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A Comprehensive Review of Enset Processing Technologies and their Importance in Ethiopia

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Abstract

For millions of people in Ethiopia, enset (*Ensete ventricosum*) is a staple food crop, but conventional processing techniques come with several drawbacks. Among the many challenges farmers face, especially women in the central highlands are issues with hygiene, labor intensity, time commitment, high expenses and yield loss. Through the analysis of data gathered from published literature spanning 25-30 years, drawn from credible journals, papers and research organizations, the goals of this review are to investigate and optimize enset processing technologies. To find opportunities for improvement, a critical analysis of indigenous tools used for enset processing was conducted, emphasizing low-cost solutions that try to address the problems faced by small-scale farmers. Extensive research has been conducted recently on the performance of different engine-driven machines regarding grating efficiency, decorticating efficiency and pulp loss. The analysis demonstrates how, over the moment, improvements in technology have increased efficiency and decreased waste in enset processing. To be more accurate, pulp loss dropped and grating and decorticating efficiency rose. To optimize enset processing for increased productivity and effectiveness, the review concludes that portable, multifunctional engine-driven machines that integrate the capabilities of current machines must be developed. The technologies used in Ethiopian enset processing and harvesting are thoroughly examined in this review. Traditional labor-intensive methods with a strong cultural foundation are used to process the enset. Modern technologies have been introduced to increase efficiency, but farmers' awareness of them, as well as their cost and accessibility, have limited their adoption. Important results show that mechanization has the potential to lower labor costs and health risks related to traditional methods, but there are still major obstacles that need to be overcome. The review suggests more government support, research on environmentally sustainable methods that respect cultural values, farmers' capacity building and adaptable technologies.

Keywords : Decortication, Efficiency, Enset, Grating, Processing, Pulp loss, Technology

Enset (*Ensete ventricosum*), commonly known as the 'false banana,' is an essential staple crop in Ethiopia, particularly in the southwest and south of the nation (Dejene, 2024). From Central Statistical Agency (CSA) as studied in 2022 (Abate *et al.,* 2024) and according to the Agricultural Sample Survey report, enset farming is practiced on approximately 3-4 million hectares of land, primarily in Ethiopia's southern and southwest areas (Kassie *et al.,* 2023). With several important zones like Gurage, Hadiya, Sidama and Kembata-Tembaro, the Southern Nations, Nationalities and Peoples' Region (SNNPR) is Ethiopia's largest enset cultivation area. (Dilebo *et al.*, 2024). Due to the high production of Enset that these zones are known for, SNNPR serves as the main hub for this crop. The Oromia Region, which encompasses West Shewa, Bale, Arsi, Wollega and Ilu Ababor, on the other hand, grows Enset as well, albeit less than the SNNPR. Furthermore, although their production volumes are lower than those of the SNNPR, the Wolayita and Gamo Zones in southern Ethiopia contribute to the cultivation of enset (Kudama *et al.,* 2022 and Dilebo *et al.,* 2024). As shown in Table 1, even though Enset is important in several places, the SNNPR continues to be the primary growing region for it. Enset is essential to millions of people's socioeconomic livelihoods, cultural customs and food security (Egziabher *et al.,* 2020). As compared to other major crops like maize and teff, encested remains under-researched despite its resilience to drought and ability to thrive in diverse agroecological zones (Bogale, 2021 and Kolhe *et al.,* 2024). By compiling the body of knowledge currently available on Enset processing technologies and their conventional harvesting techniques, this review seeks to give a thorough picture of their development, difficulties and future directions (Borrell *et al.,* 2020 and Koch *et al.,* 2021). This means that the various harvesting techniques used throughout Ethiopia have been thoroughly examined, as well as the most recent developments in Enset processing technologies (Awulachew, 2021). To improve efficiency, quality and sustainability in the production of Enset, challenges must be identified and addressed through this review. The review seeks to offer insights to improve food security and economic stability in communities dependent on Enset by analyzing conventional and contemporary methods. The text addresses various technologies and techniques unique to Ethiopia's main Enset-growing regions and provides a comparative analysis to direct future.

TABLE 1

The Region-wise area covered and cultivation of Enset crop in Ethiopia

Region/Zone	Estimated area under Enset cultivation (hectares)
Southern Nations, Nationalities and Peoples' Region (SNNPR)	200,000 - 250,000
Gurage Zone	30,000 - 40,000
Hadiya Zone	20,000 - 30,000
Sidama Zone	40,000 - 50,000
Kembata-Tembaro Zone	30,000 - 40,000
West Shewa (Oromia Region)	15,000 - 25,000
Bale (Oromia Region)	10,000 - 20,000
Arsi (Oromia Region)	10,000 - 15,000
Wollega (Oromia Region)	15,000 - 20,000
Ilu Ababor (Oromia Region)	5,000 - 10,000
Wolayita Zone	30,000 - 40,000
Gamo Zone	15,000 - 25,000
Total Area of Enset Cultivation in Ethiopia	300,000 and 400,000

Source : Central Statistical Agency (CSA), (2022), Agricultural Sample Survey

Traditional Cultivation and Processing

Traditional knowledge has been around for ages regarding the cultivation and processing of enset (Brandt, 1997). Indigenous methods for collecting and processing enset have been described in several research. These methods include fermentation processes, processing instruments and the socio-cultural relevance of these activities (Egziabher *et al.,* 2020). Traditional Enset processing involves several steps: scraping the pseudo stem, fermentation of the pulp and the extraction of kocho (a starch-based food) (Andeta *et al.,* 2019). Enhancing these conventional techniques to increase productivity, cut labor costs, and lower health hazards has become the subject of increased research (Haines *et al.,* 2007). Though they are still in the experimental stages, modern solutions seek to alleviate labor-intensive issues by mechanizing some portions of processing (Amare and Endalew, 2016). A careful analysis reveals a disconnect between the socioeconomic variables driving the adoption of new technology and the broad diffusion of enhanced technologies: Ethiopian culture is strongly ingrained in the traditional production and processing of enset (*Ensete ventricosum*), especially in the south and southwest as illustrated in Fig 1.

Plantation, propagation and transplantation are some of the main methods used in Enset cultivation

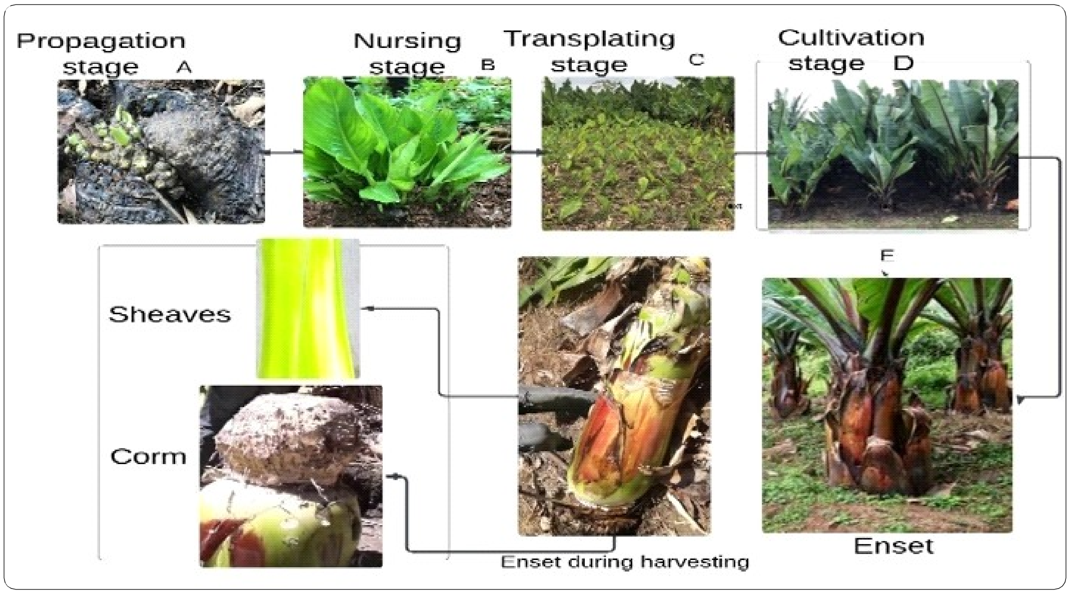

Fig. 1 : Enset cultivation practices

operations (Borrell *et al.,* 2020). The vegetative branches that emerge from the base of adult Enset plants are called suckers and they are planted to nurture the plant (Tsegaye and Struik, 2002). During the rainy season, farmers pick healthy suckers from established plants and plant them in the ground. Table 2 lists the procedures involved in Enset agriculture, from site selection to processing. Enset

Table 2

The steps involved in Enset cultivation from site selection to processing

Step	Description
Site Selection and Preparation	- Choose a well-drained, fertile site with a pH between 5.5 and 7.0 - Clear land of weeds and debris - Plow or till the soil to create a suitable seedbed
Plantation	- Space plants approximately 1-2 meters apart - Prepare planting holes or beds - Plant suckers, seedlings or cuttings in the prepared soil
Propagation	- Suckers: Select healthy, disease-free suckers from mature plants and plant them directly - Cuttings: Take 15-30 cm cuttings from the lower part of the stem, treat with fungicides or rooting hormones and plant in a well-drained mix. Maintain high humidity & warmth for root development
Care and Maintenance	- Water regularly to keep the soil consistently moist - Mulch to retain moisture and suppress weeds - Fertilize as needed based on soil conditions - Monitor for pests and diseases and take control measures
Transplantation	- Once cuttings or seedlings have a strong root system, carefully transplant them to their permanent location
Growth Monitoring	- Continue to provide care, including watering, weeding and pest management, as plants grow
Harvesting	- Harvest Enset after 2-4 years, depending on variety and conditions. Harvest pseudostems and corms when they reach desired size and maturity
Processing	- Remove outer layers of the pseudo stem and corm - Process the inner parts into products like 'kocho' or use them according to local practices

is acclimated to the highland climate, thus little irrigation is needed (Dilebo and Asfaw, 2024). Conventional farming entails routinely pulling weeds and sometimes applying mulch to improve soil fertility (Ngosong *et al.,* 2019). Enset plants are typically interplanted with other crops, including maize and beans, to maximize land use. They grow for four to five years before being harvested (Mekonnen *et al.,* 2020). According to (Mead, 2005) for a plantation, choosing a well-drained, fertile site with appropriate spacing between plants certifies optimal growth. To prepare the land for planting, it is necessary to remove any waste and till the soil (Musser & Perkins, 1969 and Robi *et al.,* 2019). Enset is normally propagated via suckers taken from mature plants, through cutting and tissue culture techniques are also used in more sophisticated procedures (Tesfaye & Haile, 2024). Although it is less often, seedlings can also be produced from seeds. To produce roots, cuttings from the lower portion of the stem are treated with fungicides or rooting hormones, planted in a well-drained mixture and then kept in a warm, humid environment (Tesfaye and Haile, 2024). The ultimate place for seedlings or cuttings is then carefully moved and constant attention is given to guarantee that they receive enough water and other support for establishing and growing (Mekonnen *et al.,* 2020). The successful cultivation of Enset is attributed to the customization of each of these approaches to the specific environment and agricultural traditions of the area. Enset usually grows in soils that are rich and well-drained (Jacobsen *et al.,* 2018).

Traditional Enset Processing Methods

The harvesting of mature plants, which typically occurs after 3–7 years of growth is the first step in the conventional techniques of enset processing. Farmers choose plants based on the size of the corm and the thickness of the pseudostem (Jacobsen *et al.,* 2018). The description of conventional techniques for enset processing is shown in Table 3. One of the main byproducts of enset is fermented starch called kocho

Table 3

Description of traditional methods related to Enset processing

Traditional Method	Description	Source
Harvesting	Mature Enset plants (3-7 years old) are carefully selected and harvested based on pseudo stem thickness and corm size	Brandt *et al.,* 1997
Kocho Preparation	Peeling: Outer layers of the pseudo stem are removed Scraping: Soft inner tissues are scraped, pulped and placed in pits to ferment	(Awulachew, 2021)
Fermentation	Kocho Fermentation: The scraped pulp is buried in fermentation pits for 1-6 months, covered with leaves and soil to manage moisture and temperature.	(Robi *et al.,* 2019)
Bulla Extraction	Pulverization: The pseudo stem and corm are crushed Sedimentation: Starch is extracted by mixing with water and allowing it to settle, then dried	(Kibi, 2018)
Fiber (Amicho) Production	Fiber extracted from the pseudo stem and leaves is used for making ropes, mats and baskets after the edible parts are removed during scraping	(El Nemr, 2012)
Fermentation Control	The fermentation process is managed through traditional knowledge to regulate moisture, aeration and temperature, preventing spoilage	(Robi *et al.,* 2019)
Enset Leaves Use	Enset leaves are used for wrapping fermented Kocho, as animal fodder, roofing and packaging food during cooking	(Tamrat *et al.,* 2020)
Kocho and Bulla Cooking	Kocho: Fermented dough is kneaded, shaped and baked on a hot griddle Bulla: Dried starch is rehydrated and cooked as porridge or bread	(Robi *et al.,* 2024)
Seedling Transplantation	Suckers are separated from the mother plant and replanted under shade to promote growth	(Karlsson *et al.,* 2013) (Tsegaye & Struik, 2002)

Fig. 2 : Sequential steps of Enset processing technology

(Seboka *et al.,* 2023). Peeling the pseudo stem's outer layers and scraping its softer interior tissues creates a pulp that is prepared and placed in pits lined with enset leaves to ferment (Kudama *et al.,* 2022). During the one to six month fermentation process, traditional knowledge is used to regulate temperature, aeration, and moisture to prevent spoilage of the kocho (Robi *et al.,* 2019). Bulla is a significant product that is made from starch that is taken from the pseudostem and corm. The plant components are ground up and the pulp is combined with water during the extraction process (Yirmaga, 2013). Before the starch is dried, this mixture is filtered and given time to settle. Bulla is regarded as a delicacy and is added to bread and porridge (Robi *et al.,* 2019 and Kudama *et al.,* 2022). The pseudo stem and leaves of enset, which are traditionally used to make ropes, mats and baskets, can be used as a source of fiber in addition to food products (Bekele *et al.,* 2022).

In addition to being necessary for encasing kocho during fermentation, enset leaves have other uses as well (Robi *et al.,* 2019). However; they also act as natural cooking packaging and cattle fodder. After the fermentation process is finished, kocho is typically kneaded, formed into flatbreads and cooked over a griddle (Egziabher *et al.,* 2020), while bulla is rehydrated and cooked into porridge or bread (Robi *et al.,* 2024). Lastly, to propagate enset, transplant suckers that have been split off from the parent plant and replant them in shaded areas to promote growth (Diro *et al.,* 2008). The efficient processing, food security and cultural continuity among enset-growing communities are guaranteed by these age-old techniques that have been passed down through the generations.

Traditional Processing Tools and Sequential Steps

It is revolting to use the traditional enset method of decorticating, grating and squeezing materials (Garedew *et al.,* 2017; Mohammed & Tariku, 2010; Tiruneh, 2020 and Kudama *et al.,* 2022). To accomplish this, a leaf sheath needs to be positioned on an inclined piece of water, secured with a rope and

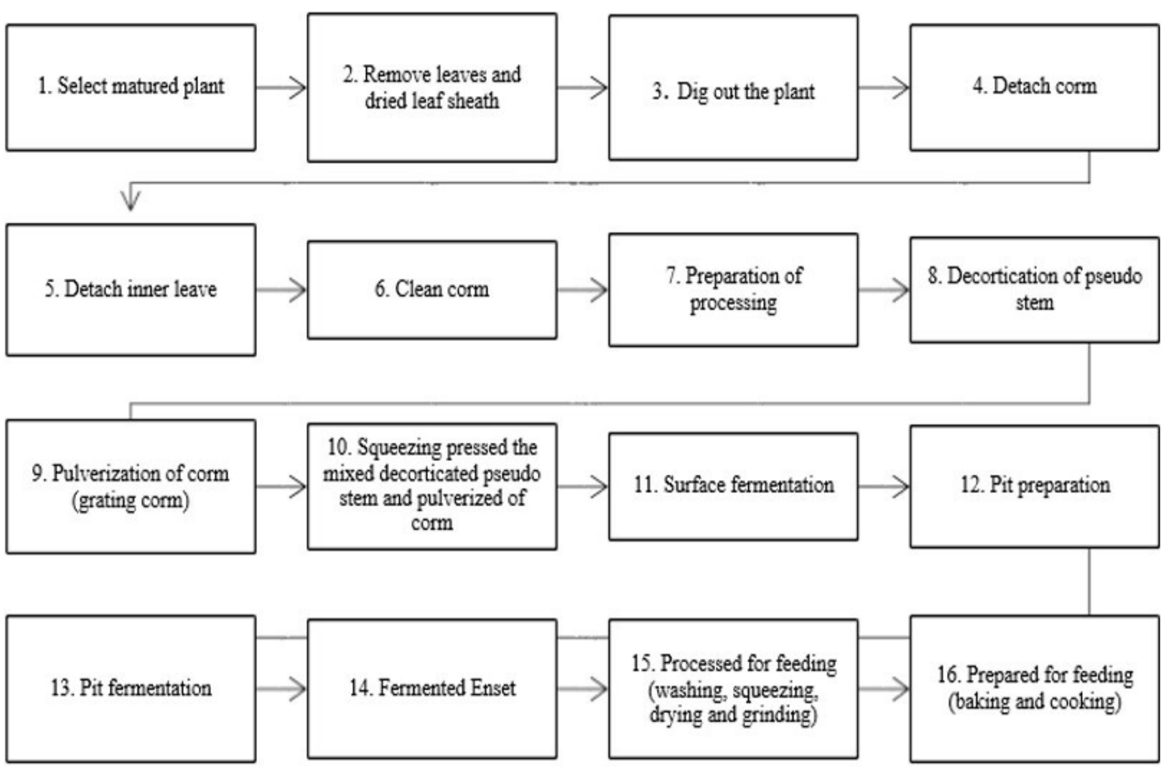

Fig. 3 : Enset processing overall methodology

either seated or standing with one foot supporting the sheath while scraping with both hands using a sibiksa, hadu, or other scraping tool. The javga was bitten into the enset's corm to make it grating (Bedada & Abebaw, 2021). Fully grown enset plants were given a corm grating after the pulp was decorticated and the fluid bulla was extracted by squeezing and pressing the plant material through a sieve (Kudama *et al.,* 2022). If not, the decorticating pulp is combined with corm grating for additional processing and fed into the pit to be fermented. The steps are expressed sequentially in Fig. 2. This practice is very inconvenient, labor-intensive, time-consuming, unhygienic and has been linked to a significant yield loss for female workers (Duguma *et al.,* 2023). Fig. 3 illustrates how manual processes such as harvesting, decorticating, grating, squeezing and fermenting are outlined in the traditional processing flowchart using simple tools.

The Mechanized Processing Machine System and Sequential Steps

In terms of mechanized machines, many institutions have introduced technologies to help with such household problems (Kibi, 2018; Workesa *et al.,* 2021 and Deressa *et al.,* 2023). During the mechanized process perform work on the matured Enset harvest and identify the pseudo stem husking sheave and corm (Workesa *et al.,* 2021). The husking sheave from the pseudo stem is scraped by the decorticator machine and the corm is cut for grating to pulverized in the grating machine (Kibi, 2018). The mix of decorticated pulp of kocho and the grated corm the operation of bulla extract squeeze pressing in the squeezer press machine the left kocho is admitted into the box or jar for fermentation (Garedew *et al.,* 2017). The mechanized processing diagram in contrast, illustrates the use of engine-driven machines for similar steps,

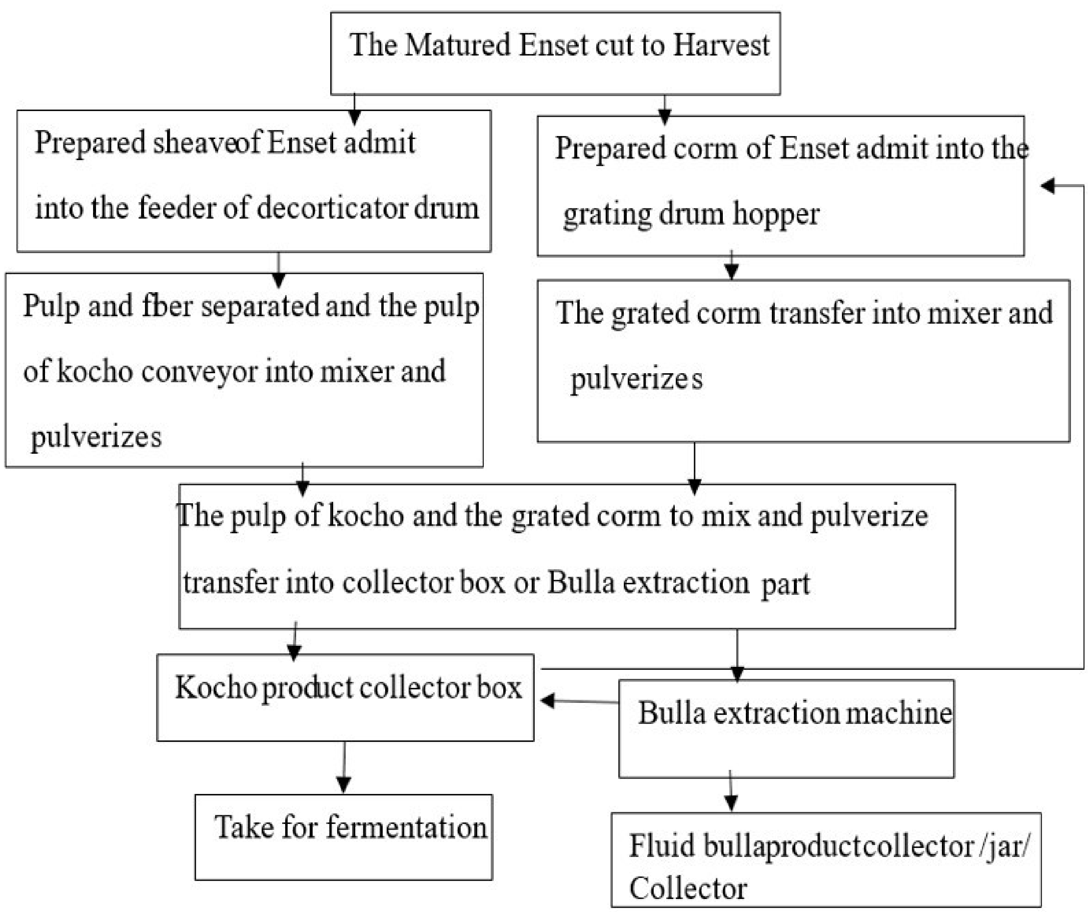

Fig. 4 : The diagram of the principle of working the machine

emphasizing efficiency improvements. These innovations collectively aim to modernize enset processing while preserving its cultural and nutritional importance (Peveri, 2021). The sequential processing steps are similar to the traditional ones expressed in the diagram figure above but the machine needed is different shown in Fig. 4.

The Available Technologies and Design for Mechanization of Enset Processing Machines

The mechanical processing technology preparation methods of enset-based foods and their nutritional composition (Kudama *et al.,* 2022 and Deressa *et al.,* 2023). Also well approved the engine driven for both decorticator, corm grating and integrated machines are shown in Fig. 5 (a-c), (Kibi, 2018 and Workesa *et al.,* 2021). The traditional method determined in the last several investigations on enset crop processing food products and use has been carried out by numerous researchers (Tsegaye & Struik, 2002 and Awulachew, 2021). The performance studies of these machines showed that five enset could be decorticated using an engine-driven decorticator in 1.08 hours at 790–880 rpm, compared to the 8 hours that three women would take to decorticate five enset using a traditional method. An engine-operated corm grating machine took 10 minutes at 2200 rpm to grate a corm of five medium enset, a task that would have typically taken eight hours for three to four women (Deressa *et al.,* 2023).

Recent research has concentrated on strengthening conventional enset processing techniques (see Table 3) with the goal of using technological improvements to increase productivity, decrease labor costs and mitigate health hazards related to traditional practices (Wonchesa *et al.,* 2018). Enhancing efficiency, sustainability and nutritional benefits have been the main goals of recent research and advances in Enset processing techniques (Deressa *et al*., 2023). At the forefront of advancements in fermentation science are research that maximize the utilization of regulated microbial inoculants and starter cultures, such as strains of bacteria and yeast (Robi *et al*., 2024). By expediting the fermentation process and guaranteeing uniformity in flavor, texture and safety, these advancements contribute to the increased quality of Kocho (Yirmaga, 2013). In order to decrease the labor-intensive traditional methods especially when it comes to decorticating and pulverizing enset mechanized processing machines have also been created, increasing processing efficiency (Workesa *et al*., 2021). Furthermore, solar drying methods have been developed to extend the shelf life and enhance hygienic conditions of goods such as Bulla and Kocho (Tuffa, 2019).

a). Enset corm grating machine

b). Enset sheave decorticator machine

Fig. 5 : (a & b) Enset corm grating and enset sheave decorticator machines available at BAERC

Fig. 5(c) : An integrated enset processing machine available at BAERC

Better filtration and settling methods have made bulla extraction more advanced, resulting in a larger yield and better product quality (Yirmaga, 2013). To improve the nutritional profile of Bulla, researchers are also looking at fortifying it with extra nutrients. Utilizing waste from enset processing is another important area of innovation. By-products from this process are utilized to produce bioenergy, such as biogas and biochar and organic fertilizers, which support waste management and sustainable farming techniques (Callo-Concha *et al.,* 2020). Together, these advancements seek to preserve the nutritional value and cultural significance of enset processing while modernizing it (Peveri, 2021).

Enset Harvesting and Processing for Food Production

The maturity, harvesting time and storage place were different from place to place and various types of enset (Tiruneh, 2020). However, after being cut, the matured enset was sorted, placed and scraped pulp tissue to decorate the sheath leaf. The corm was then shredded and blended for a while (Ashango, 2017). The response that Kocho supplied for the bulla extraction press squeeze. The best enset food, bulla is mostly generated from fully developed enset plants (Haile *et al.,* 2020). The two principal food crops that these enset plants produce are kocho and bulla. Thus, the enset produces these two main food bases. There are almost 20 different food products that have been traditionally documented, including yogurts, cakes, dumplings, ashashat or dapuha, yichochee, amicho, aterkuye, zebore, wussa techochim, buya, amtet kintahuwa, doyisa uutta, baccira, shendera like eretta, kitfo, aximit and porridges. Decorticated leaf sheaths and grated corm combine to produce kocho, a sort of fermented starch (Garedew *et al.,* 2017). Processing and nutritional improvements have been the subject of many studies (Fanta & Neela, 2019). Fermentation contributes to a food product's distinct qualities, including color, flavor, texture, aroma and shelf life, by means of microbial metabolic activities (Robi *et al.,* 2024).

Available Enset Processing Technologies in the Community

Before it is fit for human consumption, enset processing must go through a number of processing methods (decortication, pulverization, shredding, fermenting and squeezing) (Mohammed & Tariku, 2010). Plant removal through excavating and trimming. The enset plant's thick, dry outer bark is cut off with a Banja, serrate and sickle. After the grating and pulverization processes, the pit was ready and the densely packed crushed material was left at room temperature. Next, the dirt is covered with the leaf, and the outside sheave enset section. The flexible enset bark of the pit is covered in wide enset leaves

(Tedla & Abebe, 1994). The leaves' function is to gather the juicy portion and protect it from dripping onto the ground while keeping the scraped pseudo stem clean (Papini, 2018). After the first thin layer of bark is discarded, layers of the pseudo stem are removed and ready for scraping and grating. Woficho string holds a solitary pseudo stem affixed to the wooden pole. From a hard sitting position, the lady uses a bamboo split on the board by raising one leg and pressing it with her knees, scraping the fleshy section of the pseudo stem down towards the hole surrounded byenset leaves (Tiruneh, 2020). The fiber remains in the stem after this operation. The fiber taken from the first scraping is used to bind the opposite half of the scrapped pseudo stem, which is likewise turned upside down (Tadesse, 2003). Bulla is obtained by squeezing out the liquid containing starch from scraped leaf sheathes and grated corm (Tiruneh, 2020). The remaining thick sticky white substance, bulla is spread to be dehydrated (Duguma

TABLE 4

Comparison of Enset processing technologies in literature by the different researchers

Researcher	Processing Method	Efficiency	Time Required	Labor	Output Quality	Cost	Additional Notes
(Tedla & Abebe, 1994) (Egziabher *et al.,* 2020)	Traditional	Variable	8 hours	High	Inconsistent	Low	Focused on manual techniques and variability in quality
Gebremariam (1996)	Traditional	Variable	8 hours	High	Variable	Low	Emphasized manual labor and its impact on processing efficiency
(Garedew *et al.,* 2017)	Traditional	Variable	8 hours	High	Inconsistent	Low	Detailed traditional tools and steps; labor-intensive
(Mohammed & Tariku, 2010)	Traditional	Variable	8 hours	High	Inconsistent	Low	Similar to other traditional studies; focused on manual effort
Tiruneh (2020)	Traditional	Variable	8 hours	High	Variable	Low	Provided insights into traditional methods and challenges
Kudama *et al.* (2022)	Traditional	Variable	8 hours	High	Variable	Low	Comprehensive review of traditional practices
Deressa *et al.* (2023)	Mechanized	High	1.08 hours (Decorticating) + 10 minutes (Grating)	Reduced	Consistent	High	Significant improvements in time efficiency and quality
Workesa Dula (2018)	Mechanized	High	1.08 hours (Decorticating) + 10 minutes (Grating)	Reduced	Consistent	High	Focused on technological advancements and efficiency
Kibi (2018)	Mechanized	High	1.08 hours (Decorticating) + 10 minutes (Grating)	Reduced	Consistent	High	Emphasized the benefits of mechanized systems
Workesa *et al.* (2021)	Mechanized	High	1.08 hours (Decorticating) + 10 minutes (Grating)	Reduced	Consistent	High	Highlighted efficiency gains and technological improvements
(Amare & Endalew, 2016)	Mechanized	High	1.08 hours (Decorticating) + 10 minutes (Grating)	Reduced	Consistent	High	Reviewed mechanized systems and their impact
Deressa *et al.* (2023)	Mechanized	High	1.08 hours (Decorticating) + 10 minutes (Grating)	Reduced	Consistent	High	Detailed performance metrics for mechanized processing

et al., 2023). After that, a handful of the bulla is strung with woficho string and wrapped in fresh enset leaves to preserve the market and prevent the bulla from changing color unintentionally (Tadesse, 2003 and Robi *et al.,* 2024). Table 4 displays the comparison of the enset processing technologies by various researchers concerning processing techniques, productivity, labor quality, time and cost.

Assess Appropriate Technology

The study (Gebre Mariam *et al.,* 1996; Mohammed & Tariku, 2010; Tadesse, 2003 and Tiruneh, 2020) indicates that serious social constraints on women's access to technology include poor organization or poor project management, credit problems and lack of time, training and support from the community in enset research and development experiences and (Kibi, 2018; Workesa *et al.,* 2021and Deressa *et al.,* 2023) control over technology also includes access to and control over the resources women require to use and benefit from the technology defines appropriate technology as those objects, techniques, skills and process which facilitate human activity in terms of reducing human energy expenditure, reducing labour time, improving spatial mobility and alleviating material uncertainty (Kudama *et al.,* 2022). Efficiency and time required in mechanized processing offer a marked improvement in efficiency and a substantial reduction in time compared to traditional methods (Workesa *et al.,* 2021). The labor in mechanized systems is significantly reduced, which translates into less physical strain and fewer tools required (Balcha *et al.,* 2021). The output quality in mechanized processing provides a more consistent quality of output due to machine precision. The initial costs are higher for mechanized systems, but they offer long-term savings through increased efficiency (Deressa *et al.,* 2023).

This paper provides an in-depth analysis of the production and processing of enset (Ensete ventricosum), emphasizing its vital significance in Ethiopia's agricultural environment. Covering over 3.4 million hectares, enset is mainly grown in the Southern Nations, Nationalities and Peoples' Region (SNNPR). For millions of people, enset is essential to both food security and cultural identity. To improve efficiency and lower the health hazards connected with manual work, the review skillfully (Gebre Mariam *et al.,* 1996; Mohammed & Tariku, 2010; Tadesse, 2003 and Tiruneh, 2020) and (Kibi, 2018; Workesa *et al.,* 2021 and Deressa *et al.,* 2023) compares and contrasts contemporary automation break throughs with labor-intensive traditional processing methods such labor-intensive scraping and fermentation procedures. Significant time reductions have been shown by mechanized techniques; for example, an engine-driven decorticator may handle five ensets in less than an hour as opposed to eight hours for human methods Workesa *et al.,* 2021 and Deressa *et al.,* 2023). This change tackles the socioeconomic issues that women who perform these labor-intensive jobs mostly confront in addition to increasing productivity. The book emphasizes the necessity for more research to strike a balance between modernization and cultural preservation, but it also notes a gap between the acceptance of new technologies and traditional traditions (Robi *et al.,* 2024 and Fetene & Kishor, 2021). In general, this analysis offers insightful information about the difficulties involved in producing and processing enset, suggesting ways to enhance food security and stability in communities dependent on enset while honoring their rich agricultural history (Kudama *et al.,* 2022; Deressa *et al.,* 2023 and Ertebo & Girma, 2024).

Subsequent studies ought to concentrate on refining mechanization methods while making sure they conform to regional norms and habits. Furthermore, investigating microbial inoculants for fermentation may improve the safety and quality of the final product, thus endorsing enset as an essential food source in Ethiopia. Stakeholders can enhance the socioeconomic stability of enset-dependent communities and the productivity of enset production by tackling these issues.

Traditional Versus Mechanized Processing

Table 5 illustrates how labor-intensive and time-consuming the manual, traditional enset processing method carried out by knowledgeable local women's.

TABLE 5

Traditional versus mechanized processing (Deressa *et al.*, 2023)

Aspect	Traditional Processing	Mechanized Processing
Time Efficiency	8 hours to process 5 enset plants	1.08 hours (decorticating) + 10 minutes (grating) for 5 plants
Labor Required	High; manual scraping, grating and squeezing	Reduced; machines handle scraping, grating, and squeezing
Resource use	Multiple hand tools, significant physical effort	Engine-driven machines reduced manual tools
Output Quality	Variable, less consistent	More consistent and high-quality output
Visual Representation	Detailed steps with tool illustrations	Simplified steps with machine illustrations

Bulla extraction, fermentation, grating, harvesting, decorticating and feeding are some of the phases in the process. Basic hand tools like sickles, blades and diggers are used in every step. The enset pulp and corm are scraped, grated and squeezed by women using these tools. Due to manpower shortages and inefficiencies, the entire traditional process is frequently described as cumbersome and associated with a large yield loss (Mohammed & Tariku, 2010 and Tiruneh, 2020). On the other hand, mechanized enset processing has introduced engine-driven machines for various tasks including decorticating and grating (Kibi, 2018 and Workesa *et al.,* 2021). In another case, Mechanized processing improves productivity, reduces production loss and cuts costs (Kolhe, 2015 and Deressa *et al.,* 2023). Mechanical labor is less efficient than machine labor when it comes to enset processing tasks like squeezing, decorticating and grinding. These devices significantly cut down on labor and processing time. For example, five enset plants can be prepared in 1.08 hours by an engine-driven decorticator, compared to eight hours by traditional methods. In contrast, the same process takes only ten minutes to complete with an engine-powered corm grating machine (Deressa *et al.,* 2023). In addition to increasing productivity, this switch to automated processes lessens the physical strain on employees. The amount of time and work needed is greatly decreased by the automated techniques. For example, the machine's grating capacity varied from 604 to 1277 kg/h, which was higher than existing techniques. By decreasing manual labor and speeding up processing, the use of mechanical equipment reduces overall costs. Using a 0.5 × 0.5 mm^2 sieve, the machines in recent research obtained a grating uniformity of 91.63 per cent at 2000 rpm. 1.03 was the lowest pulp loss (Kibi, 2018, Teshome and Kolhe, 2021) while a maximum of 27.60 per cent was reported under specific conditions.

Modern Interventions

Modern interventions in enset processing technology have resulted in notable gains in terms of effectiveness, influence on the economy and quality (Kudama *et al.,* 2022 and Deressa *et al.,* 2023). Less than 20 per cent of enset farmers currently use mechanized scraping machines, however this equipment has significantly accelerated processing speeds, allowing for the handling of 1-2 tons of Enset per hour and minimizing manual work. More control over fermentation conditions has been made possible by the development of fermentation tanks that can process up to 500 liters of enset mash, producing products that are more reliable and of higher quality (Robi *et al.,* 2024). Furthermore, drying durations with solar dryers have been drastically reduced from a week to two to three days, increasing efficiency and lowering reliance on weather (Ayele & Sahu, 2014). Enset products now have a longer shelf life and less spoiling thanks to the construction of better storage facilities with controlled humidity and temperature. Temperature, humidity and pH levels can all be regulated with controlled fermentation systems, which have further improved the process and produced more consistent and excellent results (Mengesha *et al.,* 2022). Enset products are subjected to stringent quality control procedures, including laboratory testing for microbiological contamination and nutrient content. With some treatments reducing processing time by as much as 50 per cent, these contemporary technologies have combined to decrease labor costs and processing times (Mengesha *et al.,* 2022). Programmes for training and instruction are being put in place to enable local farmers and processors embrace and efficiently use these technologies to optimize the advantages of these break throughs (Robi *et al.,* 2024). Enset processing has benefited economically from these advancements as well as from higher productivity and improved quality control overall (Blomme *et al.,* 2023). For more developments and widespread adoption in the sector, there must be ongoing investments in training and technology.

Data Analysis

Numerous sources of data were used in the analysis, including reports from development organizations, scholarly journals and field investigations. Performance indicators were evaluated between the various systems, including processing time savings, a decrease in human labor and increased yield. Research showed that gains in processing efficiency of up to 40 per cent have been made possible by advances such as contemporary scraping machines and ways for accelerating fermentation.

The statistics does, however, also demonstrate that there is uneven use of technology, especially in remote and less accessible areas where manual processing is still prevalent. High equipment costs, a dearth of technical expertise and inadequate infrastructure, such as restricted access to electricity, are major obstacles.

A thorough comparison of Ethiopian crop's expected yearly production and market availability is given in Fig. 6. Leading staple crops are maize, teff, sorghum and wheat; maize has the largest production, at more than 8 million tonnes. These staple crops are less readily available on the market since, despite their high yield, a large percentage of them are consumed locally. For example, only around 7 million of the 8.6 million tons of maize produced each year are marketed, demonstrating the crop's importance in both market and subsistence economies. With an annual

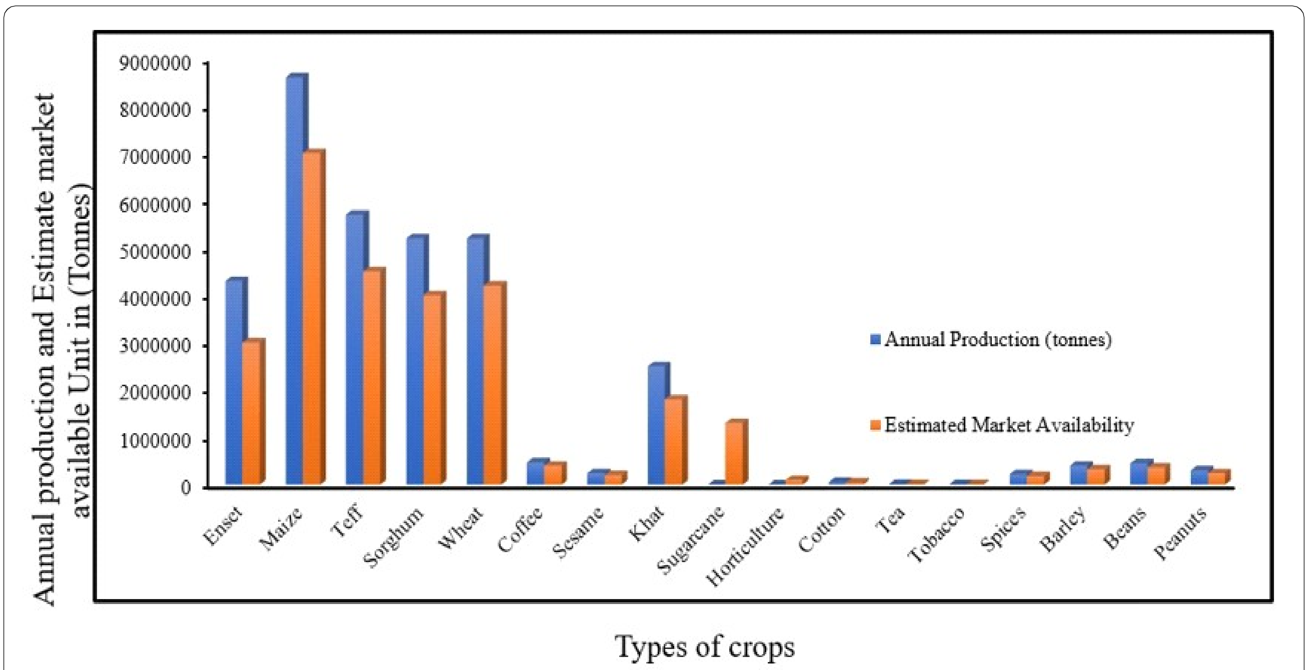

Fig. 6 : Comparison of annual production and estimated market availability for various crops in Ethiopia

yield of 4.3 million tonnes and a reduced market availability, enset (false banana), a major crop in Southern Ethiopia, stands out as primarily serving as a subsistence crop for local communities. Cash crops that are highly marketable, such as coffee, sesame and khat, see almost all of their produce go to market. Approximately 4,70,000 tons of coffee are produced annually, making it a major export crop and vital to Ethiopia's economy. The primary source of supplies for the domestic sugar industry is other crops, such sugarcane, which has a large production volume of 14.4 million tons. Even while flower production is lower than that of staple commodities, horticulture including flowers contributes significantly to Ethiopia's exports, especially to European markets. Comparably, but having lower production numbers, cotton, tea and tobacco are essential to certain industries like textiles and drinks. Furthermore, despite their modest scale, legumes and spices such as beans, peanuts, barley and spices show strong market availability because of their demand in both home and foreign markets. In conclusion, the graph illustrates Ethiopia's agricultural diversification, with cash commodities like coffee, khat and sesame substantially boosting the nation's export economy while staple crops maintain subsistence farming. The graph highlights the importance of both subsistence and cash crops in Ethiopia's agricultural and economic landscape. The data emphasizes the balance between subsistence and commercial agriculture, which is crucial for Ethiopia's economic and food security. Fig. 6 highlights the significant production of staple crops like maize, teff, sorghum and wheat, though a substantial portion is used domestically. Cash crops like coffee, khat and sesame exhibit high market availability and play a vital role in Ethiopia's export economy. The market availability for each crop varies based on consumption patterns, export potential and the crop's role in both subsistence and commercial agriculture.

The value and quantity of enset goods produced annually at various points in its value chain-from the plantation to several phases of processing (Kocho, Bulla and Amicho) are shown in Fig. 7. Information on the number of enset plants engaged in each stage of the manufacturing and processing system is available from the data. Plantation stage: roughly 4,00,000 enset plants are engaged, which corresponds to the first enset fields being established. During the

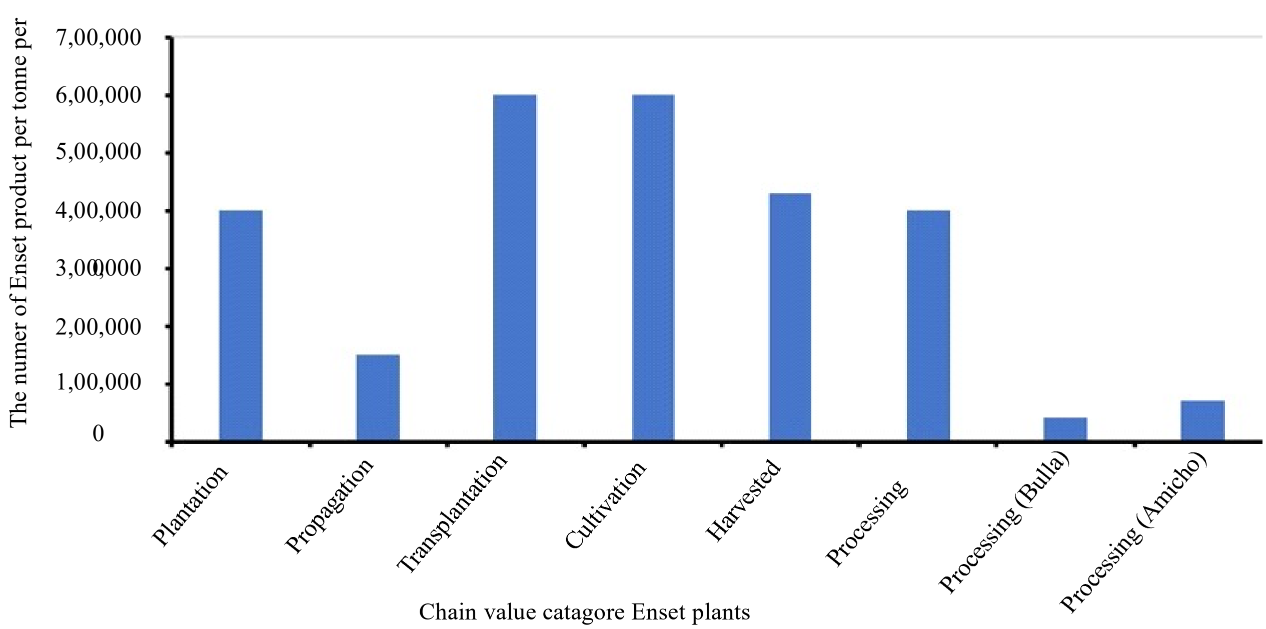

Fig. 7 : Enset products per year across different stages of its value chain from plantation to various processing stages value/number

propagation stage, there are only 15,000 plants, indicating the careful procedure employed to propagate superior plants. When 60,00,000 enset plants are transplanted during the transplanting stage, a significant rise is seen, signifying the widespread dispersal of new plants into the fields. This figure stays constant over the 60,00,000 - plant cultivation stage as well, suggesting that most transplanted enset plants are successfully grown over a number of years until they reach maturity.

Approximately 43,00,000 plants are picked at the harvesting stage, indicating that a significant amount of the farmed enset reaches maturity and is prepared for processing. The main product of enset processing is Kocho, which is processed using 40,00,000 plants. This illustrates how crucial Kocho is to many populations who depend on enset as a staple diet. 4,00,000 plants are used in the preparation of Bulla in contrast, However, because Bulla is a more refined product and requires less processing, just 4,00,000 plants are used in. Processing of Amicho, the edible corm of the Enset plant, requires only 1,50,000 plants, indicating that it plays a less role than Bulla and Kocho. According to the data, Kocho is the main product that comes from enset with smaller but still important roles going to Bulla and Amicho. Plant losses during growth or environmental problems may be indicated by the sudden spike in plant numbers during transplantation and cultivation, which is followed by a decline at the harvesting stage. The Enset value chain is clearly illustrated by this graph, which highlights the production volume and Kocho's importance as a staple food in the areas where enset is grown.

Interpretation

The data indicates that, especially for small holder farmers, the use of cutting-edge enset processing technologies offers a significant potential to increase productivity and product uniformity. Never the less, because of socioeconomic constraints, a sizable segment of the farming community continues to use conventional techniques. The gap between the potential and actual adoption of technology will continue until specific interventions are implemented, such as government subsidies, better rural infrastructure and technical training programmes.The evaluation also emphasizes the necessity of localized innovation, which involves tailoring technologies to the unique environmental and cultural context of Enset-growing locations. The affordability, accessibility and use of these technologies are equally as important to their success as their technological prowess. There has been a notable rise in the quantity of enhanced enset processing technology throughout time. Basic scraping tools were the only ones available for enset processing in 1996. But by 2024, this figure had increased dramatically as a result of the creation of 25 unique technologies meant to boost Enset processing's effectiveness. In addition to technological improvements, there has been a significant increase in the acceptance rate among farmers. More than 3,00,000 farmers will profit from these developments by 2024, compared to only 1,500 farmers or families in 1996, as shown in Fig. 8, which shows the sequence of enhanced enset process technologies and their use. These advancements have mostly targeted important areas like fermentation processes, Bulla extraction, and Kocho manufacture. Lately, advancements have broadened to include mechanization and digital tool utilization, augmenting productivity and processing effectiveness in the enset value chain.

The updated data shows a noteworthy pattern in the advancement and uptake of enhanced enset processing technologies between 1996 and 2024. In 1996, there was only one upgraded technology and only 1,500 houses used it. By 2024, there were 25 technologies, which grew to coincide with the increase in adoption to 3,00,000 households. From 1996 to 2005, there was a progressive increase in the number of technologies from one to five and the number of households adopting them reached 12,000. After 2010, though, the pace quickened dramatically with eight technologies and 25,000 adopting families reached. Adoption figures increased steadily, rising from 50,000 in 2015 to 1,50,000 in 2020 and then to 2,50,000 in 2022. By 2024, a significant fraction of the rapidly expanding enset population had adopted

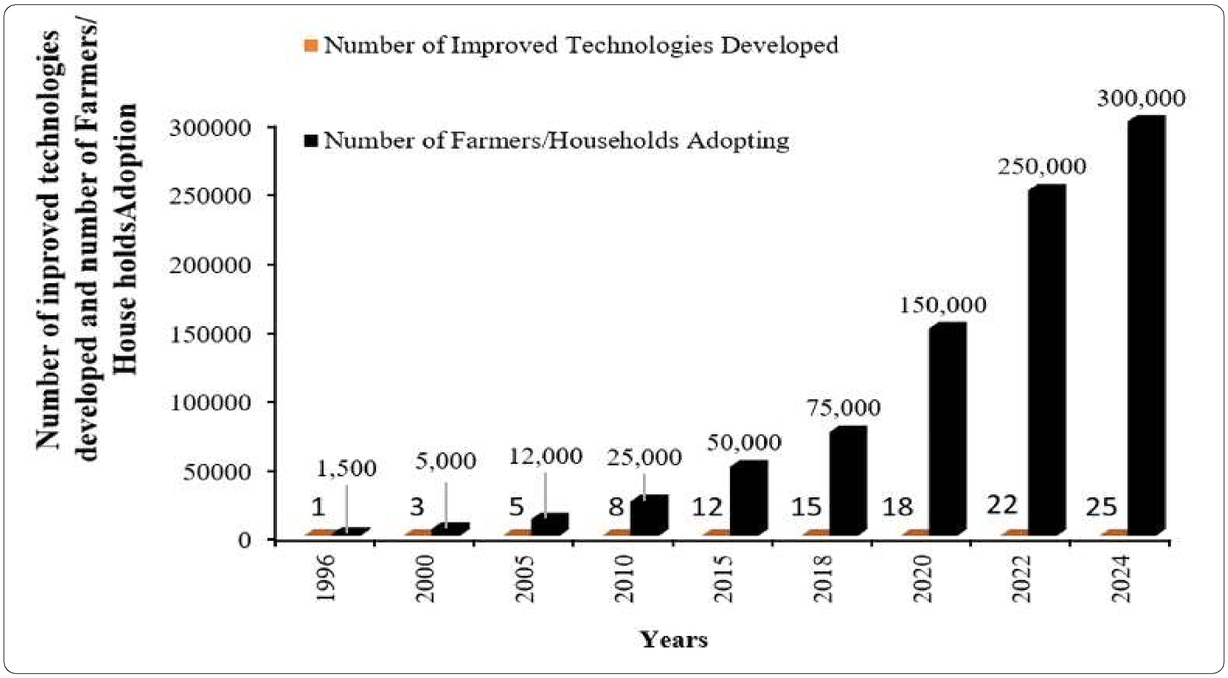

Fig. 8 : Sequence of improved Enset process technologies and their utilization

25 technologies, resulting in a profound transformation of the landscape. This exponential expansion illustrates how innovations can effectively meet farmers' demands, boost production and improve food security in communities that rely on enset. All things considered, these patterns emphasize the critical role that agriculture research and innovation play, emphasizing the need for continued assistance and training to guarantee that advances in the future be available and advantageous to However, there is a noticeable shift towards mechanization and technological advancements as the need for production and efficiency increases. Research by (Ertebo & Girma, 2024 and Heuzé *et al.,* 2017) highlight the advantages of contemporary. The creation of machinery, such the (Workesa *et al.,* 2021a) designed engine-driven decorticating machine, demonstrates a substantial progress in enset processing and allows farmers to adopt more productive methods without sacrificing the quality of the final product.

Nutritional and Processing Benefits

The efficiency and consistency of processing have also improved with mechanized technologies, which has a good effect on the quality of the final products like bulla and kocho. These innovations have been acknowledged for their contribution to improving the nutritional value of foods based on ensets and guaranteeing a more uniform end product (Deressa *et al.,* 2023 and Kudama *et al.,* 2022). Special food products with distinctive flavors, textures and nutritional profiles are produced via fermentation, which can be used in both manual and automated procedures. On the other hand, less manual labor is required during the production of these goods thanks to robotic processes.

Challenges and Opportunities

The use of these technologies is not without difficulties, not with standing the benefits of mechanization. Mechanized processing systems may not be implemented as effectively as they may be due to social restrictions such as poor project management, lack of funding for researchers and restricted access to resources (Gebre Mariam *et al.,* 1996 and Mohammed & Tariku, 2010). To fully reap the benefits of automated processing and guarantee its sustainable incorporation into regional norms, these challenges must be addressed.

This study demonstrates the many benefits of mechanized enset processing over traditional methods. While traditional methods are deeply ingrained in cultural practices, they are less efficient and require more labor. Transitioning to mechanized systems could result in broader economic benefits as well as improvements in food security and quality. However, considerations such as affordability, cultural compatibility and durability must be made to ensure the successful implementation and widespread adoption of these technologies.

The field of enset processing is changing, dynamically balancing innovation and tradition. The chart makes it quite evident that, although traditional methods are still very valuable, mechanization and new processing technologies must be integrated to effectively meet today's agricultural concerns. Enhancing the productivity and sustainability of enset agriculture in Ethiopia requires this dual strategy, which is not only advantageous but also essential.

To summarise, the body of research from 1996 to 2024 reflects a progression from documenting traditional enset processing methods to exploring innovations in mechanization and fermentation, alongside growing attention to socio-economic factors and environmental sustainability. These studies provide a comprehensive understanding of the current state of enset processing technologies and methods, highlighting the field's continued evolution. The synopsis of these studies reveals an evolving field with key contributions ranging from foundational research on traditional methods to recent innovations in mechanization and fermentation. As the field progresses, researchers are increasingly focused on improving efficiency, quality and sustainability while addressing the socio-economic implications of these advancements.

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