

REVIEW ARTICLE

# Overview of Finger Millet (*Eleusine coracana* L.) Breeding and Prospects in Ethiopia: A Review

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## Abstract

The world has faced challenges to produce more food to feed the growing population. Improved crop varieties key inputs for significant increases in production and productivity. Finger millet is thus one of a highly nutritious and food security crop. In Ethiopia, major achievements were made for major crops; however, the time and resources devoted to improving finger millet are low compared to other cereal crops. As a result, there is little scientific intervention aimed at improving finger millet. Besides, the crop is constrained by biotic, abiotic, and socioeconomic factors. As a result, the productivity of finger millet is far below its potential. Nowadays, there is an initiation and effort to develop improved finger millet varieties; hence, yield increases have been achieved in Ethiopia over the years. The available genetic resources, wide adaptability of the crop, and the current growing acreage have at times been considered opportunities to boost crop production and productivity. Strong research efforts and the transfer of technologies have to be strengthened in the country, and such efforts must be made in finger millet potential areas of the country. Thus, to lift the value as an alternative food crop capitalizing on these opportunities could ensure food and nutrition security in Ethiopia and the world. Therefore, the objective of this study was to review and document information on the breeding achievements made, as well as key challenges, opportunities, and interventions, to provide insight into the future of finger millet breeding in Ethiopia.

Keywords: achievements, intervention, opportunities, productivity, yield

## Introduction

Projections indicate that the global population will reach 9.8 billion by 2050 (United Nations Report, 2023). Meanwhile, the total global food demand is expected to increase by 35% to 56% between 2010 and 2050, while the population at risk of hunger is expected to change by -91% to +8% over the same period (Van Dijk et al., 2021). Increasing production and productivity of the crop sub-sector is also one of the measures taken in Ethiopia to ensure food security of more than 100 million people and escape from long-lived poverty persisted in the country. Thus, improved varieties are known to be responsible for a significant portion of the increase in crop yield globally, emphasizing their substantial contribution to agricultural productivity (Abdulai, 2023). In Ethiopia, major achievements were made for major crops (cereals, legumes oilseeds, industrial (cotton), tuber and roots, and horticultural crops) (Belachew et al., 2022).

Variety development has been targeted to address the needs of different maturity groups (early, medium, and late), adaptability under different agroecological conditions, quality, and farming systems like irrigation. The major characteristics sought for in the genetic improvement of cereals have been high yield, diseases, and insect pest tolerance/resistance, adaptation to varied ago-ecologies and farming systems with suitability to optimum rainfall and drought-prone (especially terminal drought) areas, various types of maturity (early, intermediate and late), quality (mainly seed color and tolerance/resistance to major biotic and abiotic stresses) (Dessie, 2018). Among such cereals, finger millet [*Eleusine coracana* (L.)] is the one which is mainly cultivated as a grain cereal in most of the tropical and subtropical regions of the world, during the rainy season. It occupies 12%

of the global millet area and is cultivated in more than 25 countries in Africa and Asia (Vetriventhan et al., 2015). It can adapt to diverse agroecological conditions, requires minimal inputs, and is tolerant to moisture stress (Gupta et al., 2017).

Finger millet is the sixth most important crop in Ethiopia after tef, wheat, maize, sorghum, and barley. It accounts for about 4.5% of the total cultivated land covered by cereals. It is widely grown in North Gondar, West Gojjam, Eastern Tigray, West Wollega, Wello, and Shewa. However, the national average grain yield of the crop is low, 2.56 t.ha<sup>-1</sup> (ESS, 2022), although it has the potential to yield up to 4-5 t.ha<sup>-1</sup> (Dessalegn et al., 2019) and 6 t.ha<sup>-1</sup> (Gebreyohannes et al., 2021). The variety development process for finger millet in Ethiopia has been dependent on selection from local genotypes. Following selection and introduction from abroad, about 30 improved varieties have been registered and released from 1999 to 2023. Yet very few studies have been made at the molecular level on finger millet. Despite the breeding achievements made on finger millet, the yield is still far below its potential. This could be due to due to biotic and abiotic stresses, as well as socio-economic constraints (Gebreyohannes et al., 2021). Thus, proper review and documentation of information regarding past and current prospects enables insight into future directions. Therefore, this study has aimed to review and document the breeding achievements made and key challenges, opportunities, and interventions to insight finger millet breeding.

### Overview of Finger Millet Breeding

Plant breeding was practiced first when people learned to look for superior plants to harvest for seed; thus selection became the earliest method of plant breeding. Plant breeding has played a crucial role in increasing agricultural productivity and ensuring

food security by developing new plant varieties with improved traits. Finger millet is categorized as a neglected and underutilized species (Kahane et al., 2013). However, researchers started breeding finger millet three decades ago to improve the crop. Much effort has been undertaken to develop finger millet for the varied agroecological niches of Africa (Mgonja et al., 2007). Finger millet is a poor man's crop grown mainly in the Amhara and Oromiya regions. Like many other grains, research on finger millet in Ethiopia was initiated at Debre Zeit Agricultural Research Station in the late 1950s. Much of the early efforts had focused on collecting, conserving, and characterizing finger millet germplasm. With the transfer of the national sorghum research program from Haramaya University to its current place at Melkassa in 1986, research on finger millet was reinitiated as part of the national sorghum program. Since then efforts have been underway to develop high-yielding and stress-resistant finger millet varieties (Degu et al., 2009). Thus, some improved finger millet varieties were released by different research centers. However, there are several gaps in addressing beneficiaries' preferences on the type of varieties developed so far. This refers to limited research attention on breeding and crop management practices for finger millet.

The current state of finger millet breeding in Ethiopia focuses on addressing the challenges and leveraging the opportunities for improvement. The national breeding program primarily focuses on enhancing agronomic traits such as yield, drought tolerance, and disease resistance (Teklu, 2024). However, the genomic resources available for finger millet are limited compared to other major cereals which hamper further improvement of this crop. Thus, more than 33,752 cultivated and wild finger millet germplasms are available in various organizations worldwide (Joshi et al., 2021). The detailed list of countries and institutions having genetic resources conserved globally is described in Table 1.

Table 1. Cultivated and wild germplasm of finger millet conserved in major gene banks

Country	Institution	Accessions
India	International Crops Research Institute for the Semi-Arid Tropics	6,804
India	ICAR-National Bureau of Plant Genetic Resources	10,507
India	All India Coordinated Small Millets Improvement Project	6,257
Kenya	Kenya Agricultural and Livestock Research Organization	2,875
Ethiopia	Ethiopian Biodiversity Institute	2,156
USA	Agricultural Research Station of the USDA in Griffin	1,452
Uganda	Serere Agricultural and Animal Production Research Institute	1,230
Zambia	SADC Plant Genetic Resources Centre	1,037
Nepal	Nepal Agricultural Research Council	869
Japan	National Institute of Agrobiological Sciences	565

Source: Joshi et al., 2021.

For instance, crop improvement through conventional breeding is slow, especially for traits controlled by quantitative gene action like drought tolerance. Hence, the use of modern crop improvement tools such as genomics to transfer information about genes from model species to the species of interest and genetic mapping to identify genes controlling traits of interest can provide a more timely and robust response to crop production threats (Rashid et al., 2017). It also provides added opportunities to develop crop varieties with multiple stress tolerance. Therefore, a crop's response to drought and/or pest attacks can be studied by the evaluation of traits that are related to these abiotic and biotic tolerances at the physiological, cellular, biochemical, and molecular levels. Genomics research has entered a new phase based on next-generation sequencing, large-scale expressed sequence tag projects, and cDNA microarray databases for identifying sets of genes associated with the expression of a target trait. Crop species of the *Poaceae*, such as rice, sorghum, finger millet, and pearl millet, display a remarkable level of genetic similarity despite their evolutionary divergence 65 million years ago (Devos, 2005).

#### *Employed Finger Millet Improvement Methods*

Finger millet breeding has traditionally relied on selecting improved lines within existing cultivars, but developing new varieties has been challenging. Recent breakthroughs in the finger millet genome have opened up possibilities for developing new varieties through targeted breeding techniques. Worldwide finger millet breeding methods encompass various techniques to enhance disease resistance, nutritional value, and environmental resilience. These methods include molecular and genetic engineering, hybridization, and speed breeding (Mbinda and Masaki, 2021; Nagaraja et al., 2023). However, in Ethiopia, such techniques are at the infant stage. Meanwhile, researchers are leveraging molecular markers to improve breeding efficiency and crop resilience. This method allows breeders to identify specific genetic markers associated with desirable traits, facilitating the selection of superior genotypes more efficiently. Finger millet has been farmed in Eastern Africa for thousands of years, but breeding the crop for better traits has been difficult. Recent breakthroughs in the finger millet genome have opened exciting possibilities for developing new varieties through targeted breeding techniques to enhance nutritional value and resilience to various challenges. Thus, finger millet breeding strategies in Eastern Africa include germplasm evaluation for resistance to lodging, blast disease, *Striga* weed, improved grain quality and yield, and acceptability for use with post-harvest technologies (Mgonja et al., 2007).

The development of an efficient hybridization protocol and exploration of finger millet molecular biology, especially the application of marker-assisted selection, could significantly increase finger millet yields (Mgonja et al., 2007). Ethiopia possesses a rich diversity of finger millet genetic resources. Breeders utilize both landraces and improved varieties to enhance genetic variability. Traditional breeding methods, including selection and hybridization, are employed to develop new varieties that are more resilient to biotic (pests and diseases) and abiotic (drought and poor soil fertility) stresses. However, the inbreeding nature of the crop, difficulties in crossbreeding, and limited genetic improvement hindered the progress in enhancing its yield and resilience. Recent advancements include the use of molecular markers to assist in the selection process. These technologies help in identifying desirable traits at the genetic level, thereby speeding up the breeding process. Accordingly, finger millet breeding in Ethiopia employs a combination of participatory approaches, conventional techniques, and modern biotechnologies to enhance crop resilience and productivity while addressing the specific needs of local farmers. Continued investment in research and development is essential to overcome existing challenges and improve food security through this vital crop. By leveraging genetic diversity and employing systematic breeding techniques, Ethiopian researchers are making strides toward developing superior finger millet varieties that meet the needs of local farmers while addressing environmental challenges. Following such breeding techniques, about 30 improved finger millet varieties are released (Table 2).

#### *Breeding Achievements in Finger Millet*

Over the years, numerous cereal production technologies and their respective management mechanisms have been developed for use by the farming community (Dessie, 2018). Successful crop improvement requires the ability to identify and access genetic diversity including new or improved variability for target traits. Plant genetic resources are the raw materials for the development of improved cultivars. Accessions ranked highly for desirable traits, including grain yield, are recommended for adoption in areas where finger millet is commonly grown after undergoing multi-location testing to verify their agronomic and utilization potential. Enhanced germplasm evaluation for targeted traits would enable breeders to develop high-yielding cultivars with a broad genetic base (Upadhyaya et al., 2006).

Ethiopia is considered one of the centers of origin and diversity for finger millet (de Wet, 1984). The

Ethiopian Biodiversity Institute has more than 2000 finger millet germplasm collections in its holding. The national research programs have access to these local germplasm resources. The Ethiopian Biodiversity Institute and the national research programs have over the years developed a platform where they jointly conduct germplasm characterization activities at research stations. Through this effort, over 1400 germplasm collections have been characterized for major agronomic traits. The joint effort has also created a unique opportunity for breeders to conduct preliminary selection among the collections. In addition, through the regional research network, the national program occasionally acquires germplasm sources from the region. The Eastern African Regional Sorghum and Millet Research Network and later the Eastern and Central African Sorghum and Millet Research Network served as an important bridge to bring the regional scientists together and facilitate the flow of germplasm in the region. Through these networks, over 500 finger millet accessions have been acquired by the Ethiopian program, and these, along with the local sources, are used as key germplasm sources for genetic improvement of the crop (Degu et al., 2009).

Over years of research on cereals, commendable achievements have been made in the generation of technologies and information useful for boosting the productivity and production of crops in Ethiopia. Variety development involves collection/acquisition and evaluation/characterization of germplasm accessions, population improvement,

hybridization (inter-and inter-specific) and generation advancement, and induced mutation techniques and generation advancement; screening of selected genotypes in observation nurseries; evaluation of promising materials initially in preliminary variety trials; undertaking series of multi-environment variety trials over environments; and finally, verification and release of variety (Dessie, 2018). Hence, developing improved varieties with high yield and wide adaptation is one of the major objectives of the national breeding finger millet improvement program in Ethiopia. So far, about 30 improved finger millet varieties have been registered and released in Ethiopia (Table 2).

The global production and productivity for finger millet are unknown since both statistics are merged and reported with other millet. Thus, the yield potential for finger millet in Ethiopia is in the range of 4-5 t.ha<sup>-1</sup> (Dessalegn et al., 2019) and can yield up to 6 t.ha<sup>-1</sup> (Gebreyohannes et al., 2021), but the yield varies greatly depending on the country and region. For instance, in Ethiopia finger millet ranks 6<sup>th</sup> among the cereals in terms of area coverage and its productivity was 2.56 t.ha<sup>-1</sup> (ESS, 2022) far below to its genetic potential. This is mainly due to several tackling causes. Following the release of improved varieties in Ethiopia, the yield of finger millet increased with an average of 0.39-0.45 t.ha<sup>-1</sup> over the past 20 years (Marefia et al., 2022). The estimated production, productivity, and area devoted to finger millet in Ethiopia are presented in Figure 1.

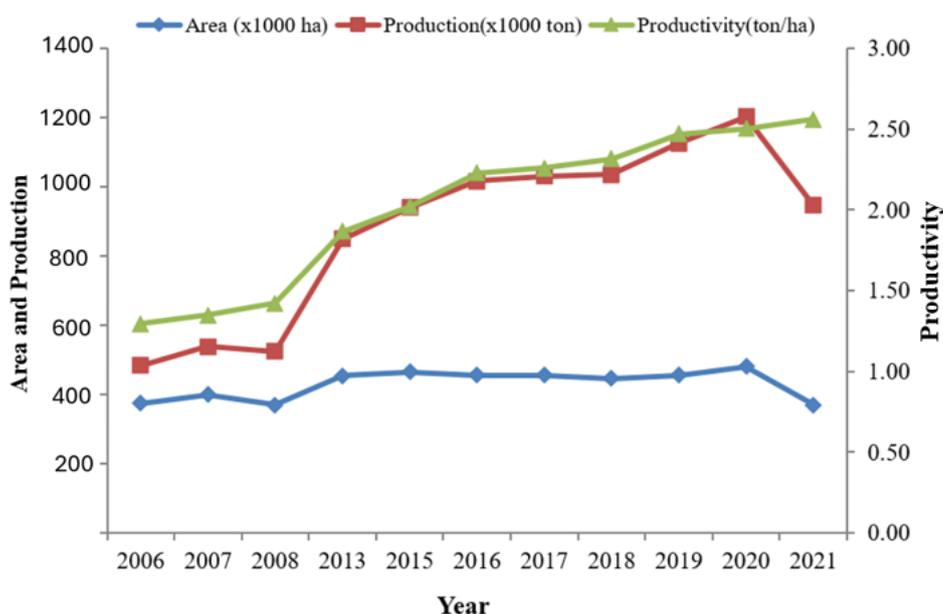


Figure 1. Trends in area, production, and productivity of finger millet in Ethiopia. Source: Ethiopian Statistical Services (ESS).

Table 2. List of released finger millet varieties and their productivity in Ethiopia

Variety	Pedigree	Year of release	Altitude (m)	Grain yield (t.ha <sup>-1</sup> )		Seed color	Methods employed for release	Releasing Agricultural Center
				On farmers' field	On research station			
Padet	KNE#409	1999	1600-1900	-	2.4	Brown	Selection from cultivars	Meikassa
Tadese	KNE#1098	1999	"	-	2.5	Brown	"	Meikassa
Boneya	KNE#411	2002	1400-1900	2.0-2.4	2.5-3.0	Red	"	Bako
Degu	PGRC/E 215874	2005	1900-2500	1.7-2.1	2.3-3.0	Black	"	Adet
Wama	KNE#392	2007	1400-1900	1.6-2.0	1.7-3.5	Brown	"	Bako
Baruda	Pw01-075	2007	1000-1500	-	3.0-3.5	Red	"	Pawi
Bareda	BRE 356-1	2009	1200-1900	1.8-2.5	2.0-2.8	Brown	"	Bako
Gutie	229373	2009	1200-1900	2.0-3.2	2.0-3.5	Brown	"	Bako
Dibatie	-	2010	1100-1600	15-20	2.0-2.5	Brown	"	Pawi
Necho	PGRC/E 203572	2011	"	1.5-2.0	2.0-3.0	White	"	Adet
Mecha	PGRC/E 229371	2014	"	1.6-2.3	2.0-2.9	Red-brown	"	Adet
Tesema	Acc#229469	2014	"	1.4-1.8	1.8-2.2	Brown	"	Meikassa
Gudeta	Acc.215990	2014	1400-1900	2.0-2.1	2.1-2.3	Light-brown	"	Bako
Addis-01	Acc.203544	2015	1400-2200	2.5-3.1	2.6-4.2	Light-brown	"	Bako
Kako-1	LR005	2015	1310-1700	1.6-2.0	2.6-2.95	Light-brown	"	Jinka
Meba	GBK-01111A	2016	"	2.3	2.1-3.5	Brown	"	Meikassa
Axum	Acc#229355	2016	"	2.1	2.2-3.6	Brown	"	Meikassa
Diga-1	Acc.216036	2016	1600-2300	2.4-3.2	2.2-2.8	Black	"	Bako
Urji	Acc.242617	2016	1600-2300	2.1-2.6	1.8-2.7	White	"	Bako
Mereb-1	KNE#622	2016	1300-2100	23.75-27.5	2.45-3.15	Light-brown	"	Axum
Bako-09	Acc.214995	2017	1400-2200	2.4-2.6	2.98	Light-brown	"	Bako
Diga-2	BKFM 0010	2018	1200-2300	2.32-2.98	2.24-3.42	Black	"	Bako
Tekeze-1	SMARC coll.60	2018	1350-2200	-	2.8-3.5	Brown	"	Shire
Jabi	PGRC/E 229626	2019	"	2.0-2.5	2.5-3.0	Reddish	"	Adet
Kumsa	BKFM 0063 (1)	2019	1500-2200	2.2-2.9	2.5-3.2	Light-brown	"	Bako
Metekili	Acc. 005pw-2012	2020	1000-2000	25.5-30	2.8-3.8	Brown-red	"	Pawi
Ikhulule	-	2021	1700-1900	3.8	6.3	Light-brown	"	Mechara
Adet-05	AD14-SEL045	2022	1700-2300	2.4-2.8	2.6-3.3	Black	"	Adet
Jabesa	Wama x PW-001-002(P1-1)-1-2)	2022	1500-2200	3.18	2.24-2.57	Light-brown	Selection from crossing	Bako
Adet-06	Necho x Degu	2023	1900-2500	2.5-3.0	2.7-3.5	Light-brown	Selection from crossing	Adet

Notes: All of the noted varieties are resistant to blast disease at a moderate to highly resistant level and are in the early to medium maturing group. Source: Ethiopian Agricultural Authority (EAA).

### *Implications of Breeding for Yield*

It is obvious that the world has faced challenges in producing more food to feed a projected 9 billion people worldwide, including 2.5 billion in Africa. Currently, rice, wheat, and maize feed the world by providing 60% of the total population's energy intake. Finger millet belongs to a group of secondary crops that provide another 25% of the world's food energy (Opole, 2019). So, increasing global agricultural production is imperative to sustainably meet the nutritional needs of a growing population. This requires a multifaceted approach that includes enhancing productivity through technological advancements, addressing environmental challenges, and implementing supportive policies. Without these efforts, food security may become increasingly threatened as global demands rise. Development of high-yielding and widely adapted varieties under rain-fed conditions and technologies suitable for irrigated farming systems are given considerable focus to ensure food security and sustainable development (Dessie, 2018). In such cases, breeding can play an enormous role in developing varieties. Cereals are the major food crops that ensure food security in Ethiopia as they constitute the major component of the staple diet for most of the population and contribute approximately 70% of the average Ethiopian calorie intake (Yitayeh, 2021).

Finger millet in Ethiopia has a variety of uses. It is used for making "Injera," thin, pancake-like bread commonly served in the national dishes, bread, and porridge. It is also used for making traditional alcoholic beverages such as "Tella", the local beer, and "Arekie", the local spirit. The straw is used for animal feed and thatching roofs. The grains fetch better prices than maize. Most of the produced yield in the country is consumed locally or sold in local markets for traditional uses. Finger millet is rich in macro and micronutrients making the crop an important ingredient of dietary and nutritional balanced foods. This, in turn, shows that the crop has the potential to enhance household food and nutrition security for the growing population of Ethiopia, where energy-protein malnutrition affects a greater part of the country. Being rich in minerals and consisting significant amount of vitamins, finger millet can also be a potential crop to fight hidden hunger. In addition, the crop is high in dietary fiber content, minerals, and phytochemicals, low in glycemic index, and gluten-free, finger millet-based products have been considered functional foods (Gebre, 2019).

After the recent release of high-yielding varieties, currently, millet has become popular due to its advantages. Besides the acreage, the productivity of the crop over the last few years has steadily increased

(Marefia et al., 2022). The national average yield has grown from 0.85 t.ha<sup>-1</sup> in 1998 to 1.3 t.ha<sup>-1</sup> in 2006 and 1.5 t.ha<sup>-1</sup> in 2011 to 2.5 t.ha<sup>-1</sup> in 2021 (Figure 1). In general, in one or another way, this yield increment is the result of generated agronomic management and breeding efforts sought for the crop. Therefore, the impact of breeding along with the improved cultivation system on the yield of finger millet has been notable, with an increase in yield potential over the years; however, there is still room for further enhancement, especially in the context of the unique nutritional properties and the importance of finger millet as a food crop in Ethiopia.

### *Challenges, Prospects, and Interventions of Finger Millet Breeding*

Finger millet is one of the neglected orphan crops. It is an important cereal crop in Ethiopia, and the crop is among the food security crops. Despite its importance, its productivity is relatively low in Ethiopia. The low productivity is attributed to a range of biotic and abiotic stresses, as well as socio-economic constraints, including shortage of seeds of improved variety meeting the requirements of beneficiaries, poor agronomic practices, high lodging, moisture stress, disease (mainly blast), weeds and drought (Degu et al., 2009; Gebreyohannes et al., 2021). There is also a limited intervention regarding the molecular genetic diversity in finger millet, limiting the efficiency of breeding programs. This denotes further efforts on molecular breeding approaches.

However, opportunities now exist for enhanced technology development, which may increase production, product development, value addition, marketing, and consumption of finger millet. Capitalizing on these opportunities could ensure that finger millet, as a "Novel" crop, increases food and nutrition security in Africa and the world. Thus, its wide adaptability to diverse environments and cultural practices makes it a potential food crop. Thus, it can grow as a staple food grain in parts of Ethiopia where drought takes its highest toll on crop production and as a food security crop in several other parts of the country where low and erratic rainfall has been adverse on other food grains. Finger millet is a hardy crop capable of providing reasonable grain yield under circumstances where other crops give negligible yield. It is grown in a wide ecological range of up to 3000 m elevation. Seeds of finger millet can be stored for a long time without damage and are less prone to attack by storage pests. Although blast disease caused by *Magnaporthe grisea* poses serious biotic constraints in some years, finger millet generally suffers less from diseases than common cereals grown in the country (Degu et al., 2009; Opole, 2019).

The growing acreage under finger millet has at times attracted the attention of policymakers and research administrators that, at one point, millet research has stood as an independent program within the Ethiopian National Agricultural Research System. With its importance as food grain steadily growing, the need to improve the productivity of the crop is mounting. At the moment Ethiopia is the second largest producer of finger millet, and millions of people directly depend on the crop as a major source of energy and protein (Degu et al., 2009). The declining soil fertility and the ever-increasing problem of drought call for the development and use of crop species that are resilient in the face of these stresses. Finger millet holds great potential for the dry lowlands where economic production of other food cereals is constrained by these stresses. We believe that interventions are required from many angles to lift the value of the millets as alternative food and feed crops and strengthen the national effort to develop and deliver improved production technologies. Some of these include; research capacity building; strengthening transfer of technologies and developing seed production and delivery mechanisms (Degu et al., 2009; Gebreyohannes et al., 2021). By implementing these interventions, it is possible to improve the productivity of finger millet in Ethiopia, thereby enhancing food security and livelihoods in the region.

## Summary

Finger millet breeding in Ethiopia reveals opportunities and challenges associated with enhancing the crop's yield. At the same time, there have been achievements in breeding for higher yields. However, the productivity of finger millet in Ethiopia remains below its potential due to a range of biotic, abiotic, and socio-economic factors and little research attention given to the crop. As a result, local varieties are still dominant in the farming community. Addressing these challenges and opportunities is crucial for realizing the full potential of finger millet production in Ethiopia. Delivering the available crop packages and generating new technologies, including post-harvest handling, food recipes, and utilization options, has to be prioritized. Therefore, further attention and research efforts must be strengthened in the country. Thus, the present review would provide valuable insights into the current state of finger millet breeding in Ethiopia, and the implications of breeding for yield improvement, laying the groundwork for future research and breeding efforts in the country.

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