Finger Millet Production in Ethiopia

Subjects: Anthropology

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Finger millet (Eleusine coracana (L.) Gaertn) is a highly nutritious crop, predominantly grown in the semi-arid tropics of the world. The crop has medicinal value to human beings due to its human health benefits and being rich in calcium, iron and dietary fiber and gluten-free. Ethiopia is the center of the genetic diversity of the crop. However, the productivity of finger millet in the country is low (<2.4 tons ha−1) compared with its potential yield (6 tons ha−1). The yield gap in Ethiopia is due to a range of biotic and abiotic stresses and socio-economic constraints that are yet to be systemically documented and prioritized to guide future production and improved variety development and release. The objective of this study was to document finger millet production opportunities, constraints and farmer-preferred traits in Ethiopia as a guide to variety design in improvement programs.

Keywords: Eleusine coracana ; drought stress ; finger millet ; participatory rural appraisal ; indigenous knowledge

1. Introduction

Finger millet (*Eleusine coracana* (L.) Gaertn) is an important cereal crop in the semi-arid and tropical regions of the world. The name finger millet is derived from the appearance of spikes or fingers, which are arranged and appear like human fingers. Compared with other major cereals such as rice, wheat and barley, it is relatively drought-tolerant due to its C4 photosynthesis system and adaption to grow under harsh and marginal agro-ecologies. Agriculture is an important economic sector in Africa, including Ethiopia. The sector accounts for 25% of Africa's GDP, 21% of exports, and 65–70% of the workforce supporting the livelihoods of 90% of population [1][2][3]. In Ethiopia, agriculture contributes to 44% of GDP, 70% of export earnings and 80% of employment opportunity [4]. Finger millet is grown mainly for its grain, which is utilized to make traditional food and drinks, while the stalks are used for livestock feed, construction and fuel. Finger millet has various human health benefits such as reducing diabetes [5], obesity [6], osteoporosis [7][8], anemia [6], malaria [9][10] and diarrhea [9][10]. The health values of finger millet are linked to its high calcium, iron and dietary fiber content and being gluten-free. These health benefits will render finger millet as a crop of niche market opportunity in the future. Finger millet is cultivated in more than 25 countries in Africa and Asia [11]. Ethiopia is the second largest producer of finger millet in the world after India [12][13]. In Ethiopia, the grain is processed to make unleavened bread (locally referred to as enjera) and for malting to prepare local drinks such as a distilled spirit 'Areki' or local beers such as 'tella' and non-alcoholic drinks such as 'karibu' and 'shamita', while the straw is vital as a livestock feed and for thatching of houses [14][15].

The global production area and total production for finger millet are unknown since both statistics are merged and reported with other millets. An estimated total production area of 32,554,127 ha is devoted to millets production worldwide [12]. It is estimated that the share of the global finger millet production area is about 12.5% of the millet. Ethiopia's total finger millet production area is 455,581 ha [16], making an 11.2% global share [12][16]. A total of 3,834,021 tons of finger millet grain is produced per annum globally [12], while Ethiopia's output is estimated at 1,125,958 tons [16], equivalent to 29.4% of global production. Finger millet is the sixth most important cereal crop in Ethiopia in total area and production after tef (*Eragrostis tef* (Zucc.)Trotter), maize (*Zea mays* (L.)), sorghum (*Sorghum bicolor* (L.) Moench), wheat (*Triticum aestivum* (L.)) and barley (*Hordeum vulgare* (L.)) [16]. It accounts for 5% of the total area allotted to cereal production in Ethiopia [17]. Finger millet is grown in more than 1.8 million households on more than 455,000 hectares of land in the northern, north-western, western, the Central Great Rift Valley and West Hararghe zones of Ethiopia [16]. In 2017 the total grain production was 1,017,059 tons, increasing by 87% in the preceding 20 years [17].

Despite the importance of finger millet for food security and livelihoods, its productivity is relatively low (2.47 t/ha) [16] in Ethiopia compared with the potential yield of the crop (6 t/ha) achieved under experimental conditions [18]. The low productivity of the crop in the country is attributable to a range of biotic and abiotic stresses and socio-economic constraints prevalent in the smallholder production systems in Ethiopia. Finger millet blast caused by *Magnaporthe grisea* (Barr) (teleomorph) is the most damaging disease, causing yield losses in the range of 7.32–54.07%, depending on climatic conditions and cultivar susceptibility [19]. Notable insect pests of the crop include grasshoppers (Caelifera) and shoot fly (*Atherigona soccata* (Rondani)) [15], pink stem borer (*Sesamia inferens* (Walker)), finger millet root aphid (*Tetraneura nigriabdominalis* (Sasaki)) and aphids (aphidoidea) [20][21]. Yield losses have been reported due to several insect pests such as termites (isopteran) (with a loss of 23%) [22], aphids (35.1%) [20] and pink stem borer (56%) [21]. Weeds cause severe yield loss during the early growth stages of finger millet. In Ethiopia, yield losses of up to 73.5% have been reported due to weeds [23]. The most problematic weed species of finger millet in Ethiopia include *Digitaria ternata* (A. Rich.) Stapf, *Guizotia scabra* (Vis.) Chiov, *Cyperus rotundus* L. [23] and *Striga hermonthica* (Delile) Benth [24].

Recurrent drought stress associated with climate change is the leading constraint affecting finger millet production and other main crops in Ethiopia. The impact of drought stress on finger millet production depends on cultivar susceptibility, the onset date, the intensity and duration of the drought stress and the associated prevailing environmental conditions. Although finger millet is relatively drought-tolerant, 100% yield losses can be incurred due to intense and early onset of drought stress [25]. Supplementary irrigation, early planting and moisture conservation techniques such as mulching, zero tillage and tie ridging are often used to mitigate drought stress [26]. However, most smallholder farmers do not have access to irrigation and other resources to manage drought stress. Drought stress also significantly affects grain quality and yield components [27]. Hence, drought-tolerant varieties could be the most economical and environmentally friendly approach to controlling drought under smallholder production systems.

In Ethiopia, formal research on finger millet improvement started in the early 1980s [28]. In the last four decades, finger millet improvement activities in Ethiopia have focused on characterization and evaluation of locally collected and introduced germplasm for pure line selection. As a result, some 23 finger millet varieties have been registered and released for production [29]. Two varieties, Tadesse (KNE#1098) and Tessema (ACC#229469), were released with the beneficial traits of wide adaptability, high grain yield potential, good biomass and compact head shape. However, these varieties are late maturing, susceptible to insect pests and diseases, have relatively low human nutrition value and a seed shattering problem. The mean grain yield of improved finger millet varieties in Ethiopia is low at 2.7 t/ha [30], compared with 4.74 and 4.79 t/ha reported for Kenya [31] and India [32], respectively. Ethiopia is the primary centre of origin and diversity for finger millet [33]. The finger millet landraces grown by farmers are essential genetic resources that are known to hold useful genetic variation for desirable traits. Therefore, these landraces can be evaluated and selected for their desirable characteristics for new variety development, genetic analysis and gene discovery, leading to high yielding varieties that have all the essential farmer-preferred traits [34]. The finger millet production opportunities, farming systems, production constraints and preferred traits of the end-users are essential components for variety design and breeding strategies. Incorporating the needs and preferences of farmers would increase the adoption of new varieties of finger millet.

Farmers have a wealth of knowledge about their crops, farming systems and the constraints [35] that can be harnessed through a participatory rural appraisal (PRA). A PRA is a research tool used to gather useful information on farmers and their production systems for designing intervention strategies [36]. The PRA approach provides a platform for farmers and breeders to engage in information sharing actively. Plant breeders must understand farmers' situations and choices to design appropriate varieties to meet their needs. Several studies have used the PRA approach to gain insight into farmer production systems and varietal choices to prioritize breeding objectives, including in tef [37], sorghum [38], wheat [39]), pearl millet (*Pennisetum glaucum* (L.) R. Br) [40] and finger millet [41]. For example, drought is the major production constraint of finger millet in Eastern Uganda, according to Owere et al. [24], and in sorghum production in Ethiopia [42][43]. Similarly, a lack of access to improved seeds of groundnut [44] and sesame [34], a lack of improved varieties of sorghum [43] and a shortage of arable land and poor soil fertility in sorghum [42] were also identified as production limiting factors in Ethiopia. Likewise, a lack of improved finger millet and sorghum varieties in Uganda [24][38] and limited access to fertilizers in pearl millet production in Burkina Faso [40] have also been documented as production constraints. However, no recent study has documented farmers' perceptions of production constraints and trait preferences in finger millet in Ethiopia.

2. Finger millet production in Ethiopia: opportunities, problem diagnosis, key challenges and recommendations for breeding

2.1. Demographic Attributes

The demographic characteristics of the respondents were documented (**Table 1**) because they influence farming practices, intervention strategies and technology adoption among farming communities. The most significant proportion of respondents were male, which is concomitant with the fact that most households in the study area were male headed (**Table 1**). Patriarchy is dominant in the study area, with a negligible number of females having decision-making powers. The disenfranchisement of females, as discovered in other PRA studies, also reflects their peripheral roles in decision-making in agricultural activities and their ongoing exclusion from social services such as training and agricultural extension services [45], despite their active participation in farming operations such as ploughing, weeding and harvesting.

Table 1. Proportion of respondents' gender, age, family size and level of education in the study districts.

Variables	Categories	Districts						Frequency	Percent
		Atote Ulo	Wera	Shala	Siraro	Habro	Daro Lebu		
Gender of household head	Female	9	4	15	3	5	5	41	17.1
	Male	31	36	25	37	35	35	199	82.9
	Chi-square test		$X^2 = 17.8$			df = 5		*p*-value = 0.003	
Age of household head (year)	18–40	29	31	24	31	33	26	174	72.5
	41–50	8	7	14	8	7	10	54	22.5
	>50	3	2	2	1	0	4	12	5
	Chi-square test		$X^2 = 11.0$			df = 10		*p*-value = 0.358	
Number of children	≤2	5	18	6	5	13	5	52	21.7
	3–5	14	8	7	11	19	13	72	30
	≥6	21	14	27	24	8	22	116	48.3
	Chi-square test		$X^2 = 38.4$			df = 10		*p*-value = 0.000	
Educational status of household head	Illiterate	12	5	16	4	16	6	59	24.6
	Read and write	0	2	5	2	4	3	16	6.7
	Grade 1–5	16	10	7	20	7	15	75	31.3
	Grade 6–8	4	5	6	11	6	12	44	18.3
	High school	5	10	6	2	6	3	32	13.3
	College	3	8	0	1	1	1	14	5.8
	Chi-square test		$X^2 = 66.1$			df = 25		*p*-value = 0.000	

Note: X^2 = chi-square test, df = degree of freedom, *p*-value = probability value.

In terms of age, most of the interviewed farmers were within the active age group of 18–40 years (**Table 1**). This group consists of young and middle-aged adults that participate in the economy by providing labour and engaging in economic activities, such as trade, and in decision-making. Mulalem and Melak [22] also identified this group as vital for agricultural functioning as an active, productive age group. The young adults in this group can adopt new agricultural technologies, given their high literacy level and lack of prior experience [46]. The middle-aged adults in the active productive group were involved in decision-making and influenced choices of agricultural technologies, which in turn have an impact on crop production and productivity [36].

The respondent farmers had large families of more than five children per household, which positively impacts the provision of labour for crop production but is a concern for food insecurity in the study districts. Large families provide readily available labour for farming activities in subsistence farming systems because the farmers cannot afford to hire external labour [43]. Smaller households struggle to implement essential activities such as ploughing and weeding, given that most operations in smallholder farming are manual. Provision of labour is also related to the age of family members. Families composed of mostly young children struggle to provide the required labour. However, large families require more significant amounts of food for sustenance, and the risk of food insecurity increases in subsistence farming where crop productivity is generally low. Tadele [47] noted that large families have an adverse impact on food security, especially in Africa, where the population growth rate is very high.

The low literacy levels among the sampled farmers are of concern, especially for the successful introduction of new technologies and dissemination of information. A low level of education has been identified as a significant factor leading to poor adoption of agricultural technologies and access to information in rural and smallholder farming communities.

Interventions such as farmer training and provision of information have less impact on agriculture systems where farmers have low levels of literacy [45][48]. Farmers who have a higher level of literacy are likely to adopt improved technologies and improve their farming practices for higher crop productivity and have the potential to engage in more profitable markets or negotiate for better prices with service providers [45][49].

2.2. Dominant Crops Cultivated in the Study Areas

Crop production was dominated by maize and finger millet (**Table 2**), consistent with previous reports showing that smallholder farmers cultivated mainly maize and other cereals crops [50]. The land allocated for finger millet production by a household was equivalent to the national average of 0.25 ha [17], showing that the selected study sites could represent finger millet production systems in Ethiopia. The production of finger millet is essential for mitigating the impact of drought stress on food security. Finger millet is more drought tolerant than crops such as maize. However, the dominance of cereals is a concern for nutritional security. Cereal-based diets are carbohydrate-rich, leading to hidden hunger caused by deficiencies in essential nutrients such as specific amino acids, minerals and vitamins. Finger millet, and sorghum to an extent, are high in micronutrients, and farmers in the study areas get the various health benefits in their food sources from the two crops. The farmers reported trading their grains for cash income generation to buy other foods containing proteins, vitamins and minerals to supplement their cereal diets. However, low productivity and a lack of surplus grain yield frequently limit potential income generation. Yields below 1.5 t/ha have been commonly recorded in the study areas, below the national average for all crops. The dominance of maize in production systems of the study areas has been enhanced by its potential due to its early sowing dates, where green maize is grown to avert food shortages in the lean season (when the previous season's grain harvest becomes depleted but the new crop is not available), and its relative ease of marketing compared to finger millet or other cereals.

Table 2. Proportion (%) of respondents' farmland size (ha) allocation and productivity of major crops in the study districts during 2020/21 cropping season.

Districts	Crops											
	Finger Millet			Maize			Tef			Sorghum		
	Production Area (ha) of Crops and Proportion of Respondents (%)											
	<0.25 ha	0.25–0.5 ha	>0.5 ha	<0.25 ha	0.25–0.5 ha	>0.5 ha	<0.25 ha	0.25–0.5 ha	>0.5 ha	<0.25 ha	0.25–0.5 ha	>0.5 ha
Shala	53	38	10	15	30	55	46	43	11	100	–	–
Siraro	63	28	10	8	36	56	48	29	23	100	–	–
Atote Ulo	70	20	10	16	21	63	24	38	38	–	–	–
Wera	83	18	–	18	30	53	60	28	13	50	50	–
Habro	80	18	3	89	5	5	75	15	10	65	26	10
Daro Lebu	63	38	–	92	4	4	85	8	8	62	29	10
Mean (%)	68	26	5	31	24	46	51	30	19	67	25	8
Chi-square	$X^2 = 20.3$, df = 10, *p*-value = 0.03			$X^2 = 96.8$, df = 10, *p*-value = 0.000			$X^2 = 28.5$, df = 10, *p*-value = 0.002			$X^2 = 4.6$, df = 10, *p*-value = 0.800		
	Productivity (t/ha) of crops and proportion of respondents (%)											
Districts	<1.5 t/ha	1.5–3.0 t/ha	>3 t/ha	<1.5 t/ha	1.5–3.0 t/ha	>3 t/ha	<1.5 t/ha	1.5–3.0 t/ha	>3 t/ha	<1.5 t/ha	1.5–3.0 t/ha	>3 t/ha
Shala	25	50	25	21	29	50	100	–	–	75	25	–
Siraro	58	33	10	21	64	15	100	–	–	100	–	–
Atote Ulo	8	58	35	3	40	58	87	14	–	57	14	29
Wera	3	33	64	5	47	47	97	3	–	14	43	43
Habro	11	61	29	–	30	70	63	38	–	15	44	41
Daro Lebu	38	38	24	13	33	53	85	15	–	18	55	27

Districts	Crops											
	Finger Millet			Maize			Tef			Sorghum		
	Production Area (ha) of Crops and Proportion of Respondents (%)											
	<0.25 ha	0.25–0.5 ha	>0.5 ha	<0.25 ha	0.25–0.5 ha	>0.5 ha	<0.25 ha	0.25–0.5 ha	>0.5 ha	<0.25 ha	0.25–0.5 ha	>0.5 ha
Mean (%)	24	45	31	11	42	48	90	10	–	28	41	31
Chi-square	X^2 = 64.392, df = 10, *p*-value = 0.000			X^2 = 34.255, df = 10, *p*-value = 0.000			X^2 = 31.862, df = 5, *p*-value = 0.000			X^2 = 23.424, df = 10, *p*-value = 0.009		

Note: X^2 = chi-square, df = degree of freedom, t/ha = ton per hectare and *p*-value = probability value.

2.3. Various Uses of Finger Millet

Foremost, finger millet is used as a food crop in the study areas (**Table 3**). It is commonly ground into flour for making leavened bread known locally as ‘enjera’. However, finger millet has relatively poor ‘enjera’-making qualities and the farmers usually blend the finger millet flour with maize flour. Alternatively, finger millet is coarsely ground to make porridge. However, porridge made from finger millet is not common in Habro and Daro Lebu districts, where the farmers mentioned that they do not use finger millet to make porridge. Cultural differences and access to information influence the uses of finger millet. Training and awareness campaigns on the potential uses of finger millet and bio-fortification of finger millet could improve its utilization and contribute to food security.

Table 3. Proportion (%) of farmers who grow finger millet for various roles in the study areas.

Roles of Finger Millet	Districts						Mean (%)	X^2	df	*p*-Value
	Shala	Siraro	Atote Ulo	Wera	Habro	Daro lebu				
Food	8.3	22.5	2.5	5.0	14.3	16.7	11.5	101.55	35	0.00
Feed	–	–	–	–	–	–	–			
Cash	–	–	–	–	–	–	–			
Food and feed	13.9	20.0	15.0	2.5	14.3	22.2	14.5			
Food and cash	8.3	10.0	5.0	7.5	31.4	22.2	13.7			
Food and construction material	5.6	2.5	–	–	–	–-	1.3			
Food, feed and cash	13.9	17.5	55.0	65.0	40.0	38.9	38.8			
Food, feed and construction material	11.1	12.5	5.0	5.0	–	–	5.7			
Food, cash and construction material	19.4	2.5	7.5	–	–	–	4.8			
Food, income, feed and construction material	19.4	12.5	10.0	15.0	–	–	9.7			

Notes: X^2 = chi square test; *p*-value = probability value, df = degree of freedom.

Finger millet straw is also vital for livestock feed (**Table 3**). The farmers have small land holdings, and their livestock are raised on communal grazing lands. After harvest, the livestock are allowed into the fields to graze on crop residues. Most of the farmers in the study areas harvested the stover to feed the livestock when there was scarcity. While this stover’s nutritional value and palatability are relatively low relative to a green fodder crop [51], its impact on animal health is vital given the lack of alternative grazing in the dry season. Mululam and Melak [22] reported that 69% of farmers in North-Western Ethiopia used finger millet straw for animal feed, while 12% used the straw as a construction material. Studies in China showed that the replacement of other straws like corn straw with finger millet straw improved the growth of sheep and was recommended in fattened lamb production [52].

2.4. Socio-Economic and Environmental Factors Affecting Finger Millet Production

While the ranking of the importance of production constraints varied across the districts, erratic rainfall, a lack of improved varieties, a lack of financial resources to procure inputs, land shortages, a limited supply of seeds of improved varieties, a lack of access to fertilizers and declining soil fertility were the most common challenges affecting finger millet production (**Table 4**). Erratic rains were also identified as a major production constraint in Kenya [53], Myanmar [54] and Ethiopia [55][56]. A lack of financial resources has been previously identified as the single most crucial socio-economic challenge affecting crop production in most sub-Saharan African countries [57]. Limited access to agricultural inputs such as fertilizers, pesticides and improved seeds is related to limited financial resources and has been widely reported in Africa [58] and, particularly, Ethiopia [48][59][60].

Table 4. Proportion of farmers (%) who ranked the constraints to finger millet production in six districts of Ethiopia.

Constraints	Districts						Mean (%)	df	X^2	*p*-Value
	Atote Ulo	Daro Lebu	Habro	Shala	Siraro	Wera				
Drought stress	47.5	35.0	35.0	40.0	35.0	55.0	41.3			
Lack of improved varieties	7.5	30.0	12.5	10.0	7.5	10.0	12.9			
Lack of financial resources	15.0	–	–	30.0	22.5	–	11.3			
Land size limitation	10.0	5.0	25.0	2.5	12.5	10.0	10.8			
Limited access to seed	10.0	–	10.0	15.0	12.5	12.5	10.0			
Shortage of fertilizers	2.5	15.0	2.5	–	10.0	2.5	5.4	45	100.5	0.000
Poor soil fertility	–	12.5	10.0	2.5	–	2.5	4.6			
Shortage of draught power	–	2.5	2.5	–	–	2.5	1.3			
Labour shortage	2.5	–	2.5	–	–	2.5	1.3			
High labour costs	5.0	–	0.0	–	–	2.5	1.3			
Mean (%)	100	100	100	100	100	100	100			

df = degree of freedom; X^2 = chi-square; *p*-value = probability level.

Smallholder farmers face a multitude of production constraints that limit crop productivity. Biotic and abiotic constraints, such as pests and diseases and declining soil fertility, may be mitigated with breeding for varieties with the necessary resistance or tolerance level to support crop production in stress-prone environments. On the other hand, socio-economic constraints can be rectified by implementing necessary policy changes, training intervention and improving extension services. Both policy regulations to improve the socio-economic environment and breeding are still lagging, which significantly compromises crop production in general, particularly finger millet.

2.5. Farmers' Trait Preferences of a Finger Millet Variety

The most desirable traits of finger millet were compared and their order of importance were assessed via PCA. The biplot shows the interrelationship among the variables. The cosine of the angle between the vectors of two variables is almost equal to the correlation coefficient between them [61]. The angle between the two variables is an indication of how closely or distantly related the variables are. Therefore, the smaller the angle between them the stronger the relationship they have and vice versa. Comparison of the angles in **Figure 1** and the principal component analysis of **Table 5** showed a high correspondence between them. Identifying farmer-preferred traits is an essential step for variety design and development. High grain yield, 'enjera'-making quality, large head size and compacted head shape can be prioritized in variety development to meet the aspirations of the farmers (**Table 5**). The inclusion of farmer-preferred traits in variety development is essential to promote cultivar adoption but also to mitigate production constraints. Traits such as insect pest and disease resistance and drought and heat tolerance are vital for inclusion in new varieties, given that the farmers alluded to the impact of biotic and abiotic constraints on finger millet production (**Table 5**). While the ranking of farmer-preferred traits varied across the districts, the identified traits were consistent and could potentially be pyramided into a single variety. After identifying farmer-preferred traits in finger millet, the next step would be to understand the genetic basis of the traits and devise suitable strategies for their improvement in new cultivars. Traits such as high grain yield and drought tolerance are quantitative traits that are difficult to improve due to their polygenic nature and high environmental variance. They will require the collection of diverse genetic resources for evaluation and selection to develop suitable varieties. For traits such as blast disease resistance, additive gene action has been predominant for finger millet and showed that progress would be made through recurrent selection [62].

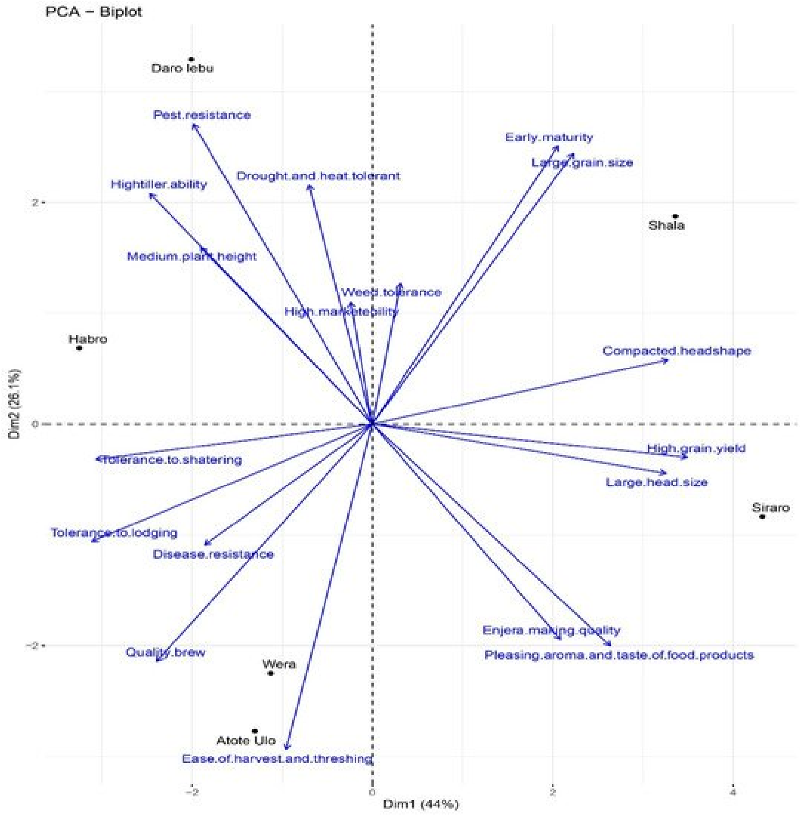

Figure 1. Biplot showing the interrelationships among the variables.

Table 5. Principal components and their contributions to finger millet agronomic and quality attributes reported in six districts in Ethiopia.

Variables	PC1	Contribution	PC2	Contribution	PC3	Contribution
High grain yield	**0.99**	**12.50**	**−0.09**	**0.16**	**0.02**	**0.01**
Large head size	**0.93**	**10.86**	**−0.13**	**0.34**	**0.09**	**0.30**
Weed tolerance	**0.09**	**0.10**	**0.36**	**2.79**	**0.84**	**25.65**
Disease resistance	**−0.53**	**3.54**	**−0.31**	**2.05**	**0.40**	**5.82**
Ease of harvest and threshing	**−0.27**	**0.94**	**−0.84**	**14.87**	**0.36**	**4.85**
Large grain size	**0.64**	**5.10**	**0.70**	**10.29**	**0.33**	**4.02**
Compact head shape	**0.94**	**11.03**	**0.17**	**0.58**	**0.28**	**2.89**
Insect pest resistance	**−0.57**	**4.04**	**0.77**	**12.65**	**0.27**	**2.69**
Tolerance to lodging	**−0.89**	**9.92**	**−0.30**	**1.94**	**0.23**	**1.89**
Brew-making quality	**−0.68**	**5.87**	**−0.61**	**7.91**	**0.13**	**0.57**
High tillering ability	**−0.70**	**6.23**	**0.59**	**7.47**	**−0.06**	**0.11**
Early maturity	**0.59**	**4.34**	**0.72**	**10.87**	**−0.08**	**0.26**
Pleasing aroma andtaste of food products	**0.75**	**7.13**	**−0.57**	**6.91**	**−0.18**	**1.19**
Drought and heat tolerant	**−0.20**	**0.51**	**0.61**	**8.03**	**−0.23**	**1.95**
Medium plant height	**−0.54**	**3.72**	**0.45**	**4.39**	**−0.26**	**2.47**
Tolerance to shattering	**−0.88**	**9.65**	**−0.09**	**0.18**	**−0.36**	**4.74**
‘Enjera’-making quality	**0.60**	**4.46**	**−0.55**	**6.51**	**−0.54**	**10.53**

Variables	PC1	Contribution	PC2	Contribution	PC3	Contribution
High marketability	**−0.07**	**0.06**	**0.31**	**2.08**	**−0.91**	**30.05**
Eigenvalues	**7.9**		**4.7**		**2.7**	
% of total variance	**44.0**		**26.1**		**15.2**	
Cumulative variance (%)	**44.0**		**70.1**		**85.3**	

PC = principal component, bold face values denote high score values.

Similarly, traits like high ‘enjera’-making quality are likely to be governed by a few major genes; the selection process and variety development may be relatively easier and faster than high yield and drought-tolerant variety development. Given that farmers desired multiple traits in a single finger millet variety, breeding an ideal variety will not be a straightforward process. This process of soliciting information from farmers can be conducted periodically and iteratively at all stages of variety design to incorporate new ideas and insights and respond to changes in environment and lifestyle. Owere et al. [24] also reported that high grain yield, compact head shape and early maturity were the most preferred attributes of finger millet. Likewise, high yield, drought tolerance, early maturity and big heads were key farmer-preferred traits reported by Ojulong et al. [63] and Tracyline et al. [64].

2.6. Cropping Patterns of Finger Millet and its Management Practices

Weed control was one of the major tasks carried out by farmers, and the use of manual labour to control weeds is both inefficient and time-consuming (**Table 6**). The combination of herbicides and manual labour is more efficient but was limited by the farmers’ shortage of inputs and lack of financial resources. Finger millet was planted as a sole crop, which agreed with another report showing that finger millet is commonly grown as a sole crop [9]. Unlike maize, which is sometimes intercropped with legumes, there are very few cases where finger millet is intercropped with legumes. The most common practice is to rotate finger millet with other cereals or legumes, which farmers in the study areas practiced. During group discussions, the respondents pointed out that finger millet was planted as a sole crop but in rotation with haricot bean and hot pepper. In addition to crop rotation, farmers used double cropping systems involving tef and haricot bean. However, the double cropping system was not possible with finger millet because the currently cultivated finger millet varieties are too late-maturing to fit into a double cropping system. Developing and deploying early maturing varieties would facilitate its inclusion in a double cropping system for enhanced food production.

Table 6. The proportion (%) of respondents who used different crop management practices in finger millet production across the districts during 2020/20121 cropping season.

Districts	Crop Management											
	Weeding			Cropping System			Crop Rotation		Transplanting		Planting Methods	
	Hand Weeding	Chemical Herbicides	Hand Weeding and Chemical	Sole	Mixed	Sole and Mixed	Yes	No	Yes	No	Row	Broadcasting
Atote Ulo	**55.0**	**–**	**45.0**	**100.0**	**–**	**–**	**100.0**	**0.0**	**–**	**100.0**	**100.0**	**–**
Wera	**77.5**	**–**	**22.5**	**100.0**	**–**	**–**	**100.0**	**0.0**	**–**	**100.0**	**95.0**	**5.0**
Shala	**35.0**	**–**	**65.0**	**91.9**	**2.7**	**5.4**	**100.0**	**0.0**	**100.0**	**–**	**100.0**	**–**
Siraro	**45.0**	**–**	**55.0**	**97.5**	**–**	**2.5**	**72.5**	**27.5**	**80.0**	**20.0**	**97.5**	**2.5**
Habro	**67.5**	**2.5**	**30.0**	**–**	**–**	**–**	**20.0**	**80.0**	**–**	**100.0**	**48.6**	**51.4**
Daro Lebu	**78.8**	**–**	**21.2**	**100.0**	**5.4**	**–**	**58.8**	**41.2**	**–**	**82.5**	**84.6**	**15.4**
Mean (%)	**59.2**	**0.5**	**40.3**	**97.0**	**1.7**	**1.3**	**75.6**	**24.4**	**30.9**	**69.1**	**88.0**	**12.0**
Chi-square test	**X^2 = 30.7 df = 10 *p*-value = 0.00**			**X^2 = 12.7 df = 10 *p*-value = 0.24**			**X^2 = 111.3 df = 5 *p*-value = 0.00**		**X^2 = 203.0 df = 5 *p*-value = 0.00**		**X^2 = 70.4 df = 5 *p*-value = 0.00**	

Notes: X^2 = chi-square test; *p*-value = probability value, df = degree of freedom.

2.7. Seed Source of Finger Millet

Currently, there is a poorly developed seed system industry for finger millet in Ethiopia. A significant dependence on BOA and farmer-to-farmer seed exchange is linked to poor access to seeds of improved varieties (**Table 7**). Farmer saved seeds are not pure, have low germination rates and often carry seed-borne diseases [65], contributing to yield losses. While the BOA was a seed source for most farmers, it often has limited supplies and cannot reach all the farmers simultaneously for planting. It is imperative that as breeding programs commence, they can be developed in parallel with a commercial seed system to ensure efficient and effective distribution. There are also few registered finger millet varieties in Ethiopia despite the importance of finger millet as a crop. This is concordant with previous reports on the neglect of traditional cereals in breeding programs compared to crops such as maize and wheat. Of the 23 released varieties, only five were in production, which begs the question why the farmers poorly adopt them. A possible reason is lack of farmer involvement in previous breeding programs that focused on product development with little regard to farmer input. Recently, most programs have developed varieties that were high yielding but lacked other vital and complementary attributes desired by farmers, leading to their rejection by the market. In this regard, Jerop et al. [45] reported that the significant seed sources of finger millet in Kenya were self-saved seed and the government extension program, which corroborate the findings of this study. Tsehaye et al. [9] reported that most farmers in Northern Ethiopia also used self-saved seed or obtained seed from the local informal market.

Table 7. The proportion (%) of respondents and corresponding seed sources of finger millet varieties in the study districts in 2020/21 cropping season.

Seed Sources	Districts						Mean (%)
	Atote Ulo	Wera	Shala	Siraro	Habro	Daro Lebu	
Research institutions	**5.0**	**–**	**32.0**	**–**	**2.7**	**–**	**5.8**
Bureau of Agriculture	**87.5**	**92.5**	**35.50**	**22.5**	**35.1**	**15.8**	**49.1**
Local producers	**2.5**	**2.5**	**6.50**	**27.5**	**2.7**	**2.6**	**7.5**
Farmer-to-farmer seed exchange	**2.5**	**–**	**22.60**	**35.0**	**24.3**	**50.0**	**22.1**
Own saved seed	**-**	**5.0**	**–**	**–**	**21.6**	**18.4**	**7.5**
Cooperatives	**2.5**	**–**	**–**	**–**	**–**	**–**	**0.4**
Local market	**–**	**–**	**–**	**7.5**	**5.4**	**7.9**	**3.5**
Unknown source	**–**	**–**	**3.20**	**7.5**	**8.1**	**5.3**	**4.1**
Chi-square test	**X^2 = 191.597, df = 35, *p*-value = 0.000**						

2.8. Cost-Benefit Analysis of Major Crops Grown in the Study Areas

The high cost of production for finger millet was probably driven up by the high labour costs for weeding due to its susceptibility to weed competition during its early stages of growth. Manual weeding was practiced at a higher frequency for finger millet than other crops, requiring more man hours and increasing production costs. In addition to weeding, harvesting and threshing of finger millet are tedious and labour-intensive. In general, weeding, harvesting and winnowing were the significant labour demanding tasks in finger millet production. Even though finger millet is a highly profitable crop (890 USD/ha), the respondents expressed reluctance to produce it on a large scale, citing the high labour requirements as an impediment. Higher labour requirements for finger millet production than other crops have been identified as a major deterrent to its production, productivity and market potential [40]. In India, the average cost of production for finger millet was estimated to be 544.3 USD/ha, with average yield productivity of 1.44 t/ha and a net profit of 138.1 USD/ha [66]. The cost-benefit ratio calculated for finger millet was similar to 1.05 reported by Adhikari [67] and within the range of 1.05–2.15 that was reported by Kaushal and Choudhary [68]. There is a need to increase the benefit to cost ratio to motivate the farmers to adopt finger millet production. Improved resistance to weeds, increased thresh ability and early maturity would reduce labour costs associated with the respective agronomic practices and encourage farmers to adopt the crop. Therefore, there is a need for finger millet improvement to deliver high yielding and farmer-preferred varieties to enhance the economic benefits of the crop. Maize is one of the major crops in Ethiopia, including in the study areas. Nevertheless, farmers are not deriving profits from the production and marketing of this crop due to various reasons. The primary reason is that, in the country, the grain prices of maize are unpredictable due to the high market supply during the production season. This condition is the major constraint for maize farmers given that most of them have access to the local markets to sell maize [69]. In addition, there are no adequate postharvest infrastructures in the country, including transport, storage and processing.

2.9. Cultural Methods to Cope with Low Moisture Stress

Production of drought-tolerant crops such as finger millet has been promoted as a strategy for climate change mitigation [66]. Farmers in the study areas were aware of climate change, its adverse effects and possible mechanisms to cope with its effects. As a result, they used various strategies to cope with low moisture stress to minimize crop loss and food insecurity. These included various soil moisture conservation and soil fertility enhancement technologies (**Table 8**). The frequency, depth and period of ploughing and the timing of crop management practices such as planting, weeding, and adjusting plant population were used to mitigate the impact of moisture stress, with various levels of success. Similarly, during the period of low moisture stress, most farmers in South and North Welo grew early maturing sorghum to escape drought stress [42]. The breeding of short duration finger millet varieties would also help the crop to escape drought stress. Mulching and the use of tie ridges were practiced because these practices are commonly used for moisture conservation. Early planting, use of organic inputs, adoption of new tillage practices and applying tied ridges have been previously reported among strategies used by smallholder farmers to mitigate the impact of low soil moisture [69].

Table 8. Various methods used by finger millet growers to cope with moisture stress, reported during the focus group discussion.

Methods to Cope with Moisture Stress	Perceived Advantages
High ploughing frequency before the onset of rainfall	Assists in infiltrating the available soil moisture, exposure to sunlight of eggs of insect pests present in the soil.
Deep ploughing by using tractor	Improves moisture-holding capacity of the soil, exposure to sunlight of eggs of insect pests present in the soil
Early ploughing and land preparation as soon as the onset of the first rain shower after harvesting	Effective use of the available soil moisture
Hoeing at the right stage	Maintains the available soil moisture
Weed control	Protects the crop from the competition of the soil moisture and other nutrients
Irrigation if available	Provides supplemental moisture required by the crop
Adjustment of sowing date	Manages flowering time so as not to coincide with drought times and utilizes the available soil moisture
Sowing in tie ridging	Holds available soil moisture
Row planting	Manages the appropriate plant population
Sowing the seed relatively deep in the soil	Assists the seed to access the available soil moisture for germination
Use of higher seed rate than the recommended one	Assists to get the required plant population during low moisture period
Soil mulching using different grass species	Increases soil fertility and water holding capacity and lowers soil temperature
Use of cattle dung and application of urea fertilizer after the first weeding and when there is a relatively good soil moisture	Increases soil fertility and moisture-holding capacity and provides healthy and vigorous crop to cope with low moisture stress period
Varietal selection	Better and cheap alternative to alleviate the problem of low moisture stress

3. Conclusions

Finger millet is one of the staple food crops in Ethiopia, but its productivity is constrained by a range of biotic and abiotic stresses and socio-economic factors. Drought stress was considered to be the most important constraint in all the districts, followed by a lack of improved varieties, limited access to seed and a lack of financial resources. Land size limitations, poor soil fertility and a lack of access to fertilizers were also ranked important constraints affecting finger millet production. The most critical farmer-preferred traits in finger millet were high grain yield, compact head shape, 'enjera'-making quality, high marketability and early maturity. Therefore, to enhance finger millet productivity, plant breeding aimed at solving the above-mentioned production constraints and incorporating the farmer-preferred traits needs to be undertaken in Ethiopia.

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