

A COMPREHENSIVE REVIEW OF THE PERFORMANCE STATUS OF SELECTED MECHANIZATION TECHNOLOGIES DEVELOPED FOR TUBER CROPS IN ETHIOPIA

የተመረጡት የሜካናይዜሽን ቴክኖሎጂዎች የትዩቦር ሰብሎች ሁኔታ በኢትዮጵያ አጠቃላይ ግምገማ

Amanuel ERCHAFO*

Ethiopian Institute of Agricultural Research, Melkassa Agricultural Research Centre, Department of Agricultural Engineering, P.O. Box 436, Adama, Ethiopia.

E-mail: amanbaaman40@gmail.com; ORCID: <https://orcid.org/0009-0002-2436-430>.

DOI: <https://doi.org/10.35633/inmateh-78-01>

Keywords: Capacity, Efficiency, Percentage of loss, Mechanization technologies, Tuber crops

ABSTRACT

The study aimed to investigate the performance status of technologies developed for tuber crops in order to identify technological gaps and guide improvement, participatory evaluation, scale-up, and distribution. The method used in this study to review the performance status of technologies was based on a secondary data collection approach. The review focused on literature published between 2000 and 2025. The scope of this review is deliberately limited to technologies developed and tested for major tuber crops in Ethiopia, specifically enset, cassava, potato, carrot, and turmeric. Studies were prioritized according to the availability of quantitative performance indicators or evaluation criteria such as capacity, efficiency, loss percentage, and power source. A systematic review was conducted on nine categories of mechanization technologies for tuber crops, namely decorticators, pulverizers, fermenters, washers, polishers, boilers, peelers, graders, and diggers. Decorticators showed processing capacities ranging from 150 to 900 kg h⁻¹ with efficiencies of 70–88%, mechanical losses of 5–12%, and operating speeds of 400–1,200 rpm. Pulverizers had capacities of 100–800 kg h⁻¹, efficiencies of 65–90%, product losses of 6–15%, and rotor speeds of 600–1,500 rpm. Polishers operated at capacities of 120–700 kg h⁻¹ with efficiencies of 68–85%, losses of 6–14%, and speeds of 500–1,100 rpm. Mechanical peelers achieved capacities of 100–1,000 kg h⁻¹, peeling efficiencies of 65–88%, peel losses of 8–18%, and operating speeds of 350–1,000 rpm. Overall, the reviewed technologies reported general processing capacities ranging from 50 to 1,200 kg h⁻¹, operational efficiencies of 60–92%, mechanical damage and product losses of 3–18%, and machine operating speeds of 300–1,500 rpm. The review findings indicated that less than 15% of national postharvest research efforts have focused on root crops, while more than 70% have concentrated on grain crops. Nevertheless, recent progress has been observed in enset processing technologies, where performance efficiencies above 85% and capacities up to 800 kg h⁻¹ have been achieved. The results demonstrate that additional research, development, and investment are required to increase the availability and adoption of improved tuber-crop processing technologies. Based on a review, the effective technologies identified in this study are the corm grater, enset decorticator, turmeric slicer, cassava slicer, and carrot grader, which are recommended for innovative interventions, minor improvements, participatory evaluation, scale-up, and distribution for end-users. The review suggested that future efforts should prioritize user-centered design, gender based, socio-economic feasibility, cost reduction, renewable energy integration, and rigorous multi-location field validation to convert prototypes into widely adopted and sustainable solutions.

አገልግሎት ጥናት

ይህ ጥናት በኢትዮጵያ ለትዩቦር ሰብሎች የተለያዩ ቴክኖሎጂዎች የአፈጻጸም ሁኔታን ለመገምገም፣ የቴክኖሎጂ ክፍተቶችን ለመለየት እና ለማሻሻያ፣ ለተሳትፎ ግምገማ፣ ለስፋት ማስፋፋት እና ለማሰራጨት መመሪያ ለመስጠት ተከሂዷል። ጥናቱ በሁለተኛ ደረጃ ውሂብ ስብስብ የተመሰረተ ሲሆን ከ2000 እስከ 2025 ድረስ የታተሙ ስነ-ጽሁፎችን ተመልክቷል፤ ትኩረቱም በኢትዮጵያ ላይ በተሞከሩ እና በተፈጠሩ የመካኒካል ቴክኖሎጂዎች ላይ ሲሆን በተለይ እንሰት፣ ካሳሻ፣ ድንች፣ ካሮት እና ቱርመር ላይ ተመስርቷል። ጥናቶች በታተሙት ጊዜ፣ በቴክኖሎጂ ደረጃ እና በመጠን የሚለካ ውጤቶች መሰረት ተመርጠዋል። ከዚህም በመነሳት በ9 የኋለ-ምርት ቴክኖሎጂ ክፍሎች ላይ (ዲኮርቲኬተሮች፣ ፓልሽ-ራይዘሮች፣ ፈረመንተሮች፣ ዋሽሮች፣ ፖሊሽሮች፣ ቦይለሮች፣ ፕላሮች፣ ግሬደሮች እና ዳግሮች) ስርዓተ-ጥናት ተደርጓል። ውጤቶች ቴክኖሎጂዎች በአፈጻጸም ላይ ከፍተኛ ልዩነት እንዳላቸው አሳይተዋል፤ አጠቃላይ የሂደት ክህሎታቸው ከ50 እስከ 1,200 ኪ.ግ/ሰ ድረስ፣ ውጤታማነታቸው 60–92%፣ የንብረት ጉዳትና ኪሳራ 3–18% እና የማሽን ፍጥነት 300–1,500 rpm መሆኑ ተገልጿል። ግምገማው ከአገር አቀፍ የኋለ-ምርት ምርምር ከ15% በታች ብቻ በሥር ሰብሎች ላይ

እንደተኩረ እና ከ70% በላይ በእህል ሰብሎች ላይ እንደተጠናከረ አሳይቷል፤ ቢሆንም በእንሰት ማቀናበሪያ ቴክኖሎጂዎች ላይ 85% በላይ ውጤታማነት እና እስከ 800 ኪ.ግ/ሰ ክህሎት ያለው እድገት ታይቷል። ጥናቱ በኢትዮጵያ ውስጥ የተፈጠሩ ቴክኖሎጂዎችን ብቻ ስሙረመር ተጨማሪ ምርምር፣ ልማት እና ኢንቨስትመንት እንዲከፈልግ አመልክቷል፤ እንዲሁም ተገኙ ተግባራዊ ቴክኖሎጂዎች ለቀላል ማሻሻያ፣ ለተሳታፊ ግምገማ፣ ለስፋት ማስፋፋት እና ለመጠቀሚያ እንዲሰራጩ መመከቱን ገልጿል፤ በወደፊትም ተጠቃሚን የሚመራ ዲዛይን፣ ጄንደር አካታችነት፣ ማህበራዊ-ኢኮኖሚያዊ ተግባራዊነት፣ ዋጋ ቅጥን፣ ነፃ ኃይል አጠቃቀም እና በብዙ ቦታዎች የመስክ ማረጋገጫ እንዲሰጥ መከራከሩን ያመለክታል።

INTRODUCTION

Agriculture is a key component of economic development, food security, and livelihoods, especially in developing countries. It provides food for the population, raw materials for industries, employment opportunities, and income for farmers (Siwar *et al.*, 2022). Agricultural production is not only fundamental to improving nutrition, but it is also the main source of income for many people (Gillespie & den, 2017). Increases in crop production are key to ending hunger, as well as fostering economic and social development (Hiywotu, 2025). Crop production is vital for food security, economic stability, and the provision of raw materials for various industries (García-Díez *et al.*, 2021). Global crop production has changed dramatically in recent decades (Iqbal, 2020). Cereals are the leading group of crops produced worldwide, with 3.1 billion tons produced in 2022, followed by sugar crops at 2.2 billion tons, vegetables at 1.2 billion tons, oil crops at 1.1 billion tons, fruit at 0.9 billion tons, and roots and tubers at 0.9 billion tons (Brief, 2022).

Tuber crops are underground plant parts, including true roots like taproots and tuberous roots, as well as structures that are not technically roots, such as bulbs, corms, rhizomes, and stem tubers (Gregory & Wojciechowski, 2020). They are cultivated for their food value and are a vital part of food security, especially in developing countries (Nanbol & Namo, 2019). Root and tuber crops are a vital food source in Ethiopia, grown in various agro-ecologies and production systems (Yimer & Babege, 2018). The major root and tuber crops include cassava, yams, potato, sweet potato, enset, taro, beets, carrots, turnips, radishes, garlic, and horseradish (Nayak *et al.*, 2025). Based on their demand for processed products, the following tuber crops, such as enset, cassava, potato, turmeric, and carrot, were used in the investigation.

Enset is one of the most widely used foods in southern Ethiopia and is often offered to Ethiopians as their primary source of food security due to its importance and versatility (Borrell *et al.*, 2020). Its production includes 34.8 million quintals of kocho, 1.1 million quintals of bulla, and 29.4 million quintals of amicho (Bassa *et al.*, 2026). The southern region of Ethiopia, it offers a sustainable food supply to roughly twenty-four million people (Olango *et al.*, 2014). Enset plays a significant role in ensuring access to nutritious food throughout the year, generating income, protecting assets, and maintaining the availability of food (Sirany *et al.*, 2022). Processing and preparation of enset takes a long time, and this work is carried out by women (Kolhe & Adugna, 2025). Along with handling daily tasks at home, it is a further duty for women. The conventional processing methods are complex, laborious, and unhygienic, causing great stress for working women and resulting in a significant loss (Zewdie, 2012).

Cassava is a perennial woody plant with a delicious root, which grows in tropical and subtropical regions of the world (Parmar *et al.*, 2017). Cassava is one of the most popular foods in Africa and the foundation of food security in Africa because of its significance and adaptability (Immanuel *et al.*, 2024). It is an important staple food in the south, southwest, eastern, and northwest regions of the country. Its production is about 53,036 tons annually from roughly 4,942 hectares (Udochukwu, 2024). A major drawback of cassava is its fast post-harvest physiological deterioration (Saravanan *et al.*, 2016). Deterioration usually starts within 48 to 72 hours after it is taken from the ground. Processing cassava tubers using the manual method makes the process tedious, labor-intensive, time-consuming, less effective, and low in quality and quantity of product (Adeniyi, 2022).

Potato is a starchy, underground tuber of the plant *Solanum tuberosum*, a perennial in the nightshade family, that is a staple food in many parts of the world (Barbaś *et al.*, 2023). Potatoes are the world's most important tuber vegetable and a vital part of the global food system, contributing to the energy and nutritional needs of over a billion people (Wijesinha-Bettoni & Mouillé, 2019). Ethiopia has a significant potential for potato production, with suitable agro-ecological conditions (Bekele, 2024). Production is estimated at approximately 5.9 million tons annually, but its current productivity is lower than the global average (Muthoni & Shimelis, 2023). Ethiopia's average potato productivity is around 13.27 tons per hectare, which is lower than the global average of 21.77 tons per hectare (Milkiyas & Keba, 2021). Primarily due to factors like post-harvest losses and a lack of technologies.

Turmeric is one of the most significant spice crops produced in tropical and subtropical regions. Turmeric is a source of income for many Ethiopians, supporting a large number of people in their lives (Melese & Gurmis, 2024). It is reaching approximately the production of 22,750 tons per year (Varma & Gopi, 2020). As a key component of the regional sauce, Alichu Wot, Ethiopian homemakers consider turmeric to be one of the most flavorful spices (Gachena Negera, 2021). Problems associated with turmeric processing using conventional methods include irregularity, which can lead to uneven drying or infected dry slices (Hailemariam et al., 2023). A major obstacle for producers of turmeric is the lack of turmeric post-harvest technologies in the areas where turmeric is grown (Dhivya et al., 2024).

Carrots are one of the most popular root vegetables. It is one of the top ten vegetable crops in the entire world in terms of economic significance (Que et al., 2019). The total production of carrot estimated to be about 17,333 tons annually in Ethiopia (Mulugeta et al., 2025). Carrots are one of the most widely consumed agricultural products by millions of people worldwide (Barzee et al., 2019). It is a useful food crop that is frequently eaten by the general public in the form of fresh veggies or drinks containing juice, as well as processed into various culinary delights. Carrot crops are processed through a series of size-reduction steps, such as washing, peeling, chipping, slicing, and drying (Sumonsiri & Barringer, 2014). Technology-induced automation has significantly reduced the amount of time and effort that humans must spend. The use of carrot processing machines by consumers to cut carrots has become increasingly important as technology advances (Seljåsen et al., 2013).

Post-harvest loss

Post-harvest crop losses are a critical issue in Ethiopia, which refers to the measurable reduction in the quantity as well as quality of food products from the time of harvest until they reach the consumer, encompassing spoilage, damage, and other issues that occur during handling, storage, transportation, and processing. The studies indicate that post-harvest losses for root and tuber crops in Ethiopia can range from 33% to 60% (Abewoy, 2021). Studies indicate that postharvest losses of processed enset products are estimated at 34–45% along the value chain (Amentae, 2016). Cassava experiences the highest level of losses, ranging from 30–50%, while potato losses typically range from 20–25% (Parmar et al., 2018). Turmeric losses are estimated at 15.1–45.2%. In contrast, carrot losses are comparatively low, at approximately 3–5% (Mohamed et al., 2023).

According to recent studies, the average magnitude of post-harvest loss in Ethiopia ranges from 15.5 to 27.2% for major grain crops and 23% average loss for all crops (Boxall, 1998). It can be even higher for horticultural crops, reaching up to 50%. Fruit and vegetables 33.38% led the losses, followed by cereals at 23.36% and pulse and oilseed crops at 23.25%. Post-harvest losses for root crops in developing countries can be significant, with estimates ranging from 40% to 50% of the total harvest (Ridolfi et al., 2018). A study found that the average annual perceived post-harvest losses of crops in Ethiopia were 25.81%, with losses varying across crop types (Debebe, 2022).

Post-harvest technologies

Post-harvest technology involves processing, handling, storing, and distributing agricultural products after harvest, with the goal of minimizing losses and improving quality and shelf life (Santosh & Ali, 2024). It is the technique applied to agricultural produce after harvest for its protection, processing, packaging, distribution, marketing, and utilization to meet the food and nutritional requirements of the people. The main roles of applying postharvest technology to crops are to maintain quality, appearance, texture, flavor, and nutritive value, to protect food safety and to reduce losses between harvest and consumption (Urugo et al., 2024). Root crop processing technologies encompass methods to improve storage, extend shelf life, and create value-added products from roots and tubers like enset, cassava, potato, turmeric, carrot and yam, including peeling, chipping, drying, grinding, and fermentation unit operations (Santosh & Ali, 2024).

The importance of post-harvest technology lies in the fact that it can meet the food requirements of a growing population by eliminating losses and making more nutritious food items from raw commodities through proper processing and fortification (Kiaya, 2014). Reducing crop post-harvest losses is crucial to ensuring food and nutrition security (Vutula, 2024). However, a lack of knowledge on the extent of post-harvest losses and their associated impeding factors is posing major challenges to the effectiveness of the post-harvest loss management strategy and to scaling up for all other crop types in Ethiopia. Processing root crops enhances the quality and quantity of the product, ensures uniform drying, minimize drying time, and lessen spoilage,

damage, and other losses that may occur during the post-harvest period, which can be considerable, particularly for perishable crops (*Hasan et al., 2019*).

Problems associated with tuber crops are that they are the most perishable crops, which can deteriorate within days after harvesting, leading to significant post-harvest losses if not handled, processed and stored properly. Therefore, this study aimed to review the current status of mechanization technologies developed for tuber crops to facilitate future interventions that will make the technologies available.

The objectives of the study are to comprehensively review the status of selected mechanization technologies for tuber crops in order to facilitate future interventions that enhance their availability, to generate secondary information for minor improvements, participatory evaluation, scaling up, and distribution of selected technologies, to investigate the performance of each mechanization technology developed for tuber crops, and to identify technological gaps and limitations in the existing mechanization practices.

METHODOLOGY

This study was conducted as a structured and comprehensive review to assess the performance status of selected mechanization technologies developed for tuber crops in Ethiopia. The review methodology employed to assess the status of selected mechanization technologies developed for tuber crops in Ethiopia followed a systematic and structured approach. A systematic approach was followed to collect and investigate relevant scientific and technical information.

Sources of information

Relevant literature was gathered from multiple academic and institutional sources to ensure broad coverage of available information. The main databases and repositories used included: Google Scholar, ScienceDirect, Scopus, Web of Science, ResearchGate, Institutional repositories of Ethiopian Universities and agricultural research centers (such as Adama Science and Technology University, Wolkite University, Bako Agricultural Research Centre, and Melkassa Agricultural Research Centre). In addition to peer-reviewed journal articles, technical reports, theses, conference proceedings, and unpublished research outputs from Ethiopian research institutions were also consulted to capture locally developed technologies that may not appear in international journals.

Time frame of the review

The review focused on literature published between 2000 and 2025. This time span was selected to capture both early efforts and recent advancements in the development of tuber crop mechanization technologies in Ethiopia.

Search strategy

Key search terms and combinations were used to retrieve relevant documents, including: Tuber crop mechanization in Ethiopia, cassava processing machines in Ethiopia, enset processing technology, root and tuber crop postharvest technologies, performance evaluation of tuber crop machines, agricultural mechanization technologies in Ethiopia, Boolean operators (AND, OR) were applied to refine the searches and obtain the most relevant publications.

Selection or inclusion and exclusion criteria

To maintain focus and consistency, explicit criteria were applied in selecting literature for review.

Inclusion criteria

Studies and documents were included if they met the following criteria: focused on mechanization technologies related to major Ethiopian tuber crops (enset, cassava, potato, and turmeric); reported design, development, or performance evaluation of machines and equipment; were conducted in Ethiopia or under Ethiopian production conditions; contained quantitative or qualitative performance indicators such as capacity, efficiency, quality of output, or power source; were published within the defined time frame (2000–2025).

Exclusion criteria

Publications were excluded if they met any of the following criteria: were not directly related to tuber crop mechanization; lacked technical performance data or evaluation results; focused only on agronomic aspects without mechanization components; were duplicates or inaccessible full texts; or were outside the specified review period.

Screening and data extraction

All retrieved documents were first screened based on titles and abstracts to determine relevance. Full texts of potentially relevant publications were then reviewed in detail. From each selected document, the following information was extracted: type of tuber crop addressed, type and purpose of the machine developed, institution responsible for technology development, performance parameters (capacity, efficiency, losses, quality of output, etc.), stage of technology development (prototype, field tested, adopted), identified limitations and recommendations.

Data analysis and synthesis

The extracted information was organized thematically according to: type of tuber crop, type of mechanization technology (peelers, graters, decorticators, slicers, etc.), performance status of each technology, level of institutional involvement, gaps and future research needs, a descriptive and comparative analysis was conducted to evaluate the performance trends of different technologies and to identify the major achievements, challenges, and opportunities in tuber crop mechanization in Ethiopia.

Outcome of the review process

Through this structured methodology, the review synthesized existing knowledge on the development and performance of tuber crop mechanization technologies in Ethiopia and provided evidence-based insights for future research, technology improvement, and scaling strategies.

Basis for selecting, prioritizing, and comparing the reviewed technologies

Technologies were selected based on predefined inclusion criteria, including: relevance to major tuber crops in Ethiopia (enset, cassava, potato, carrot, and turmeric); development or testing within Ethiopian research institutions and universities; and availability of documented performance evaluation results. Studies were prioritized based on: recency of publication; level of technological maturity (e.g., prototype versus field-tested machines); and availability of quantitative performance indicators, such as capacity, efficiency, loss percentage, and energy requirements. The comparison and evaluation of technologies were conducted using common performance parameters extracted from the reviewed studies, including throughput capacity (kg/h), processing efficiency (%), product quality indicators, and operational suitability under Ethiopian conditions. Where possible, the performance results reported in different studies were synthesized and presented in comparative tables to enable objective assessment rather than purely descriptive reporting.

To maintain a focused and coherent analysis, the review was restricted based on the following scope limitations: Mechanization technologies developed, tested, or evaluated within Ethiopia were considered. The review covers enset, cassava, potato, carrot, and turmeric, as these are the primary tuber and root crops with documented mechanization research outputs in the country. Emphasis was placed on prototype and locally fabricated machines for planting, harvesting, peeling, slicing, drying, and processing operations. Only studies that reported at least one measurable performance parameter (e.g., capacity, efficiency, loss, energy requirement, or cost) were included. Technologies lacking quantitative performance evaluation, purely conceptual designs, and non-mechanized traditional practices were excluded. These limitations were necessary to ensure that comparisons and conclusions are based on verifiable technical evidence rather than anecdotal reports.

This review focuses specifically on mechanization technologies developed within Ethiopia to assess their performance under local agronomic, socio-economic, and institutional conditions. While comparable technologies exist in other countries, their direct applicability to Ethiopia is limited due to differences in crop varieties, farm sizes, labor availability, and supporting infrastructure. For benchmarking purposes, relevant international technologies are briefly discussed where appropriate, highlighting differences in design, efficiency, and adoption potential. This approach allows for contextualized evaluation of Ethiopian innovations while providing readers with a global perspective.

A study on the status of selected technologies for tuber was conducted on key pieces of equipment, namely decorticators, pulverizers, fermenters, washers, polishers, boilers, peelers, graders, and diggers. The investigation focused on processing technologies used for enset, potato, turmeric, cassava, and carrot, with particular attention to product losses associated with each device. For enset processing, the use of decorticators and fermenters was found to result in material losses ranging from approximately 12–18%, mainly due to incomplete separation and fermentation inefficiencies (*Deressa et al., 2023*). In potato processing, peelers, graders, and washers contributed to losses of about 8–15%, primarily from mechanical

damage and trimming (*Kosgollegedara et al., 2021*). Turmeric processing using boilers, polishers, and pulverizers showed losses between 10–20% as a result of over-drying, breakage, and powder residues (*Parimaladevi, 2024*). Cassava processing with peelers, pulverizers, and fermenters recorded comparatively higher losses of 15–25% owing to peeling inefficiency and fermentation shrinkage (*Amoah et al., 2022*). Carrot handling through washers, graders, and diggers exhibited relatively lower losses, estimated at 5–10%, mainly caused by bruising and sorting rejects. These loss statistics highlight the performance gaps of the existing technologies and indicate the need for design improvement and operational optimization for each specific crop and equipment type.

The status of these selected post-harvest technologies was reviewed in terms of key performance parameters. Based on their impact on root crop processing, technologies such as the decorticator, pulverizer, fermenter, washer, polisher, boiler, peeler, grader, and digger were chosen for intervention status review. Relevant peer-reviewed journal articles, technical reports, institutional publications, and project documents were collected from national and international databases. The selected technologies were evaluated based on clearly defined performance indicators, including operational capacity, efficiency, product loss, cost effectiveness, adaptability, and user acceptability. Comparative analysis was conducted to examine the performance of each technology under different conditions, scales of operation, and management practices. In addition, qualitative information from evaluations and stakeholder feedback was incorporated to assess practicality, sustainability, and scalability. The data obtained from multiple sources were combined and critically examined to identify technological gaps, limitations, and opportunities for further improvement and dissemination.

The methodology used in this study to review the status of technologies was based on a secondary data collection approach. This involved an extensive review of published journal articles, conference proceedings, and reports from previous studies. In addition, relevant unpublished research conducted by the Melkassa Agricultural Research Centre and other institutions was incorporated into the analysis. Accordingly, the findings of this study emphasize the need for targeted interventions to improve the status, performance, and adoption of the selected technologies.

Evaluation criteria

To enable systematic comparison of the diverse mechanization technologies developed for tuber crops in Ethiopia, this review adopts a standardized performance evaluation framework. The assessment is structured around five core performance indicators: operational capacity, processing efficiency, product loss or damage rate, power source, and usability. These indicators were selected because they are the most commonly reported and practically relevant parameters in agricultural mechanization studies. Wherever possible, performance data from different sources were normalized into comparable units, such as capacity, percentage for efficiency and losses. Technologies were compared within and across crop types based on these uniform criteria in order to minimize inconsistencies arising from differences in experimental conditions, measurement methods, and reporting styles. This harmonized framework provides a structured basis for identifying the relative strengths and weaknesses of available technologies and for highlighting areas requiring further improvement.

INVESTIGATION OF SELECTED TUBER CROP PROCESSING TECHNOLOGIES

Enset processing technologies

Enset processing technologies include traditional methods like using a watani or flat wooden board for decorticating, a javga or wooden tool for pulverizing, and a "sibisa," longitudinally split bamboo, for scraping (*Hunduma & Mogessie, 2011*). Improved technologies include enset scrapers, squeezer machines, and fermenting machines. Enset processing technologies, traditionally labor-intensive and handled by women, involve identifying mature plants, preparing fermentation pits, decorticating, pulverizing, bulla extraction, and fermenting the mass, with recent efforts focusing on improving these technologies to save time and labor. Enset processing with technologies produces the popular local staples kocho, amicho, and bulla for pancakes and porridge as staple food (*Feleke & Tekalign, 2022*). The conventional enset processing tools include watani, javga, sibisa, and fermentation pits or boxes (*Hunduma & Mogessie, 2011*). Watani is a flat, locally prepared wooden board used to decorticate (remove the outer layers) the enset pseudostem. Javga is a wooden tool with two ends: one serrated for pulverizing the corm and macerating bolla gamma, and the other flat for smashing the pseudostem.

Sibisa is a longitudinally split bamboo used for scraping the fleshy part of the enset leaf sheath. Fermentation pits or boxes are used to store the extracted product for fermentation. Traditional processing methods are still predominantly used by farmers. Traditionally, the bamboo scraper is used to decorticate the leaf sheath tied with rope to an inclined wooden plank that leans at an angle of 40° against a vertical pole. A woman sits in front of the plank, keeping a pseudostem piece with its convex side against the plank and securing it in position, as shown in Figure 1, by placing her foot on it as high as possible (Feleke & Tekalign, 2022).



Fig. 1 - Manual method of enset processing; a) decorticating b) grating

Mechanical enset processing technologies

The mechanical enset processing technologies include a decorticator, grater, scrapers, and squeezer (Deressa *et al.*, 2023). Enset scrapers are used to separate the leaf sheath from the fiber, whereas decorticating machines are used to separate the fiber from the stem (Workesa Dula, 2018). Grating machines are used to chop the enset corm. Squeezing machines are used to separate the liquid part from the solid. Fermenting boxes are containers that help in the fermentation process for a short or long period during the preparation of enset products. Integrated enset processing machines are used that combine multiple functions, such as decorticating the enset stem, grating the corm, and performing operations, including pulverizing and squeezing (Asfaw, 2024). The enset processing technologies were investigated as follows:

DECORTICATING MACHINES

Engine-driven enset decorticator

A study on this decorticator was conducted by Woldeyesus *et al.* (2025) to address the issues related to enset processing and to develop and evaluate the performance of the constructed engine-driven enset decortication machine at Wolkite University. The machine's performance was tested in the laboratory and field, as it was reported. The result for this machine reported that the maximum decorticating capacity of 97.88 kg h⁻¹ was obtained at a drum speed of 850 rpm when the concave clearance was 1 mm, and the feeding rate was 0.077 kg s⁻¹. The highest decorticating efficiency of the machine was 98.98% at a drum speed of 850 rpm, with a concave clearance of 1 mm and a feed rate of 0.077 kg s⁻¹ while the lowest decorticating efficiency of 75.63% occurred at a drum speed of 950 rpm, a concave clearance of 4 mm and a feed rate of 0.40 kg s⁻¹. While the lowest loss of 1.03% was recorded at drum speed 850 rpm, concave clearance 1 mm and feed rate 0.077 kg s⁻¹. The highest fuel consumption of 15.91 mL kg⁻¹ was observed at drum speed 950 rpm, feeding 0.077 kg s⁻¹ and concave clearance 1 mm as reported.

The material selected for fabricating this decorticator was free from corrosion. However, as a limitation, the throughput capacity of the machine was low, so it needs further improvement of its main components to increase its output, but also the engine setting also needs minor improvement. The status of the decorticator indicated that the farmers who produce enset were promoted to use this machine for decorticating enset. This technology is currently at the field-tested stage.

Improved warqe decorticating machine

This machine was developed by Workesa *et al.* (2021). Its functional parts included a drum beater, breastplate, reduction gears, collecting box, chain and sprocket, feeding table, pulleys, transmission belts, rollers, engine seat, and bearings. As proposed, the design can further be improved to have better decorticating efficiency and throughput and lower cost through the use of materials like aluminum and plastics rather than stainless steel. The performance evaluation for this decorticator was carried out at three levels of drum speeds (850, 950, and 1050 rpm), concave clearances (1, 3, and 6 mm), and feeding rates (0.037, 0.056, and 0.074 kg s⁻¹). The maximum decorticating capacity of 255.38 kg h⁻¹ was obtained at a drum speed of 850 rpm, concave clearance of 1 mm, and a feeding rate of 0.074 kg s⁻¹. The maximum decorticating efficiency of

98.97% and minimum pulp loss of 1.03% were achieved at a drum beater speed of 850 rpm and a concave clearance of 1mm. From the review, the performance status of this improved decorticator indicates that it still requires a detailed redesign for optimal processing output during use. This technology is currently at the field-tested stage.

Improved kocho, bulla, and fiber production machine

This enset product production machine was improved by *Dalelo & Alandu (2022)*; the machine parts (Figure 2) consist of the decorticating drum, blade, shaft, belt, pulley, bearings, bearing housing, safety cover, bucket, inclined plate, rollers and the main frame. The decorticator could obtain power from a 3 HP engine motor for decorticating the enset sheave. This motor-powered mechanism changed the power from the motor through the belt to the rotational movement of a decorticator drum, blade fitted to the shaft. For this machine, an adjustable decortication clearance varies from 1mm to 5 mm between the blade tip and the inclined plate. The reported average decorticating capacity of the machine was 57.63 kg h⁻¹, whereas the machine's output capacity was 54.48 kg h⁻¹ of kocho and fiber per hour, 10.16 % broken fiber and 1.92% un decorticated kocho, machine decorticating efficiency of 89.5% with a fiber cleaning efficiency of 77.64%. The overall status for this improved machine indicated that this machine is not efficient for processing enset. Therefore, it must be re-improved for end-user use; otherwise, it is better to use other, more effective machines that have good performance results. This technology is currently at the field-tested stage.



Fig. 2 - Enset production machine

Manual enset decorticator

This manual enset decorticator was improved by the Melkasa Agricultural Research Center, which tried to improve the clamping mechanism of the decorticator (*Firew, 2006, unpublished*). This represents a significant improvement over the traditional method, in which one of the operator's feet was used to hold the pseudostem in position during scraping. The improvement made on the manual decorticator was based on the consideration of work comfort and affordability by smallholder enset growers. The major parts of the manual decorticator (Figure 3) were the decorticating board and the clamping mechanism, which consists of a rope and pedal assembly.

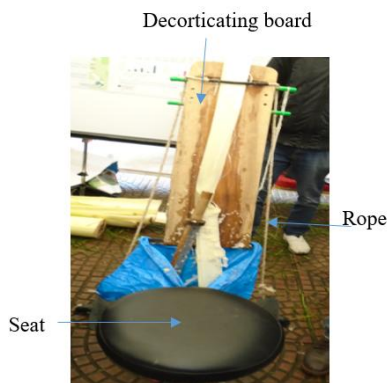


Fig. 3 - Manual enset decorticator

The improved decorticator had a capacity of decorticating one enset plant in 3.36 h with a decorticating efficiency of 91.00%, as reported. From the point of review, its status indicates that it is not significantly different from the conventional method, so it is preferable to use a mechanical decorticator. This technology is currently at the prototype stage.

Treadle-operated enset decorticator

The decorticator had some benefit, which ended the improved clamping mechanism by *Firew (2006, unpublished)*. A treadle pedal-operated enset decorticator was postulated to be a solution to the problem of enset processing in growing areas. In this decorticator, the reciprocating motion of a scraping unit is achieved by a quick-return mechanism that converts the rotary motion of a shaft into straight-line linear motion. It did not change the labor-intensive work of enset decorticating processes since the decorticator required uninterrupted pedaling, and the decorticator did not pass beyond the improvement stage, and the prototype is yet to be needed for enset processing by users.

Fiber decorticator

The modified a roller crusher, which was originally meant to crush and decorticate flax and retted hemp to extract long fiber bundles (*Feleke & Tekalign, 2022*). The roller crusher had three pairs of fluted rollers running at different speeds, followed by a high-speed pinned rotor to remove the remaining cores attached to the fibers. The fiber yield of this decorticator is estimated to be up to 30% by mass. Similarly, a field-going unit with a cylindrical cutter head to provide fibers for non-textile applications. This decorticator is important in the production of fiber for making rope by users.

GRATING MACHINES

Engine-driven corm grating machine

This machine was developed by *Kibi (2018)*. It consists of three main units: the hopper unit, the grating drum, and the delivery chute or collector. All these components are mounted on an angle iron frame. The grater assembly was powered by an engine of small horsepower output, five horsepower. This enset corm grating machine was tested at three levels of drum speeds, 2000, 2200 and 2400 rpm, for the most dominant three varieties, Baladati, Farise, and Sharte, in the field. The performance of the decorticator was assessed in terms of capacity and uniformity for three varieties. Based on the results reported by the author, the mean grating capacity of 1048.3 kg h⁻¹ was recorded for the grater. The optimum capacity of 1277 kg h⁻¹ was observed when the drum was operated at a velocity of 2200 rpm at Sharte variety; whereas the minimum capacity of 604.0 Kg h⁻¹ was observed when the drum speed was 2000 rpm at Baladati variety. From the test report, this machine can be used by farmers for all varieties of enset corm.

From its performance status, this machine requires field evaluation and demonstration with the participation of end users to enhance awareness and promote its adoption. Such activities would help address the challenges associated with grating enset corm using conventional methods. Furthermore, it would be beneficial to multiply the machine and facilitate its wider distribution to end users. This technology is currently at the commercially adopted stage.



Fig. 4 - Corm grating machine

Enset corm pulverizer

This pulverizer is mainly composed of a pulverizing unit, a feeding table and a transmission unit (*Kebede et al., 2018*). The basic parts, like the engine and transmission system, and the clamping and transportation parts, were constructed, which gave the current assembled engine-operated mobile corm pulverizer. This corm

pulverizer recorded a capacity of 320-360 kg h⁻¹, which is more than 150 times compared to the traditional practice as reported. Its status indicated that the machine is not suggested for pulverizing corm because there is a problem with the feeding mechanism, which causes staking during the operation.

Corm pulverizing machine

This developed enset corm pulverizing machine by *Ertebo & Girma (2024)*, as shown in Figure 5, was composed of the following parts: hopper, housing, drum, chute, frame, shaft, pulley, and power transmission unit. The drum was made up of a cylindrical perforated stainless steel sheet metal, which was held by a shaft passing through the rolled cylindrical sheet metal. The motorized corm pulverizing machine consists of a trapezoidal feeding hopper made of 2 mm thick stainless steel sheet. The outlet, also constructed from stainless steel, is inclined to facilitate the discharge of the pulp into a storage container.

The performance result for this machine showed that an operating speed of 1800 rpm and a feeding rate of 10 kg min⁻¹, a maximum pulverizing capacity of 721.4 kg h⁻¹ was found; at a speed of 1600 rpm and a feeding rate of 15 kg min⁻¹, the minimum pulverizing capacity of 611.6 kg h⁻¹ was found. The highest pulverizing efficiency of 97% was found at an operational speed of 1800 rpm and a feeding rate of 15 kg min⁻¹, whereas the minimum pulverizing efficiency of 93.5% was found at an operating speed of 1600 rpm and a feeding rate of 10 kg min⁻¹. The percentage of loss for this machine ranged from 3.5% to 6.5%. The performance status for this motorized machine indicated that a minor improvement was needed for the optimization of its output for processing enset by end users before using it. This technology is currently at the field-tested stage.



Fig. 5 - Corm pulverizing machine

Integrated machines

Integrated enset processing machine

This integrated machine was developed by *Adugna et al. (2025)* and powered by a single-phase electric motor, enabling an integration of four unit operations: decortication, corm grating, pulverization, and bulla extraction. Furthermore, this machine can process five to six ensets at an operational speed of 864 rpm within 1.1 hours. The status for this machine indicated that this designed integrated enset processing machine may be utilized by farmers for processing enset because it was well designed, but it is only at the design stage and has not been fabricated and evaluated. This technology is currently at the prototype stage.

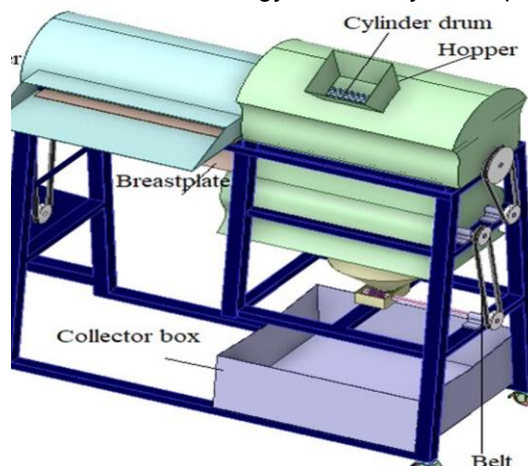


Fig. 6 - Integrated enset processing machine

Corm grater and leaf sheath decorticator

The corm grater and leaf sheath decorticator machine was developed by Kibi & Tefera (2024). This machine mainly comprised three components: the hopper, the grating, and the decortivating drum. The machine assembly is powered by a small engine of 5 HP. The components are mounted on an angle iron frame that has a trapezoidal shape. This integrated corm grater and leaf sheath decorticator machine was tested at three levels of drum speed, 1900, 2000, and 2100 rpm for corm grating and four levels of drum speed, 800, 900, 1000, and 1100 rpm for leaf sheath decortivating for the most dominant two varieties (Baladat and Lemate). Based on the results obtained, the grand mean grating capacity of 1658 kg h⁻¹ for corm and decortivating capacity, decortivating efficiency of 497 kg h⁻¹ and 90.3% for leaf sheath was recorded for the prototype at 1 mm concave clearance during processing.

From a review of its status, this machine was easy to transport from place to place and was simple for use by farmers. It was suggested to conduct an improvement on the hopper and feeding unit, and participant evaluation of the machine for further use by farmers. This integrated version is a modified one from the previous grating machine, but is no longer different from the first one. This technology is currently at the field-tested stage.

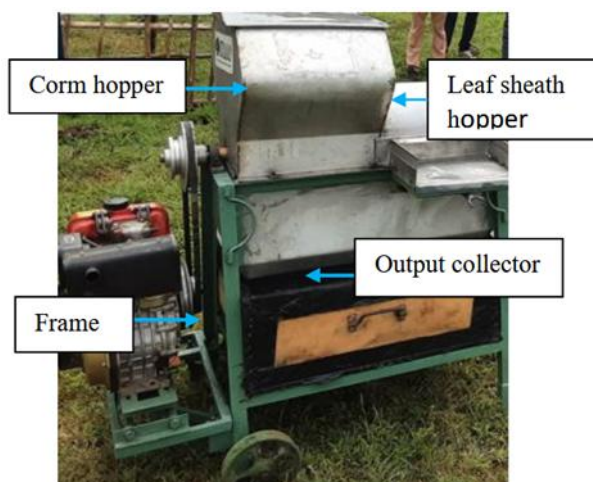


Fig. 7 - Corm grater and leaf sheath decorticator

Fermenter box

This fermenter was developed by Gizachew Tefera (2019) and consisted of a frame made from angle iron used for supporting and carrying the whole body of the fermenter box. As it is reported, the fermenter has three compartments and can ferment up to 300 kg at once, and its volume is 0.441m³. From the point of view of the review, this fermenter is not used for large-scale fermentation of processed enset, and its design does not consider farmer practices that follow conventional procedures. Due to the material choices of mild steel, which makes up the majority of his design, it contaminates food for long-term use of the fermenter. This technology is currently at the prototype stage.

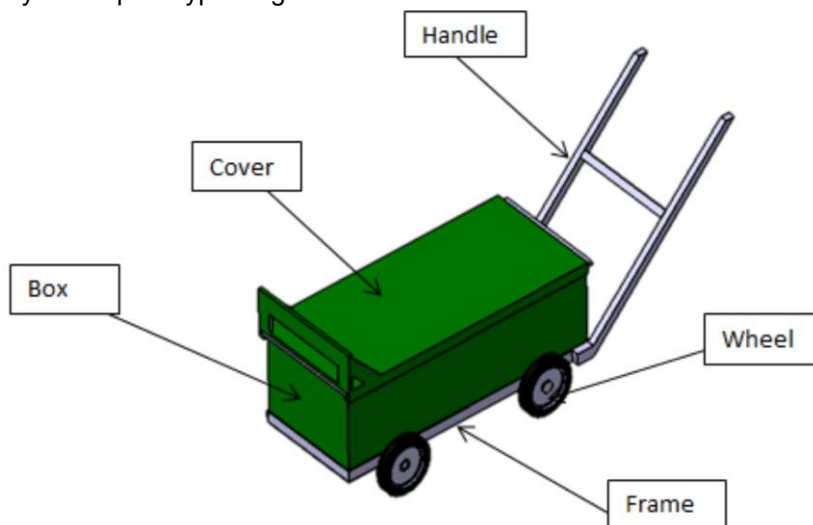


Fig. 8 - Fermenter box

CASSAVA TUBER PROCESSING TECHNOLOGIES

Cassava processing technologies, crucial for increasing shelf life, reducing cyanide content, and improving palatability, involve methods like peeling, grating, pressing, drying, and milling (Howeler, 2006). These processes are essential for transforming cassava into various food products. Cassava contains cyanogenic glycosides, which produce hydrogen cyanide upon breakdown (Ndubuisi & Chidiebere, 2018). Processing helps remove or reduce this toxic substance. Processing can improve the taste and texture of cassava, making it more palatable. Processing methods like drying and milling can significantly extend the shelf life of cassava products (Nainggolan et al., 2024). Processing can make cassava easier to transport and market in various forms.

Traditional cassava processing tools

Traditional cassava processing is often a labor-intensive process, traditionally performed by women (Taiwo & Fasoyiro, 2015). It can also be slow, prone to rust, and difficult to keep clean. Traditional cassava processing in Africa primarily relies on tools like perforated metal sheets, cassava grinders, pestles, hoes, shovels, and mortars for milling and locally made sieves, with minimal reliance on improved technologies. It is made from flattened kerosene tins or iron sheets perforated with nails and fastened to a wooden board with handles. Traditional cassava processing involves manual methods like peeling, grating, fermenting, and drying, often used by women to create various products like gari, fufu, and attieke (Karim et al., 2014).

Cassava tuber processing methods

The common cassava processing methods include peeling, washing, slicing, grating, drying, milling, fermentation, boiling, roasting, pressing and dewatering (TAAT, 2021). Peeling is removing the outer skin of the cassava root after washing the peeled roots to remove dirt and debris, whereas grating is using a grater to produce a pulp or fine pieces. Pressing and dewatering is removing excess water from the grated cassava pulp. Drying is carried out after slicing to reduce moisture content, prevent spoilage and extend shelf life. Milling is grinding the dried cassava into flour. Fermentation allows cassava to ferment, which can alter its flavor and texture. Boiling is cooking cassava to soften it and reduce cyanide content. Roasting is cooking cassava in an oven or over an open fire (Etejere & Bhat, 1985).

Mechanical cassava processing technologies

The most common cassava processing technologies are peeling, slicing, and grating (TAAT, 2021). Mechanical cassava processing technologies encompass machines and techniques for tasks like peeling, grating, chipping, and dewatering, which can improve efficiency and increase the demand for cassava in rural areas. The mechanical cassava processing technologies include a peeler, washer, grater, slicer, chipper, presser, dryer, miller, grinder, and crusher. These involve raw material selection, peeling, washing, grating, pressing and dewatering, drying, milling, screening, packaging, and storage (Edoh Ognakossan et al., 2016).

Electrical motor-operated cassava peeler

The developed cassava-peeling machine by Mekonnen & Wako (2021, unpublished) works on the principles of abrasion and consists of a drum, speed-reducing gear, a set of pulley arrangements that were used to rotate the drum at a predetermined speed, and a 3-hp electrical motor. The drum was made from an internally perforated stainless steel sheet. The speed-reducer gear with a gear-reduction ratio of 50:1 was assembled in the middle of the electrical motor and drum to reduce the speed of the electrical motor. The test for this peeler was carried out at 30 and 60 rpm peeling drum speed and 10, 15, and 20% drum fill by holding the operation at 7 minutes. The maximum throughput capacity of 120 kg h⁻¹ was recorded at 20% drum fill, independent of drum speed. The maximum tuber flesh loss of 7.8%, on the other hand, was recorded when the drum speed was 60 rpm, and the drum was filled at 10%. The maximum peeling efficiency of 74.87% of developed cassava peeling machines was recorded when the machine was operated at 60 rpm drum speed, 10% drum fill, and 7 minutes' retention time.

According to the performance evaluation reported by the author, the machine requires further modification to improve its efficiency and enhance throughput capacity. Additionally, it is preferable to scale out to end users, as farmers in cassava-growing areas of Ethiopia currently do not use any peeling machines. This technology is currently at the field-tested stage.



Fig. 9 - Cassava peeler

Manually operated cassava slicer

This manual cassava slicer was developed by the Melkassa Agricultural Research Centre, the agricultural engineering research department. It mainly consists of a blade, hopper, flywheel, and outlet. During the slicing, the blade can be adjusted. Flywheel guard fabrication is considered for safety. According to the results of the evaluation, the machine's capacity, material loss, and slicing efficiency for cassava were 81.4 kg h⁻¹, 20%, and 73.6%, respectively. It can slice cassava at a thickness range of 1.5 to 3 mm. Because of the irregular shape of the cassava, the circular feeding parts are uncomfortable for feeding the tubers and should be improved. The slices are trapped by the inside chamfered frame components, creating a pile. To make it easier for the slices to flow to the collection box, this section has to be improved. This technology is currently at the prototype stage.

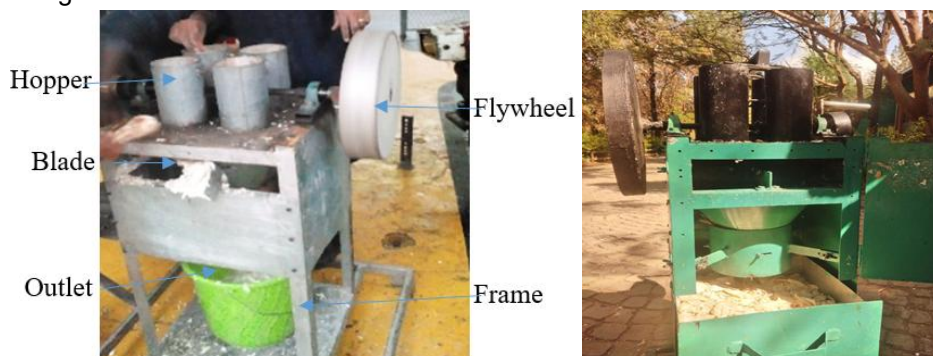


Fig. 10 - Manually operated slicer

Combined cassava slicer and grater

This motorized combined machine was developed by *Temam (2020)*. It could grate 114.94 kg of cassava per hour with a fuel consumption of 325 ml and chip 30.3 kg of cassava per hour with a fuel consumption of 150 ml. It was made up of the chipping and grating units as well as the power motor that was positioned in the middle of the two machines and could be shared based on the task at hand. This machine performed a very poor job of grating and chipping the cassava tuber. Farmers would be better off using other efficient machines because this one is ineffective at processing cassava due to improperly designed machine components. This technology is currently at the prototype stage.



Fig. 11 - Combined cassava grater and slicer

Electrical motor-driven cassava slicer

The cassava slicing machine developed by *Girma et al. (2023)* runs with a 2.5 hp single-phase electrical motor to a circular slicer disc using a shaft mounted on a frame made of milled steel. The performance of this prototype was evaluated based on parameters such as machine capacity, slicing efficiency, and slicing damage. The developed cassava slicing machine indicated a slicing capacity of 982.45 kg h⁻¹, a slicing efficiency of 87%, and damaged slices at 9.78% at a slicing disc speed of 500 rpm and a feed rate of 11 kg min⁻¹. The impact of speed on slicing capacity, efficiency, and damage was significant based on the results obtained. From the review, developing this cassava-slicing machine is a significant step towards improving cassava processing by addressing postharvest challenges in cassava-growing areas. This technology is currently at the commercially adopted stage.



Fig. 12 - Electrical motor-driven cassava slicer

Engine-operated cassava grater

This grating machine was developed by *Erchafo (2024a)*; tests of this grater can be carried out at a moisture content of 54.6% on a wet basis for the 'Kello' variety according to operating speeds of 28.27 m s⁻¹, 26.18 m s⁻¹, and 21.99 m s⁻¹ in line with a feeding rate of 15 kg min⁻¹. The test results showed that the operating speed of 28.27 m s⁻¹ achieved the maximum grating capacity with a mean of 386.2 kg h⁻¹, followed by 26.18 m s⁻¹ and 21.99 m s⁻¹, which achieved a grating capacity of 341.6 and 248.5 kg h⁻¹, respectively. It was also observed that the operating speeds of 28.27 m s⁻¹ achieved the maximum grating efficiency with a mean of 97.1%, followed by 26.18 m s⁻¹ and 21.99 m s⁻¹, which achieved the grating efficiency of 94.9% and 87.9%. This cassava grating machine was accessible to farmers who grow cassava, featuring a minor improved grating unit for the effective processing of cassava tubers. Additionally, it is advisable to conduct a participatory evaluation to raise awareness among end users. This technology is currently at the field-tested stage.

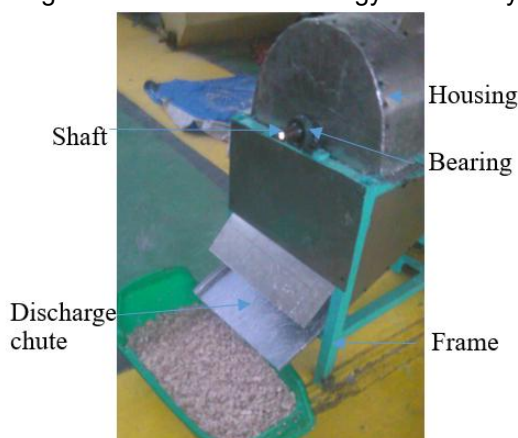


Fig. 13 - Engine-operated cassava grater

POTATO PROCESSING TECHNOLOGIES

Processing potatoes into various products like chips, fries, and flakes diversifies income streams and adds value (*Lal et al., 2023*). Potato processing technologies encompass various methods and equipment used to transform raw potatoes into a wide array of products, including fries, chips, starch, and more, utilizing techniques such as pulsed electric field, optical sorting, and robotic handling to enhance efficiency and quality.

Potato processing technologies enable the creation of various products like French fries, crisps, starch, flour, and snacks while also improving post-harvest handling, storage, and quality control, ultimately enhancing the efficiency and sustainability of the potato industry. Potato processing technologies are crucial for producing popular products like French fries, potato chips, and various other potato-based snacks (Hu et al., 2025).

Traditional potato processing tools

Traditional potato processing tools often include simple manual methods like hand-peeling, slicing with knives or mandolins, and using a potato ricer or press for mashed potatoes. Manual peeling and slicing of potatoes are done by hand using knives and other tools. Conventional technologies, such as thermal blanching, frying, and drying, have been widely used for processing potatoes over the years.

Mechanical potato processing technologies

Mechanical technologies ensure high-quality products and food safety (Yuan et al., 2025). Mechanical potato processing technologies encompass a range of methods, including cleaning, peeling, sorting, cutting, grading, washing, blanching, slicing, and various forms of processing to create products like fries, chips, and starch (Haverkort et al., 2023). Potato processing involves transforming raw potatoes into various products like chips, fries, and starch through manufacturing processes, including washing, peeling, slicing, frying, and drying. Also, destoning, washing, peeling, cutting, cooking, mashing, drying, granulating, and packaging are all potato processing methods that are effortlessly performed. Implementing quality control measures during processing ensures the quality and safety of the final products, building trust with buyers and consumers.

Power-driven potato peeler

The peeler was evaluated using different potato bulb sizes: small, medium, and large (Mohammed, 2017). The test process was conducted between 1000 and 1440 rpm drum rotational speeds, three different peeling residence times, 10, 15, and 20 seconds, and two different batch loads, 1 and 1.5 kg. The optimum peeling efficiency of 52.55%, 87.99%, and 98% was obtained at 10, 15, and 20 seconds, respectively, and at the recommended drum speed of 1440 rpm. The average value of the mean field capacity of the potato peeler obtained from the trials for small, medium, large, and mixed sizes was 0.092 kg s⁻¹, 0.093 kg s⁻¹, 0.091 kg s⁻¹, and 0.093 kg s⁻¹, respectively. Generally, the mean capacity of the potato peeler obtained from the trials for small, medium, large and mixed sizes was 333.7164 kg h⁻¹. This peeler can be used on a small scale, so intervention for its use is not very important.

Animal-drawn potato digger

The Agricultural Engineering Research Directorate at Melkassa Agricultural Research Centre modified an improved groundnut digger to harvest potato tubers, which is an attachment to the local plow, Maresha (Figure 14a). The potato harvester was then compared with the conventional potato digging using the Maresha plough. The two harvesting methods were compared for their technical performance concerning exposure efficiency. From the result, the improved potato digger had better exposure efficiency in the first ploughing and had a cumulative exposure efficiency of 97.68% when ploughed twice. Cumulative exposure percentage with the use of the local plough, on the other hand, was 89.36% in two ploughings. This indicates that ploughing once with the improved digger is almost equivalent to ploughing twice with the traditional practice. Compared to the local plough, the unexposed potato remained in the soil after the second ploughing was lower for the improved one. Another improvement in potato digger design is the Selam potato lifter, improved by Selam Vocational Training Centers in the private sector, which the prototype implements. The lifter has depth control mechanisms, good exposing capacity, and an increased angle of shear compared to the rest of the tuber harvesting tools (Figure 14b). This technology is currently at the prototype stage

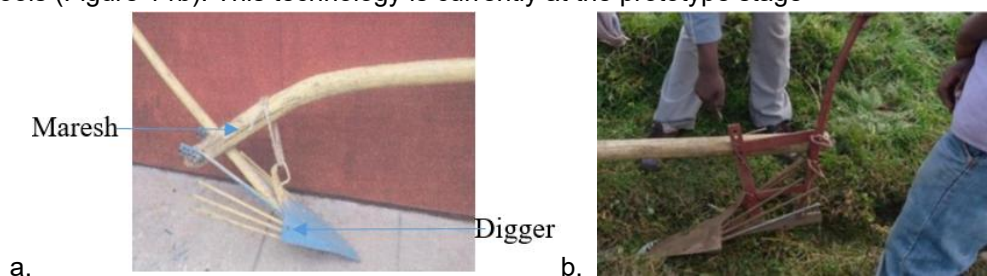


Fig. 14 - Melkassa digger (a) and Selam potato lifter (b)

Two-wheel tractor-driven potato digger

The developed prototype potato digger elevator was drawn by a 15-hp power tiller or single-axle tractor (*Tikuneh & Beri, 2023*). The developed machine was a single-axle tractor-operated potato digger elevator, which was designed, constructed, and evaluated. The investigation for this digger indicated that the optimum combination of rake angle and elevator slope was 15 and 20°, respectively. At this optimum condition, damage percentage, conveyance efficiency, cleaning efficiency, drawbar pull, fuel consumption, wheel slip, soil swelling factor, soil mean weight diameter, pulverization ratio, and field capacity were 3.39%, 89.64%, 91.87%, 2959.1N, 14.87 l ha⁻¹, 17.67%, 20.25%, 17.44 mm, 78.09% and 0.127 ha h⁻¹. In the future, the prototype machine is usable with a prospect of amendment and adoption for small-scale farmers, but it is to be driven with a four-wheel tractor rather than two-wheel tractors.



Fig. 15 - Tractor-operated potato digger

TURMERIC PROCESSING TECHNOLOGIES

Turmeric processing technologies encompass the various methods and techniques used to transform fresh turmeric rhizomes into marketable products like powder, extracts, and other forms while preserving quality and maximizing output (*Girma & Mohammedsani, 2021*). Turmeric processing technologies enable the creation of various products like powder, oil, and oleoresin, used in food, medicine, and cosmetics, by utilizing techniques like boiling, drying, polishing, and grinding. Before turmeric can be used, the turmeric rhizomes must be processed. Rhizomes are boiled or steamed to remove the raw odor, gelatinize the starch, and produce a more uniformly colored product (*Kumar, 2021*).

Traditional turmeric processing tools

Traditional turmeric processing involves boiling or steaming rhizomes, followed by sun-drying and polishing to remove rough surfaces; tools used include pans, vats, and polishing drums (*Manuraj et al., 2020*). It also involves polishing and grinding the rhizomes with tools like pots for boiling, drying trays, and simple polishing drums or bags with stones. Rhizomes are boiled or steamed in pans or earthenware filled with water or in shallow pans within large iron vats containing alkaline water. After boiling, the rhizomes are removed from the water and dried in the sun to prevent overcooking, with a final moisture content of 8% to 10% (wet basis) being desired. The dried rhizomes are polished to remove the rough surface, which can be done by hand or by shaking them in a gunny bag filled with stones. The rhizomes are traditionally sliced by hand due to the lack of machines available to carry out the slicing process. It is a traditional barrel-type turmeric curing machine. During cooking, rhizomes are added into a clear barrel filled with clean water, leaving a 5-7 cm gap and packed or covered with dry turmeric leaves.



Fig. 16 - Traditional boiling barrel

Mechanical turmeric processing technologies

Mechanical turmeric processing technologies involve various machines, including washing, peeling, slicing, boiling, polishing, extraction, drying (using tray, cross-flow, solar, or cabinet driers), and grinding, aiming to enhance quality and shelf life (Thul & Shirsat, 2021). Mechanical technologies play a crucial role in turmeric processing, facilitating efficient and high-quality outcomes in washing, drying, and grinding, ultimately enhancing the spice's quality and yield. These machines automate the processing, improving efficiency, reducing labor costs, and transforming fresh rhizomes into a stable, marketable product, primarily turmeric powder.

Electric motor-driven turmeric slicing machine

This turmeric slicing machine is powered by a three-horsepower electric motor that rotates at a constant rotor speed (Erchafo, 2024b). This slicer mainly consists of a feeding table, hopper, cylindrical disc, cutting blade, blade holder, outlet, frame, shaft, and power transmission units. Its slicing mechanism could be based on a cutting blade when the actual slicing operation takes place on it. From the performance results, at 500 rpm speed and 10 kg min⁻¹ feeding rates, the maximum slicing capacity of 824.7 kg h⁻¹ was recorded; at 300 rpm speed and 15 kg min⁻¹ feeding rates, the minimum slicing capacity was recorded. At 500 rpm of speed and 15 kg min⁻¹ of feeding rate, a maximum slicing efficiency of 97.4% was found, while at 300 rpm and 10 kg min⁻¹ feeding rate, a minimum slicing efficiency of 93.9% was noted. For this machine, the material loss ranged from 4.06 to 7.6%.

The overall status indicated that this slicing machine is simple to use, requires only one or two people to run, and is easy to operate. Turmeric grower farmers found this slicing machine to be a great option because of its easy-to-use operation. This turmeric slicing machine is highly recommended because, according to the performance evaluation results of the machine as reported by the author, it performed incredibly well when it came to slicing the turmeric rhizome. Therefore, this machine needs the intervention of participatory evaluation, scaling out and distributing to the end user. This technology is currently at the commercially adopted stage.

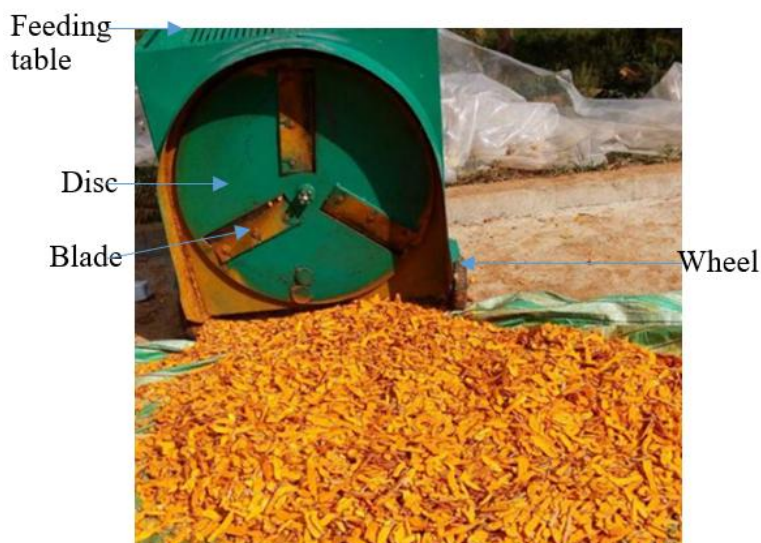


Fig. 17 - Turmeric slicer

Turmeric polishing machine

This polishing machine for turmeric was considered on the basis of different engineering inputs like the rpm of the motor, the capacity of the polishing drum, feed rates, and the speed of the polishing drum (Dawudi, 2023, unpublished). The phenomenon of abrasion used in polishing is caused by the friction between expanded-wire metal mesh and turmeric. The scale and unwanted impurities fall down on the base easily, which seems to be quite difficult in hand polishing. This machine is very simple to operate and efficient in polishing harvested turmeric at a good production speed. The performance of the polishing machine was tested at three different capacities, 8, 10, and 12 kg, and three speeds, 45, 60, and 90 rpm. At a speed of 60 rpm and 8 kg capacity, the highest polishing percentage is obtained, which is 7.68%. The polishing capacity is high compared to hand polishing, 30 kg per hour. The polishing machine is easy to operate and useful on the farm. So, machine polishing is recommended for raw turmeric processing. This technology is currently at the prototype stage.



Fig. 18 - Turmeric polishing machine

Mesh-type turmeric barrel boiler

The mesh-type turmeric barrel boiler consists of a single, large-sized, solid outer container made up of three inner containers to hold rhizomes (Kebede, 2023). The external part of the cylinder is made up of mild steel, and the internal parts of the mesh type are again mild steel and coated with anti-rust. Anti-rust for corrosion resistance and thick for heat resistance purposes. Washed rhizomes are loaded in water added to the outer cylinder. Rhizomes are boiled by steam; this helps in reducing drying time. The traditional method has an average capacity of 20.15 kg h^{-1} compared to 49.42 kg h^{-1} overall average for the improved boiler, and 83.73 kg h^{-1} capacity at optimal 100°C , 15 min setting. This shows over 4 times higher throughput using the mesh barrel option with ideal parameters. This technology is currently at the prototype stage.

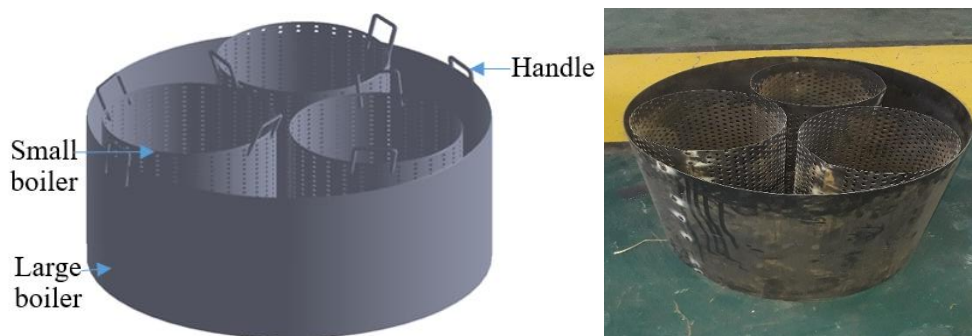


Fig. 19 - Turmeric boiler

CARROT PROCESSING TECHNOLOGIES

Processing carrots with technology can preserve and enhance their health benefits, such as antioxidant and fiber content, to meet consumer demand for healthy and nutritious foods (Ding & Liu, 2024). Carrot processing technologies encompass various methods to extend shelf life, enhance nutritional value, and create diverse products, including drying, canning, freezing, and juice extraction, with emerging technologies focusing on preserving quality and functionality. Also, carrot processing technologies enable the creation of various products like juice, dried forms, and baby carrots while also utilizing by-products to create value-added products and improve efficiency. Processing technologies can help preserve the nutritional value of carrots, including carotenoids and other beneficial compounds (Haq & Prasad, 2015).

Traditional carrot processing tools

Traditional carrot processing methods, while simple, often lead to reduced quality, shelf life, and nutritional value due to heat, mechanical damage, and microbial growth, impacting market value and consumer acceptance (Motegaonkar et al., 2024). Traditional methods, like hand washing and manual peeling, are labor-intensive and time-consuming, leading to lower processing speeds and potentially higher labor costs. Carrots are typically washed by hand in a bucket or trough of water. It can be peeled using a knife or a simple peeler. Carrots are cut or sliced using a knife or a simple chopping board.

Mechanical carrot processing technologies

Mechanical carrot processing technologies involve a series of operations such as washing, peeling, cutting, grading, drying, and packaging to transform raw carrots into marketable products (Ding & Liu, 2024). In this study, the performance status of each processing device was reviewed under key performance

parameters. The mechanical washer was assessed for its cleaning efficiency, throughput capacity, and loss, and it demonstrated the ability to clean large quantities of carrots within a short time. The peeling machine was assessed based on peeling efficiency, material loss, and uniformity of the peeled surface, showing effective removal of the outer skin with minimal damage to the product. Cutting and slicing machines were investigated for cutting accuracy, output capacity, and product uniformity, enabling carrots to be processed into different shapes and sizes suitable for fresh markets or further processing. Grading equipment was reviewed for its ability to classify carrots according to size and quality, while drying technologies were assessed for moisture reduction rate and final product quality. Overall, the investigation status indicated that mechanical processing significantly reduces labor requirements, improves working conditions, enhances product quality, and increases processing efficiency compared to traditional manual methods (Paparella et al., 2024).

Power-operated carrot slicer

This carrot slicer machine was driven by a 3.7 kW motor that revolves at a continuous machine speed (Erchafo, 2025). The main components of the slicer machine are the inlet, cover, cutting blade, blade holder, chute, main frame, and shaft. All of the machine's other parts are supported by the mainframe. From the performance evaluation results, the maximum capacity of 621.4 kg h⁻¹ was recorded at 550 rpm speed, while the minimum capacity of 511.6 kg h⁻¹ was recorded at 350 rpm speed. It has been found that the maximum efficiency was 96.03% at 550 rpm speed, whereas the minimum efficiency was 92.5% at 350 rpm speed. For this slicer, the percentage of loss ranged from 4.2 to 7.8 at the above speed range. This carrot slicer machine's user-friendly mechanism makes it a good option for farmers who cultivate carrots as a vegetable crop. From the performance results, this carrot-slicing machine was determined to be highly efficient in processing carrots for end-users. This technology is currently at the field-tested stage.



Fig. 20 - Carrot slicer

Carrot washing and grading machine

The pedal-operated carrot washing and grading machine was developed by Jarso & Wako (2023) and consists mainly of four parts: the pedal assembly, the reciprocating pump assembly, the washing and grading cylinder, and the supporting frame. The washing and grading drum is kept at an angle to allow the product to move easily to the outlet port without stopping the activities based on the calculated coefficient of friction of carrot roots. The unwashed and ungraded carrots are entered into the unit by opening the door hinged on the washing parts. This machine test was carried out with Nantey variety at two levels of feeding loads, 10 kg and 15 kg, at different drum speeds: 1.47 m s⁻¹, 2.20 m s⁻¹, and 2.93 m s⁻¹. The overall mean results obtained for performance indicators in terms of time required to complete washing and grading operations, washing efficiency, grading efficiency, percentage of damaged root, and capacity were recorded as 2.22 min, 98.70%, 92.23%, 1.21%, and 242.17 kg h⁻¹, as reported by the author.

Based on the performance status of machine, it is recommended that the pedal turning mechanism be altered to perform the dual purpose of producing power that might be stored while in use and to improve rural electrification for carrot processing. This machine is better suited to be motorized rather than pedal as an intervention for reducing workload for farmers. This technology is currently at the field-tested stage.



Fig. 21- Carrot washing and grading machine

Most of the mechanization technologies reviewed for tuber crops in Ethiopia are still at early development stages. A substantial proportion of machines, particularly for enset and cassava processing, remain laboratory prototypes that have only undergone controlled performance evaluation. Only a few implements, mainly basic hand tools and small-scale potato processing equipment, can currently be considered commercially viable. This gap between prototype development and practical adoption is mainly attributed to limited on-farm validation, inadequate consideration of smallholder socio-economic conditions, high initial costs, and weak linkage with private manufacturers. Therefore, it is essential to clearly distinguish between laboratory-tested, field-tested, and market-ready technologies when interpreting performance claims and adoption potential.

Table 1

Classification of technologies based on development stage, testing level, and adoption status

Technology	Crop	Development stage	testing level	Adoption status
Enset decorticator	Enset	Prototype	Laboratory	Not adopted
Cassava grater	Cassava	Prototype	Field tested	Limited pilot use
Potato peeler	Potato	Improved prototype	Multi-location field test	Emerging adoption
Turmeric slicer	Turmeric	Prototype	Laboratory	Not adopted
Carrot washer	Carrot	Commercial	Farmer level	Locally adopted

To enable systematic comparison of the diverse mechanization technologies reviewed in this study, a structured comparative framework was developed consisting of four interrelated dimensions: technical performance, cost and economic viability, scalability, and adoption readiness. Technical performance indicators include operational capacity, field efficiency, quality of output, energy or fuel requirement, reliability, and ease of operation and maintenance. The cost dimension evaluates initial investment cost, operating and maintenance expenses, affordability for smallholder farmers, and potential return on investment. Scalability considers the suitability of each technology for different farm sizes, availability of local manufacturing capacity, spare parts accessibility, and compatibility with existing farming systems. Adoption readiness assesses the maturity level of the technology (prototype, field-tested, or commercial), required skill level, gender and labor implications, institutional support, and demonstrated farmer acceptance. Using this framework, each technology is evaluated against standardized criteria, allowing transparent benchmarking and clearer identification of technologies that are technically sound, economically feasible, and practically deployable under Ethiopian smallholder conditions.

DISCUSSIONS

The review revealed that only a limited number of studies have been conducted in Ethiopia to address tuber crop processing challenges. As a result, there remains a high demand for mechanization technologies to improve processing efficiency, reduce labor-intensive tasks, and minimize time requirements. Compared to grain crops, the development and adoption of mechanization technologies for root crops have been significantly limited, indicating that technological interventions in this sector have been inadequate. However, recent progress has been observed in enset processing, where improved technologies are gradually being introduced.

The adoption of mechanization technologies has also influenced gender roles in some areas, with men increasingly participating in processing activities while women seek alternative income-generating opportunities. In enset-growing regions, processing remains a highly labor-intensive and time-consuming activity, placing a substantial burden on women. Therefore, the introduction and expansion of appropriate mechanization technologies are essential to enhance productivity, reduce workloads, and improve the livelihoods of women involved in tuber crop processing.

Different institutions, including Adama University, Wolkite University, Melkassa Agricultural Research Centre, and Bako Agricultural Research Centre, have been working on the development of mechanization technologies for tuber crops to reduce the time and labor required for processing. Among these, Adama and Wolkite Universities have developed cassava peeler and enset decorticator technologies with processing capacities of 120 kg h⁻¹ and 97 kg h⁻¹, and efficiencies of 74% and 98%, respectively. Similarly, the Melkassa and Bako Agricultural Research Centers have developed manually operated cassava slicer and enset grater technologies with capacities of 81 kg h⁻¹ and 1,048 kg h⁻¹, and efficiencies of 73% and 96.4%, respectively. Though, Bako Agricultural Research Centre has made significant progress in enset research and development as a center of excellence, while Melkassa Agricultural Research Centre has achieved considerable advancements in cassava. A comprehensive strategy that promotes the adoption of mechanization technologies, with particular emphasis on strengthening institutional support structures, could substantially reduce post-harvest losses of root crops. Based on the review of available technologies, the grater developed by Kibi (2018) is recommended for enset grating, and the enset decorticator machine developed by Woldeyesus et al. (2025) is recommended for enset decortication due to its comparatively superior performance.

Cross-technology comparative summary

To facilitate clearer comparison among the diverse mechanization technologies reviewed, summary matrices were developed based on reported performance indicators, development status, and adoption levels. These Tables synthesize scattered experimental results into a standardized format, enabling objective benchmarking across crops and operations. Comparative assessment of the reviewed mechanization technologies for root crops in Ethiopia reveals considerable variation in performance parameters such as processing capacity, efficiency, power requirement, and operational cost, largely due to differences in design approaches, testing conditions, and target crops. While some machines, particularly cassava peelers, enset decorticators, and potato harvesters, demonstrate relatively high laboratory efficiencies and throughput, their field performance often declines because of material variability, inconsistent power supply, and inadequate durability.

Limitations commonly observed across the technologies include high initial cost, dependence on imported components, limited adaptability to smallholder farm conditions, and insufficient consideration of ergonomics and gender-sensitive design. Adoption challenges are further intensified by weak technology dissemination mechanisms, lack of trained operators, poor after-sales service, and limited access to credit for small-scale processors. These constraints highlight major research gaps, including the need for standardized performance evaluation protocols, long-term field validation, cost benefit analysis, integration of renewable energy options, and participatory design approaches that better align technologies with user needs and local socio-economic realities.

Table 2

Comparative performance matrix of tuber crop mechanization technologies in Ethiopia

Crop	Technology Type	Capacity (ha h ⁻¹ or kg h ⁻¹)	Efficiency (%)	Loss (%)	Power Requirement	Development Stage	Adoption Level
Enset	Decorticator	250–350 kg h ⁻¹	70–80	8–12	Manual/Motorized	Field-tested	Low
Cassava	Chopper/Grater	300–500 kg h ⁻¹	75–85	5–10	3–5 kW	Prototype	Moderate
Potato	Harvester	0.15–0.22 ha h ⁻¹	60–75	10–15	18–22 hp	Prototype	Very low
Turmeric	Washer/Polisher	200–280 kg h ⁻¹	72–80	6–11	2–3 kW	Experimental	Minimal
Carrot	Slicer/Grader	180–260 kg h ⁻¹	70–82	4–8	1.5–2.5 kW	Field-tested	Low

Development stage categories: Experimental (laboratory level), Prototype (limited field trials), Field-tested (on-farm validation), Commercial (market available).

The cross-technology comparison reveals substantial variability in performance and readiness levels. Processing machines such as cassava graters and enset decorticators generally demonstrate higher capacities, lower power requirements, and better labor-saving potential than field operation equipment such as potato planters and harvesters. Technologies at the prototype stage tend to report promising technical efficiency but often lack evidence of economic viability and user acceptance. Adoption levels remain low across most equipment due to high cost, limited commercial availability, and inadequate institutional support. The matrices further highlight the absence of standardized evaluation criteria, which complicates direct comparison among studies. These summarized comparisons provide a structured basis for identifying priority areas for redesign, further testing, and scaling up interventions.

Table 3

Performance comparison of major mechanization technologies for tuber crops in Ethiopia

Crop Technology	Capacity (kg h ⁻¹)	Efficiency (%)	Energy Requirement	Approx. Cost (ETB)	Field Performance	Adoption Level
Enset Decorticator	90–120 kg h ⁻¹	70–80	3–5 kW electric motor	35,000–60,000	Moderate – sensitive to fiber moisture	Low–Medium
Cassava Peeler	80–120 kg h ⁻¹	65–85	2–3 kW	25,000–45,000	Good in dry conditions, clogging in wet roots	Medium
Potato Harvester	0.15–0.30 ha h ⁻¹	85–92	Tractor driven (20–35 hp)	120,000–250,000	Good on light soils, poor on heavy soils	Low
Potato Slicer/Chipper	100–150 kg h ⁻¹	80–90	1–2 kW	15,000–25,000	Stable and reliable	Medium–High
Turmeric Slicer	70–100 kg h ⁻¹	75–85	1–2 kW	18,000–30,000	Limited by rhizome size variability	Low
Carrot Washer/Peeler	120–180 kg h ⁻¹	80–88	2–4 kW	40,000–70,000	Performs well near water sources	Low

Table 4

Operational and economic comparison of reviewed technologies

Technology	Labor Saving (%)	Fuel/Energy Use	Estimated Cost (ETB)	Maintenance Complexity	Gender Friendliness	Commercial Availability
Enset scraper	60–70	Low	6,000–10,000	Low	High	Limited
Cassava grater	65–80	Moderate	18,000–30,000	Medium	Moderate	Emerging
Potato harvester	50–60	High	150,000–220,000	High	Low	Not available
Turmeric polisher	70–75	Moderate	25,000–40,000	Medium	Moderate	Prototype
Carrot grader	60–72	Low	20,000–35,000	Low	High	Limited

Table 5

Comparative evaluation of operational and socio-economic aspects

Technology	Maintenance Requirement	Local Feasibility	Fabrication	Operating Needed	Skill Gender Suitability	Commercialization Status
Enset Decorticator	High	Medium		High	Moderate	Prototype stage
Cassava Peeler	Medium	High		Medium	Good	Semi-commercial
Potato Harvester	Very High	Low		High	Low	Experimental
Potato Slicer	Low	High		Low	Very Good	Commercialized
Turmeric Slicer	Medium	Medium		Medium	Good	Limited
Carrot Washer	Medium	Medium		Medium	Good	Prototype

Table 6

Key adoption constraints across technologies	
Constraint Category	Observed Issues
Technical	Inadequate durability, high crop damage, limited field adaptability
Economic	High initial cost, lack of credit access, small farm size
Institutional	Weak extension support, poor after-sales service
Socio-cultural	Limited involvement of women in design, low user awareness
Manufacturing	Limited local fabrication capacity and standardization
Evaluation	Lack of standardized testing protocols

CRITICAL ANALYSIS

The reviewed mechanization technologies for tuber crops in Ethiopia demonstrate promising technical potential but reveal significant limitations when critically evaluated in terms of practical performance and sustainability. While several prototypes developed for operations such as peeling, grating, slicing, harvesting, and drying show acceptable laboratory efficiencies and processing capacities, most have not progressed beyond experimental stages or limited field trials. Reported performance indicators are often inconsistent and lack standardization, making meaningful comparison difficult. Moreover, many technologies do not adequately address key practical considerations such as affordability, energy requirements, ease of maintenance, durability under rural conditions, and compatibility with smallholder farming systems. Adoption levels remain generally low due to weak commercialization pathways, limited local manufacturing capacity, and insufficient extension support. Consequently, despite notable institutional efforts, the overall impact of these technologies on reducing labor, improving productivity, and minimizing post-harvest losses remains modest, indicating the need for more user-centered design, rigorous field validation, and stronger integration of technical, economic, and socio-institutional factors in future mechanization initiatives.

The review of the performance status of mechanization technologies developed for tuber crops such as enset, cassava, potato, turmeric, and carrot in Ethiopia addresses a highly relevant issue for improving agricultural productivity and post-harvest management. The manuscript successfully highlights the efforts of various research institutions and universities in developing locally appropriate machines for operations such as harvesting, peeling, grating, and slicing. It brings attention to the potential of mechanization to reduce labor drudgery, minimize post-harvest losses, and enhance processing efficiency. Nevertheless, the analysis remains largely descriptive, focusing primarily on listing available technologies and their reported capacities without adequately examining their real-world performance, economic viability, or level of adoption by farmers and small-scale processors. The absence of a clearly defined methodological approach for selecting and evaluating the technologies further limits the credibility and comprehensiveness of the review.

Technologies success, failure, trade-offs, and adoption constraints

The success or failure of root crop mechanization technologies in Ethiopia has been strongly influenced by a combination of technical, economic, and institutional factors rather than by machine performance alone. Technologies with simple designs, locally available materials, and low initial costs such as manually operated enset decorticators and cassava graters have shown relatively higher acceptance because they are affordable, easy to repair, and compatible with smallholder farming systems. In contrast, more sophisticated motorized equipment often failed to achieve widespread adoption due to high purchase prices, limited access to spare parts, lack of technical skills for operation and maintenance, and unreliable rural power supply. Usability and ergonomics have also played a decisive role; machines requiring excessive labor, complex adjustments, or specialized training were frequently abandoned even when their technical efficiency was high. Furthermore, inadequate after-sales service, weak extension support, and absence of organized supply chains have constrained the sustainability of many promising prototypes developed by research centers. Socio-cultural preferences, fragmented land holdings, and limited access to credit have additionally reduced farmers' willingness to invest in new technologies.

The performance of tuber crop mechanization technologies in Ethiopia involves clear trade-offs between efficiency, cost, and usability. High-capacity machines often require greater energy and investment, limiting adoption by smallholder farmers, while simpler, low-cost tools may reduce labor but compromise throughput. Adoption is further constrained by maintenance needs, operator skills, and compatibility with local practices. Considering these trade-offs alongside socio-economic factors such as affordability and gendered labor roles provides a more realistic assessment of each technology's potential for wider use.

Table 7

Summary of success and failure factors of mechanization technologies for selected tuber crops in Ethiopia

Crop	Technology Type	Main Leading to Success	Strengths Key Observed	Limitations	Adoption Barriers	Overall Outcome
Enset	Manual and semi-mechanized decorticators, scrapers, graters	Simple design, low cost, locally compatible traditional practices, maintenance	fabricated, Moderate capacity, with labor requirement high, easy product quality	High purchase price, need for fuel or electricity, complex maintenance	Limited commercialization, lack of standardization, weak extension support	Relatively successful at smallholder level
Enset	Motorized processing units	Higher throughput and better hygiene	Dependence on engines and fuel, safety concerns in some designs	High purchase price, need for fuel or electricity, complex maintenance	Poor rural power supply, absence of spare parts, and lack of technical skills	Limited adoption despite good performance
Cassava	Motorized graters and chippers	High efficiency, reduced drudgery, good processing quality	Affordable and easy to use	Low capacity, high labor demand	High initial cost, weak after-sales service, credit constraints	Moderate success in commercial settings
Cassava	Manual peelers and cutters	Potential to reduce labor and time, improved uniformity	Low capacity, high labor demand	Heavy weight, poor maneuverability on small plots	Low incentive for farmers due to small scale production	Low to moderate adoption
Potato	Planters and harvesters	Improved market quality and reduced post-harvest losses	Limited mobility and power requirement	Heavy weight, poor maneuverability on small plots	Fragmented landholding, high equipment cost	Mostly unsuccessful at farm level
Potato	Sorting and grading machines	Better hygiene, faster processing, improved product quality	Limited local fabrication experience	Limited mobility and power requirement	Limited awareness, weak market linkage	Adopted mainly by cooperatives
Turmeric	Washing, slicing and drying equipment	Enhanced value addition and market price	Need for electricity and technical skill	Limited local fabrication experience	High investment cost, seasonal utilization	Adoption confined to few processors
Turmeric	Polishing and grinding machines	Reduced post-harvest damage, faster handling	Design not well adapted to local soil conditions	Need for electricity and technical skill	Lack of organized processing centers	Moderate potential but low diffusion
Carrot	Harvesting and cleaning devices	Improves shelf life and product diversification	Requires reliable energy and packaging materials	Design not well adapted to local soil conditions	Small farm sizes, insufficient testing	Low adoption
Carrot	Processing (cutting, drying, packaging) technologies	Improves shelf life and product diversification	Requires reliable energy and packaging materials	Requires reliable energy and packaging materials	Weak value chain, limited market demand	Adopted only at pilot scale

The comparative assessment in Table 7 shows that the success of mechanization technologies across crops has depended more on socio-economic and operational compatibility than on technical efficiency alone. Enset and cassava technologies that were manually operated or locally fabricated achieved relatively higher acceptance because they matched farmers' financial capacity, skill level, and maintenance conditions. Conversely, potato, turmeric, and carrot technologies, although technically promising, generally failed to diffuse due to high capital requirements, dependence on external power sources, and poor suitability to small, fragmented plots. Across all crops, common barriers included a lack of spare parts, weak after-sales service, inadequate training, and limited access to credit. Technologies that demanded electricity or sophisticated maintenance showed particularly low sustainability in rural areas. Table 7 further indicates that institutional factors such as weak extension systems, absence of commercialization pathways, and limited private sector engagement repeatedly constrained scaling-up efforts. These comparisons highlight that future mechanization interventions must prioritize affordability, simplicity, local manufacturability, and strong support systems in order to achieve meaningful adoption.

A comparative evaluation of the reviewed technologies indicates clear differences in performance and practical applicability across crops and machine types. In terms of capacity and efficiency, post-harvest processing machines such as potato slicers, cassava peelers, and carrot washers generally demonstrate higher and more consistent efficiencies (above 80%) compared to primary production machines like potato harvesters and enset decorticators. Technologies designed for size reduction and slicing tend to be simpler, require lower power, and show stable performance under varied conditions.

Conversely, machines that interact directly with soil or complex biological materials such as potato harvesters and enset processors, face greater variability, leading to reduced field reliability despite promising laboratory results.

Regarding energy requirements and cost, most small processing machines operate within 1–4 kW ranges and are relatively affordable for cooperatives or small enterprises. However, tractor-mounted technologies, particularly potato harvesters, demand high power input and substantial capital investment, making them largely inaccessible to smallholder farmers. This explains why adoption levels remain low despite good technical efficiency. In contrast, low-cost machines such as potato slicers and simple cassava peelers have achieved comparatively better dissemination due to affordability, ease of operation, and local manufacturability. Field performance and adoption levels remain the weakest aspects of most technologies. Many prototypes perform well under controlled testing but struggle under real farm conditions due to root size variability, moisture differences, and poor rural infrastructure. Limited availability of spare parts, lack of trained operators, and weak extension services further constrain adoption. Additionally, inadequate consideration of user needs, such as ergonomics, gender suitability, and maintenance simplicity, has restricted widespread utilization.

Overall, the comparison reveals that while Ethiopia has made commendable progress in developing indigenous mechanization technologies, most remain at early developmental stages with limited commercial impact. Strengths lie in the growing local design capacity and promising technical efficiencies of some machines. Weaknesses include inconsistent performance evaluation, high costs of field equipment, and insufficient technology transfer mechanisms. Future efforts should prioritize user-centered design, cost reduction, renewable energy integration, and rigorous multi-location field validation to convert prototypes into widely adopted and sustainable solutions.

The implementation of modern processing technologies for tuber crops should be prioritized, as traditional methods are labor-intensive, time-consuming, and inefficient. Therefore, the introduction of appropriate processing technologies is essential to reduce post-harvest losses. Tuber crops are among the most perishable agricultural products after fruits and vegetables and can deteriorate within two to three days after harvesting. Effective processing provides several benefits, including improved product quality and quantity, extended shelf life, reduced labor requirements, and minimized losses. To address the existing challenges in root crop processing, researchers, institutions, and relevant stakeholders must work together to develop and promote innovative technologies. Furthermore, to improve farmers' livelihoods and enhance cost-effectiveness, responsible bodies should facilitate the introduction, dissemination, and scaling up of well-performing technologies currently available within various institutions.

Flow diagrams for tuber crops such as enset, cassava, potato, turmeric and carrot

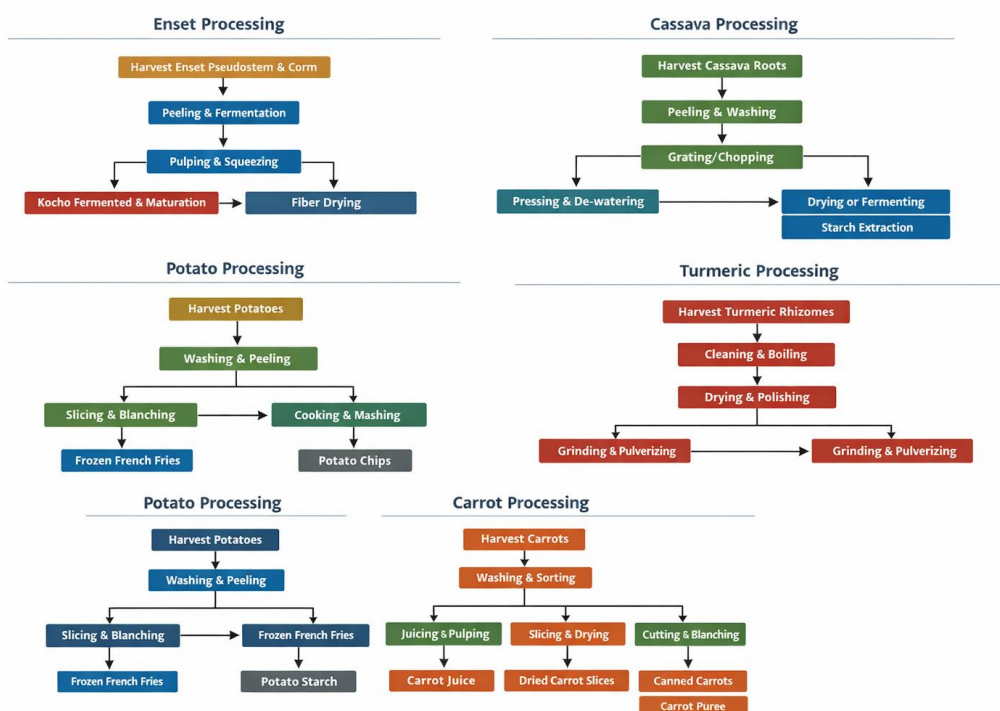


Fig. 22 – Processing technology flow diagrams

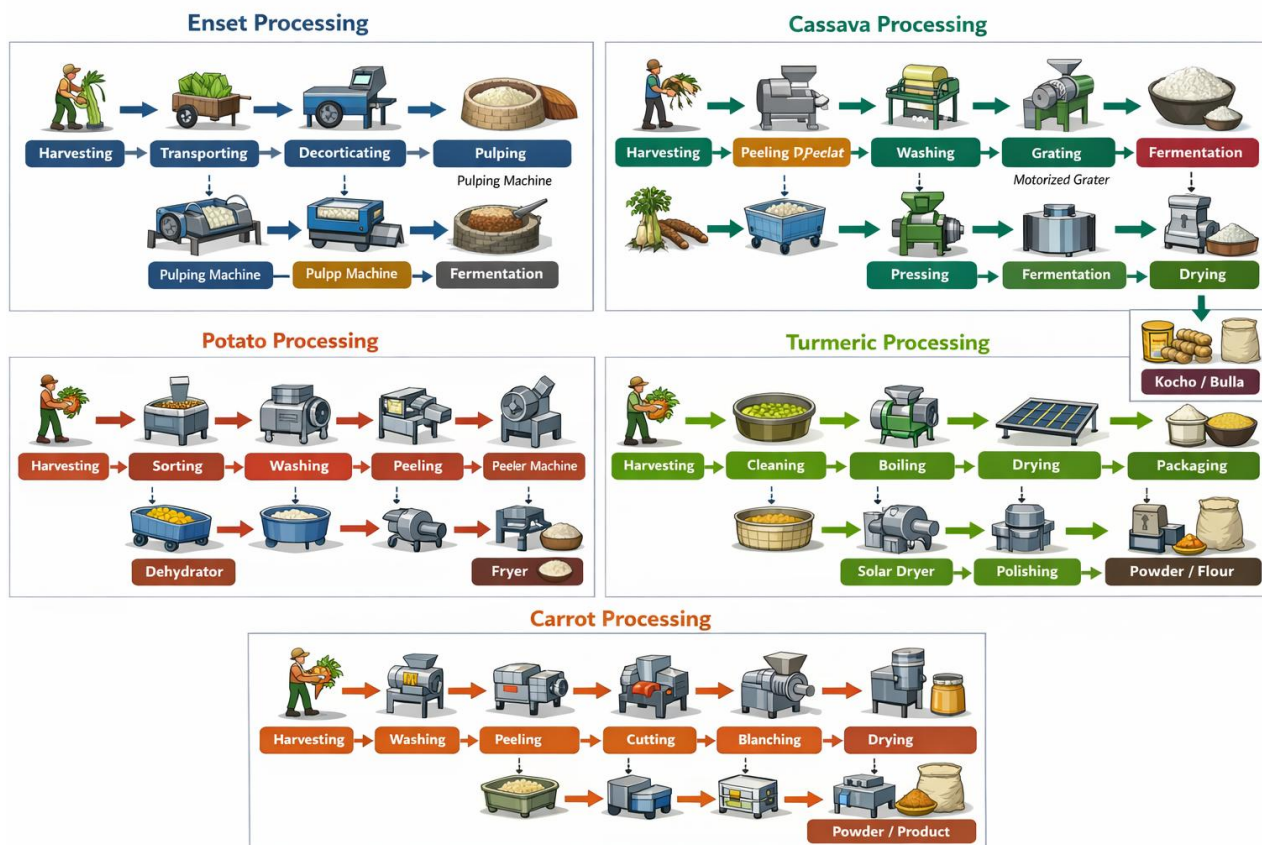


Fig. 23 - Technology flow diagrams

The technology flow diagrams present a clear sequence of operations involved in processing enset, cassava, potato, turmeric, and carrot, highlighting the progression from raw material handling to value-added products and the role of mechanization at each stage. They show that while certain processes, such as grating, drying, and milling, are increasingly supported by improved technologies, many early-stage operations like peeling, decortication, and sorting, remain largely manual and labor-intensive. The diagrams also reflect differences among crops in terms of processing complexity and level of technological advancement, with some value chains being more mechanized than others. Overall, these visual representations help identify critical gaps and intervention points where the introduction or improvement of appropriate mechanization technologies can enhance efficiency, product quality, and scalability in root and tuber crop processing systems.

Table 8

A synoptic table for mechanization technologies for selected tuber crops in Ethiopia

Crop	Major Products	Mechanization Technologies	Key Processing Operations	Challenges
Enset	Kocho, Bulla, Amicho	Enset scraper, decorticator, squeezer, fermentation chamber, integrated enset processing machine	Harvesting → Decortication → Pulverizing → Fermentation (2–6 months) → Drying/Baking	Labor-intensive, mostly done by women; improved machines reduce drudgery and losses.
Cassava	Flour, starch, chips	Mechanical peeler, grater, chipper, starch extraction unit, drying machine	Peeling → Grating → Fermentation → Pressing → Drying → Milling	Perishable crop; processing reduces spoilage and adds value (flour, starch)
Turmeric	Powder, oleoresin, spice	Mechanical washer, slicer, boiler, pulverizer	Cleaning → Boiling → Drying → Grinding → Packaging	Quality affected by drying method; improved dryers enhance color and quality
Potato	Chips, flour, starch	Potato washer, peeler, slicer, dryer, starch extractor	Washing → Peeling → Slicing → Blanching → Frying/Drying → Packaging	Processing improves shelf life and market value
Carrot	Juice, dried slices	Slicer, dryer, pulverizer, grading machine	Washing → Peeling → Cutting → Drying/Juicing → Grinding	High moisture; needs proper drying/storage to avoid spoilage

CONCLUSIONS

The status of mechanization technologies developed for tuber crops was investigated based on key performance indicators. The review indicates that only a limited number of studies have been conducted in Ethiopia to address challenges in tuber crop processing. Furthermore, the development of mechanization technologies for tuber crops remains significantly behind that of grain crops, suggesting that technological interventions in this area have been minimal. The review suggested that future efforts should prioritize user-centered design, gender-based approaches, cost reduction, and rigorous multi-location validation to convert prototypes into widely sustainable solutions. This study suggests that researchers, institutions, and all stakeholders should explore innovative technologies to address the challenges of tuber crop processing. Based on a review, the effective technologies that were identified in this study are recommended for intervention of minor improvement, participatory evaluation, scale-up, and distribution for end users.

REFERENCES

- [1] Abewoy, D. (2021). Review on postharvest handling practices of root and tuber crops. *International Journal of Plant Breeding and Crop Science*, 8(1), 992–1000.
- [2] ADENIYI, V. A. (2022). Cassava processing technology usage and livelihood of women processors in North Central Nigeria. Landmark University, Omu Aran, Kwara State.
- [3] Adugna, B., Kishor, J., Kolhe, P., & Gutu, M. (2025). Design and development of an integrated enset processing machine suitable for central highland farmers of West Shewa Zone, Ethiopia. *Discover Agriculture*. <https://doi.org/10.1007/s44279-024-00114-2>
- [4] Amentae, T. K. (2016). Evaluation of supply chains and post-harvest losses of selected food commodities in Ethiopia (Issue 088).
- [5] Amoah, F., Bobobee, E. Y. H., Addo, A., Darko, J. O., & Oppong, J. (2022). A review of mechanical cassava peeling and its adoption by processors. *Journal of the Ghana Institution of Engineering*, 22, 4.
- [6] Asfaw, Z. (2024). Indigenous knowledge of farmers on classification, utilization and on-farm management of enset (*Ensete ventricosum*) diversity in Hadiya, Southern Ethiopia. *Research Square (Research Square)*.
- [7] Barbaś, P., Noaema, A. H., & Sawicka, B. (2023). Potato (*Solanum tuberosum* L.) as a rich source of nutrients and bioactive compounds: a review. *Journal of Cell and Tissue Research*, 23(2), 7337–7355.
- [8] Barzee, T. J., El-Mashad, H. M., Zhang, R., & Pan, Z. (2019). Carrots. Integrated processing technologies for food and agricultural by-products (pp. 297–330). Elsevier.
- [9] Bassa, Z. F., Ketema, M., Kuma, B., & Mehare, A. (2026). Economic attributes of ensete ventricosum production for the farming communities in Wolaita and Kembata Zones of South and Central Ethiopia.
- [10] Bekele, D. (2024). Opportunities and potentials of potato (*Solanum tuberosum* L.) production and future prospects in Ethiopia. *Global Research in Environment and Sustainability*, 2(1), 42–46.
- [11] Borrell, J. S., Goodwin, M., Blomme, G., Jacobsen, K., Wendawek, A. M., Gashu, D., Lulekal, E., Asfaw, Z., Demissew, S., & Wilkin, P. (2020). Enset-based agricultural systems in Ethiopia: A systematic review of production trends, agronomy, processing and the wider food security applications of a neglected banana relative. *Plants People Planet*, 2(3), 212–228. <https://doi.org/10.1002/ppp3.10084>
- [12] Boxall, R. (1998). Grains post-harvest loss assessment in Ethiopia. Final report. *Project No. T0725 (NRI Report No. 2377)*.
- [13] Brief, F. A. (2022). Agricultural production statistics 2000–2021. *Agricultural Production Statistics 2000–2021*. <https://doi.org/10.4060/cc3751en>
- [14] Dalelo, T. E., & Alandu, K. A. (2022). Design Improvement and performance analysis of kocho, bulla and fiber production machine to achieve good product. 10(4), 2321–2391. www.globalscientificjournal.com
www.globalscientificjournal.com
- [15] Debebe, S. (2022). Post-harvest losses of crops and its determinants in Ethiopia: tobit model analysis. *Agriculture and Food Security*, 11(1), 1–8. <https://doi.org/10.1186/s40066-022-00357-6>
- [16] Deressa, A. A., Derese, G. K., & Dula, M. W. (2023). Pre-extension demonstration and evaluation of enset processing technologies in selected districts of West Shewa and Southwest Shewa Zones, Oromia, Ethiopia. *Journal of Science and Development*, 11(11(1)), 61–66.
- [17] Deressa, A. A., Derese, G. K., & Dula, M. W. (2023). Pre-extension demonstration and evaluation of enset processing technologies in selected districts of west Shewa and southwest Shewa zones, Oromia, Ethiopia. *Journal of Science and Development*, 11(1), 61–66.
- [18] Dhivya, C., Arunkumar, R., & Muthukumar, R. (2024). Turmeric cultivation in Erode district: an analysis

- of farmer constraints. *Journal of Scientific Research and Reports*, 30(9), 439–447.
- [19] Ding, H., & Liu, M. (2024). From root to seed: Unearthing the potential of carrot processing and comprehensive utilization. *Food Science and Nutrition*, 12(11), 8762–8778. <https://doi.org/10.1002/fsn3.4542>
- [20] Edoh Ognakossan, K., Kouakou, J., Mazalo Pali, A., Nanga Nanga, S., & Plagne-Ismail, C. (2016). Cassava: Production and processing. CTA.
- [21] Erchafo, A. (2024a). Performance evaluation of diesel engine operated cassava grating machine. *Turkish Journal of Agricultural Engineering Research*, 5(1), 49–65. <https://doi.org/10.46592/turkager.1420986>
- [22] Erchafo, A. (2024b). Performance evaluation of electric motor driven turmeric slicing machine. *Turkish Journal of Agricultural Engineering Research*, 5(2), 199–218.
- [23] Erchafo, A. (2025). Evaluating the performance of the carrot slicer machine. *Black Sea Journal of Agriculture*, 8(1), 62–72.
- [24] Ertebo, A. E., & Girma, A. (2024). Development and performance evaluation of enset corm pulverizing machine in Hadiya Zone , Central. 8(5), 25–31.
- [25] Etejere, E. O., & Bhat, R. B. (1985). Traditional preparation and uses of cassava in Nigeria. *Economic Botany*, 39(2), 157–164.
- [26] Feleke, N., & Tekalign, W. (2022). The neglected traditional enset (*Ensete ventricosum*) crop landraces for the sustainable livelihood of the local people in Southern Ethiopia. *International Journal of Food Science*, 2022. <https://doi.org/10.1155/2022/6026763>
- [27] Gachena Negera, D. (2021). Value chain analysis of major spices (turmeric and korarima) in Sheka and Kaffa Zones, South-Western Ethiopia. Haramaya university.
- [28] García-Díez, J., Gonçalves, C., Grispoldi, L., Cenci-Goga, B., & Saraiva, C. (2021). Determining food stability to achieve food security. *Sustainability*, 13(13), 7222.
- [29] Gillespie, S., & van den Bold, M. (2017). Agriculture, food systems, and nutrition: meeting the challenge. *Global Challenges*, 1(3). <https://doi.org/10.1002/gch2.201600002>
- [30] Girma, A., Moges, G., & Kidanemariam, G. (2023). Development and performance evaluation of cassava slicing machine. Bahir Dar University.
- [31] Girma, H., & Mohammadsani, Z. (2021). Pre- and post-harvest practices influencing yield and quality of turmeric (*Curcuma longa* L.) in Southwestern Ethiopia: A review. *African Journal of Agricultural Research*, 17(8), 1096–1105. <https://doi.org/10.5897/ajar2020.15409>
- [32] Gregory, P. J., & Wojciechowski, T. (2020). Root systems of major tropical root and tuber crops: Root architecture, size, and growth and initiation of storage organs. In *Advances in Agronomy* (1st ed., Vol. 161). Elsevier Inc. <https://doi.org/10.1016/bs.agron.2020.01.001>
- [33] Hailemariam, M. M., Abera, S., & Neme, G. (2023). Effects of processing methods on the quality of turmeric (*Curcuma longa* L.). Haramaya University.
- [34] Haq, R., & Prasad, K. (2015). Nutritional and processing aspects of carrot (*Daucus carota*)-A review. *South Asian Journal of Food Technology and Environment*, 01(01), 1–14. <https://doi.org/10.46370/sajfte.2015.v01i01.01>
- [35] Hasan, M. U., Malik, A. U., Ali, S., Imtiaz, A., Munir, A., Amjad, W., & Anwar, R. (2019). Modern drying techniques in fruits and vegetables to overcome postharvest losses: A review. *Journal of Food Processing and Preservation*, 43(12), e14280.
- [36] Haverkort, A. J., Linnemann, A. R., Struik, P. C., & Wiskerke, J. S. C. (2023). On processing potato 2 . survey of products , processes and operations in manufacturing. Potato Research.
- [37] Hiywotu, A. M. (2025). Advancing sustainable agriculture for goal 2: Zero hunger - a comprehensive overview of practices, policies, and technologies. *Agroecology and Sustainable Food Systems*, 49(7), 1027–1055. <https://doi.org/10.1080/21683565.2025.2451344>
- [38] Howeler, R. (2006). Cassava in Asia: Trends in cassava production, processing and marketing. *Partnership in Modern Science to Develop a Strong Cassava Commercial Sector in Africa and Appropriate Varieties by 2020, 2006*, 1–38. [http://ciat-library.ciat.cgiar.org/documentos_electronicos_ciat/Articulos_Ciat/0605_Bellagio_Cassava_Production .pdf](http://ciat-library.ciat.cgiar.org/documentos_electronicos_ciat/Articulos_Ciat/0605_Bellagio_Cassava_Production.pdf)
- [39] Hu, X., Jiang, H., Liu, Z., Gao, M., Liu, G., Tian, S., & Zeng, F. (2025). The global potato-processing industry : A review of production, products, quality and sustainability.
- [40] Hunduma, T., & Mogessie, A. (2011). Traditional enset (*Ensete ventricosum*) processing techniques in

- some parts of West Shewa Zone, Ethiopia. *Journal of Agriculture and Development*, 2(1), 37–57. <http://opendocs.ids.ac.uk/opendocs/handle/123456789/8730>
- [41] Immanuel, S., Jaganathan, D., Prakash, P., & Sivakumar, P. S. (2024). Cassava for food security, poverty reduction and climate resilience: A review. *Indian Journal of Ecology*, 51(1), 21–31.
- [42] Iqbal, M. A. (2020). Crop production under changing climate: A global perspective. *Sustainable Crop Production*, 293.
- [43] Jarso, M., & Wako, A. (2023). Design of carrot washing and grading machine. *Agricultural Engineering International: CIGR Journal*, 25(1), 225–249.
- [44] Karim, O. R., Oyeyinka, S. A., & Adekunle, O. A. (2014). Upgrading traditional food processing technologies: The cassava example in Nigeria. *Food Studies*, 3(1), 1–8.
- [45] Kebede, L., Getnet, B., Teamir, M., Moges, G., & Kelemu, F. (2018). Results of agricultural machinery and post-harvest engineering research. In *Results of Agricultural Machinery and Post-harvest Engineering Research*. <https://doi.org/10.13140/RG.2.2.24706.02249>
- [46] Kiaya, V. (2014). Post-harvest losses and strategies to reduce them. Technical paper on postharvest losses, *Action Contre La Faim (ACF)*, 25(3), 1–25.
- [47] Kibi, G. (2018). Development and evaluation of engine driven corm grating machine. 16–21.
- [48] Kibi, G., & Tefera, G. (2024). Integrating of corm grating and leaf sheath decorticating machine. 8–12.
- [49] KOLHE, K. P., & ADUGNA, B. (2025). A comprehensive review of enset processing technologies and their importance in Ethiopia. *Mysore Journal of Agricultural Sciences*, 59(2).
- [50] Kosgolgedara, E., Dharmasena, N., & Jayatissa, N. (2021). Design, fabrication and performance evaluation of a rotary drum abrasion, continuous type peeling machine for solanum tuberosum (*Potato*).
- [51] Kumar, R. (2021). *A review on processing of turmeric rhizome*. 13(2), 55–58.
- [52] Lal, M. K., Tiwari, R. K., Jaiswal, A. K., Kumar, R., Kumar, D., Kumar, A., Dutt, S., Kumar, D., & Singh, B. (2023). Post-harvest management and value addition in potato: emerging technologies in preserving quality and sustainability in potato processing. *XXII Biennial National Symposium Special Issue*, 68, 241–261.
- [53] Manuraj, D., Gharge, K. S., & Pise, A. T. (2020). A Review on post processing of turmeric rhizome. *International Research Journal of Engineering and Technology*, 7(3), 4800–4803. www.irjet.net
- [54] Melese, T., & Gurmis, N. (2024). Smallholder farmers technical efficiency and production constraints in turmeric production: in South-western Ethiopia. *Journal of Medicinal Plants and By-Products*, 13(1), 209–218. <https://doi.org/10.22034/JMPB.2023.358017.1459>
- [55] Milkias, D., & Keba, A. (2021). Potato production and marketing by small holder farmers in Ethiopia: A review study. *Journal of Natural Sciences Research*, 12(16), 9–15.
- [56] Mohamed, A. S., El-Sayed, S. M., Elsayed, S. I. M., & Mazher, A. A. M. (2023). Impact of turmeric and carrot extracts on morphological, chemical composition and isozymes patterns of *Azadirachta indica* seedlings under water deficiency conditions. *Egyptian Pharmaceutical Journal*, 22(3), 466–480.
- [57] Mohammed, T. (2017). Design, construction and performance evaluation of power driven potato peeling machine. *International Journal of Engineering Research-Online*, 5(6).
- [58] Motegaonkar, S., Shankar, A., Tazeen, H., Gunjal, M., & Payyanad, S. (2024). A comprehensive review on carrot (*Daucus carota* L.): the effect of different drying methods on nutritional properties and its processing as value-added foods. *Sustainable Food Technology*, 2(3), 667–688. <https://doi.org/10.1039/d3fb00162h>
- [59] Mulugeta, A., Asrat, F., Asres, D., & Mebrat, S. (2025). Evaluation of carrot (*Daucus carota* L.) varieties for growth and yield as affected by NPSB fertilizer rates in Gondar district, Ethiopia. *Frontiers in Plant Science*, 16, 1505302.
- [60] Muthoni, J., & Shimelis, H. (2023). An overview of potato production in Africa. *Potato Production Worldwide*, 435–456.
- [61] Nainggolan, E. A., Banout, J., & Urbanova, K. (2024). Recent trends in the pre-drying, drying, and post-drying processes for cassava tuber: a review. *Foods*, 13(11), 1778.
- [62] Nanbol, K. K., & Namo, O. (2019). The contribution of root and tuber crops to food security: A review. *J. Agric. Sci. Technol. B*, 9(10.17265), 2161–6264.
- [63] Nayak, L., Barik, M., Tiwari, R. K., Kumar, R., Kumar, A., & Lal, M. K. (2025). Overview of underground vegetable crops. In *Abiotic Stress in Underground Vegetables* (pp. 3–11). Elsevier.
- [64] Ndubuisi, N. D., & Chidiebere, A. C. U. (2018). Cyanide in cassava: a review. *International Journal of Genomics and Data Mining*, 118.

- [65] Olango, T. M., Tesfaye, B., Catellani, M., & Pè, M. E. (2014). Indigenous knowledge, use and on-farm management of enset (*Ensete ventricosum* (Welw.) Cheesman) diversity in Wolaita, Southern Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, 10, 1–18.
- [66] Paparella, A., Kongala, P. R., Serio, A., Rossi, C., Shaltiel-Harpaza, L., Husaini, A. M., & Ibdah, M. (2024). Challenges and opportunities in the sustainable improvement of carrot production. *Plants*, 13(15).
- [67] Parimaladevi, M. A. (2024). A critical observation on agricultural development of turmeric procedure in Erode, Tamilnadu. *Journal Of Agriculture*, 3(1), 1–10.
- [68] Parmar, A., Fikre, A., Sturm, B., & Hensel, O. (2018). Post-harvest management and associated food losses and by-products of cassava in southern Ethiopia. *Food Security (TSI)*, 10(2), 419–435.
- [69] Parmar, A., Sturm, B., & Hensel, O. (2017). Crops that feed the world: Production and improvement of cassava for food, feed, and industrial uses. *Food Security*, 9(5), 907–927.
- [70] Que, F., Hou, X. L., Wang, G. L., Xu, Z. S., Tan, G. F., Li, T., Wang, Y. H., Khadr, A., & Xiong, A. S. (2019). Advances in research on the carrot, an important root vegetable in the Apiaceae family. *Horticulture Research*, 6(1). <https://doi.org/10.1038/s41438-019-0150-6>
- [71] Ridolfi, C., Vivian, H., & Siddhartha, B. (2018). Post-harvest losses in fruits and vegetables : The Kenyan context. *International Food Policy Research Institute, March*, 1–15.
- [72] Santosh, D. T., & Ali, S. M. (2024). Post-harvest technologies: Enhancing shelf life and quality. *Modern Agronomy, June*, 111–129.
- [73] Saravanan, R., Ravi, V., Stephen, R., Thajudhin, S., & George, J. (2016). Post-harvest physiological deterioration of cassava (*Manihot esculenta*)-A review. *Indian Journal of Agricultural Sciences*, 86(11), 1383–1390.
- [74] Seljåsen, R., Kristensen, H. L., Lauridsen, C., Wyss, G. S., Kretzschmar, U., Birlouez-Aragone, I., & Kahl, J. (2013). Quality of carrots as affected by pre-and postharvest factors and processing. *Journal of the Science of Food and Agriculture*, 93(11), 2611–2626.
- [75] Sirany, T., Tadele, E., Hibistu, T., Kefalew, A., & Reta, H. (2022). Economic viability and use dynamics of the enset food system in Ethiopia: its implications for food security. *Advances in Agriculture*, 2022(1), 5741528.
- [76] Siwar, C., Ghazali, R., & Ibrahim, M. (2022). Agriculture and food security. In *Malaysia's leap into the future: The Building Blocks Towards Balanced Development* (pp. 117–139). Springer.
- [77] Sumonsiri, N., & Barringer, S. A. (2014). Fruits and vegetables—processing technologies and applications. *Food Processing: Principles and Applications*, 363–381.
- [78] Taiwo, K. A., & Fasoyiro, S. B. (2015). Women and cassava processing in Nigeria. *International Journal of Development Research*, 5(2), 3513–3517.
- [79] Technologies for African Agricultural Transformation (TAAT). (2021). Cassava technology toolkit *Catalogue*. 1–48.
- [80] Temam, M. (2020). Development and evaluation of power driven cassava grater and chipper machine. *International Journal of Engineering Research*. <https://doi.org/10.33329/ijoer.8.5.1>
- [81] Thul, P. P., & Shirsat, B. S. (2021). Effect of curing and drying process of turmeric on its quality: A review. *International Journal of Advanced Biochemistry Research*, 5(2), 61–68. <https://doi.org/10.33545/26174693.2021.v5.i2a.1236>
- [82] Tikuneh, D. B., & Beri, A. F. (2023). Design, manufacture, and performance evaluation of a single-axle tractor-operated potato digger elevator. *Cogent Engineering*, 10(2). <https://doi.org/10.1080/23311916.2023.2251744>
- [83] Udochukwu, P. D. (2024). Climate change effect on land use, cassava production and yield in Nigeria. Promise Delight Udochukwu.
- [84] Urugo, M. M., Yohannis, E., Teka, T. A., Gemedo, H. F., Tola, Y. B., Forsido, S. F., Tessema, A., Suraj, M., & Abdu, J. (2024). Addressing post-harvest losses through agro-processing for sustainable development in Ethiopia. *Journal of Agriculture and Food Research*, 18(April), 101316. <https://doi.org/10.1016/j.jafr.2024.101316>
- [85] Varma, K., & Gopi, S. (2020). *Production, economics and marketing of turmeric*.
- [86] Vutula, N. (2024). The reduction of post-harvest losses is crucial for a successful cassava value chain and food security in Africa. *The Open Agriculture Journal*, 18(1), 1–11. <https://doi.org/10.2174/0118743315333391241205114914>
- [87] Wijesinha-Bettoni, R., & Mouillé, B. (2019). The contribution of potatoes to global food security, nutrition

- and healthy diets. *American Journal of Potato Research*, 96(2), 139–149. <https://doi.org/10.1007/s12230-018-09697-1>
- [88] Woldeyesus, Y., Weldemichael, H., Abeje, M., & Tadesse, A. (2025). Performance evaluation of the enset decorticator machine and comparison of the end product with manual decortication method. 27(1), 52–60.
- [89] Workesa Dula, M. (2018). Design, construction and performance evaluation of engine driven enset (*Enset ventricosum*) decorticator. Haramaya University.
- [90] Workesa, M., Gebresenbet, G., Fanta, A., & Chaka, A. (2021). Design and development of engine driven decorticating machine. *American Journal of Mechanical and Industrial Engineering*, 6(2), 17. <https://doi.org/10.11648/j.ajmie.20210602.11>
- [91] Yimer, S., & Babege, T. (2018). Evaluation of constraints in production of root and tuber crops in Ethiopia : Overview of policy neglected climate resilient food security crops. *Journal of Plant Breeding and Crop Science*, 10(8), 210–217. <https://doi.org/10.5897/JPBCS2018.0732>
- [92] Yuan, Y., Wei, X., Mao, Y., Zheng, Y., He, N., Guo, Y., Wu, M., Dumpler, J., Li, B., Chen, X., Cai, X., Wu, J., Tian, Y., Xie, S., Subbiah, J., & Wang, S. (2025). Innovative food processing technologies promoting efficient utilization of nutrients in staple food crops. *Engineering*, 50, 229–244. <https://doi.org/10.1016/j.eng.2025.04.014>
- [93] Zewdie, A. (2012). Assessment of performance and adoption of improved enset processing technologies. *Agric Sci*, 8(3), 345–355.