

REVIEW

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Good farm practices and improved processing technology of enset for sustainable hunger solution in Ethiopia

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Abstract

Given the multi-benefits, enset cultivation has been continuously underutilized in Ethiopia. We assess best practices, processing technologies, environmental maintenance, multi-benefits of enset and its potency in hunger reduction in Ethiopia by reviewing evidence on good farm practices, improved technologies, sustainability, hunger reduction, inputs cost, and yields advantage of enset. The review results identify those best practices that optimize enset yield, technologies that facilitate extension services, processing and food qualities of enset. Moreover, we find that enset is a first-rated climate-smart crop, superior hunger solution because of its apparent capability to endure long periods (more than 5 years) of drought, highest yield, energy food supply, and costs advantages. In contrast, its long-period maturity, cultural perceptions, and little development policy attention given to enset limit its expansion. Therefore, exploring and creating universal access mechanism of early maturing and high-yielding varieties, processing technologies and mobile-based advices, involving best practices of enset in regular agricultural extension services, changing social perceptions optimize enset yield and production thereby it contributes environmental sustainability and cuts hunger challenges.

Keywords: Environmental sustainability, Enset, Enset app, Food supply, Good farm practices, Hunger, Processing technologies

Introduction

Ethiopia is second-most populous in Africa, with an estimated population of 102.4 million in 2016 (WFP, 2019), is still categorized as one of the seriously hunger-affected countries in the world through the Hunger Index (GHI) score of the country has declined from 53.7 (extremely alarming) in 2000 to 26.2 in 2020. As of the GHI's most recent data, the country holds the 92nd position among 107 countries in the world (Von Grebmer et al., 2020). Moreover, about 25.5% (26 million people) of the population was food insecure, and 23.5% of the population fell under the national poverty line in 2016 (WFP, 2019). The hunger cost of child malnutrition is also a series problem in Ethiopia. The total annual cost of child undernutrition is estimated at 17% of the country's earnings in

terms of GDP (Gross Domestic Product) (African Union Commission, NEPAD Planning and Coordinating Agency, UN Economic Commission for Africa, 2014).

Food security is vastly exposed to climate shocks in Ethiopia, since the economies of the country extremely rely on the climate-sensitive farming system (Alemu & Mengistu, 2019). Droughts and climate-related calamities are substantial triggers that aggravate vulnerability to food insecurity and destabilized livelihoods in the country (WFP, 2019). Furthermore, despite climate changes believed to have only moderate influences on crop productivities in Ethiopia, the future weather outcomes are expected to become more variable, suggesting that severe droughts and floods and have a greater effect on cereal production in the future than in the past (Thomas et al., 2019). On the other hand, enset and other indigenous crops that have long helped guard families against hunger due to their low production and high yields, and which are potential to improve food security, nutrition, and environmental sustainability are underutilized in the country. Consequently, Ethiopia has been the major receiver of food aid and net food importer despite it being a center of diversity and domestication for various food crops.

Enset (*Ensete ventricosum* (Welw.) Cheesman), occasionally named as false-banana, is a non-woody perennial plant indigenous to Ethiopia. Enset has been domesticated about 10,000 years back in Ethiopia (Brandt et al., 1997; Jacobsen et al., 2018), currently it provides the staple food for about 20 million people in the Ethiopian Highlands (Borrell et al., 2019). Even if the wild-grown of the genus *Ensete* are widely distributed all over Africa and Southern Asia, it is grown as a food crop in a limited area of the southwest part of the country (Blench, 2007) as cited in (Yemata, 2020). The distribution of enset cultivation is highly varied in Ethiopia based on environmental situations and social choices. Enset is plentiful to the greatest extent in northern and eastern parties of the Southern Nations, Nationalities, and Peoples Region (SNNPR), but is also a vital crop in parts of Oromia and eastern Gambela regions (Borrell et al., 2020). According to 2021 Central statistical Agency (CSA) report about 57,189,207.53, 63,445,734.58, and 1,850,753.10 quintals of enset yield in forms of amicho, kocho, and bula, respectively, were produced from a total of 206,659,076 enset crops in 2021/2021 cropping season (CSA, 2021).

Although enset is largely produced for human food, it is also used as animal feeds (Olango et al., 2015). Different parts of enset and processed products of several domesticated enset landraces provide socio-cultural, medicinal, and economic benefits (Olango et al., 2015). Furthermore, its fibers are used for making ropes, as well as the other strands the crop used for roofing and packaging.

Enset grows under a wide range of agro-ecological zones (Jacobsen et al., 2018; Olango et al., 2015). It mainly succeeds within altitudes of 1500–3100 m above sea level, with an average temperature of 10–20 °C, and annual rainfall of 1000–1800 mm dispersed in 8–10 months (Abebe, 2005). Temperature plays a substantial role in the growth of enset. Consequently, at the altitudinal ranges of 1500–2300 m, where the average annual temperature is 15–20 °C, enset attains full maturity within 5–7 years. Alternatively, in the high altitudes of 2300–3100 m, where the average temperature falls to 10–15 °C, it takes 8–10 years (Abebe, 2005; Shank & Ertiro, 1996) to reach full maturity. Enset thrives in a variety of soil types with appropriate nutrition and drainage, pH values ranging from 5.6 to 7.3, and 2–3% organic (Workneh & Satheesh, 2019).

Enset can be ripened at any stage (including when it is immature) and at any season of the year, and starch resulting from enset can also be stored over several years (Birmeta, 2004; Borrell et al., 2019). With relatively small inputs and farm management practices, it has been stated to provide the highest yield as compared to other starch crops in Ethiopia (Borrell et al., 2019; Tsegayei & Struik, 2001). However, many factors influence the enset yield, involving erraticism in transplanting frequency, plant spacing, time of harvest, rainfall, altitude, type of cultivars, husbandry methods and cultural practices (Blomme et al., 2018).

Enset can also be capable to support a larger population per unit area than regions depending on cereals (Borrell et al., 2019). Specially it is used as food security crop in over-populated areas (Yemataw et al., 2016b). Consequently, enset is characterized as a tree against hunger' (Borrell et al., 2019; Brandt et al., 1997) because of its essential features for food security. These attributes were realized during the distressing starvations in 1984 in Ethiopia, where enset-growing areas stated little-to-no food security problems (Borrell et al., 2019). Withstanding drought and harsh environmental stress are the most important attributes of enset (Borrell et al., 2019; Olango et al., 2015).

On the other hand, the clue of agroecology comprises development of agroecosystems with the negligible necessity on high agrochemical and energy inputs, focusing multifaceted farming systems in which ecological interactions and synergisms between biological mechanisms deliver the means for the systems to promoter their own soil fertility, productivity and crop guard (Altieri & Nicholls, 2005). Moreover, agroecology is potential to perform a vital role in building resilience and adjusting to climate change (Altieri & Nicholls, 2017; Pronti & Coccia, 2020). With this regard, many features of tradition enset-based farming system make the best suited to agroecology and environmentally resilient agricultural system. For example, the enset-based practices maintain species diversity, reduce or eliminate chemical fertilizers and pesticides, increase the use of farmyard manure, and need little or no external resources. In addition to this, the enset-based agroforestry systems produce a variety of food and other products for millions of households in Southern Ethiopia along with environmental protection (Abebe, 2018).

Despite its high potential and quality attributes in terms of sustainable food supply for long period, protecting against cyclical and periodic food deficits, with small farm input can be prolonged to other regions, where it grows as a wild crop, enset is limited to South–West Ethiopia (Borrell et al., 2019; Olango et al., 2015).

Given its high importance in the diet of contemporary Ethiopians and act as a famine buffer, enset has been so neglected partly due to cultural perceptions, politics, and history. In addition, enset production didn't included in agricultural extension service program for long-period of as the chief sector because of a little attention given by development programs (Sahle et al., 2021). Moreover, enset has been continuously underutilized as the development agendas of Western aid agencies still an emphasis on cereal grains, such as maize (Brandt et al., 1997). On the other hand, due to socioeconomic shifts and a lack of technological progress, the diverse uses of enset have been declining (Sahle et al., 2021). This deterioration could lead to the elimination of the home garden system, putting the community's food security at risk and decreasing the regulating and nonmaterial advantages of enset (Sahle et al., 2021). Moreover, with growing population

numbers and decrease farm sizes, traditional farming practices are under stress to continue the same levels of productivity (Blomme et al., 2018; Tsegaye & Struik, 2002).

In recent time little effort has been made to advance enset processing technologies (such as enset scraper, squeezer, and fermenting machine) that save time and labor. However, traditional processing is predominantly used by farmers still to date (Tiruneh, 2020). Similarly, Enset App, mobile based technology has been developed to deliver information on best agronomic practices to agricultural extension workers and farmers on best agronomic practices (Apps on Google Play, 2022), but the impact is not evaluated yet.

In contrast to multiple qualities of enset, literature is hardly existing in several important areas of enset (Borrell et al., 2019). Particularly, merely a limited amount of information supporting good farm management practice management for optimum yield of enset is existed in the literature. Most publications emphasis on studies of enset-farming regions to explain farmer practices, varietal diversity and sometimes yield of enset (Blomme et al., 2018). Similarly, the same is true for enset related technologies.

To increase the visibility of enset, the underutilized multi-benefit plant to the research community and any development programs, this paper aims to review the relevant literature, where possible from field experiment, that support best farm practices of enset, and technologies related to enset processing for optimum yield and sustainable hunger solution in Ethiopia and additional attributes.

Moreover, this review paper aims to investigate the following research questions: What are the best farm practices and technologies in enset production and processing? How the best farm practices and technologies can improve yield and efficiency enset production and processing? How enset contributes to environmental sustainability and overcome hunger? Thus, this paper will add values to existing literature and serve as a significant knowledge base.

Methodology

The systematic literature review (SLR) is an assessment of a prevailing body of published work that follows a clear and logical methodology in browsing, evaluating its quality and analyzing it, with a great level of rationality (Kraus et al., 2020; Tranfield et al., 2003). Consequently, in searching, collecting, selecting, and reviewing literature for this study, the works of Fink (2019), and Tranfield et al., (2003) were followed to increase the quality and level of transparency the review. Accordingly, the forementioned sub-research questions were developed for this study.

To distinguish the key literature streams and emphasis on sources that are expected to provide highest level of impact (Podsakoff et al., 2005). Consequently, relevant articles were searched in Scopus, the foremost abstract and reference database of peer-reviewed literature (Falagas et al., 2008).

I used the keywords of “good (and similar terms)”, “improved (and similar terms)”, “practices (and similar terms)”, “improved (and similar terms)”, “technologies (and similar terms)”, “enset (and similar terms)”, “sustainable (and similar terms)”, “hunger (and similar terms)”, “solution (and similar terms)”, restricting results to peer-reviewed journals focusing on sources with a high level of impact regardless of year of publications. By limiting the search to articles published in English, in the subject area and peer-reviewed

journals, a total of 106 articles were collected in Scopus. Finally, the first 38 results were selected by relevance to the scope of the review. However, the author couldn't generate the suffice information relying merely on articles in Scopus. As a result, we searched the bibliographies of key article and the papers that cited these key article (a procedure known as backward and forward "snowballing") to detect extra academic and grey literature. Accordingly, we searched key institutional websites, involving: IFPRI, World Bank, FAO, Royal Botanic Gardens Kew, and open repository for enset data with aid of Google and Bing search engine, for which we screened the first 188 results sorted by relevance to the study. Among which 29 seminal studies were sampled based on the purpose of the review.

Results

We were able to identify good farm practices in enset production, and improved processing technology of enset, contribution of enset for environmental sustainability and hunger solution, and alternative benefits of enset described in the articles and to build, accordingly, five core categories. These categories are related to: into (1) yield and inputs-cost advantages of *enset* production (e.g., comparative advantages of enset over other crops in terms of productivity, inputs utilization, cost advantage of enset's food); (2) good farm practices and technologies in *enset* production and processing (e.g., best agronomic practices, propagation, transplanting, high and early yield cultivars selection, crop protection, mobile based application for landraces optimally matched to local climates and extension services, improved technologies for enset scraping and fermentation); *enset* foods for nutritional food security improvement (how enset provide solution for hunger); (4) *enset* for environmental sustainability (e.g., how enset production contributes to environmental sustainability); and (5) alternative benefits of *enset* (e.g., *enset* as a source of forage, medicinal importance, industrial and other addition benefits of enset).

Discussion of results

We screened literature perspectives and theories related to the scope of the review. This resulted in an overview, which is presented in synthesis in Table 1 and detailed in the following paragraphs.

Yield and inputs-cost advantages of *enset* production

Enset yield

Enset is reported to be the second most-produced crop and the fourth highest yield per hectare crop in the 2017/2018 cropping season in Ethiopia. According to data obtained from Ethiopia's Central Statistics Agency (CSA, 1995–2017), the area for enset land cover and its yield has increased by about 46%, and 12 fold over the last two decades, respectively (Borrell et al., 2020). The productivity of *kocho*, in-unit per area of land, in terms of eatable dry weight and energy, by far exceeds any crops produced in the country (Tsegayei & Struik, 2001). Furthermore, enset provides up to 4000 cal or 20 folds of calories generated by cereal per square meter per year. It renders about 20% of national carbohydrate requirements, only from 300,000 ha of land due to its higher yield per area of land (Christensen Fund, 2014).

Table 1 Summary of the results

Main finding	Authors
<i>Enset</i> yield	
Enset provides about 50.3 kg (involving 27 kg Kocho, 23 kg amicho, and 1 kg bulla) per plant per annum	Borrell et al. (2019)
Eatable dry weight and energy of <i>enset</i> , by far exceeds any crops produced in the country	Tsegayei and Struik (2001)
Enset provides up to 4000 cal or 20 folds of calories generated by cereal per square meter per year	Christensen Fund (2014)
Inputs-cost advantages of <i>enset</i> production	
<i>Enset</i> needs a little cost of production (about \$50) when compared to different crops	Christensen Fund (2014)
It offers food security with little cost	Berhane et al. (2011), Christensen Fund (2014)
Good farm practices	
Enset corm multiplication requires 2–3-year-old mother plant with a 10–35 cm corm diameter, the pseudostem cut at 10–30 cm above the ground, and half corm pieces for optimum growth, and yield	Bezuneh and Feleke (1996), Diro et al. (1999), Yemataw et al. (2014)
From January to June is the suitable period of planting corms for good establishment and successive growth of suckers	Yemataw et al. (2018a, 2018b)
With a final of 4 m ² spacing is appropriate for optimum vegetative growth, and yield	Yemataw et al. (2018a, 2018b)
Direct transplanting is recommended for early yield, but recurrent transplanting will result in a higher yield per plant	Tsegaye and Struik (2000)
Once equilibrium (planting equals to harvesting) has been attained, annual yields will be higher for twice transplanting related to once transplanted	Blomme et al. (2018), Borrell et al. (2020), Tsegaye (2007)
The optimal moment to harvest is at inflorescence emergence for highest dry matter yield	Borrell et al. (2020), Tsegaye and Struik (2000)
5–10 kg of farmyard manure application per plant per year leads to better vegetative growth and yield with an early maturity time of about 2 years	Yemataw et al. (2018a, 2018b)
High yielding and early maturing <i>enset</i> 's varieties	
The early maturing varieties complete their full maturation period within 3–4 years, and these involve, Yanbule, Gewada, and Endale	Yemataw et al. (2018a, 2018b)
The late maturing varieties needs 4–5 year maturation, and these include, Kelisa, Zerita, and Mesena	Yemataw et al. (2018a, 2018b)
The high-yielding varieties of <i>enset</i> for kocho production provides up to sevenfolds of kocho when compared to national average yield per hectare per year	Hiebsch (1996), Yemataw et al. (2018a, 2018b)
Chohot, Ashakit, Bose, and Gazner are superior corm yield varieties and provides 20 to 23 tons of corm per ha per year	Yemataw et al. (2016a, 2018a, 2018b)
Enset protection	
Among all, bacterial wilt (EBW), caused by <i>Xanthomonas ampelstris</i> pv. <i>musacearum</i> (Xcm) is the most destructive diseases happening in all <i>enset</i> growing areas. of Ethiopia	Haile et al. (2020), Wolde et al. (2016)
Gudiro, Maziya, and Nobo <i>enset</i> were found to be a tolerant reaction to EBW, whereas clones Arkia, Ataro, Yeko, Chikaro, and Ogisso were the most susceptible <i>enset</i> clones	Haile et al. (2020)
EBW can be prevented by disinfecting <i>enset</i> -cutting tools, preventing animals from browsing and removal of infected plants, and use of disease-free suckers for propagation	Borrell et al. (2019)

Table 1 (continued)

Main finding	Authors
Improved technologies	
Enset App (mobile based application) has a potential to advance enset farm management advice through delivering information on best farm practices, crop protection, landraces optimally matched to local climates	Wilkin (2021)
The improved enset scraper, and squeezer cut down women's workload, and modified labor division trends, and enhanced income for processed enset	Tiruneh (2020)
The enset fermenting box technology reduced the duration of fermentation and women's workload, and improved the quality of fermented enset	Tefera et al. (2019)
Enset foods for nutritional food security improvement	
The types of traditional food products resulting from enset are reported to exceed 20	Workneh and Satheesh (2019)
Enset is rich in carbohydrates and improves the food security for an estimated 20 million people	Borrell et al. (2020), Jacobsen et al. (2018)
Among the common foods items resulting from enset, <i>kocho</i> and <i>bulla</i> are superior energy sources and <i>Kocho</i> provides 400 kcal/100 g energy	Bosha et al. (2016)
<i>Bulla</i> and <i>amicho</i> provide about 395 kcal/100 g and 333 kcal/100 g energy, respectively	Daba and Shigeta (2016), Workneh and Satheesh (2019)
<i>Kocho</i> and <i>amicho</i> are populous for cholesterol regulation	Workneh and Satheesh (2019)
An enset-based diet contributes to a pregnant woman's and infant's nutritional improvements through minimizing the risk of vitamin B-12 deficit	Gibson et al. (2008)
Given the conducive adaptability of <i>enset</i> to different agro-ecologies, it has the potential to expand elsewhere in Southern and East Africa and guarantee smallholders' food security	Borrell et al. (2020)
<i>Enset</i> for environmental sustainability	
<i>Enset</i> production is considered as best suited to environmental sustainability and agroforestry systems, since it grows friendly with coffee, vegetables, fruits, root and tuber crops, cereals and different types of trees, and maintains soils without any chemical application and zero tillage	Abebe (2018)
It is possibly vital as a climate-smart crop for the future because of its apparent capability to endure long periods (more than 5 years) of drought	Wilkin (2021)
<i>Enset</i> has the potential to support many other LMICs in Africa and can help challenge of the SDGs	Wilkin (2021)
Alternative benefits of <i>enset</i>	
Enset is an imperative animal fodder particularly during dry seasons due to its high-water content, and its leaves contains 13% protein (the highest protein concentration fodder existing in Ethiopia), 20% crude fiber, and 10% sugar	Mohammed et al. (2013)
Some <i>enset</i> landraces, such as <i>sweetie</i> and <i>tayo</i> , are largely used for curative for a person suffering from bone-related problems	Daba and Shigeta (2016), Tsehaye and Kebebew (2006)
<i>Bulla</i> is consumed by a mother who is born baby for strengthening and immediate return to normal health	Daba and Shigeta (2016)
The starch from enset has a crucial function in numerous industrial processes, such as food, pharmaceuticals, cloth, paper, and adhesives products	Gebre-Mariam (2016)

Table 1 (continued)

Main finding	Authors
The high-quality fiber of enset can be used for the production of specialty papers, such as currency notes, and tea bags, that require durable fibers	Gessesse (2016)
Fiber obtained from the pseudostem and leaves, is used to make sacks, ropes, sieves, and mats	Borrell et al. (2020)
The leaf sheath, petioles, and midrib of enset are used for mulching, compost preparation, packaging, fire fuel, houses, and fencing construction	Borrell et al. (2020)

The productivity of enset per unit area of land is significantly higher than that of other common Ethiopian staples, such as cereals, potatoes, sweet potato, and bananas. The annual enset yield per plant is estimated to be 50.3 kg (involving 27 kg Kocho, 23 kg amicho, and 1 kg bulla) (Borrell et al., 2019). The high productivity of the crop aids to overcome food security problems in densely populated areas (Christensen Fund, 2014). Enset production is, therefore, believed to have a higher potential in sustaining the population as compared to other crops, in highly populous areas with resource-poor situations in Ethiopia or elsewhere in the world given conducive agroecology for enset cultivation.

Inputs-cost advantages of enset production

Enset is commonly produced with a little cost when compared to different crops as it requires no cash outlays, and minimum labor and land for production. Considering zero cash outlay for production and opportunity cost of labor, the total cost of production for one metric ton of *kocho* is estimated to be \$51 (Christensen Fund, 2014).

Furthermore, *enset* offers food security with little cost. Although enset-growing areas are recognized as the poorest and leading densely populous areas in the country, they have the highest daily caloric consumption and expend the lowest cost per kilo of food of any zone (Christensen Fund, 2014). A similar source also confirms that the most *enset*-producing areas (SNNPR and Oromia) were found to have the largest daily caloric consumption and lowermost expenditure per unit of diet (Berhane et al., 2011).

Good farm practices and technologies in *enset* production and processing

Research and development programs in Ethiopia have concentrated on cereal grains, mainly maize, while enset has received little attention. So far, very few of agronomic recommendations are exists that may be beneficial for extension services or farmers (Blomme et al., 2018). Therefore, this section describes the optimal farming practices, technologies that facilitates the practices, and increase efficiencies in enset processing.

Propagation of enset

While wild enset plants are regenerated from seeds, domesticated enset is largely vegetatively propagated (Karlsson et al., 2013). The reproduction of enset from seed is not advisable to practice, since its germination is very low, and takes a long period for juvenilities, and low seed germination. The germination rate and period of enset's seed is about 12%, and 12 weeks, respectively (Karlsson et al., 2013). The low germination rate of enset's seed might be emanated from a lack of sufficient carbohydrates for the viability

of the seed, since enset exploits its stored carbohydrate during the fruiting period. By nature, enset uses its carbohydrate accumulation during the fruiting stage thereby reducing the viability of the seed (Diro et al., 2002). Moreover, seedlings rising from seed are testified to be less vigorous when compared to the suckers obtained through vegetative propagation (Yemataw et al., 2018a, 2018b). As a result, the cultivated enset is commonly vegetatively propagated through suckers produced from corms of mother plants (Diro et al., 2002; Karlsson et al., 2013; Yemataw et al., 2018a, 2018b).

Unlike the banana, enset does not produce suckers, as it possesses a single apical dominant apical meristem, which hinders lateral bud development. The apical meristem must be removed to stimulate sucker production (Borrell et al., 2019; Karlsson et al., 2013). Farmers in Ethiopia usually use 4–6-year-old parent plants are used to produce suckers (Ashango, 2017). However, the magnitude of suckers (plant height, pseudostem height, and pseudostem diameter) is not meaningfully influenced by age of parent plants (Diro et al., 1999). Farmers may use the whole intact corm or a split corm (usually halved and quarter corms) to produce suckers. Several trials made on enset corm multiplication suggest that 2–3-year-old mother plant with a 10–35 cm corm diameter, the pseudostem cut at 10–30 cm above the ground, and half corm pieces for optimum growth, and yield. The age of enset corm on multiplication rate of the whole corm of 2–3 years gave rise to in that higher number of shoots than 1-year-old corm (19 per corm) and also half corm pieces provided higher number than others (Diro et al., 1999), and about 10–35 cm in diameter are recommended (Bezuneh & Feleke, 1996; Yemataw et al., 2014). Soon after the removal of the apical meristem, the corm/corm pieces are uprooted and replanted 20–30 cm deep in loosened soil, mixed with compost, or can be kept in situ to produce suckers (Diro et al., 2002). Each corm (piece) produces between 40 and 200 suckers, based on the cultivar, size, and age of the mother plant, soil type, rainfall, land preparation, and time of planting (Shumbulo et al., 2012). Suckers begin to emerge 2–3 months after planting (Tsegaye & Struik, 2002), and remain on corms for about a year before transplanting (Tsegaye, 2007).

Suckers from split corms more become more vigorous, which encourages success of establishment, higher and earlier yield (Karlsson et al., 2015). However, in areas with prolonged droughts and watering is difficult, it may be desirable to use whole corms to reduce corm dehydration; in other areas irrigating and application of compost is recommended (Karlsson et al., 2015). From January to June is the suitable period of planting corms for good establishment and successive growth of suckers (Yemataw et al., 2018a, 2018b).

Transplanting

After propagation, the harvested suckers are separated and transplanted out in a row in a nursery plot (0.5–1 m²/plant), where they grow for approximately 1 year. Afterward, suckers are repeatedly transplanted into ever more widely spaced arrangements, with a final minimal spacing of 2–4 m²/plant (Tsegaye & Struik, 2002), with extensive spacing more common in areas of lesser soil moistness (Sahle et al., 2018). Moreover, research results at Areka Agricultural Research Centre disclosed that spacing 4 m² is appropriate for optimum vegetative growth, and yield of enset (Yemataw et al., 2018a, 2018b). In

general, the incidence of transplanting ranges from 2 to 6 times in different enset growing areas.

Transplanting rate influences the crop cycle period and yield (Blomme et al., 2018). Successive transplanting delays flowering, therefore, increasing the vegetative growth, and the assimilation of starch in the pseudostem and corm. Consequently, direct transplanting is recommended when early yield is the target of the production, but recurrent transplanting will result in a higher yield per plant (Tsegaye & Struik, 2000). Once equilibrium (planting equals to harvesting) has been attained, annual yields will be higher for twice transplanting related to once transplanted, since it increases the share of dry matter to the harvestable parts (Blomme et al., 2018; Borrell et al., 2020; Tsegaye, 2007). Enset reaches its full maturity from 4 to 12 years. The optimal moment to harvest is at inflorescence emergence when dry matter yield is highest (Borrell et al., 2020; Tsegaye & Struik, 2000). After flowering, assimilates are transmitted to the inflorescence and left the pseudostem and corm (Borrell et al., 2020; Tsegaye & Struik, 2000).

Manuring and weeding are the major farm management practices for enset production. The major type of fertilizer applied on enset fields is farmyard manure. It is recommended to apply 5 to 10 kg of farmyard manure per plant per year to obtain better vegetative growth and yield with an early maturity time of about 2 years (Yemataw et al., 2018a, 2018b), and weeding at least once a year.

High yielding and early maturing enset's varieties

Enset Research Program based in Areka in Wolaita zone had an underway result for variety selection for Koch, amicho yield and quality and enset bacterial wilt (EBW) disease-tolerant varieties after many years of selection and multi-location testing (Yemataw et al., 2018a, 2018b). The program released six high-yielding and better-quality varieties of enset for kocho production. The varieties are categorized into early and late maturing. The early maturing varieties complete their full maturation period within 3–4 years, and these involve, Yanbule, Gewada, and Endale. On the other hand, it takes 4–5 years for the late-maturing varieties to complete their maturation, and these include, Kelisa, Zerita, and Mesena. The mean fresh kocho yield of the released enset varieties ranges from 20 to 31 tons per hectare per year (Yemataw et al., 2018a, 2018b). Under normal conditions, the average fresh yield of kocho was estimated to be 4.4 tons per hectare per year (Hiebsch, 1996). Further comparing the newly released cultivar with the national average yield of kocho, it provides 5–7 times more kocho yield tons per hectare per year.

The study results conducted in Areka and Chichu during the 2012 to 2013 cropping season shows that Chohot, Ashakit, Bose, and Gazner enset varieties have recorded the highest corm yields among 35 cultivars of enset (Yemataw et al., 2016a). The average corm yield of these enset varieties was 20 to 23 tons per ha per year. These four superior corm yield varieties of enset for amicho (corm) have been nominated and are underway for release (Yemataw et al., 2016a, 2018a, 2018b).

Research achievement and experience in enset protection

Despite its higher importance, enset is constrained by numerous biotic and abiotic factors that influence its production and yield. Among the biotic constraints, diseases, insect pests, and wild animals are important encounters of enset (Haile et al., 2020). The

most common diseases of enset are enset bacterial wilt (EBW), and enset root mealybug (*Cataenococcus ensete*) (Borrell et al., 2019). Among all, EBW is caused by *Xanthomonas ampelstris* pv. *musacearum* (Xcm) is the most destructive constraint contributing a large portion to the reduction of enset yield in all enset growing areas of Ethiopia (Haile et al., 2020; Wolde et al., 2016).

It begins wilting (yellowing) of the center of the leaf and spread to all parts followed by progressive, and eventual death of the plant (Haile et al., 2020). Total yield loss is predictable after the disease takes hold, although plant recovery has been noticed of the tolerant landraces, such as Mazia, Badadeti, and Astara, (Borrell et al., 2019; Hunduma et al., 2015). Similarly, a study conducted on 15 select enset clones showed that Gudiro, Maziya, and Nobo were found to be a tolerant reaction to EBW, whereas clones Arkia, Ataro, Yeko, Chikaro, and Ogisso were the most susceptible enset clones (Haile et al., 2020). Symptoms of the disease involve, leaf yellowing, damaging and wilting, and bags of yellow or cream-colored slimy ooze are noticeable in cut vascular tissues in leaf sheaths, leaf midribs, and real stem (Borrell et al., 2019). The foremost mode of spread of EBW is through farming tools and contaminated planting material. In addition, porcupines, warthogs, and mole rats that often eat rhizomes can spread the disease (Borrell et al., 2019; Brandt et al., 1997). Control practices that could avoid, lessen or eliminate the spread of EBW involve, disinfection enset cutting tools, preventing animals from browsing infected plants, fencing diseased area, removal of infected plants (Borrell et al., 2019), and use of disease-free suckers for propagation.

Enset App (mobile-based technology)

In recent time, Enset App (application developed in collaboration with Royal Botanic Gardens Kew, Hawassa University, Wolkite University, Addis Ababa University, Ethiopian Biodiversity Institute, South Agricultural Research Institute, University of Leicester, and Queen Mary Landon University) has been developed to improve enset performance with mobile agri-data, knowledge exchange and climate-adapted genotypes (Apps on Google Play, 2022). The Enset App is a free Android application aimed at providing key commanding project-generated information to agricultural extension workers and farmers on best agronomic practices, a means for easier disease detection and a tool for optimal landrace selection at any locality in the enset growing areas. The application was started in February 2020 via the google play page: <https://play.google.com/store/apps/details?id=com.ensetemap> (Wilkin, 2021).

Therefore, the Enset App is the potential to advance the agricultural management advice including information on planting density, fertilization, seasonal activity, and intercropping of enset through generating information on management best practice, as well as facilitate crop protection via providing disease diagnostic diagrams and photographs on a field-portable tool. In addition, the platform uses genomic analysis accomplished by the project to identify landraces optimally matched to local climates that it helps improve the yield of enset, reduce the time from planting to maturity and enhance resilience (by selecting appropriate landraces) thereby increasing the climate adaptation of farmers (Wilkin, 2021). Despite paramount importance of the application, the technology is less familiar among the enset farm-holders and concerned extension workers. Therefore, it needs more promotion. In addition to this, the designation of landraces released on the application based on the

names given by few ethnic groups and the name of the landraces varies from place to place within a country. In most cases, therefore, it is difficult to identify the best match of the landraces to local climates relying on the application. Accordingly, it seeks to incorporate alternative names for each landrace as it designated by different groups or support with photographic representation.

Improved enset processing technologies

Despite the multi-benefit of enset, little effort has been made to advance the processing aspect of the crop. Consequently, traditional processes are predominantly used by farmers still to date (Tiruneh, 2020). Although enset's cultivation and farm practices accommodate both men and women, its harvesting and processing impose a high burden on women because of cultural value. Moreover, enset processing is labor demanding activity (Tefera et al., 2019; Tiruneh, 2020). Thus, it remains challenging for women, since the era of enset's domestication. In addition, the traditional harvesting, and post-harvesting handlings are awkward, exhaustive, unsanitary, and accompanied by great yield loss (Tefera et al., 2019; Tiruneh, 2020).

On the other hand, the recently introduced technologies (such as enset scraper, squeezer, and fermenting machine) have the potentials to improve the traditional enset processing challenges to some extent. To this end, enset processing tools (e.g., scraping, and squeezing) that have been developed by Sodo Rural Technology Promotion Research Centre and Melkassa Agriculture Research Institution have been distributed at different times to farmers by different organizations. However, studies are hardly existing on the adoption of improved enset processing technologies and their impacts. On the other hand, a case study conducted by Tiruneh (2020) on performance and adoption of improved enset processing technologies Enemorena Ener district shows that the introduced technologies cut down women's workload. According to the same study results, the introduced technologies over traditional methods could save 48 and 37 min of women's workload of time for scraping and squeezing per plant, respectively. Moreover, it has changed the trend of labor division in enset processing among household members in a way that more boys, girls, and men are involved. It also led to higher income for processed enset (Tiruneh, 2020). Perhaps, this might be associated with the better quality of attributes of the new processing technologies. However, the adoption rate of the technologies is very low because of the inaccessibility and unaffordability of the tools (Zewdie, 2012).

Traditionally, the processed enset is kept for fermentation either in an earthen pit or above ground wrinkled with leaf, and leaf sheath (Abadura & Beyene, 2021). The old-style processing systems cause contamination by flood, dust, rodents, and insect, colony infestation, exposure for theft, problematic to manage, and takes a long period of fermentation (Tefera et al., 2019). On the other hand, the enset fermenting box that was recently developed by Bako Agricultural Engineering Research Center is capable to reduce the duration of fermentation by half, improve the quality of fermented enset, and reduce women's workload (Tefera et al., 2019). However, it is still under demonstration it requires further investigation and promotion.

Enset foods for nutritional food security improvement

Enset foods for nutritional improvement

Enset is a staple food crop that is preserved preferably suited to fill the food shortage gap, usually in Ethiopia (Tsegaye, 2002; Yemata, 2020). Enset is also consumed as a cooked vegetable in a different area of Southeast Asia, and its flowering part is also eaten in Malawi as fun (Yemata, 2020). The types of traditional food products resulting from enset (including yogurts, cakes, dumplings, and porridges) are reported to exceed 20 in Ethiopia (Workneh & Satheesh, 2019). However, the major foods items obtained from enset involve, *Kocho*, *Bulla*, and *Amicho* (Forsido et al., 2013; Yemata, 2020). *Kocho*, the most predominant product, is rich in starch product prepared by fermenting the pulp (from scraping the pseudostem and crushing the corm) wrapped in enset leaves in an underground pit inside the enset home garden (Borrell et al., 2020). *Bulla* is a dehydrated product of the juice from the decortication of the pseudostem and corm, and *Amicho*, the boiled corm enset (Forsido et al., 2013; Yemata, 2020).

Enset is rich in carbohydrates with a minimum amount of essential amino acids, such as methionine and isoleucine (Jacobsen et al., 2018). In the area, where enset is a staple food, it is mainly used for meals, on average 0.5 kg is consumed per person daily, and provides 68% of the total energy intake, 20% protein, 28% iron, but no vitamin A (Jacobsen et al., 2018; Negash & Niehof, 2004). Among the common foods items resulting from enset, *kocho* and *bulla* are superior energy sources. *Kocho* provides 400 kcal/100 g energy (Bosha et al., 2016), and like *kocho*, *bulla* also has about 395 kcal/100 g energy, but *amicho* has less energy (333 kcal/100 g) (Daba & Shigeta, 2016; Workneh & Satheesh, 2019). The energy value of enset is similar to potato (Mohammed et al., 2013), and the low content of amino acids of the enset meal is frequently supplemented with protein from milk, meat, or leguminous, such as peas and beans (Bvenura & Afolayan, 2015; Jacobsen et al., 2018). Similarly, the nonappearance of vitamin A is compensated by vegetables such as cabbage in most enset-cultivating farm households (Jacobsen et al., 2018). Furthermore, the low compositions of fats and proteins in the enset diet are highly preferred by people who require low-fat meals. *Kocho* and *amicho* are populous for their fiber content also essential for cholesterol regulation and help constipation avoidance (Workneh & Satheesh, 2019).

On the other hand, the research finding by Gibson et al. (2008) indicated that pregnant women who depended on enset as a staple food had higher vitamin B-12 levels than their maize-based peers in southern Ethiopia. In addition, chemical analysis of vitamin B-12 levels for the enset-diet group were found to exceed twofold the standard set by WHO/FAO the mean requirement for pregnant women (Gibson et al., 2008). An enset-based diet, therefore, contributes to a pregnant woman's and infant's nutritional improvements through minimizing the risk of vitamin B-12 deficit.

Enset corm provides 17 of 20 amino acids, which is similar or more level of amino acids as compared to potato. The pseudostem provides a higher level of soluble carbohydrates (80%) and starch (65%), but a low protein level (4%). Hence it seeks to be complemented with protein and complementary amino acids; for instance from beans, which are appropriate to intercrop with enset (Mohammed et al., 2013).

Enset for food security enhancement

Enset-based agriculture is the economic mainstay for Southern parties of Ethiopia (McKnight Foundation, 2013). Despite enset is wild growing across several parts of East and Southern Africa, its farming system hasn't been virtually known outside of these areas. It is the starch-riched staple of the Ethiopian Highlands, where its unique characters improve the food security for an estimated 20 million people (Borrell et al., 2019). Enset's resilience and adaptability have got it the designation of "The Tree Against Hunger" (Borrell et al., 2020; Brandt et al., 1997).

Despite enset-cultivating areas are characterized by small land size and the largest overcrowded population in the count (Tsegayei & Struik, 2001), they tended to experience low levels of food insecurity or face no food security challenges as compared to non-enset growing areas in the country (Borrell et al., 2019) For example, the share of food-insecure households was highest for Amhara region, a non-enset growing region with (36%) of food-insecure households in 2016, while the share of food-insecure households was the lowest for Southern Nations, Nationalities, and People Region (SNNPR), the largest enset-growing region, with (8.4%) of food-insecure households for the same period. Likewise, the Amhara region was found to be the least in terms of adult average kilocalorie intake per day, at 2398 kcals per adult per day (related to the countrywide mean of 3008 kcals), while SNNPR had the highest kcal intake per adult at 3558 kcals for the aforementioned period (WFP, 2019).

The big difference across *enset*-cultivating and non-*enset* cultivating regions in terms of food insecurity and kilocalorie intake imply the highest value contribution of *enset* for food security improvement and hunger solution of the crop. In general, given the conducive adaptability of *enset* to different agro-ecologies, it has the potential to expand elsewhere in Southern and East Africa and guarantee smallholders' food security (Borrell et al., 2020).

Enset for environmental sustainability

The benefit of enset is not limited to meeting the food security demand of current generations. It can also be recognized as an imminent food security plant, since it has the potential to sustain and maintain the quality of soil (Woldetensaye, 2016). The capability to deliver a long-term, food supply continuously, with the lowest off-farm input, is possibly the most remarkable feature of enset.

On the other hand, as a perennial plant, enset does not need plowing. The negligible soil erosion involved in enset production is the key contribution of enset to sustainability (Brandt et al., 1997). Moreover, the wide shelter of enset's leaves interferes, divert, resizes as well as minimizes the energy of rainfall with which it could have hit the ground. Enset, therefore, helps to minimize soil erosion and is considered as a soil building plant. Besides, the deep roots of the enset permeate water to percolate and reduce surface overflow, save more water in the soil, and increase groundwater. As a result, it enhances quantity, availability and lengthens the period of water flows to springs, and minimizes the risk of long period drought (Brandt et al., 1997; Heuzé et al., 2017).

The cultures of enset (such as leaf midribs, pseudostem sheath, pseudostem core) are easily convertible to crop nutrients that improve soil organic matter and nutrients. After

harvesting, enset leaves can serve as mulching, which improves organic matter and soil conservation. Enset also reported increasing soil fertility than fields or pastures counterparts (Heuzé et al., 2017; Shank & Ertiro, 1996). Similarly, the research finding by Tamire and Argaw (2015) disclosed that enset improves soil maintenance under different agro-ecologies in Ethiopia. Moreover, the extended occurrence of its canopy has an ecological benefit comparable to a forest (Admasu and Struik 2001) and offers shade to the coffee and other crops.

On the other hand, agroecology is the act of applying ecological science and principles to the plan and management of sustainable agricultural systems (Altieri & Nicholls, 2005; Pronti & Coccia, 2021). Specially, agroecology emphasizes on traditional practices, often applied by indigenous peoples, for sustainable agroecological systems at modest (Altieri & Nicholls, 2017; Pronti & Coccia, 2020). Furthermore, for at least 3 years, agroecological farms adopt at least one of the following sustainable practices: agroforestry systems, intercropping, no tillage, pest and disease management, pesticide-free farming, chemical fertilization reduction, and crop rotation (Pronti & Coccia, 2020). Accordingly, enset production best suited to agroforestry systems, since it is grown friendly mixing with coffee, vegetables, fruits, root and tuber crops, cereals and different types of trees, and contributes highly to environmental protection. Moreover, the enset-based agroforestry systems provide a variety of sustainable food and other benefits for millions of households in Southern Ethiopia (Abebe, 2018), without any chemical application and zero tillage.

Enset has a vital benefit for the ecosystem amenities as it is an important food source for bees, and maintains soils. Moreover, enset is extremely important, since it is capable to resist extensive drought (Willis, 2016). It withstands drought due to its osmotic modification and water holding capacity (Fetene & Yemata, 2016). Upon extreme drought, therefore, enset looks to be a first-rated crop to be encouraged to overcome forthcoming climate change, pest and pathogen outbreak adverse effects on future food security and supply in Ethiopia. Moreover, enset is possibly vital as a climate-smart crop for the future because of its apparent capability to endure long periods (more than 5 years) of drought (Wilkin, 2021). Because of such features, enset is commonly recognized to have the ability to be a climate-smart plant of the future (Willis, 2016). Furthermore, enset has the potential to support many other Low and/or Middle-Income Countries (LMICs) in Africa. Thus, can help challenge of the sustainable development goals (SDGs) particularly UN SDG2 (end hunger), and SDG15 (use terrestrial ecosystems sustainably) (Wilkin, 2021).

Despite significant roles of enset-based agroforestry systems towards the economic and ecological sustainability, currently the systems are getting declined because of emerging problems and opportunities. Because of snowballing fragmentation of land from time to time, especially small size farm holder poor farmers are switching their enset farms' to early maturing crops such as maize and sweet potato to alleviate their immediate food demand. Moreover, farmers with good market access allot a smaller part of their land to growing enset and a larger share to cash crops, such as chat (Abebe, 2018). This is mainly because better income source of cash crops over enset. Farmers with good market access allot a smaller part of their land to growing enset and a larger share to cash crops, such as chat. This is mainly because better income source of cash crops over enset.

Alternative benefits of *enset*

Enset for forage improvement

Enset is an imperative animal fodder particularly during dry seasons due to its high-water content (85 to 90%). The leaf of *enset* is recognized as a good source of animal feedstuff, holding 13% protein (the highest protein concentration fodder existing in Ethiopia), 20% crude fiber, and 10% sugar. In addition, the high sugar content of *enset* leaves makes it appropriate for ensilage (Mohammed et al., 2013). It also possesses more than adequate levels of potassium, magnesium, zinc, and manganese, with no toxicity effects for ruminants, but it was completely scarce in P, Na, Cu, Co, and Se. *Enset* leaves are commonly appropriate fodder for ruminants. However, *enset* leaves alone are not sufficient to be optimal ruminants and it seeks to be supplemented additional feed comprising some minerals and energy to be balance feeds (Mohammed et al., 2013).

Medicinal importance of *enset*

Enset is culturally considered an important medicinal crop in Ethiopia. Different types of *enset* are stated to have curative and cultural importance for anticipating, healing, and therapeutic benefits. Few types *enset* are supposed to serve as medicine among *enset* cultivating society. Accordingly, *sweetie*, a type *enset* is largely used for curative for a person suffering from bone-related problems in the Areka area. Similarly, the boiled *corm* and *bull* of *Tayo* (*Werkie-bidu* called in West Shoa Zone), a type of *enset* with a light red pseudostem and midrib with deep green leaf are consumed with milk for joint dislocation, inflammation, and broken bone fractures treatments. It also offers the same function for animals when it is fed with salt (Daba & Shigeta, 2016; Tsehaye & Kebebew, 2006).

In addition, in an area where *enset* is not common, such as the central highlands and cities, *bull* is consumed by a mother who is born baby for strengthening and immediate return to normal health (Daba & Shigeta, 2016).

Industrial and other benefits of *enset*

In addition to its main dietary starch source, medicinal, environmental rehabilitation benefits, *enset* also serve as a multipurpose industrial crop and has the potential to produce different other valuable by-products (Gessesse, 2016). The starch from *enset* has a crucial function in numerous industrial processes, such as food, pharmaceuticals, cloth, paper, and adhesives products (Gebre-Mariam, 2016). The high-quality fiber of *enset* can be used for the production of specialty papers, such as currency notes, and tea bags, that require durable fibers. However, traditionally processing has been the major holdup for its widespread usage (Gessesse, 2016).

Fiber which is obtained from the pseudostem and leaves, mainly as a byproduct of *kocho* production (Borrell et al., 2020; Yemataw et al., 2018a, 2018b) is used to make sacks, ropes, sieves, and mats. The leaf sheath, petioles, and midrib of *enset* are used for compost preparation and fire fuel. The leaves of *enset* are also used for packaging *kocho*, butter, honey, making mattresses and pillows, and coating the fermentation pits for *kocho*. Leaves and midribs are also used for mulching, houses, and fencing construction (Borrell et al., 2020).

Conclusions

This systematic review results were able to identify good farm practices, high yielding cultivars, and crop protection mechanism for optimum yield of enset; processing technologies that improve labor use efficiency, food quality, and income; mobile based application that easily enables to detect enset's landraces that optimally matched to local climates, and facilitates extension services. Furthermore, the results identified that enset's suitability to support SDGs and a climate-smart crop, hunger reduction via nutritional and food security improvement, cost and yield advantages, and other alternatives benefits of the crop.

Given the multi-benefits, adaptable of enset to different agro-ecologies, and its potency to expand to elsewhere in Southern and East Africa, enset cultivation has been continuously underutilized and almost confined to the southwest part of the country due to cultural perceptions politics, historical reasons, less research and policy attention given to the crop. Moreover, because of socioeconomic shifts and a lack of technological progress, the diverse uses of enset have been declining, and may lead to community's food security at risk. In addition, the adoption rate of the enset scraper and squeezer that saves labor, is very low because of the inaccessibility and unaffordability of the tools.

On the other hand, this study is limited in providing sufficient evidences on enset fermenting-box, and Enset App (mobile based technology), since the former yet under demonstration and no study is found yet for the later. Moreover, the landraces released on the Enset App is limited is based on the names given by few groups that it is limited to generate the required information. Therefore, to generate sufficient information about the contributions of enset fermenting-box and Enset App, it needs further studies in the future.

Therefore, expanding the early maturing and high yielding cultivars and exploring improved varieties via research discovery, including enset best farm practices in extension services, investing on technologies enset processing tools that provide the services to all with reasonable prices, modifying Enset App in different languages, supplementing enset-growing areas with important components of the enset system as well as bringing changes in social perceptions on enset and expanding enset to non-enset producing potential areas through media promotion are vitally important to improve food security, nutrition, and environmental sustainability over the long-term.

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