Exploring the On-Farm Potential of Improved Sorghum Varieties forScalingin Dry Lowland Areas of Ethiopia

Abstract

Feeding the world's growing population has become a global issue due to climate change, which has resulted in low agricultural productivity. Although an attempt has been made to feed this growing population by introducing improved agricultural technologies that boost productivity, the sustainability of these introduced technologies is not promising as farmers insist to use traditional way of production. The study was conducted in the districts of Gololcha and Shanana Kolu to investigate the on-farm potentials of Melkam, Tilahun, and Argiti varieties. Melkam had a higher grain yield (3628 kg/ha) than Argiti (3234 kg/ha), Tilahun (3050 kg/ha), and the districts average sorghum productivity (2320 kg/ha). The mean yield comparison results of yield performances revealed a significant difference (p0.05). Melkam variety had the highest net benefit of 97,432 ETB.The higher gross margin (97,432 ETB per hectare) was received from Melkamwith marginal benefit advantage of 57,306 ETBover the local, Argiti (44,698) and Tilahun (38,810 ETB) per hectare. The mean weight score of the selected traits revealed that grain yield and injera-making quality were the top priorities for women farmers, while grain yield and earliness were the top priorities for men farmers. The preference of the men and women found to be different which indicates considering gender needs during scaling of technologies. As a result, it is recommended that Melkam variety to be scaled up with the recommended production practices in the study areas and areas with similar agroecology to improve production and farmers' income.

Keywords: Grain yield, cost-benefit, sorghum, trait preference, improved varieties.

Introduction

Sorghum [Sorghum bicolour (L.) Moench] is one of the major cereal crops produced in the world. It is a major food security crop in sub-Saharan Africa, supporting some 300 million people. It is a relatively drought-tolerant crop adapted to grow under harsh production conditions (FAOSTAT, 2021; Hadebe et al., 2016).

In Ethiopia, sorghum is ranking third after teff and maize in the total production area. It ranks fourth after maize, teff, and wheat in grain production. It is grown in almost all regions, covering a total area of 1.6 million ha (CSA, 2021). Its productivity is constrained by several factors since it is grown in a variety of environments. Moisture stress, insect pests, striga, low soil fertility, diseases, and low-yielding local cultivarsare reported as major constraints (Rebeka et al., 2013, Amelework et al., 2016 and Habte et al., 2022.

In the study areas, sorghum takes first rank in production. It is largely produced by smallholder farmers. Sorghum cultivars cultivated in the study areas are characterized by their long height (3 meters and above) and late maturing (more than 8 months) with low productivity. The red-colored sorghum (grain) is also the dominant one.

Ethiopian Institute of Agricultural Research (EIAR) developed and released more than 25 drought-tolerant, yielder, and early maturing sorghum varieties suitable for dry lowland areas with improved production management practices to improve the productivity level (Hailegebriel and Adane, 2018). However, the cultivation of landraces/local cultivars persists among smallholder farmers across the country. The number of farmers growing the improved sorghum varieties is 28%, which is very low, (Taye et al., 2019). The low level of improved sorghum varieties cultivation is attributed to the low access to improved seeds or information and availability of farmer-preferred varieties (Nega, 2006; Ermias, 2013; Bedru and Mekonen, 2013).

To boost sorghum productivity, increasing the availability of improved varieties through demonstration, promotion, and scaling out will assist the farming community for further adoption. To accomplish this, many varieties have been demonstrated in certain areas, and work to address the wider farming community is currently underway. The goal of this study is to find a promising variety that meets farmers' demand for further expansion.

Materials and Methods

Description of the study area

The Experiments have been conducted in the districts of Gololcha and Shanan Kolu, the districts, which represent lowland and midland agroecologies, are situated in north-eastern Ethiopia. Mixed crop and livestock farming is the main form of agricultural production in both districts. The main crops grown are sorghum, coffee, maize, teff, and khat. The main rainy season for the district was from May to September, with 400–1112 mm, and was followed by a prolonged dry period of seven months. According to GDOoANR and SKOoANR, the temperature ranges from 26 to 40 degrees Celsius. The main cultivars that farmers cultivate are the locally popular cultivars known as Arkabas (matures in 5–6 months) and Alewalem (matures in 9 months).Different stakeholders introduce improved and early matured sorghum varieties like Gobiye, Abshir, Teshale, and Dekeba as local cultivars in use are late mature. Due to the farmers' preference for certain traits and the lack of strong extension services, the varieties were not scaled up to the larger sorghum producer farmers. Farmers insist on using their local cultivars at large.

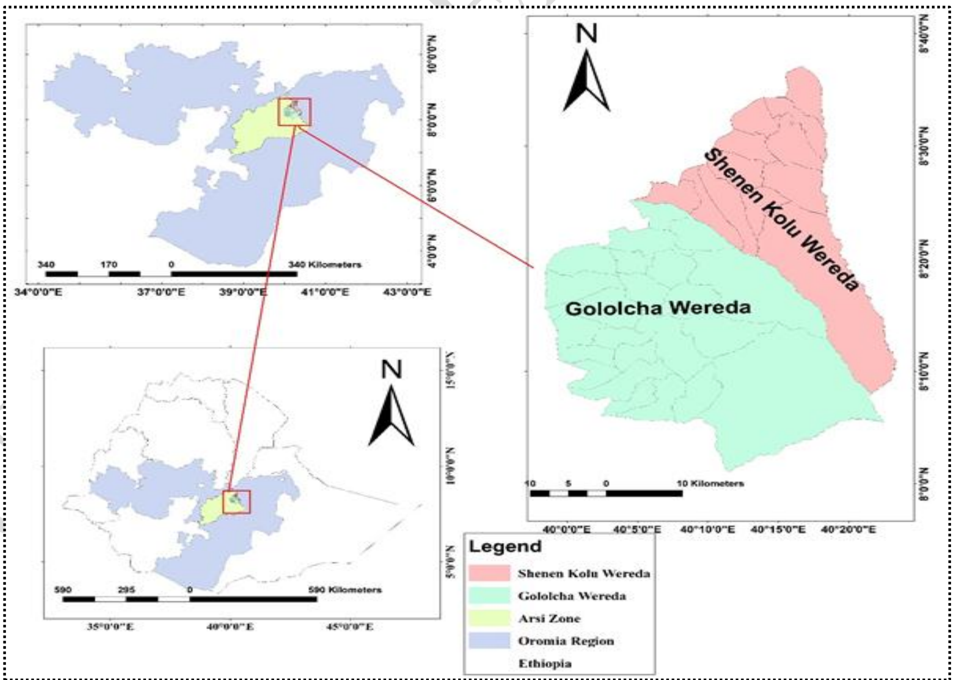

Figure 1: Study area map

Site and farmers' selection

Based on their sorghum production volume, the Gololcha and Shanan Kolu districtswere specifically selected from the Arsi Zone. The Arsi Zone Agricultural and Natural Resource Office was consulted before making the choice. Ten kebeles from the Gololcha district and four kebeles from Shanan Kolu were the targets. Additionally, the kebeles were chosen at random from the study area. Farmers who are interested in the technology, willing to manage the experimental field, willing to allocate land for the experiment, and willing to share the results with other farmers are just a few of the selection criteria for experiment host farmers. The improved sorghum management practices were introduced, and practical training was given, before the start of the experiment. In total, 93 host farmers' fields (fifty-seven in 2020 and thirty-six in 2021) were established on 23.25 hectares where each farmer allocated 0.25 hectares on average for three varieties. Farmers who established the experiments were considered asa replication. The replication of the experiment in two consecutive years was to increase the reliability of the data and conclusions to be drawn.

Materials and management used

Three released sorghum varieties were evaluated in 2020 and 2021 during the main cropping seasons in both districts. Improved sorghum varieties; namely Tilahun, Argiti, and Melkam were used for the experiment. These varieties are adapted to dry lowland areas. The varieties were planted side-by-side to compare and evaluate their performance. During planting, the seeds were manually drilled at a seed rate of 10 kg/ha. Each variety was planted on a plot size of 400 m2 (20 m long by 20 m width), with an intra- and inter-row spacing of 20 cm and 70 cm, respectively. Land preparation was done according to the recommended practice. Fertilizer, 100 kg/ha of the NPS was applied at the time of planting and 50 kg/ha of Urea was applied in the form of split application; half of it was at planting and the rest was top-dressed at the knee-height stage.

Table 1. Description of improved sorghum varieties used for the experiment

Variety	Flowering date	Plant height (cm)	Productivity	Maturity date (days)	Types
Melkam	76-82	126-163	3500-5800	118	Semi-compacted head and white grain color
Argiti	79	200	3750-6000	125	Compacted head and white grain

					color
Tilahun	78	190	3400-6000	120	Semi-compacted head and white grain color

Source: EIAR, 2022. MoAL. 2016

Quantification of yield gaps

The researchers recorded qualitative and quantitative data during scheduled farm visits and follow-ups. Data were collected using a data sheet. Yield gaps were calculated using the definition and concepts provided by Lobell et al. (2009). These are Research Station Yields (Maximum possible yield with improved management practices, under controlled field conditions, taken from the crop variety registry book MoAL, (2016) for this case), On-Farm Demonstration Yields (obtained yields with improved management practices under on-farm situations) and District-Level Average Yields (yield obtained under farmers condition with traditional management practices). The yield gaps were divided into two groups. The yield gap between the research station yields and on-farm demonstration field yield. The second gap is the demonstration yield and district-level average yields. The difference between the research station yields and the district-level average yield is the total yield gap.

Data collection and data analysis

Data were collected on grain yield, farmers preferred treats, and cost of production. For simplicity, the yield obtained from the plot was converted to a kg/ha. The data were analysed using descriptive statistics, preference ranking, yield gap, and profitability(gross margin, net return, total return, and the benefit-cost ratio). In profitability analysis land was taken as a fixed asset in the assessment of its opportunity cost. Costs of land preparation, seed, fertilizer, and hired labor were calculated based on the existing market price of inputs during the experimental period. The total cost was estimated by adding variable costs and fixed costs. To estimate the cost of sorghum cultivation, BCR methods were used (Gines, 2021).

Results and Discussion

Description of sorghum producer households

Of the total demonstration host farmers, 51 are fromthe Shanan Kolu district while 42 are fromthe Gololcha district. The number of female demonstration host farmers was lower than male farmers (Table 2). Male farmers represented 81%, whereas female farmers were at 19%. A majority of sorghum farmers have no formal education (86%) and only 12% attended a primary level of education. More than half of the sorghum producers (76%) are aged between 31 to 50 years with an average year of 38. The sorghum farmers' family size ranged from 1 to 10, with an average size of less than two. The majority, 60% had a family size of 1-5. The farmers' experience in sorghum production ranges from 5 to 38 years, with an average farming experience of 18 years. The total farm size owned by the farmers ranged from 0.25ha to 11ha. Most farmers had a farm size of 1-3ha (45%) followed by less than 1ha (43%). This shows that the study area is dominated by smallholder farmers. Most farmers (73.1%) grow sorghum on a plot size of less than 0.5ha.

Table 2. Demographic characteristics of farmers (N=93)

Variables		Number of farmers	Percent	Mean	SD
Education level	No formal education	80	86	-	
	Primary education	11	11.8		
	Secondary	2	2.2		
Age (years)	≤30	13	14	38	6.88
	31-50	76	81.7		
	51-70	4	4.3		
Sex	Male	75	80.6	-	
	Female	18	19.4		
Experience (years)	≤10	20	21.5	18	6.89
	11-20	49	52.7		
	21-30	19	20.4		
	>30	5	5.4		
Farm size (ha)	<1	43	46.2	1.35	1.47
	1-3	45	48.4		
	>3	5	5.4		
Area allocated to sorghum (ha)	≤0.5	68	73.1	0.47	0.26
	0.5-1	23	24.7		
	>1	2	2.2		
Family size	1-5	56	60.2	1.35	1.47

On-farm yield performance of sorghum varieties

The mean grain yield of the improved sorghum varieties demonstrated was 3050 kg/ha, 3234 kg/ha, and 3628 kg/ha for Tilahun, Argiti, and Melkam varieties respectively. The highest mean yield was recorded by the Melkam variety in 3682 kg/ha in Shanan Kola district. This means that the Melkam variety has a grain yield advantage over Tilahun and Argiti with 15% and 11% respectively. Comparing the improved varieties with the local control (district average yield), a 36% grain yield advantage was recorded by the Melkam variety, the highest mean grain yield gap.

The average yield of Argiti and Tilahun was also more than the district average yield which was 2320 kg/ha (CSA, 2021). According to EIAR (2016), the average sorghum productivity at farmers' fields is about 2800 kg/ha, while it is 3000 kg/ha to 5000kg/ha at experimental plots. The mean yield obtained from the improved varieties in this study is therefore superior and promising to smallholder farmers in the study area and similar agroecology. The high yield potential of the improved varieties therefore will provide to improve food security and income of sorghum-producing households in the study area. The yield difference observed was due to the suitability of the environment for the Melkam variety in the study area. The result in Figure1 is evident that the performance of the Melkam variety was found better than Tilahun, Argiti varieties, and the local cultivars. This result clearly showed that new varieties have a higher grain yield. This conforms to that of EIAR, 2021 and Girma et al., 2019. The adoption of Melkam variety by farmers around Babile district also showed a positive and significant impact on household food security, as reported by Abdukerim et al. (2023). Thus, large scale production of Melkam variety of sorghum would contribute in improving the amount of sorghum produced, as well as the income of farmers.

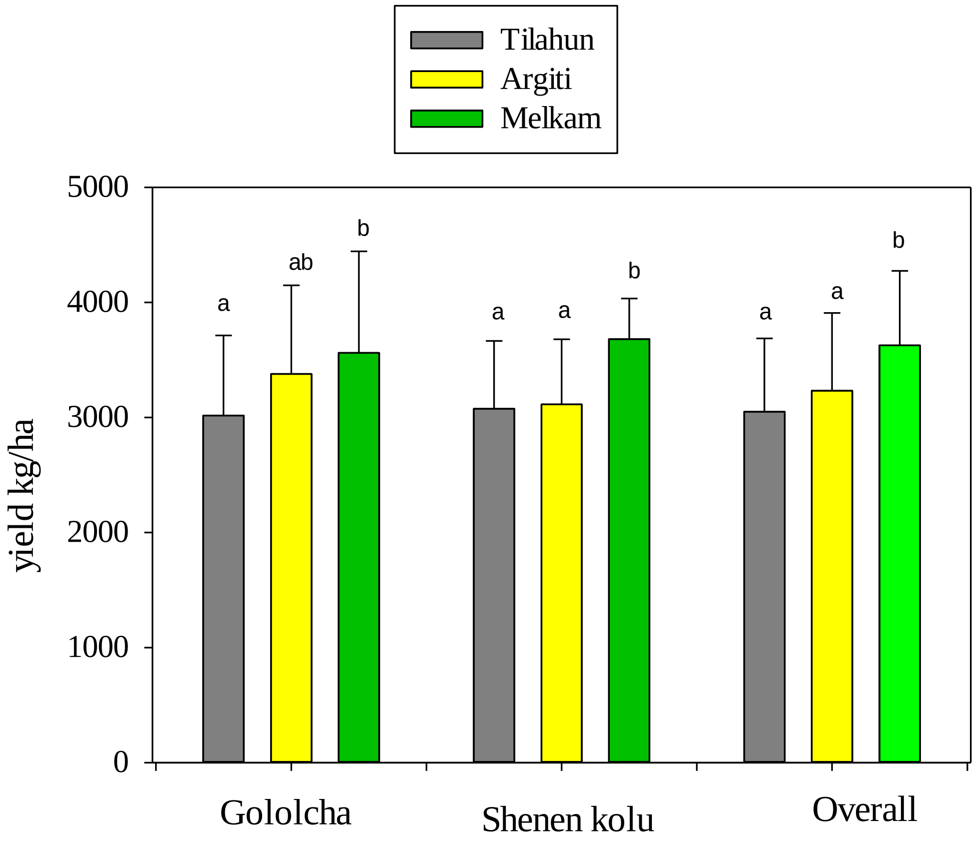

Figure2 On-farm yield performance of sorghum varieties. The same letters in the same group are not significantly different at 5% using the Dunkan test.

Table 3. Mean yield gap of sorghum varieties (kg/ha)

Location	Variety	Experimental station yield	District averaged yield	On-farm demonstration Yield	Technology gap	Total yield gap
Gololcha	Tilahun	4700.00	1840.00	3017.88	1177.88	2,860.00
	Argiti	4800.00		3378.64	1538.64	2,960.00
	Melka	5100.00		3562.79	1722.79	3,260.00
Shanan Kolu	Tilahun	4700.00	2800.00	3077.00	277.00	1,900.00
	Argiti	4800.00		3115.31	315.31	2,000.00
	Melkam	5100.00		3682.06	882.06	2,300.00
Mean/ total	Tilahun	4700.00	2320.00	3050.30	730.30	2,380.00
	Argiti	4800.00		3234.24	914.24	2,480.00
	Melkam	5100.00		3628.19	1308.19	2,780.00

Gender-based preference analysis

Farmers considered different traits of a sorghum as important when selecting varieties for cultivation or preparing foods. Tsedal et al. (2022) also urged understanding cultural and social preferences of farmers towards sorghum varieties is argued as an important for the success of breeding programs and technology promotion.

A group of women and men farmers were formed from sorghum producer farmers in the study area as the preference may varyamong the group. As a result, it is found grain yield, good injera-makingquality (Ethiopian bread made from teff/ sorghum), earliness, higher market price, white grain color, large grain size, grain threshability, striga resistance, stalk sweetness, diseases and pest tolerance, large biomass, tallest plant height, and birds attack tolerant are the criteria taken into account. Accordingly, the mean weight score of the selected traits result showed that in the case of women farmers grain yield and injera-making quality ranked as their top priority while grain yield and earliness for the men farmers. Although both genders have the same demand for grain yield, the preference between the two groups is different showing that genders matter for the scaling out of improved variety introduced to the farming community (Table 6). The analysis shows that the Melkam variety was preferred for most of the characteristics except large grain size, stalk sweetness, large biomass, and plant height. Argiti variety was ranked as the second most preferred variety. A research report conducted in Ethiopia by Abebe et al. (2020) also revealed that there is a difference among men and female farmers in treat preference.

Table 4. Farmers prioritized traits and mean score

Farmers prioritized trait	Women score	Rank	Male score	Rank	Mean score	Rank
Grain Yield	29	1	30	1	29.5	1
Good injera-making quality	29	1	25	2	27	2
Earliness	16	6	30	1	23	3
Highest market price	23	2	19	5	21	4
Grain Colour (white)	19	5	22	4	20.5	5
Grain Size (large)	21	3	19	5	20	6
Grain threshes ability	19	5	16	7	17.5	7
Striga resistance	8	10	23	3	15.5	8
Stalk sweetness	9	8	18	6	13.5	9
Diseases and pest-tolerant	16	6	10	8	13	10
Biomass (Large)	2	11	18	6	10	11
Plant height (tallest)	9	8	9	9	9	12
Bird tolerant	8	9	6	10	7	13

Sorghum production costs

The costs of sorghum production are categorized under materials (fertilizer and seed) and operations incurred by farmers. From the total variable costs, more than 80% of the expenditure is operation costs. The costs of operation include, labor for ploughing, planting, weeding, harvesting, threshing & transport, and post-harvest handling formed the largest cost item and accounted for 72% of the total variable costs (Table 7). The average variable cost of sorghum production was 18, 664 ETB per hectare for improved varieties and 17, 874 ETB per hectare for local cultivars. The cost difference between the improved and the local cultivar was due to the price difference of a seed price and the fertilizer amount used. The lion's share of the cost was incurred for ploughing (24%), followed by threshing, and transport costs (20%). As the result shows all costs of sorghum production are the same except costs of seed and fertilizer.

Table 5. The operational cost of sorghum production

Type of expenses	Average cost (ETB/ha)		Total cost (%)	
	Local	Improved	Local	Improved
Cost of input	**2610**	**3400**	**14.6**	**18.2**
Fertilizer	2,250	3,000	12.6	16.1
Seed	360	400	2.0	2.1
Operation cost	**15264**	**15,264**	**85.4**	**81.8**
Ploughing (three times)	4,466	4,466	25.0	23.9
Planting &fertilizer application	2,200	2,200	12.3	11.8
Total wedding	3,332	3,332	18.6	17.9
Harvesting	1,666	1,666	9.3	8.9
Threshing & transport	3,600	3,600	20.1	19.3
Total production cost (variable)	17,874	18,664	100.0	100.0

Source: On-farm demonstration (2020-2021)

Cost Benefit Analysis of sorghum production

The total costs for sorghum production vary from farmer to farmer and location to location. The costs and benefits for each variety were calculated by considering variable costs (Table 7). Melkam variety had the highest benefit-to-cost ratio with 97,432 ETB. It is followed by Tilahun (78,936 ETB) and Argiti(84,824 ETB) per hectare. However, the net benefit for the local sorghum cultivars was 40,126 ETB per hectare. This shows that the improved varieties give a better net benefit compared to the local one. Melkam has a higher benefit-cost ratio (4.4) followed byArgiti (3.9) and Tilahun (2.2). The benefit-cost ratios for local cultivars were 2.2. A study conducted by Regassa et al., (2023) also reported the improved varieties gave a maximum benefit with benefit-cost ratios of 2.60.

The profitability of sorghum production relates directly to the productivity and grain price. Thus, farmers will be at a high level of profit if they cultivate the Melkam variety using associated production practices followed by the Argiti variety in the study areas.

Table 6. Cost and Benefit analysis of the demonstrated varieties per hectare

Operations	**Local**	**Melkam**	**Tilahun**	**Argiti**
Total variable cost	17,874	18,664	18,664	18,664
Fixed cost (Land cost /ha)	8,000	8,000	8,000	8,000
Total cost (fixed and variable cost)	25,874	26,664	26,664	26,664
Grain yield (kg/ha)	2,320	3,628	3,050	3,234
Grain price (ETB/kg)	25	32	32	32
Gross Income	58,000	116,096	97,600	103,488
Net benefit /Total revenue/	40,126	97,432	78,936	84,824
Total Net benefit (including fixed)	32,126	89,432	70,936	76,824
Marginal benefit (ETB)	Base	57,306	38,810	44,698
BCR	2.2	4.4	3.7	3.9

Source: On-farm demonstration fields (2020-2021)

Marginal Analysis

Farmer's net benefit is raised by cultivating the improved varieties. Based on the finding, the highest marginal yield was earned by Melkam and followed by Argiti. The marginal yield of Melkam, Argiti, and Tilahun was 73%, 57% and 49% respectively. This shows that Melkam was the first chic and Argiti was the second one. Since the marginal yield of the Tilahun variety was under 50%, it is not recommended to be cultivated by the farmer. The improved varieties gavean additional one kg of grain yield with additional costs of 0.6, 0.9, and 1.1 ETB for Melkam, Argiti, and Tilahun respectively. In the rule of marginal cost analysis, the lowest cost that increases a unit yield is the best option. Accordingly, the Melkam variety is the best choice for sorghum producer farmers.

Table 7. Marginal analysis for improved varieties compared to local cultivars

Treatment	Variable cost	Net Benefit	Productivity (kg)	Marginal cost	Marginal benefit	Marginal rate of return
Melkam	18,644	97,432	3628.19	0.6	57,306	72.5
Argiti	18,664	84,824	3234.24	0.9	44,698	56.6
Tilahun	18,664	78,936	3050.30	1.1	38,810	49.14
Local	17,874	40,126	2320.00			

Source: On-farm demonstration fields (2020-2021)

Conclusion and Recommendation

Sorghum is an ideal crop for improving farmers' food security and resilience in marginal areas such as Gololcha and Shanan Kolu. As a result, scaling out the improved varieties, particularly the Melkam variety, is the most effective way to increase productivity. The Melkam variety was found to be the most productive when compared to local cultivars and improved varieties such as Argiti and Tilahun. As compared to farmer productivity, its high yield potential can increase up to 1308 kg/ha. Melkam variety had also the highest benefit-to-cost ratio with 97,432 ETB. It is found that men and women farmers have different prioritized traits for sorghum. In the case of women farmers grain yield and injera-making quality are the top priority while grain yield and earliness are priority for men farmers. However, both groups have the same demand for grain yield. This shows the need to consider gender when doing research and scaling of sorghum to the farming community.Thus, adopting the Melkam variety along with recommended production practices will increase food availability and farmers' income. It is recommended that district agricultural offices scale up the Melkam variety with the full production package to farmers in the study area and similar agroecologies.

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