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Finger millet (*Eleusine coracana* (l.) Gaertn) breeding, major production challenges and future prospects

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ABSTRACT

Ethiopia is a country which is known for its rich biodiversity and being a centre of origins for many crop species and diversities due to its wide range of altitudes, temperature extremes, huge amounts of rainfall, and different soil characteristics. Finger millet (Eleusine coracana L.) Gaertn) is an allotetraploid (2n = 4× = 36) annual cereal crop that includes two distinct subspecies: subsp. coracana (cultivated finger millet) and subsp. Africana (wild finger millet). Finger millet is potentially a climate-resilient and nutritious crop with highly nutritive and antioxidant properties. Finger millet breeding has focus on collection, conservation and characterization of finger millet germplasm. The productivity of this crop is limited by drought, lack of agronomic packages, diseases (head blast) and lodging. This paper attempts to review the finger millet breeding, production constraints and future prospects of fingermillet. The reviewers believe that the paper gives better insight to basic information of finger millet breeding, production constraints and future directions.

Keywords: Breeding, Challenges, *Eleusine coracana.*

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Introduction

Ethiopia is a country which is known for its rich biodiversity and being a centre of origins for many crop species and diversities due to its wide range of altitudes, temperature extremes, huge amounts of rainfall, and different soil characteristics. Therefore, due to this variation in the environment, it has evolved and gave a great opportunity for the existence of diverse vegetation types, crop species, and land race varieties of crops that have been used for generations, conserved by farmers in their fields (Vavilov, 1951).

Finger millet (*Eleusine coracana* L.) Gaertn) is an allotetraploid (2n = 4× = 36) annual cereal crop that includes two distinct sub species: subsp. *coracana* (cultivated finger millet) and subsp. Africana (wild finger millet) (Hilu, 1994). It is an important food crop cultivated widely in arid and semi-arid regions of the world, especially in East Africa, India and in other Asian countries (Rudin *et al.*, 2004).

Finger millet is potentially a climate-resilient and nutritious crop with highly nutritive and antioxidant properties (Kumar *et al*, 2017) and very importantly, finger millet grain is gluten-free, rich in calcium, fiber, iron and, has excellent malting qualities (Chandrashekar, 2010 and Pradhan *et al*, 2010). In Ethiopia also, finger millet is an important staple food crop widely grown.

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 ‘arakie’, local sprit. The straw is used for animal feed and for thatching roofs. The grains fetch better price than maize (Chimdo *et al.* 2006). Most of the finger millet produced in the country are consumed locally or sold in local markets for traditional uses. The crop is considered as nutritious cereal with enhanced levels of essential nutrients compared to rice, maize or sorghum (Hulse *et al.*, 1980). Oil from finger millet is considered to be good quality (polyunsaturated); that it provides health benefits to humans through reducing cholesterol levels

(National Research Council 1996). Finger millet is particularly rich in dietry fiber and minerals such as calcium and iron (Table 1). Babu *et al*. (1987) reported that some high-yielding varieties also contain high protein content (8 to 12%) and also rich in calcium content (294 to 390 mg per 100 g).

In Ethiopia finger millet [*Eleusine coracana* (L.) Gaertn] is one of the most important indigenous cereal crop grown largely by small holder farmers. Finger millet has been mainly grown in Amhara, Benishangul-Gumuz, Oromia, Southern Nations, Nationalities and People's Region of Ethiopia, and Tigray. Finger millet covers about 453,909.38 ha of land with production of 915,314.518 tons (CSA, 2015). It had 3.62 and 3.39% share as compared to the national cereal crops area and production, respectively. Amhara Region is the largest finger millet producer, which has 53.5 and 53.56% share from national finger millet area and production, respectively. West Gojam Zone from Amhara Region has substantially a large share in area coverage with 35.21% and production 28.97% (CSA, 2015). West Gojam Zone from Amhara Region has substantially a large share in area coverage with 35.21% and production 28.97% (CSA, 2015). Finger millet breeding has focus on collection, conservation and characterization of finger millet germplasm. The productivity of this crop is limited by drought, lack of agronomic packages, diseases (head blast) and lodging. Therefore, this article aimed to review finger millet breeding, production constraints and future prospects of finger millet.

Finger millet breeding

Like for many other grains, research on finger millet was initiated at Debre Zeit Agricultural Experiment Station in the late 1950s. Much of the early efforts have focused on collection, conservation and characterization of 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 finger millet varieties with improved resistance to major biotic and abiotic stresses (New approaches to Plant Breeding of Orphan Crops in Africa, 2007). Schematic presentation of finger millet variety development process is showed (Fig 1).

Germplasm acquisition and evaluation

Ethiopia is considered as one of the centers of diversity for finger millet. The IBC has over 2000 finger millet germplasm collections in its holding. The national research programs have access to these local germplasm resources. The IBC and the national breeding program have over 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 (Table 3). The joint effort has also created 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 (EARSAM) and later the Eastern and Central African Sorghum and Millet Research Network (ECARSAM) served as an important bridge to bring the regional scientists together and facilitate the flow of germplasm in the region.

Table 1: Nutrient composition of finger millet as compared to major food cereals grown in Ethiopia

Contents	Unit	Millet	Sorghum	Tef	Barley	Maize	Wheat
Energy	Cal./100g	326	338	336	334	356	339
Protein	g/100g	7.2	7.1	8.3	9.3	8.3	10.3
Oil	g/100g	1.4	2.8	2.9	1.9	4.6	1.9
Carbohydrate	g/100g	77.1	76.5	75.2	75.4	73.4	71.9
Fiber	g/100g	5.6	2.3	3.6	3.7	2.2	3.0
Calcium	mg/100g	386	30	140	47	6	49
Phosphorous	mg/100g	220	282	368	325	276	276
Iron	mg/100g	85.1	7.8	59.0	10.2	4.2	7.5

Through these networks, over 500 finger millet accessions have been acquired by the Ethiopian national program and these along with the local sources are used as key germplasm sources for genetic improvement of the crop.

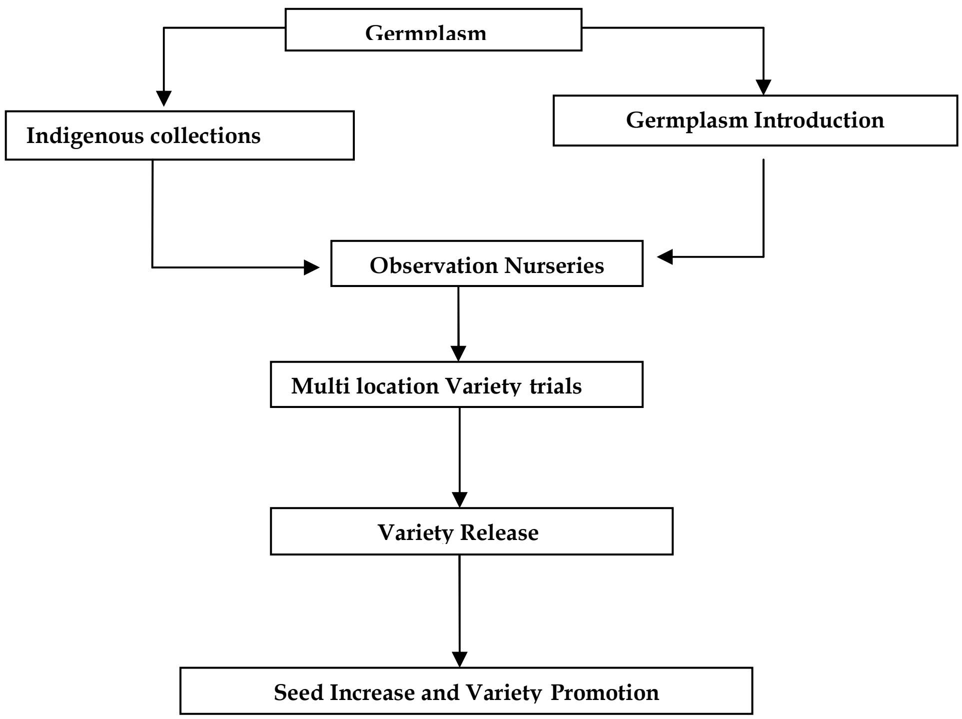

Fig 1. A schematic presentation of the variety development process in finger millet improvement program
Source: New approaches to Plant Breeding of Orphan Crops in Africa, 2007

The productivity of finger millet in the country generally is low because of shortage of improved varieties, disease and pests, poor application of seed and fertilizer, moisture stress in dry areas and little research concern given to the crop (Ayalew, 2015; Tesfaye and Mengistu, 2017; Zewdu *et al*., 2018). Between 2001 and 2017 finger millet production area in Ethiopia increased from 346,780 to 463,992 ha with an increase of 33.8%, and the total production in the same duration increased from 316,166 to 1,077,616 tones which is more than a threefold increment. Similarly, 912 kg/ha yield of finger millet at 2001 increased to 2,323 kg/ha at 2017. According to Ayalew (2015), the release of finger millet varieties in the country is the most important factor for the improvement of yield in 2000s. The author indicated that yield of finger millet in Ethiopia increased by 66% over the past three decades. Fourteen finger millet varieties are released between 1999 and 2015 (Table 3).

The germplasm materials are evaluated in two target environments, the lowland and mid-altitude. Although the country has diverse agro-ecologies with varying crop production potentials and limitation, two broad agro-ecologies are targeted for finger millet germplasm evaluation subsequent testing and release of varieties. The low-land agro ecology includes finger millet production areas located below 1500m elevation and the mid altitude above 1500m. The major characteristics of the lowland environment include low and erratic rainfall, high temperature with drought standing as the major constraint. Early maturity and high yielding potential are the major traits desired for this agro-ecology. The intermediate altitude growing areas receive relatively higher amount of rainfall which in warmer locations leads to high humidity. The key constraint under this condition is the head blast disease.

Table 2: Major agronomic characteristics of the national finger millet collections in Ethiopia

Characters	No. of Accession characterized	Min.	Max.	Mean	Standard deviation
Days to flowering	1420	55	184	101	2.68
Number of fingers	1216	1	16	8	1.73
Length of fingers (cm)	524	3	14	7	2.32
Plant height (cm)	1358	34	935	94	64.41
Days to maturity	1344	100	198	147	17.00

Source: New approaches to Plant Breeding of Orphan Crops in Africa, 2007

Table 3: Finger millet released varieties between 1999 to 2015

No.	Variety name	Year of release	Altitude (m.a.s.l)	Rainfall (mm)	Days to maturity	Grain yield (qt/ha)	
						On station	On farm
1.	Tadesse (KNE #1098)	1999	1600-1900	>700	NA	25	-
2.	Padet (KNE #409)	1999	1600-1900	>700	NA	24	-
3.	Boneya (KNE#411)	2002	1400-1600	1200-1300	145	25-30	20-24
4.	Degu (PGRC/E215874	2005	1900-2500	>900	137-160	23-30	17-21
5.	Baruda (Pw01-075)	2007	1000-1500	700-1500	149-159	30-35	-
6.	Wama (KNE#392)	2007	1400-1900	1000-1200	145-150	17-35	16-30
7.	Gute (229373)	2009	1200-1900	1000-1200	140-153	20-35	20-32
8.	Bareda (BRC-356-1)	2009	1200-1900	1000-1200	146-169	20-28	18-25
9.	Debatsi	2010	1100-1600	1000-1800	155-167	20-25	15-20
10.	Necho(PGRC/E203572)	2011	1900-2500	>900	145-175	20-30	15-20
11.	Mecha (Acc # 229371)	2014	1900-2500	>900	140-154	20-29	16-23
12.	Gudeta (Acc.215990)	2014	1400-1900	200-1300	145-150	21-23	20-21
13.	Tessema (ACC#229469)	2014	1600 -1900	>900	145-150	18-22	14-18
14.	Kako-I (LR005)	2015	1310 -1700	>900	139	26-29	16-20

Source: Crop Variety Register of different years NA=not available

Major production challenges

Finger millet production is severely affected by both biotic and abiotic stresses (Saha *et al*., 2016).

Diseases: Fungal blastis a major disease affecting growth and yield of finger millet (Kumar and Kumar, 2011). Blast diseases are caused by an *ascomycete fungus, Magnaporthe oryzae* (anamorph: Pyricularia grisea) (Singh and Kumar, 2010). The fungus mostly infects young leaf and causes leaf blast, whereas under highly favorable conditions, neck and finger blasts are also formed at flowering (Babu *et al*., 2013). Ekwamu (1991) reported that the head blast significantly reduced the spikelet length, grain weight, number of grains per head and grain yield. The blast fungus enters and causes the breakdown of parenchymatous, sclerenchymatous, and vascular tissues of the neck region, thereby inhibiting the flow of nutrients into the grains (Rath and Mishra, 1975).Subsequently, grain formation are partially or totally inhibited (Rath and Mishra, 1975; Ekwamu, 1991). The infected spikelets were shorter than healthy spikelets, which affects the grain formation. Eventually, the high seed infection reduced the seed germination in the field (Gashaw *et al*., 2014). The average loss owing to the blast has been reported to be around 28–36% per hectare (Nagaraja *et al*., 2007) and according to an earlier study, the yield losses could be as high as 80–90% per hectare (Rao,1990).

Nutrient Deficiencies: Major abiotic stresses such as deficiencies of nutrients [nitrogen (N), phosphorus (P), and zinc (Zn)], drought, and salinity also seem to affect the growth and yield of finger millet (Yamunarani *et al*., 2016; Ramakrishnan *et al*., 2017; Maharajan *et al*., 2018). According to a recent study, N deficiency decreased the tiller number in finger millet (Goron *et al*., 2015). Low P stress also affected the growth and biomass of finger millet seedlings in glass house conditions (Ramakrishnan *et al*., 2017). Zn deficiency resulted in stunted growth, delayed seed maturity, appearance of chlorosis, shortened internodes and petioles, and malformed leaves (Yamunarani *et al*., 2016).

Nutrient deficiency may be one of the major abiotic stresses affecting the finger millet production in the future. For example,the demand for fertilizers like N is expected to rise steadily,during the forecast period, from 8.8% in 2017 and reaching 9.5% in 2018 (Food and Agriculture Organization of the United States

(FAO 2015). In 2018, the global potential balance of P fertilizer is expected to rise from 6.4 to 8.5% of total demand (Khabarov and Obersteiner, 2017). Developing plants with improved P-use efficiency has been considered as essential to reduce the P fertilizer usage (Baker *et al*., 2015; Ceasar, 2018). Based on the Food and Agriculture Organization (FAO) analysis, N and P demands may also affect the production of finger millet in future. This is an important issue since crops like finger millet are majorly grown by resource poor farmers in low input agricultural systems of Asia and Africa who cannot afford to buy expensive fertilizers (Thilakarathna and Raizada, 2015).

Drought: Drought is also one of the major abiotic constraints of finger millet production.Parvathi *et al*. (2013) studied the effect of drought stress on the expression of candidate genes in genotype GPU-28. Drought stress caused wilting and leaf rolling and resulted in the reduction of leaf solute potential and chlorophyll content with the induction of many drought stress responsive genes when compared to control condition (Parvathi *et al*., 2013).

Salinity: Salinity also reduced the water content, plant height, leaf expansion, finger length and width, grain weight, and delayed the flowering (Anjaneyulu *et al*., 2014). Seedlings of finger millet genotype GPU-28 exposed to salinity stress, PEG and oxidative stress showed significant reduction in plant growth and shoots and root biomass (Parvathi and Nataraja, 2017).

Shortage of improved varieties: only few suitable varieties are available particularly for dry lowland areas. Few varieties primarily developed for optimum rainfall areas proved to be adapted to the dry lowlands of central and eastern Ethiopia with average yield of 3 t/ha on farmers field. Future research should target similar environments and use these varieties as potential breeding material to identify new genotypes for similar agro-ecologies.

Lack of agronomic packages: little research have been conducted to develop agronomic practices to maximize productivity.

Lodging: this poses a formidable challenge to finger millet production. Lodging occurs late after flowering or during grain filling and the problem is particularly severe on tall local cultivars.

Utilization: although the crop is considered highly nutritious, information on its processing are limited. As a result, in many parts of Ethiopia, the use of the crop is highly redistricted to production of local alcoholic beverages, although it is often mixed with other grains to make injera. Elsewhere in Africa, the crop is used in several food applications including Ujii (thin porridge) that is served in public restaurants.

Conclusion

Finger millet (*Eleucine coracana* (L.) Gaertn.) is a staple cereal food crop for millions of people in the semi arid region of the world, particularly in Africa and India, and especially those who live by subsistence farming.Ethiopia is the center of diversity for finger millet. It is mainly grown in northern, north-western and south-western part of the country**.** It is used in many forms for human food. The grain serves for preparation of both food and malt items. Finger millet is particularly rich in dietry fiber and minerals such as calcium and iron. The productivity of this crop is limited by drought, lack of agronomic packages, diseases (head blast) and lodging.

Future prospects

Finger millet is a nutrient rich and drought hardy crop majorly cultivated and consumed by resource poor farmers in the developing countries. In future research must focus on the areas of;

Research capacity building: Developing the capacity of research programs working on the improvement of the millets is the first step. This includes formal training of staff assigned on millet research, supporting and strengthening linkage with regional and sub-regional research programs and increasing access to fresh germplasm sources.

Strengthening transfer of technologies: The effort by the national program to disseminate improved technologies over the last decade has been encouraging. This effort should also embrace the existing millet technologies. A pilot extension activity conducted over the last five years in south central Ethiopia has resulted in large scale adoption of finger millet in an areas the crop has never been known. These efforts should be scaled up and out to reach more stakeholders in other areas where the crop is expected to have potential impact.

Developing seed production and delivery mechanisms: Non hybrid crops rarely attract interest of private entrepreneurs. Researchers, local government and non-governmental development organization should be encouraged to work together and develop a workable format where local communities can participate in production and distribution of quality seeds.

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