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Economic performance of introduced cassava processing technologies in coastal regions, Tanzania

Meda Theodory

Mechanical cassava processing technologies have been recently introduced in Tanzania, yet their economic viability and farmer-level profitability remain underexplored. This study provides one of the first multidimensional evaluations of cassava mechanization in coastal regions (Tanga and Pwani) by integrating Net Present Value (NPV), Benefit–Cost Ratio (BCR), sensitivity analysis, and partial budgeting within a single analytical framework. Data from household surveys, focus groups, and machine trials were analyzed to assess technical efficiency, cost structures, and profitability of manual and engine-powered chippers and graters compared with traditional drying and fermentation. Results reveal that mechanized technologies shorten the drying time from 6–12 days to 1–3 days and produce flour of better quality. All machines showed profitable returns, with the cassava grater achieving the highest absolute returns, while the manual chipper achieved the best cost–benefit balance (3.25) and highest daily profitability (TZS 320.40/kg), which makes it a practical choice for small-scale farmers. The study's novelty lies in combining investment appraisal with per-kilogram profitability measures that translate economic viability into actionable farmer decisions. These findings contribute new evidence on region-specific cassava mechanization and offer policy pathways to scale adoption through subsidies, co-operative ownership, and credit access.

Keywords Cassava processing, Mechanization, Technical efficiency, Profitability, Benefit–cost analysis

Cassava (*Manihot esculenta* Crantz) remains one of the most important root crops in sub-Saharan Africa, contributing to food security, household incomes, and rural livelihoods. In Tanzania, it is cultivated across diverse ecological zones, with Tanga, Pwani, Mwanza, and Lindi among the leading production regions. Recent estimates show that the country produced over 8 million tonnes in 2022, representing about 3% of global output and more than 5% of Africa's total supply[1,2]. Cassava's resilience to drought and poor soils underscores its importance under changing climatic conditions, while its multiple uses in food, feed, and industry highlight its potential for agro-industrial development[3,4]. Despite this promise, cassava production and utilization face major challenges. Fresh roots deteriorate rapidly, often within 48 to 72 h, limiting their marketability and discouraging long-distance trade[5]. Nutritional limitations, particularly low protein levels and the presence of cyanogenic compounds, reduce the crop's dietary appeal unless it is processed properly[6]. Cultural perceptions in some communities, where cassava is associated with poverty, further weaken consumer demand[7].

Processing technologies have emerged as a solution to these constraints. Traditional approaches such as sun-drying or wet fermentation are still widely practiced but are labour-intensive, slow, and prone to post-harvest losses. More recently, mechanical chippers, graters, and presses have been introduced to enhance efficiency, improve product quality, and extend shelf-life[8–10]. These machines also improve detoxification and yield higher-value products such as high-quality cassava flour (HQCF), which is increasingly in demand from food and industrial processors[3,11]. However, their adoption remains uneven due to high purchase costs, inadequate rural service networks, and limited farmer awareness[4,12].

Cassava processing holds significant economic importance for Tanzania's coastal regions. Tanga and Pwani are not only among the leading cassava-producing zones but also strategically located near urban markets such as Dar es Salaam, where demand for high-quality cassava flour and starch is growing[2]. Processing reduces post-harvest losses often exceeding 20% in fresh roots while creating value-added products with longer shelf life and higher market prices[3,13]. Mechanized processing in particular shortens drying time, lowers labour requirements,

Department of Economics and Statistics, Moshi Co-operative University, P.O. Box 474, Moshi, Tanzania. email: medatheodory@gmail.com

and improves flour quality, thereby increasing profitability for smallholders and entrepreneurs[8,14]. Beyond household income, cassava processing also generates employment for youth and women in rural communities and contributes to import substitution by reducing reliance on wheat-based products[4,11]. These economic realities highlight the urgent need to evaluate the performance of emerging cassava processing technologies in coastal Tanzania, where adoption remains low despite the clear potential for improving rural livelihoods and supporting agro-industrial development. Cassava processing technologies in Tanzania's coastal regions are broadly classified into two categories: traditional and mechanical (mechanized) methods, as illustrated in Fig. 1.

Traditional technologies include two main approaches wet/solid-state fermentation and sun-drying. In contrast, the introduced mechanical cassava processing comprises three types of equipment: the manual chipper, the engine-powered chipper, and the cassava grater. After grating, cassava is transferred to a presser machine, which removes excess starch and cyanide, thereby enhancing both safety and product quality.

Moreover, mechanical cassava processing technologies nowadays incorporate equipment such as chippers, graters, pressers, mills, gari fryers, and sifters[15]. These methods involve steps such as chipping, grating, and crushing, which are particularly effective for cyanide reduction because the complete rupture of cassava plant cells enhances the interaction between the enzyme linamarase and the cyanogenic compound linamarin[6]. The success of mechanized processing, however, depends not only on technical efficiency but also on the initial capital outlay and recurrent costs of operation, maintenance, and repair. Careful management of these costs is essential to maximize machine profitability, ensure production efficiency, and sustain long-term adoption[4,16]. Recent scholarship highlights the growing role of cassava processing mechanization in supporting food security, rural livelihoods, and agro-industrial development in Africa. In Tanzania, Abass et al.[13] demonstrated that small-scale processing units reduce post-harvest losses and improve market opportunities, while Adegbite et al.[8] emphasized mechanization's role in reducing drudgery and creating new income streams, particularly for women. Other studies from West Africa echo similar trends: Boateng et al.[16] found that cooperative ownership of processing equipment enhances smallholder profitability, while Asempah et al.[9,10] showed that Ghanaian farmers are willing to invest in cassava peeling and grating machines when access to credit is available. Awoyale et al.[14] further revealed that processing cassava into high-quality cassava flour (HQCF) in Nigeria can improve household incomes and substitute wheat imports, thereby strengthening regional food systems.

More broadly, Li et al.[4] argue that successful mechanization requires simultaneous investments in infrastructure, financing, and extension services, while the United Republic of Tanzania[2] and Auditax International[17] outline national strategies and tax incentives that lower barriers to technology adoption. Together, these regionally relevant studies confirm that cassava mechanization is both technically feasible and economically beneficial, but its success depends on enabling policies, inclusive financing models, and strengthened value-chain linkages. Although cassava is central to food security and rural livelihoods in Tanzania, most previous studies have focused broadly on production, utilization, and adoption of improved processing methods[18,19]. However, very few have examined the economic performance of traditional and mechanical technologies side by side, especially in coastal regions where cassava is both a staple and a commercial crop. Recent research has highlighted farmer willingness to adopt mechanized options such as peeling machines[9,10], yet such studies often stop short of assessing long-term profitability, cost–benefit trade-offs, and farmer-level decision constraints. This leaves an important knowledge gap on how processing choices influence household incomes and value chain development in Tanzania's coastal areas.

Moreover, Fig. 2 presents the conceptual framework guiding this study. The framework illustrates how the adoption of cassava processing technologies influences productivity and efficiency at the processing stage, which in turn reduces costs and post-harvest losses, enhances product quality, and increases returns.

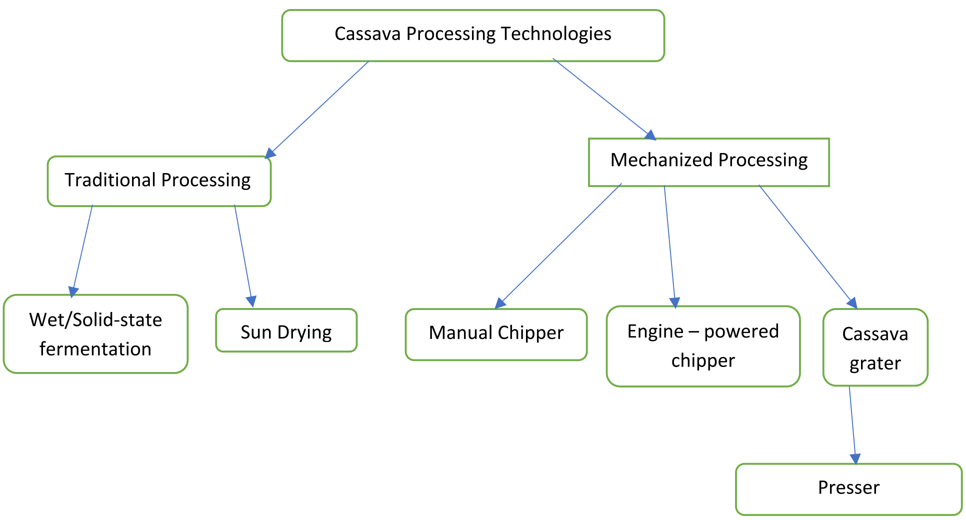

Fig. 1. Overview of cassava processing technologies in Tanzania's coastal regions.

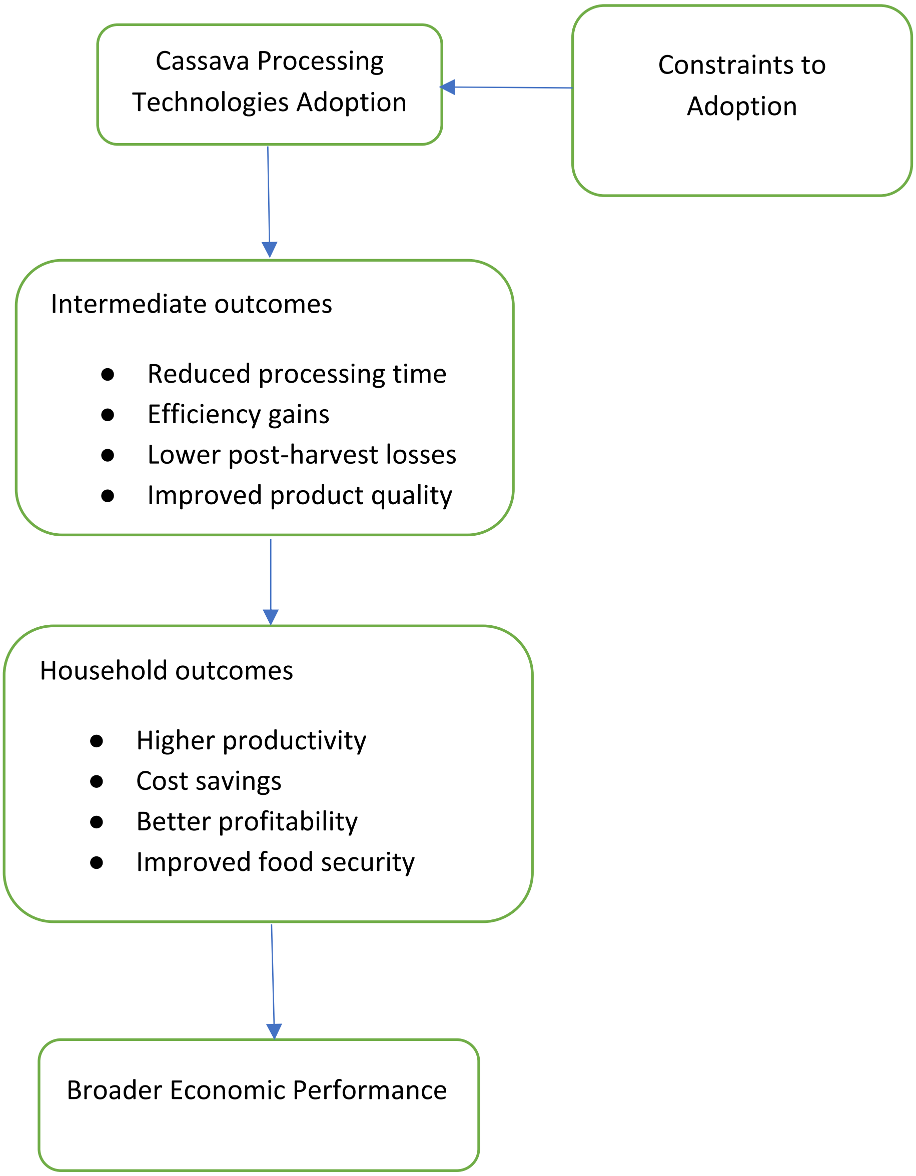

Fig. 2. Conceptual framework.

These improvements contribute to higher household income and better economic performance at the community and regional level. The framework also reflects constraints such as access to capital, infrastructure, and farmer decision-making factors, which affect technology adoption.

Therefore, present study evaluates the technical and economic performance of manual and engine-powered cassava processing machines in Tanga and Pwani, comparing them with traditional methods. Its novelty lies in employing a hybrid framework that integrates Net Present Value (NPV), Benefit–Cost Ratio (BCR), sensitivity analysis, and partial budgeting. This multidimensional approach bridges long-term investment appraisal with farmer-level profitability, thereby addressing both methodological and regional evidence gaps. To sharpen the study's focus, the following research objectives, guiding questions, and hypotheses were formulated;

Research objectives

(i) To assess the technical efficiency of traditional and mechanized cassava processing technologies in Tanzania's coastal regions.
(ii) To evaluate the economic performance of manual and engine-powered chippers and graters using Net Present Value (NPV), Benefit–Cost Ratio (BCR), sensitivity analysis, and partial budgeting.
(iii) To identify the most profitable and practical cassava processing technologies for smallholder farmers under prevailing economic realities.

Research questions

(i) How do mechanized cassava processing technologies compare with traditional methods in terms of technical efficiency and processing time?
(ii) What is the economic viability of cassava processing machines when analyzed through NPV, BCR, sensitivity analysis, and partial budgeting frameworks?
(iii) Which cassava processing technologies are most suitable for smallholder farmers given capital constraints and production scales?

Hypotheses

(i) *H1:* Mechanized cassava processing technologies significantly reduce processing time and improve flour quality compared to traditional methods.
(ii) *H2:* Mechanized cassava processing machines generate positive NPVs and BCRs, indicating long-term financial viability.
(iii) *H3:* Manual chippers yield higher benefit–cost ratios and daily profitability relative to engine-powered machines, making them more suitable for smallholder farmers.

Analytical Framework

Answering the study's objectives and questions, there was a necessity to develop an analytical framework that looks at both the technical performance and the economic viability of cassava processing machines. The framework was designed to reflect the realities farmers face, while also testing the study's guiding hypotheses. It distinguishes between costs that occur simply from owning a machine such as depreciation, insurance, and housing and those that arise only when the machine is used, such as fuel, labour, and repairs. This approach, consistent with current agricultural economics and engineering practice, provides a structured basis for estimating machine expenses such as interest, insurance, housing, depreciation, taxes, and operational inputs and profitability[20–22].

Moreover, the evaluation of these costs and benefits, four complementary tools were applied; Net Present Value (NPV), Benefit–Cost Ratio (BCR), sensitivity analysis, and partial budgeting. Each tool offers a different perspective, the NPV and BCR capture the long-term investment picture (Boardman et al. 2018; Brealey et al. 2020), sensitivity analysis tests how outcomes change when prices or costs fluctuate (Brigham & Ehrhardt 2022), and partial budgeting shows day-to-day profitability at the farmer level[20] . Taken together, these methods provide a multidimensional view of how different technologies perform, directly addressing the study's questions on efficiency, viability, and suitability for smallholder farmers. Therefore, these costs of the machines were evaluated as follows;

Costs of the machines

Recent studies continue to categorize machinery costs into two groups: use-related and time-related costs. Use-related costs occur only when the machine is actively in operation and include expenditures such as fuel, lubrication, repairs directly linked to usage, and labour. In contrast, time-related costs often referred to as overhead costs are incurred regardless of machine use. These typically encompass interest, insurance, taxes, and storage requirements[21,23]. Depreciation is generally considered both a use-related and time-related cost, as greater utilization accelerates wear and reduces salvage value, though it is also affected by age and obsolescence[22]. Standard machinery cost computations and overhead allocations follow guidelines provided by the American Society of Agricultural and Biological Engineers[24,25] as follows.

Interest

If the operator takes out a loan to purchase a machine, the interest rate is determined by the lending institution. However, when farmers use personal capital, the relevant rate is the opportunity cost of diverting funds from other farm enterprises. When financing is partly borrowed and partly personal, an average of the two rates is typically applied[21]. For example, if the average nominal interest rate is 8% and inflation is 3%, the real cost of borrowing falls to approximately 5%. This adjustment reflects the principle that inflation reduces the real burden of repaying farm machinery loans over time[22,26]. The adjusted real interest rate can then be applied to calculate annual machinery interest costs within standard cost-estimation frameworks.

$$Interest/year = \frac{PC + SV + DP}{2} \times IR \tag{1}$$

where; PC = Purchase costs, SV = Salvage value, DP = Depreciation and IR = Real interest rate,

Therefore, the interest cost hinders small farmers to purchase the farm machinery or run the machine. In addition to interest expenses, farmers also face risks associated with unexpected losses. To mitigate such risks, insurance is considered an essential component of machinery ownership costs as follows.

Insurance

In economics, insurance is widely recognized as a key tool for managing risk. It works by transferring the potential burden of loss from one party to another in exchange for a premium, essentially turning the possibility of a devastating loss into a manageable, predictable cost. The rate applied to the value of the insured asset determines the premium to be paid. In recent years, risk management has developed into a specialized field that integrates systematic methods for evaluating and controlling different types of risks[27,28]. For farm machinery, annual insurance costs can be estimated using the formula, as follows:

$$Insurance/year = \frac{PC + SV + DP}{2} \times INR \tag{2}$$

where; PC = Purchase costs, SV = Salvage value, DP = Depreciation and INR = Insurance rate.

Insuring machinery is therefore an important safeguard for farmers, ensuring that equipment can be replaced if disasters such as fires, theft, or storms occur. Without this protection, the full cost of such losses would fall directly on the farming business[27]. Beyond financial costs, appropriate storage also affects machine performance and long-term value. Therefore, housing costs must be factored into overall machinery expenses.

Housing cost

Farm machinery is stored in diverse ways depending on farm resources and management priorities. Housing equipment in sheltered facilities together with access to basic maintenance tools reduces exposure-related deterioration and field breakdowns, which in turn supports more reliable performance and preserves resale or trade-in value. Current machinery cost frameworks treat housing as an ownership (fixed) cost alongside depreciation, interest, insurance, and taxes (often grouped as TIH/THILM) and recommend including it when budgeting or benchmarking machinery economics[25,29–31]. The annual housing cost can be expressed as:

$$H/year = P/m^2 \times m^2 SS \tag{3}$$

where; H = Housing, P = Price and SS = Shelter space required.

Thus, allocating funds for equipment housing yields practical benefits longer service life, fewer repairs, better condition/appearance, and easier routine servicing which ultimately supports lower lifetime costs and improved profitability within standard machinery-management models[25,29]. While housing reduces deterioration, machinery still loses value over time due to wear, aging, and obsolescence. This decline is captured through depreciation estimations as follows.

Depreciation

Depreciation accounts for the cost attributed to wear, aging, and obsolescence of machinery. Mechanical deterioration reduces a machine's resale or trade-in value relative to similar equipment[23]. Technological advances or design improvements can also precipitate abrupt drops in value, by rendering older models obsolete. Still, the principal determinants of remaining value remain the machine's age and cumulative usage hours[23,25].

When calculating annual depreciation, one must first define the economic life (the years over which costs will be allocated) and estimate salvage value (the expected residual worth at end of life). Economic life is often shorter than actual service life, because many operators replace machinery before total exhaustion. A common guideline is 10–12 years for general farm equipment[23,32].

Salvage value reflects the anticipated trade-in or resale value at the end of economic life, which may be influenced by market demand, machine condition, and regional preferences[25]. Based on these, annual depreciation might be calculated as:

$$Depreciation/year = \frac{PC - SV}{LS} \tag{4}$$

where; PC = Purchase costs, SV = Salvage value and LS = Life span of machine.

Depreciation is a non-cash cost important for accounting and strategic planning. It represents a notional amount that should be set aside annually for equipment replacement. Depreciation also plays a critical role in tax planning, investment decision making, and estimating both current and future machine values[32,33]. Alongside depreciation, taxation policies also influence the effective cost of owning farm machinery, though these vary widely by context.

Taxes

Tax policies on farm machinery are not uniform across countries. In some settings, equipment is treated as personal property and taxed accordingly, while in others it is exempt to encourage agricultural investment. Tanzania, for instance, has adopted a policy that provides full tax exemptions on agricultural machinery. This measure is intended to reduce barriers to mechanization and make it easier for farmers to access modern equipment[17]. Finally, in addition to fixed ownership costs, farmers must consider operational costs, which arise directly from machine use. These include fuel, lubrication, labour, and repairs, and are often decisive in determining the overall profitability of machinery adoption.

Operational costs

Use-related costs, such as fuel expenses, are estimated by multiplying a machine's fuel consumption rate by the prevailing fuel price. Lubrication and filter costs are commonly estimated at around 15% of fuel costs[23]. Repair and maintenance expenses are derived by dividing the total accumulated repair costs by the total hours of machine operation[23]. These calculation procedures follow the standards of the American Society of Agricultural and Biological Engineers (ASABE), which outline methods for estimating ownership and operating costs of agricultural machinery[24]. The estimated annual hours of operation reflect typical commercial farm use and were applied in this study to compute the Net Present Value (NPV) of each machine[31].

Materials and Methods
Study area and sampling design
The study was carried out in two districts along the Tanzanian coast: Muheza (Tanga Region) and Kibaha (Pwani Region). Villages were purposively selected based on the prevalence of cassava cultivation and the co-existence of both traditional and mechanical processing methods. A stratified random sampling approach was then applied. Farmers were grouped by income level (low versus high), and from each stratum 30 respondents were randomly selected, yielding a total of 120 households. This sample size is consistent with methodological guidance suggesting that at least 30 observations per group are adequate for robust statistical inference[34–37].

Data collection procedures
Primary data were collected using a structured questionnaire that captured socio-economic characteristics, processing methods, costs, and returns. Experimental trials were conducted to measure technical efficiency: 5 kg of peeled cassava chunks were fed into each machine type (manual chipper, engine-powered chipper, cassava grater) and processing time, fuel consumption, and labor requirements were recorded. Trials were repeated five times for reliability. Focus group discussions with farmers and key informants (village leaders, agricultural officers, local processors) complemented household data, providing contextual insights and triangulation.

Data analysis
Data analysis combined descriptive statistics and economic evaluation techniques. Descriptive statistics (frequencies and means) summarized technology adoption patterns and processing time. Moreover, four complementary tools were applied: Net Present Value (NPV), Benefit–Cost Ratio (BCR), Partial Budget Analysis (PBA), and Sensitivity Analysis. Together, these tools offered a multidimensional perspective on the economic performance of cassava processing technologies.

Net Present Value (NPV)
Net Present Value (NPV) was applied as an investment appraisal tool that measures the difference between the present value of expected cash inflows and the present value of cash outflows, discounted at a chosen rate (Brealey et al. 2020). It is grounded in the time value of money principle, which recognizes that a unit of currency today is worth more than the same unit in the future (Ross et al. 2021). The formula to compute the NPV is expressed as follows;

$$NPV = \sum_{i=1}^{n} \frac{C_t}{(1+i)^t} - C_o + \frac{R_n}{(1+i)^n} \tag{5}$$

where, NPV = Net present value, C_t = Net cash flow, C_o = Initial investment, i = Discount rate in (%), t = Time of cash flow and R_n = Salvage value.

A positive NPV indicates that the investment generates returns above its costs and therefore adds value to the investor, while a negative NPV suggests that the investment destroys value and should be rejected (Damodaran, 2023). In decision making, NPV assists managers and policymakers in evaluating machines profitability, comparing alternatives, and accounting for risk. Unlike payback methods, NPV considers all cash flows over the machine's life, providing a long-term perspective (Fabozzi & Peterson Drake, 2021). Moreover, adjusting the discount rate allows decision makers to incorporate uncertainty and risk premiums, which enhances the robustness of the analysis (Brigham & Ehrhardt 2022). As a result, NPV remains one of the most reliable techniques for guiding capital budgeting decisions, especially when investments are mutually exclusive and the goal is to maximize shareholder or stakeholder value (Gitman et al. 2023). While NPV provides insights into the overall value created by an investment over time, it does not directly indicate the relative efficiency of benefits to costs. Complementing this perspective, the Benefit–Cost Ratio (BCR) was applied to compare the proportion of discounted benefits to discounted costs across technologies.

Benefit–cost ratio/analysis of the machines
Benefit–cost ratio (BCR) was calculated as the ratio of discounted benefits to discounted costs, following the standard approach outlined by Boardman et al. (2018). The Benefit–cost Ratio is specified as;

$$BCR = \frac{\sum_{i=1}^{n} \frac{B_t}{(1+i)^t}}{\sum_{i=1}^{n} \frac{C_t}{(1+i)^t}} \tag{6}$$

where; B_t = Discounted stream of benefits, C_t = Discounted stream of costs, n = number of years i = discount rate, t = time. Therefore, the technological options with a BCR equal or greater than 1 was general accepted as economical viable. Although both NPV and BCR capture long-term investment viability, they do not fully reflect the day-to-day financial realities of smallholder farmers. To address this, Partial Budget Analysis (PBA) was employed to estimate the incremental changes in profitability by comparing added returns and reduced costs with added costs and reduced returns across alternative technologies.

Partial budget analysis
A partial budgeting approach was employed to evaluate the profitability of different technologies. This method focused only on costs and returns directly affected by farmers' decisions, rather than constructing a full enterprise budget. Specifically, the framework compared added costs, reduced returns, reduced costs, and added returns

across alternatives, thereby estimating the relative economic advantage of one option over another. Total positive impacts were derived from the sum of additional returns and reduced costs, while total negative impacts were obtained from reduced returns plus added costs. The difference between these two measures represented the net change in profitability. Although partial budgeting does not incorporate the time value of money, it provides a practical and widely applied tool for assessing incremental changes in farm practices[20] (Langemeier 2022). The change in profitability using partial budget analysis has therefore been calculated using formula;

$$\Delta PR = TPI - TNI \tag{7}$$

According to the explanation above, the formula can further be manipulated as follows;

$$\Delta PR = \underbrace{(IR_{oc} + RC_{AT})}_{TPI} - \underbrace{(AC_{oc} + RR_{AT})}_{TNI} \tag{8}$$

where;ΔPR = Change in profitability, IR_{oc} = Increased returns over the oldest and most common technology, RC_{AS} = Reduced costs of alternative technologies, AC_{oc} = Added costs over the oldest and most common technology, RR_{AS} = Reduced returns of alternative technologies, TPI = Total positive impacts and, TNI = Total negative impacts.

If the net benefit is positive, the new practice is considered more profitable than the existing one. Furthermore, since partial budgeting and investment appraisal methods are based on fixed assumptions about costs and benefits, a sensitivity analysis was also conducted as follows.

Sensitivity analysis

Since both investment appraisal and partial budgeting rely on fixed assumptions, sensitivity analysis was conducted to test robustness. Key parameters, such as cassava prices and fuel costs, were systematically varied to assess how changes affect profitability indicators (NPV, IRR, and BCR). This method ensured that results remained valid even under fluctuating market and cost conditions, thus strengthening the reliability of the economic evaluation (Brigham & Ehrhardt 2022).

Limitations of the study

This study is not without limitations. The analysis was restricted to two districts in Tanzania's coastal regions, which limits the generalizability of findings to other cassava-producing areas with different ecological or market conditions. Financial evaluations also relied on assumptions regarding discount rates, inflation, and machine lifespan, meaning changes in credit or fuel costs could alter profitability outcomes. In addition, the study emphasized direct costs and returns, without considering environmental impacts, social acceptance, or gender differences in mechanization adoption. The modest sample size and some reliance on self-reported data may also introduce bias, despite triangulation with trials and focus groups. Future research should extend to multiple regions, adopt larger samples, and apply longitudinal approaches to capture long-term impacts. Integrating social, environmental, and gender perspectives would provide a more holistic assessment of mechanization. These efforts would generate stronger evidence to guide policies and investments in cassava mechanization.

Results and discussion

Technical efficiency for cassava processing technologies

In assessing technical efficiency (Table 1), observations were made on mechanical processing, traditional drying, and traditional wet and solid-state fermentation methods (Fig. 3, 4 and 5) as follows;

For mechanical processing, the manual chipping machine operates with minimal energy input and requires no more than two operators. It takes approximately 3 min and 30 s to process 5 kg of fresh cassava. The engine-powered chippers and graters consume around 5 L of petrol to process between 1 and 1.2 tonnes of fresh cassava, with a processing time of about 3 min for 5 kg (Table 1). These machines also need a maximum of two operators. The fine chipping and grating achieved with these machines significantly reduce drying time to about 1 to 3 days, which is much faster than the duration required for traditional drying or traditional wet and solid-state fermentation methods.

Regarding traditional drying methods, cassava is cut into larger pieces, requiring about 6 min to process 5 kg. This results in a longer drying period of around 6 days, making traditional drying less time-efficient compared to mechanical methods (Table 1). Additionally, traditional wet and solid-state fermentation processes consume

Input	Traditional (drying) processing	Traditional (wet and drying fermentation) processing	Mechanical processing technology	
			Manual	Engine powered
Labour	1	1	2	2
Time (days)	7	12	1–3	1–3
Fuel kg/l	-	-	-	240–300
Duration to dry (days)	6	6	1–2	1–2
Quality	Poor	Relatively high compared to traditional (drying)	High	High

Table 1. Technical efficiency of cassava processing technologies.

Fig. 3. Chunks underwent sun drying processing.

Fig. 4. Wet/solid-state fermentation (Done by soaking in water).

significantly more water, roughly twice as much as the other two processing methods for washing and soaking. While the same large cassava pieces can be used for both wet and dry fermentation, the fermentation process takes even longer, up to 12 days, to produce the final flour product. This result is consistent with earlier evidence that mechanization reduces drying periods by increasing the surface area of cassava chips and improving dehydration efficiency[3,6]. The underlying economic mechanism is that time savings allow for multiple processing cycles within the same period, thereby increasing throughput. At the same time, improved flour quality attracts higher market prices, contributing to enhanced returns. Therefore, mechanical processing remains the most time-efficient method among the technologies considered. While technical efficiency highlights differences in processing time, labour, and drying periods, it is equally important to assess whether these improvements translate into economic gains. Thus, the next step evaluates the economic efficiency of the technologies in terms of value-to-cost ratios.

Economic efficiency of cassava processing technologies

Economic efficiency is defined as the value of the output produced multiplied by its quantity, divided by the production costs. In this study, production costs were considered specifically as processing costs. The output values (Table 2) for traditional drying, wet and solid-state fermentation, and mechanical processing were TZS 300, TZS 400, and TZS 600 per kilogram, respectively. The corresponding processing costs were TZS 125 for traditional (drying) method, TZS 150 for wet and solid-state fermentation, and TZS 150 per kilogram for mechanical processing. Based on these figures, the resulting economic efficiencies were calculated as follows:

Economic efficiency was measured as the value of output relative to processing costs. Traditional drying had an efficiency score of 2.4, while wet/solid-state fermentation achieved 2.6 whereas mechanical processing recorded the highest efficiency at 4.0 (Table 2). This confirms that mechanization generates higher returns by improving product quality and reducing post-harvest losses. However, efficiency differs across machine types, and adoption ultimately depends on balancing costs with the scale of production. Moreover, economic efficiency

Fig. 5. Mechanical cassava processing technology.

Technology	Value of the output per kilogram (TZS)	Cost of processing (TZS)	Economic efficiency
Traditional (drying) processing technology	300	125	2.4
Traditional (wet and solid-state fermentation)	400	150	2.7
Mechanical processing technology	600	150	4.0

Table 2. Economic efficiency of cassava processing technologies.

reflects profitability at the processing stage, adoption decisions are also shaped by the capital and operating costs of machines. The next section therefore examines these costs across the different technologies.

Comparative costs of cassava processing machines

The mechanical processing machines used in this study were produced by Intermech Engineering Ltd, based in Morogoro. There are three main types of machines: chipping machines, grating machines, and pressing machines. The chipping machines come in two versions; manual and engine-powered. The prices for the manual chipper, engine-powered chipper, grater, and cassava presser are TZS 300,000, TZS 950,000, TZS 1,210,000, and TZS 495,000 respectively. Each of these machines has an estimated lifespan of 5 to 7 years.

Operating costs of the machines

The operating costs of the machines include expenses for repairs and maintenance, operator allowances, insurance, taxes, and depreciation. Because these are relatively small machines, repair and maintenance costs were estimated at 10% of each machine's purchase price. Operator allowances were estimated at TZS 1,500 per day, based on standard compensation rates for project participants in various activities. This total was divided among several tasks, from preparing fresh cassava to drying, with TZS 400 allocated specifically for machine operation per day. For a manually operated chipping machine, this amounts to TZS 12,000 per month per operator. Since two operators are required, the total monthly cost is TZS 24,000, resulting in TZS 72,000 in operating costs over a three-month processing season.

For the engine-powered chipping machine, two operators are also required. It was estimated that each operator would receive TZS 400 per day, amounting to TZS 12,000 per month. This results in a cost of TZS 36,000 per operator over a three-month processing season. With two operators, the total annual cost comes to TZS 72,000. These same cost estimates were applied to the cassava grating machine as well. Insurance and taxes were considered minimal and therefore excluded from the analysis.

Depreciation costs, which account for the wear and tear of the machines, were calculated using the straight-line method. For machines with a lifespan of 7 years, the estimated salvage values were TZS 20,000 for the manual chipper, TZS 45,000 for the engine-powered chipper, and TZS 60,000 for the cassava grater. Determining whether these costs can be justified by long-term financial returns, a Net Present Value (NPV) analysis was conducted. This investment appraisal technique measures whether the discounted benefits of each machine outweigh its costs.

Net present value of the machines

Table 3 presents the results of the Net Present Value (NPV) analysis for three cassava processing machines: the manual chipping machine, the engine-powered chipping machine, and the cassava grater. The NPV method assesses the sustainable profitability over time of an investment by comparing the present value of discounted benefits with the discounted costs over a given period in this case, seven years with a 20% discount rate, based on commercial bank recommendations. The analysis shows that all three machines showed profitable returns: TZS 1,465,481 for the manual chipper, TZS 1,844,168 for the engine-powered chipper, and TZS 2,093,064 for the cassava grater. Positive NPV values indicate that the expected benefits of each machine outweigh the associated costs, confirming that all three technologies are financially acceptable investments.

Although the cassava grater has the highest NPV, reflecting its higher absolute returns, it also requires the largest initial investment (TZS 1,210,000). The manual chipper, while yielding the lowest NPV among the three, remains the most affordable in terms of initial cost (TZS 300,000) and discounted cost (TZS 140,571). This suggests it is more accessible for smallholder farmers, even if its long-term profitability is lower in absolute terms compared with the other machines. The NPV analysis confirms that all machines are financially viable, but the choice of technology depends on farmers' investment capacity and scale of operations. Furthermore, NPV indicates overall value creation, it does not show the efficiency of benefits relative to costs. To complement this, the Benefit–Cost Ratio (BCR) was calculated to assess the relative attractiveness of each technology (Table 4).

Thus (Table 4), among the machines, the manual chipper recorded the highest benefit–cost ratio (3.25), confirming its attractiveness for resource-constrained smallholder farmers. Its low acquisition cost (TZS 300,000) minimizes financial risk and facilitates adoption, even when long-term profitability is lower in absolute terms compared with more capital-intensive machines. Similar observations were reported in Nigeria and Ghana, where small-scale machines were more widely adopted because of affordability rather than maximum efficiency[8,16]. The mechanism here is affordability: the low entry cost allows farmers to recover investments quickly and achieve positive returns despite smaller processing scales.

Variables	Manual chipping machine	Engine powered chipping machine	Cassava grating machine
Initial cost (TZS)	300,000	950,000	1,210,000
Discounted cost (TZS)	140,571	308,115	345,247
Discounted benefit (TZS)	456,193	456,193	456,193
Discounting factor (%)[1]	20	20	20
Number of years	7	7	7
NPV	1,465,481	1,844,168	2,093,064
Decision	Acceptable	Acceptable	Acceptable

Table 3. Net present values of machines. [1]Base on commercial banks recommendation.

Machine	Discounted benefits	Costs	Benefit–Cost Ratio
Manual chipping machine	456,193	140,571	3.25
Engine powered chipping machine	456,193	308,115	1.48
Cassava grating machine	456,193	345,247	1.32

Table 4. Benefit–cost ratio of the machines.

In contrast, the engine-powered chipper and cassava grater, while delivering higher Net Present Values (NPVs), showed lower benefit–cost ratios. Their high initial investment requirements (TZS 950,000 and 1,210,000 respectively) limit accessibility for individual farmers, particularly in contexts where access to credit is restricted. Asempah et al[9,10] similarly found that willingness to adopt mechanized cassava peeling services was constrained by liquidity and borrowing challenges. The economic mechanism is scale-driven: higher fixed costs can only be justified if farmers process sufficient volumes or operate collectively, thereby distributing costs across greater outputs. This explains why larger-scale processors or farmer cooperatives are more likely to benefit from these machines.

These results extend previous studies on cassava processing technologies, which often focused on adoption trends and technical performance without integrating detailed financial assessments[4,11,15]. By applying Net Present Value (NPV), Benefit–Cost Ratio (BCR), and partial budgeting, our study provides a more nuanced understanding of profitability differentials. The observed differences are explained by three key mechanisms: (i) capital intensity, where machines requiring larger upfront investments restrict adoption but yield higher long-term profitability at scale,(ii) labour substitution, where mechanization reduces manual workload and associated labour costs; and (iii) quality-induced price premiums, where finer and cleaner flour increases market value. Together, these findings confirm the technical and financial viability of mechanization in Tanzania's coastal regions while highlighting the importance of matching technology choice with farmers' capital capacity and production scale.

Although both NPV and BCR capture long-term viability, they may overlook the short-term financial realities faced by smallholders. To address this gap, Partial Budget Analysis (PBA) was used to examine incremental profitability at the farmer level.

Partial budget analysis

The NPV and BCR show the long-term viability of mechanized cassava processing, they do not fully reflect the day-to-day financial realities of farmers. A partial budget analysis was therefore conducted to compare added returns and reduced costs against the extra expenses introduced by mechanization. This approach highlights the net benefits per kilogram of cassava processed, offering farmers a practical guide for choosing between traditional and mechanized options.

The added returns for using the mechanized technology

Table 5 shows that the introduction of cassava processing technology led to increased returns, as the higher quality of the processed cassava products raised the market price from TZS 400 to TZS 600 per kilogram. This price difference of TZS 200 resulted in an additional return of TZS 200,000 per tonne. Furthermore, based on IITA (1996), food losses were reduced from 22.3% to 10.1% of fresh cassava, contributing an extra return of TZS 73,200 per tonne. Altogether, these improvements led to a total added return of TZS 273,000 per tonne.

The reduced costs for using the mechanized technologies

This section focuses on the reduction in operating costs. The study found that the introduced cassava processing technology significantly shortens the time required to produce cassava flour, reducing it by 6 to 9 days. As a result, fresh cassava can be processed two to three more times within the same timeframe compared to traditional methods. The additional processing cost per kilogram, when compared to local technologies, is TZS 200, which amounts to TZS 200,000 per tonne, if multiplied by two the minimum number of extra processing cycles achievable yields a total cost reduction of TZS 400,000. This translates to an estimated daily cost saving of about TZS 50,000 (as shown in Table 5).

The added costs for using the mechanized technologies

This section addresses the additional costs associated with using the introduced cassava processing technologies. The study identified depreciation, repair and maintenance, labor, and fuel as the main expenses. According to Table 6, the daily depreciation costs are TZS 110 for the manual chipping machine, TZS 355 for the engine-powered chipper, and TZS 450 for the grating machine (see Table 5). Annual repair and maintenance costs amount to TZS 30,000, TZS 95,000, and TZS 121,000 for the manual chipping, engine-powered chipping, and grating machines, respectively, which breaks down to daily costs of TZS 85, TZS 260, and TZS 330. Labour costs are approximately TZS 2,400 for three days of processing and drying, while fuel costs for the engine-powered and grating machines are about TZS 5,460 per tonne.

The reduced returns for using the mechanized technologies

There are no losses in returns when using mechanized processing technology compared to traditional local methods; thus, the reduced returns from mechanized processing are effectively zero. The overall effect can be seen by combining the added returns and cost savings from using mechanical technologies, resulting in a net

Positive impacts		Negative impacts	
Manual chipping machine			
Added returns	TZS/tonne/day	Added costs	TZS/tonne/day
Increased return due quality	200,000	Depreciation	110
A gain from food losses	73,000	Repair and maintenance	85
Reduced costs		Labour	2400
Cost due to reduction of processing time (Duration)	50,000		
		Reduced returns	-
Total positive impacts	323,000	Total negative impacts	2595
		Net benefit	320,405
Engine powered chipping machine			
Added returns		Added costs	
Increased return due quality	200,000	Depreciation	355
A gain from food losses	73,000	Repair and maintenance	260
Reduced costs		Labour	2400
Cost due to reduction of processing time (Duration)	50,000	Fuel	5460
		Reduced returns	-
Total positive impacts	323,000	Total negative impacts	8 475
		Net benefit	314 525
Cassava grater machine			
Added returns		Added costs	
Increased return due quality	200,000	Depreciation	450
A gain from food losses	73,000	Repair and maintenance	330
Reduced costs			
Cost due to reduction of Processing time (Duration)	50,000	Labour	2400
		Fuel	5460
		Reduced returns	-
Total positive impacts	323,000	Total negative impacts	8640
		Net benefit	314,360

Table 5. Partial budget analysis resulting from a change to mechanized technology.

Type of cost	Manual chipping machine (TZS)	Engine powered chipping machine (TZS)	Cassava grating machine (TZS)
Repair and Maintenances costs	30 000	95 000	121 000
Operator's allowances	72 000	72 000	72 000
Depreciation	40 000	129 300	164 300
Total	142 000	296 300	357 300

Table 6. Annual operational costs (TZS).

Machine	Total positive impact (TZS/tonne/day)	Total negative impact (TZS/tonne/day)	Profit made per kilogram (TZS)
Manual chipping machine	323,000	2595	320.40
Engine powered chipping machine	323,000	8475	314.53
Cassava grating machine	323,000	8640	314.36

Table 7. Profit made by each machine.

positive impact. Specifically, the total positive impact amounts to TZS 323,000 per tonne, while the total negative impact which includes additional costs and any reduced returns from using the manual chipping machine is TZS 2,595 per tonne. Subtracting the negative impact from the positive impact yields a net benefit of TZS 320,405 per tonne, equating to a net profit of TZS 320.40 per kilogram when using the manual chipping machine. The results obtained in Table 5 above, can summarized as shown in Table 7.

Table 7 shows that the total positive impact generated by the engine-powered chipping and cassava grating machines was TZS 323,000 per tonne, while the total negative impacts were TZS 8,475 and TZS 8,640 per tonne, respectively. After subtracting these negative impacts from the positive ones, the net benefits amount to TZS 314,525 and TZS 314,360 per tonne. This translates to a net profit of TZS 314.53 per kilogram for the engine-powered chipper and TZS 314.36 per kilogram for the cassava grater. Therefore, the results and discussion show that all the hypotheses were confirmed that mechanized cassava processing technologies suggestively decrease processing time and enhance the quality of flour produced compared to traditional methods and generate positive NPVs and BCRs, indicating sustainable profitability over time. Moreover, the manual chippers yield higher benefit–cost ratios and daily profitability relative to engine-powered machines, making them more suitable for smallholder farmers. Since all previous methods rely on fixed assumptions, a sensitivity analysis was conducted to test the robustness of the results under changing market conditions, such as fluctuations in cassava prices and fuel costs.

Sensitivity analysis to test viability

A sensitivity analysis was conducted for the mechanized technologies over a seven-year projection to assess the investment's feasibility. The calculated NPV, IRR, and BCR were TZS 743,585, 42%, and 1.66 respectively, as shown in Appendix 1. The BCR value indicates that the benefits exceed the costs, confirming the investment's viability. Additionally, variations in key factors such as sales prices and operating costs were tested. A 5% decrease in sales price resulted in an NPV of TZS 565,467 and an IRR of 36%, while a 5% increase in operating expenses led to an NPV of TZS 564,230 and an IRR of 36% (Appendix 1). These minor changes in NPV and IRR demonstrate the project's stability and viability. However, since sensitivity analysis does not measure machine-specific profits, a partial budget analysis was used to estimate the profit generated by each machine compared to traditional processing methods.

Contribution and novelty statement

This study makes several novel contributions to the literature on cassava mechanization and farm economics. First, it provides the first empirical evidence from Tanzania's coastal regions (Tanga and Pwani) on the technical and economic performance of newly introduced cassava processing machines. While most prior studies focus on West Africa, little is known about adoption dynamics and profitability in Tanzania, particularly in smallholder-dominated systems. Second, the study advances methodological practice by applying a hybrid analytical framework that integrates Net Present Value (NPV), Benefit–Cost Ratio (BCR), sensitivity analysis, and partial budgeting. This multidimensional approach captures both long-term investment viability and short-term profitability, offering a more comprehensive evaluation than studies relying on a single tool. Third, the study introduces per-kilogram profitability estimates for each machine, translating economic performance into decision-relevant terms for smallholder farmers. This practical innovation bridges the gap between economic analysis and farmer decision-making, thereby enhancing the applicability of research findings.

Together, these contributions establish clear novelty in both context and methodology, while generating evidence directly relevant for policymakers, investors, and rural households seeking to adopt sustainable cassava mechanization.

Conclusion

Summary of findings

This study compared mechanized cassava processing technologies with traditional methods in Tanga and Pwani regions. Mechanization was shown to substantially reduce processing and drying time from 6–12 days to 1–3 days while improving flour quality. All machines demonstrated financial viability with positive NPVs, while the manual chipper achieved the highest benefit–cost ratio (3.25) and net profit of TZS 320.40/kg, making it particularly suitable for smallholders. Engine-powered chippers and cassava graters recorded higher absolute NPVs but required larger initial investments, favouring medium- to large-scale operations. Partial budget analysis confirmed that mechanized processing reduces food losses and labour costs, further enhancing profitability.

Interpretation considering economic realities

These findings reflect the broader economic realities faced by smallholder farmers in Tanzania, where capital constraints, high labour costs, and post-harvest losses remain persistent challenges. Affordable technologies like the manual chipper provide an accessible entry point for resource-constrained farmers, while collective ownership of more capital-intensive machines can enhance economies of scale. By lowering costs, reducing spoilage, and increasing marketable surpluses, mechanization can directly improve household incomes and contribute to rural poverty reduction.

Policy implications

(i) Government Agencies: Should prioritize cassava mechanization within food security and agro-industrialization strategies by offering tax incentives, subsidies, and targeted credit schemes to lower the cost of acquiring machines. Public–private partnerships can also support local manufacturing and distribution networks to ensure sustainability.

(ii) Agricultural Extension Services: Must expand farmer training on machine operation, repair, and business management, while also promoting cooperative models to spread investment costs. Training programs should integrate gender-sensitive approaches to encourage wider participation. In addition, improving rural infrastructure such as roads, fuel supply, and spare parts networks will lower operating costs and strengthen adoption. Embedding cassava mechanization within national food security and agro-industrialization strategies will further enhance its impact, contributing to rural incomes, value addition, and overall economic growth.

(iii) Small-Scale Entrepreneurs: Can leverage mechanized processing to establish local enterprises that reduce processing costs and capture value addition opportunities. Affordable entry-level machines like manual chippers can serve as stepping-stones toward gradual scaling into engine-powered technologies.

Concluding remarks

Overall, mechanized cassava processing offers both technical and economic gains, but its successful adoption requires complementary policies, institutional support, and entrepreneurial initiatives. By aligning technological adoption with economic realities, cassava mechanization can play a transformative role in enhancing food security, rural incomes, and sustainable agro-industrial development in Tanzania and beyond.

Data availability

The data and materials supporting the findings of this study are available from the corresponding author upon reasonable request.

Appendix 1: Sensitivity analysis for the mechanized processing technologies

Discounted Cash flow								
Costs	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Fixed Capital	2460000							
Working Capital	79500							
Operating Costs		79500	70080	85421	89897.5	98887.25	108775.98	108226.27
Financial Costs		553500	474428.57	395357.14	316285.71	237214.29	158142.86	79071.429
Total Costs		633000	544508.57	480778.14	406183.21	336101.54	266918.83	187297.7
Discount Factor (20%)	1	0.833333	0.6944444	0.5787037	0.4822531	0.4018776	0.334898	0.2790816
Discounted Costs		527500	378130.95	278228.09	195883.11	135071.67	89390.577	52271.351
Sum (A)		1656476						
Benefits								
Revenue		1235000	1543750	1698125	1867937.5	2054731.3	2260204.4	2486224.8
Discounted Revenue		1029167	1072048.6	982711.23	900818.62	825750.41	756937.87	693859.72
Sum (B)		6261293						
BCR		3.779888						
Net cash flow		602,000	999241.43	1217346.9	1461754.3	1718629.7	1993285.5	2298927.1
Disc Cash outflow		501,667	693917.66	704483.13	704935.52	690678.74	667547.3	641588.37
NPV		743,585						
IRR		42%						
Sensitivity Analysis								
Sensitivity Analysis	% Change	IRR	NPV					
Base	0	42%	43,585					
Decline in sales price	– 5	36%	565,467					
increase in operating exp	5	36%	64,230					

Appendix 2: NPV analysis for manual chipping machine

Years	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Initial cost	300000							
Running cost		72000	72000	72000	72000	72000	72000	72000
Annual depreciation		67500	57857	48214	38571	28928	19285	9642
Repair and maintenance		30000	30000	30000	30000	30000	30000	30000
Tax and Insurance		0	0	0	0	0	0	0
Total costs		169500	159857	150214	140571	130928	121285	111642
REVENUE		300000	375000	412500	453750	499125	549037.5	603941
NET BENEFIT		130500	215142	262285	313178	368196	427751	492298
Salvage value		232500	174642	126428	87857	58928	39642	30000
Discount factor		0.8333	0.6944	0.5787	0.4822	0.4018	0.3348	0.2790
Disc. Cash outflow		302500	270684	224950	193400	171651	156529	145763
NPV		1465481						

Appendix 3: NPV analysis for engine powered chipping

Years	0	1	2	3	4	5	6	7
Initial cost	950000							
Running cost		84900	87541	89095	90805	92683	94753.2	97028.02
Annual depreciation		213750	183214.3	152678.6	122142.9	91607.14	61071.43	30535.71
Repair and maintenance		95000	95000	95000	95000	95000	95000	95000
Tax and Insurance		0	0	0	0	0	0	0
Total costs		393650	365755.3	336773.6	307947.9	279290.1	250824.6	222563.7
REVENUE		300000	375000	412500	453750	499125	549037.5	603941.3
NET BENEFIT		– 93650	9244.714	75726.43	145802.1	219834.9	298212.9	381377.5
Salvage value		736250	553035.7	400357.1	278214.3	186607.1	125535.7	95000
Discount factor		0.833333	0.694444	0.578704	0.482253	0.401878	0.334898	0.279082
Disc. Cash outflow		535500	390472.5	275511.3	204483.2	163339.9	141912.5	132948.2
NPV		1844168						

Appendix 4: NPV analysis for cassava grater machine

Years	0	1	2	3	4	5	6	7
Initial cost	1210000							
Running cost		84900	87541	89095	90805	92683	94753.2	97028.02
Annual depreciation		272250	233357.1	194464.3	155571.4	116678.6	77785.71	38892.86
Repair and maintenance		121000	95000	95000	95000	95000	95000	95000
Tax and Insurance		0	0	0	0	0	0	0
Total costs		478150	415898.1	378559.3	341376.4	304361.6	267538.9	230920.9
REVENUE		300000	375000	412500	453750	499125	549037.5	603941.3
NET BENEFIT		– 178150	– 40898.1	33940.71	112373.6	194763.4	281498.6	373020.4
Salvage value		937750	704392.9	509928.6	354357.1	237678.6	159892.9	121000
Discount factor		0.833333	0.694444	0.578704	0.482253	0.401878	0.334898	0.279082
Disc. Cash outflow		633000	460760.2	314739.2	225082.3	173788.7	147821.1	137872
NPV		2093064						

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Author contributions
The author conceived the study, reviewed the literature, designed the methodology, collected and analyzed data, interpreted the results, and drafted and approved the final manuscript.

Declarations

Competing interests
The authors declare no competing interests.

Ethics approval and consent to participate
This study was reviewed and approved by the Sokoine University of Agriculture (SUA) Research Ethics Committee, where the author pursued doctoral studies, as acknowledged later in the manuscript. All procedures complied with national and international guidelines for research involving human participants. Verbal informed consent was obtained from all participants after the objectives and procedures of the study were clearly explained in a language they understood. Written consent was not feasible due to literacy limitations, and verbal consent was deemed culturally appropriate. Participation was entirely voluntary, confidentiality was assured, and participants were informed of their right to withdraw at any time without consequence.

Additional information
Correspondence and requests for materials should be addressed to M.T.

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