (grain yield in kilograms), total biomass (total above-ground part in kilograms), harvest index (ratio of grain yield to biomass), 1000 seed weight (weight of 1000 seeds in gram drawn randomly from the bulk seeds of each plot).

Table 1. A list of finger millet varieties was used in the experiment.

Entry No.	Variety	Year of release	Breeding center
1	Diga-2	2017	Backo ARC/ORARI
2	Bako-09	2017	Backo ARC/ORARI
3	Addis-01	2015	AU/BARC/ORARI
4	Urji	2016	Backo ARC/ORARI
5	Kumasa	2015	Backo ARC/ORARI
6	Meba	2016	Melkassa ARC/EIAR
7	Axum	2016	Melkassa ARC/EIAR
8	Tessema	2014	Melkassa ARC/EIAR
9	Padet	1998	Melkassa ARC/EIAR
10	Debatsi	2010	Pawe ARC/EIAR
11	Baruda	2007	Pawe ARC/EIAR

Source: MoA (MoA, 2018), ARC = Agricultral Research Center, AU = Addis Abeba University, ORARI = Oromia Agricultural Research Institute, EIAR = Ethiopian Institute of Agricultural Research

Data analysis

The yield and yield components data were collected from the field and subjected to individual and combined analysis of variance using statistical software (SAS 9.4). Significant differences between mean values were compared using the Least Significant Difference Test (LSD) at $p < 0.05$.

The following model (1) was used for the ANOVA of individual location data.

$$Y_{ij} = \mu + G_i + B_j + e_{ij} \quad (1)$$

where
Y_{ij} = observed value of genotype i in block j,
μ = grand mean of the experiment,
G_i = the effect of genotype i,
Bj = the effect of block j,
e_{ij} = the error of genotype i in block j.

The F test was performed for the combination analysis and was carried out using the following statistical model (2).

$$Y_{ijk} = \mu + G_i + E_j + GE_{ij} + Bk_{(j)} + e_{ijk} \quad (2)$$

where
Y_{ijk} = observed value of genotype i in block k of environment (location) j,
μ = Grand mean of the experiment,
G_i = the effect of genotype i,
E_j = the effect of the j^{th} environment
GE_j = the interaction effect of genotype i with environment j,
$Bk_{(j)}$ = the effect of block k on location (environment) j,
e_{ijk} = the error effect of genotype i in block k of environment j.

RESULTS AND DISCUSSION

Analysis of variance

The analysis of variance was conducted separately per location to check for significant differences among the varieties. In both locations, the analysis of variance results revealed that there was a significant difference ($p < 0.01$) among varieties for days to flowering, days to maturity, plant height, grain yield, thousand seed weigh, and biomass yield but no significant difference was shown for number of tillers and traits of the harvest index (not in Awbare) (see Tables 2 and 4).

The combined analysis of variance over locations was done and the result is presented in Table 2 for eight traits with main: varieties (var) and location (loc), and interaction (var × loc) source of effects. The mean square of the varieties had significant differences ($p < 0.05$) for all traits except the number of tillers. Similarly, the location also had significant differences for all traits except for the number of tillers and harvest index. On the other hand, the mean square of var × loc interaction showed a significant difference for only days to the flowering trait, while the interaction factor did not have significant differences for other traits. This indicates a high genetic diversity among the finger millet varieties for most traits. These results are consistent with Fentie (Fentie, 2012), who reported similar findings on finger millet varieties for days to maturity, plant height, grain, and biomass yield.

Mean performance of varieties in the Kebribeyah District

The days to flowering ranged from 86 to 110 (see Table 3). The Bako-09 and Meba varieties flowered earlier compared to the other varieties. The variety Debatsi had the longest flowering period (110 days). Days to maturity ranged from 134 to 160 days with the longest range recorded for Diga-2 (see Table 3). The Bako-09 and Meba varieties matured earlier than the other varieties and recorded 143.6 days and 134 days, respectively. Early maturity is the major trait desired for dry land areas where low and erratic rainfall and high temperatures with recurrent drought are the major production constraints (Admasu and Belete, 2020).

The finger millet Tessema was the tallest variety (96 cm), whereas Kumasa was the shortest (52.33 cm) variety (see Table 3). The analysis of variance result showed that no significant difference was found for the number of tillers among varieties (see Table 2).

The highest thousand seed weight (3.33 g) was recorded for the variety Debatsi, followed by the variety Kumasa (3.25 g), whereas the least thousand weight (2.36 g) was recorded for the variety Addis-01. The mean grain yield of the varieties ranged from 1005 to 2583.3 kg ha^{-1}. The high-yielding varieties were Meba (2583.3 kg ha^{-1}), Bako-09 (2326.7 kg ha^{-1}), and Tessema (2273.3 kg ha^{-1}), while Kumassa (1005 kg ha^{-1}) was the lowest yielding variety. Simion et al. (2020) also reported that finger millet variety Tessema was a high-yielding variety in the lowland (altitude less than 1500 m) of southern Ethiopia. Apart from grain yield, the biomass yield is one of the traits desired by agro-pastoralists for their livestock feeds in the study area. The high biomass varieties were Meba (2583.3 kg ha^{-1}), and Tessema (2273.3 kg ha^{-1}), while Diga-2 (1353.3 kg ha^{-1}) and Kumasa (1005.0 kg ha^{-1})

Table 2. Combined ANOVA of mean squares for different traits of Finger millet

Source of variation	DF	DM	PH	NT	TSW	BY	GY	HI
Varieties (Var)	279.50**	248.01**	792.14ns	0.222ns	0.51953**	16960000**	1125424**	26.7059**
Location (Loc)	624.37**	327.40**	345.47*	5.412**	0.1064**	1230438ns	324661**	17.1564**
Var × Loc	24.61*	8.642ns	5.536ns	0.126ns	0.00236ns	340629ns	17706ns	2.88ns
Mean	94.227	145.08	73.227	3.63	2.84	9664.8	1836.5	19.002
CV (%)	3.09	1.84	12.18	18.33	2.71	11.8	7.99	12.49

*and ** denote significant difference at $p < 0.05$ and $p < 0.01$, respectively. Ns = nonsignificant
DF = days to flowering, DM = days to maturity, PH = plant height (cm), NT = number of tillers, TSW = thousand seed weight (g), BY = Biomass yield (kg ha^{-1}), GY = Grain Yield (kg ha^{-1}), HI = Harvest Index

Table 3. Mean performance of yield and yield-related characteristics of improved finger millet varieties in the Kebribeyah district of the Fafen zone SRS, Ethiopia

Entry no	Variety name	DF	DM	PH	NT	TSW	BY	GY	HI
1	Diga-2	104.67b	160a	70c	4.00	2.81cd	6723e	1353.3d	20.96
2	Bako-09	86g	143.67cd	68.33c	4.00	2.54f	9916bcd	2326.7ab	23.45
3	Addis-01	94.67de	144.33cd	70.33c	3.67	2.36g	10311a-d	1933.3c	18.84
4	Urji	98cd	154b	76.66bc	3.67	3.14b	9573cd	1946.7c	20.95
5	Kumasa	91.33ef	141.33d	52.33d	3.67	3.25ab	6739e	1005e	15.39
6	Meba	90fg	134e	87.33ab	4.33	2.66ef	12208a	2583.3a	21.18
7	Axum	94def	146c	87.33ab	4.00	2.86c	11643abc	2264.7b	19.44
8	Tessema	93.33ef	146c	96a	3.83	2.72de	11781ab	2273.3ab	19.26
9	Padet	100c	146.67c	82.33abc	3.67	2.92c	9709bcd	1940c	20.35
10	Debatsi	110.33a	153b	66.66cd	4.00	3.33a	10593a-d	1840c	17.34
11	Baruda	108ab	151.33b	73.33bc	4.33	3.13b	8620de	1506.7d	17.43
	Mean	97.30	147.30	75.52	3.92	2.89	9801.30	1906.60	19.51
	LSD	4.23	4.37	15.80	1.30	0.13	2110.60	313.56	4.93
	CV	2.55	1.74	12.28	19.49	2.62	12.64	9.66	14.83
	Varieties	**	**	**	NS	**	**	**	NS

*and ** denote significant difference at $p < 0.05$ and $p < 0.01$, respectively. NS = non-significant
The mean values followed by a similar letter(s) in each column had nonsignificant differences from each other. LSD (5%) = least significant difference at $p < 0.05$. DF = days to flowering, DM = days to maturity, PH = plant height (cm), NT = number of tillers, TSW = thousand seed weight (g), BY = Biomass yield (kg ha^{-1}), GY = Grain Yield (kg ha^{-1}), HI = Harvest Index.

were the lowest biomass yielding variety (see Table 3). These similar trends between the traits of grain and biomass yields in finger millet were consistent with the findings of Assefa et al. (2013) and Chavan et al. (2019). It is suggested that finger millet varieties Meba and Tessema are potentially high-yielding in the Kebribeyah District.

Mean performance of varieties in the Awbare district

The results showed that days to flowering ranged from 77 to 100 days in the Aweber district (see Table 4). The finger millet varieties Bako-09 (77.33 days) and Meba (85.00 days) flowered earlier than other varieties. The longest flowering period was registered for the Baruda variety (100.67 days). Days to maturity ranged from 129 to 153 days with the longest days recorded from Diga-2 (153 days) and Urji (149.33) (see Table 4) whereas the finger millet variety Meba matured earlier (129.67 days) compared with other varieties.

The finger millet Tessema (88.33 cm), Axum (84.00 cm) and Meba (80.00 cm) were the tallest varieties whereas Kumasa (50.00 cm) was the shortest variety (see Table 4). The results showed no significant differences in tiller numbers among the tested varieties.

The highest thousand seed weight was recorded for Debatsi (3.26 g), while the lowest value was for Addis-01 (2.29 g) (see Table 4). The mean grain yield of the tested varieties ranged from 950.00 to 2266.70 kg ha^{-1}. The finger millet Meba (2266.70 kg ha^{-1}), Tessema (2140.00 kg ha^{-1}), and Axum (2126.70 kg ha^{-1}) were the high-yielding varieties compared to other varieties, while Kumasa (950.00 kg ha^{-1}) was the lowest yielding variety (see Table 4). The result showed that finger millet Meba is a high-yielding variety with a 138.6% yield advantage over the Kumasa variety. The finding showed that the lack of improved finger millet variety is one of the factors affecting its productivity in Ethiopia (Zewdu et al., 2018). The variation in grain yield among the varieties could be due to genetic differences in the tested varieties. The high biomass yield was registered for Tessema (11533.0 kg ha^{-1}), Meba (11362.0 kg ha^{-1}) and Axum (11276.0 kg ha^{-1}), while the lowest was for Diga-2 (7323.0 kg ha^{-1}) and Kumasa (7200.0 kg ha^{-1}). It showed that the grain yield and the biomass showed similar trends. Similarly, Assefa et al. (2013) and Semahegn et al. (2021) reported similar trends between grain and biomass yields in finger millet. Finger millet variety with high grain yielding and biomass potential is preferred by the agro-pastoral community in the study area for food

Table 4. Mean performance of the yield and yield-related characteristics of improved finger millet varieties in the Awbare district of the Fafen zone SRS, Ethiopia

Entry no	Variety name	DF	DM	PH	NT	TSW	BY	GY	HI
1	Diga-2	98ab	153a	66bc	3.57	2.71cde	7323e	1266.7f	17.41bc
2	Bako-09	77.33f	140.33de	65bcd	3.67	2.50f	9609bcd	2046.7bc	21.32a
3	Addis-01	93.33bcd	145bcd	68bc	3.17	2.29g	10137abc	1873.3cd	18.62abc
4	Urji	95.33abc	149.33ab	73.33abc	3.40	3.04b	9346cd	1860d	20.35ab
5	Kumasa	88.67de	139.33e	50d	3.33	3.07b	7200e	950g	13.23d
6	Meba	85e	129.67f	80ab	3.67	2.62ef	11362ab	2266.7a	20.00ab
7	Axum	90.67cd	142cde	84a	3.40	2.80cd	11267ab	2126.7ab	18.87abc
8	Tessema	88de	140e	88.33a	3.33	2.67de	11533a	2140ab	18.63abc
9	Padet	91cd	142.67cde	75.67abc	3.00	2.81c	9400cd	1793.3d	19.21abc
10	Debatsi	94.67bc	146bc	61.67cd	3.33	3.26a	9600bcd	1566.7e	16.31cd
11	Baruda	100.67a	144cde	68.33bc	3.00	3.04b	8033de	1540e	19.43ab
	Mean	91.15	142.85	70.94	3.35	2.81	9528.20	1766.40	18.49
	CV	3.54	1.96	12.44	17.3	2.89	11.26	5.83	9.85
	LSD	5.50	4.77	15.03	0.99	8.64	1826.90	175.45	3.10
	Varieties	**	**	**	NS	**	**	**	**

*and ** denote significant difference at $p < 0.05$ and $p < 0.01$, respectively. NS = non-significant
Mean values followed by a similar letter(s) in each column had nonsignificant differences between them. LSD (5 %) = least significant difference at $p < 0.05$. DF = days to flowering, DM = days to maturity, PH = plant height (cm), NT = number of tillers, TSW = thousand seed weight (g), BY = Biomass yield (kg ha^{-1}), GY = Grain Yield (kg ha^{-1}), HI = Harvest Index.

and animal feed, respectively. Therefore, finger millet Meba, Tessema, and Axum varieties are suggested in the Awebare district.

The finger millet genotype with a high yield and low degree of fluctuation across different environments is preferred (Simion et al., 2020). In this study, finger millet varieties Meba and Tessema are high-yielding and consistent across the two locations. Jerjero et al. (2022) also reported that the finger millet variety Tessema was well-adapted and preferred by farmers in Southern Ethiopia. The Meba and Tessema varieties are recommended in the Kebribeyah and Awbare districts and areas with similar agroecology.

CONCLUSION

According to the analysis of variance, the tested finger millet varieties showed a highly significant variation in yield and most of the yield-related traits in the Kebribeyah and Awbare districts. The results showed that Meba and Tessema were the most stable and best-performing varieties in grain yield and other traits at both locations. Therefore, these varieties are recommended in study sites and areas with similar agro-ecologies. However, to develop a comprehensive production package for these varieties, it is suggested that further research is required on agronomic practices, pest and disease management, and post-harvest handling.

DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

COMPETING INTERESTS

The authors affirm that they have no competing interests that could influence the objectivity or validity of this work.

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CONFLICT OF INTEREST

The authors declared no conflicts of interest concerning research, authorship, and publication of this article.

ETHICAL COMPLIANCE

The authors followed ethical standards in conducting the research and preparing the manuscript.

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