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Abstract: *This paper presents a Small-Scale Integrated Saba Banana Flour Mill designed to support small-scale farmers in tropical regions by offering an affordable milling solution. The study assessed different dehydrator and flour mill treatments to optimize performance, finding that the dehydrator had a maximum efficiency of 60% and the flour mill 84.56%. Economic analysis revealed low operating costs, a high return rate of 142.26%, and a short payback period of 0.72 years. The mill shows improved banana processing efficiency and strengthens the economic stability of small farming communities.*

Keywords: Saba banana, integrated flour mill, dehydrator, milling speed

1. INTRODUCTION

Bananas play a crucial role in the diet and economy of numerous countries due to their widespread consumption. The increasing demand for processed banana products has resulted in the utilization of bananas in various forms, such as flour. Notably, Saba bananas, a distinctive variety recognized for their unique properties, have emerged as a promising source of high-quality banana flour. However, the lack of accessible and cost-effective processing equipment poses a challenge for small-scale producers interested in Saba banana flour production. Existing commercial milling machines are typically large-scale and expensive, making them unsuitable for small-scale operations.

To address these challenges, developing and implementing a small-scale integrated banana flour processing machine in the Philippines is needed. The machine will streamline the production process and improve the quality of plantain flour while reducing postharvest losses. The implementation of such a machine will also create opportunities for small-scale entrepreneurs and banana farmers with only an approximate area of usually around 1-10 acres, in rural communities, to engage in value-added production and generate income [1].

Saba banana (*Musa sapientum*) flour production holds potential for boosting food security and economic growth in tropical regions since Philippines rank as the third producer of saba banana around the world [2]. However, small-scale farmers struggle with adopting efficient processing technologies, often relying on large corporations with advanced machinery. This reliance can improve quality control but is challenged by high milling fees and logistical issues in transporting bananas to distant facilities. Dependence on corporations also exposes farmers to fee fluctuations, service disruptions, and minimum volume requirements, which can marginalize smaller farms. Developing a small-scale integrated Saba banana flour mill is crucial to address these issues. This mill would provide cost-effective milling solutions tailored to small farmers' needs. Incorporating tray dehydrators into the milling system addresses a significant gap in current research on small-scale banana flour production. There are existing studies [1, 3, 4, 5, 6] that have explored small-scale integrated milling options, most research has focused on Africa and India, leaving a gap in the Philippines. This study aims to fill that gap and provide valuable insights into small-scale banana flour production in the Philippines by designing, fabricating, and evaluating the performance of an integrated flour mill for the processing of Saba banana flour.

2. METHODS

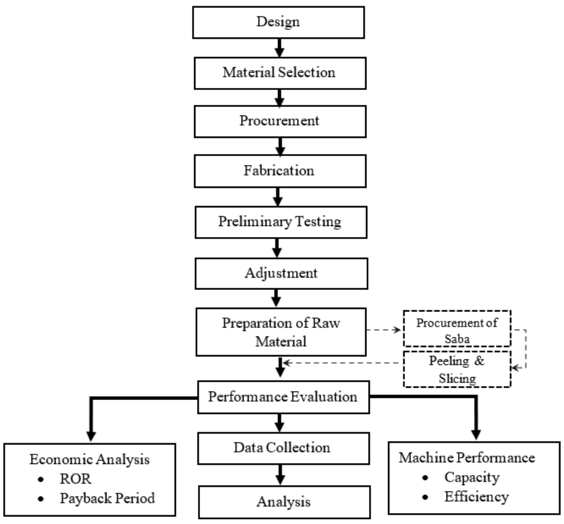

Fig. 1. General Framework of the Study.

The general framework of the study, depicted in Figure 1, outlines the entire research process. It begins with the design phase, focusing on conceptualizing and planning the machine, including its specifications and functionality. The material selection phase follows, involving the choice of suitable materials for each design component. Once the design and material selection are complete, the procurement phase involves acquiring the necessary resources for building the machine. Subsequently, the fabrication phase involves constructing the milling machine according to the planned design, including any necessary adjustments. Preliminary testing then follows, aiming to identify and resolve any issues that could affect proper performance evaluation or pose safety risks. The preparation of the raw material, which is the Saba banana, follows this step. The performance evaluation phase then provides a comprehensive assessment of the machine's performance against design specifications, considering factors such as dehydrator and milling capacities, efficiencies, and economic feasibility. This is followed by data collection and analysis, where raw data from the experiment is collected and analyzed to evaluate the financial aspects of the machine's operation, including initial investment costs, operational expenses, maintenance costs, and potential revenue generation. This analysis aims to determine the profitability and overall economic viability of utilizing the machine for Saba banana flour production. Each component will be further elaborated in the following sections.

2.1 The design

The perspective view of the small-scale integrated Saba banana flour mill design is illustrated in Figure 2, showcasing its various components. The fabrication process utilizes steel shafting, stainless steel sheets, a hammer mill, an Alternating Current (AC) wash motor, a standard V-belt pulley, and a variable speed controller.

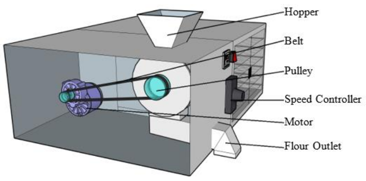

Fig. 2.a The perspective view of the flour mill and its parts.

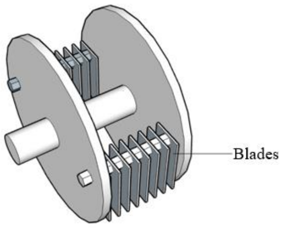

Fig. 2.b The hammer mill design.

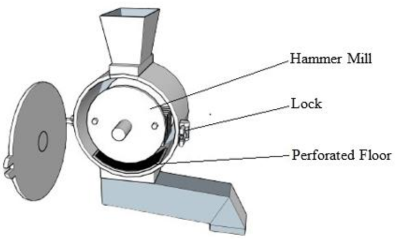

Fig. 2.c The Hammer Mill Inside the small-scale integrated Saba banana flour mill.

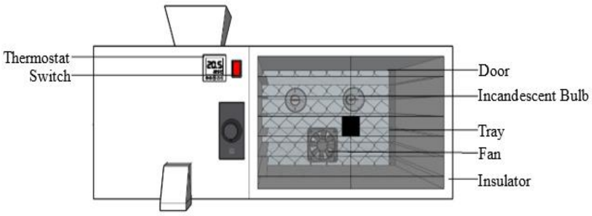

Fig. 2.d The dehydrator and its parts.

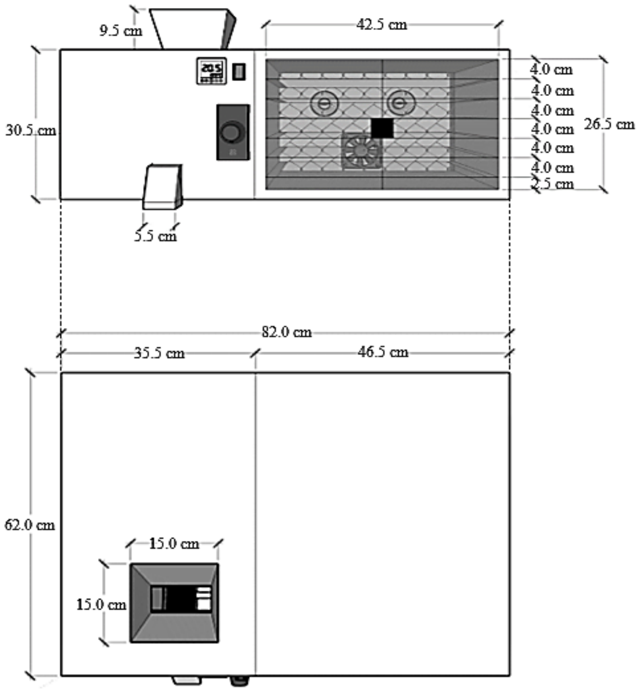

Fig. 2.e Front and top view of the small-scale integrated Saba banana flour mill and its dimensions.

The design of the hammer mill is depicted in Figure 2.a. It features blades fixed on two sides, each measuring 7.6 × 5.1 cm, with a 1.3 cm distance between each blade. Figure 2.b illustrates the internal components of the flour mill. The clearance between the hammer mill and the floor is 1 cm, and the perforated floor has 1 mm openings. The design of the dehydrator is shown in Figure 2.c. The fabrication process uses stainless steel sheets, two 100-W incandescent lamps, a metal mesh screen, glass doors, and a temperature regulator (thermostat). Figure 2.d presents the machine's dimensions: 82 cm in length, 62 cm in width, and 30.5 cm in height. The mill has a diameter of 20.3 cm, and the hopper stands at a height of 9.5 cm with openings of 15 cm on each side.

Figure 2. e shows the front and top views of the small-scale integrated Saba banana flour mill, along with its dimensions, provide a comprehensive understanding of the machine's design and spatial configuration. The front view illustrates the vertical alignment and placement of key components, including the hopper, hammer mill, and dehydrator, offering insights into the operational workflow and ergonomics of the machine. The top view complements this by showcasing the layout from an overhead perspective, highlighting the spatial arrangement and interaction between different parts. Detailed dimensions are provided to ensure precise fabrication and assembly, facilitating accurate reproduction and scalability of the design.

2.3 Material selection

The materials selected for the integrated Saba banana flour mill are outlined in this section, which describes the major components of an integrated flour mill. A detailed description of each part follows.

- **Hopper**: Constructed from stainless steel and measuring 9.5 cm in height, the hopper functions as the designated inlet mechanism facilitating the introduction of the dry banana into the flour mill.

- **Grinding blades**: These are responsible for grinding the dry material.
- **Driver and Driven Pulley**: The system utilizes a 70-watt AC wash motor with a shaft and pulley connected by a flat belt.
- **Speed controller:** The flour mill utilizes a speed controller to regulate the rotation speed of the grinding blades. This allows for precise control over the final product's particle size and texture, optimizing grinding efficiency and minimizing potential damage from overheating.
- **Incandescent bulb**: The dehydrator incorporates two 100W incandescent lamps as the heat source.
- **Thermostat:** This device functions as a temperature regulator, employing a sensor to detect temperature fluctuations and maintain a constant temperature within an enclosed environment.
- **Tray**: The dehydrator employs a drying tray fabricated from metal mesh for the placement of sliced bananas before their transfer into the drying chamber.

2.4 Preparation of raw material

This research employed mature, green Saba bananas procured from the Ampayon public market, Butuan City, Agusan del Norte Philippines. The bananas were manually peeled and washed with potable water, followed by cutting into slices of approximately 0.64 cm in thickness. The slices were then carefully arranged in a single layer on dehydrator trays, ensuring that there was sufficient air circulation during the dehydration process.

2.5 Principal of operation

The banana slicing process was performed manually, with the slices carefully arranged on trays within the dehydrator. The dehydrator, equipped with incandescent lamps for heating, maintains a temperature controlled by a thermostat preset to 55-60°C [7]. Once the desired temperature is reached, the dehydrator automatically ceases operation. After dehydration, the banana pieces are transferred to the hopper of the flour mill. The grinding process is powered by a 70-watt electric motor, with adjustable blades to achieve the desired flour consistency. The final product, banana flour, is then discharged through the mill's outlet.

2.6 Dehydrating procedure

A 1-kg sample per replica of sliced banana is placed on the trays inside the dehydrator, considering three (3) treatments. The treatments represent varying durations of operation: 6 hours, 9 hours, and 12 hours [8, 9]. Replication 1 undergoes dehydration for Treatment A, and the recorded weight loss is documented. The identical samples are subsequently utilized in Treatment B and C of Replication 1 to evaluate machine performance during dehydration. Treatments A, B, and C of Replications 2 and 3 follow the same procedure illustrated in Figure 3.

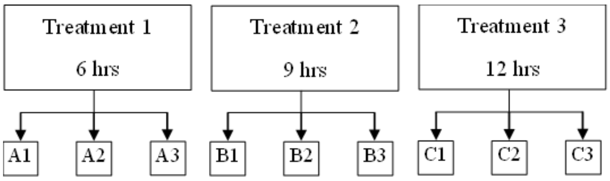

Fig. 3. Experimental Framework for Dehydration.

2.7 Milling procedure

A 1-kg sample per replica of dried banana is placed on a hopper, considering three (3) treatments. The treatments represent varying speeds of the shaft for the grinding mechanism: 495 rpm, 582 rpm, and 670 rpm. These varying speeds were recorded using a photo tachometer. Replication 1 undergoes milling for Treatment A; output weight and time of operation are recorded. The identical samples are subsequently utilized in Treatment B and C of Replication 1 to evaluate machine performance during milling. Treatments A, B, and C of Replications 2 and 3 follow the same procedures, shown in Figure 4.

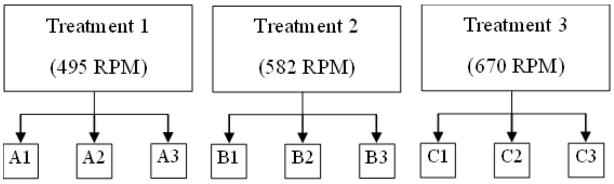

Fig. 4. Experimental Framework for Miller.

3. RESULTS AND DISCUSSION

Fig. 5. Fabricated Small-Scale Integrated Saba Banana Flour Mill.

The integrated banana flour mill was designed and constructed to be cost-effective, minimizing capital investment and operating expenses. The use of locally sourced materials enhances the feasibility and manageability of the technology for farmers. The fabricated design of the small-scale integrated Saba banana flour mill is illustrated in Figure 5.

The integrated banana flour mill was fabricated in Dela Victoria Tinsmith, Langihan Rd., Butuan City, Agusan del Norte Philippines last October 9 to December 21, 2023. The fabrication took seventy-four (74) days. This machine has a total length, width, and height of 82 cm, 62 cm, and 30.5 cm, respectively. This machine is powered by electricity and drives with a 70-watt AC motor.

3.4 Machine evaluation

3.4.1 Dehydrator capacity

Food dehydrators are an important tool for preserving food by removing moisture. The drying capacity of a dehydrator is determined by the total drying area available, which is calculated by multiplying the individual tray area by the total number of trays included in the unit [10]. The dehydrator in this study is equipped with a total drying area of 0.96 m^2, distributed across 6 trays. Each tray offers a drying area of 0.16 m2 and a capacity of 0.35 kg each. Therefore, the overall dehydrator capacity is 2.19 kg/m^2.

3.4.1 Dehydrator efficiency

The study examined the impact of various dehydration treatments on banana weight loss. The data, presented in grams of dehydrated banana following treatment, reveals interesting trends when considering the initial weight of 1000 grams per banana. Treatment C resulted in the highest average weight loss (400 g), translating to approximately 60% water removal. Conversely, Treatment A displayed the lowest weight loss (average 526.67g), suggesting a 47.33% water removal and potentially a more moisture-retentive approach. The statistical analysis indicates that Treatment A exhibits a demonstrably lower dehydrator efficiency compared to Treatments B and C. This difference can potentially be explained by the shorter dehydrating time employed in Treatment A. It may also be due to the amount of heat loss produced during the study, resulting in insufficient moisture removal. This notion is supported by the findings of [11] The data for the dehydrator's efficiency is presented in Figure 6.

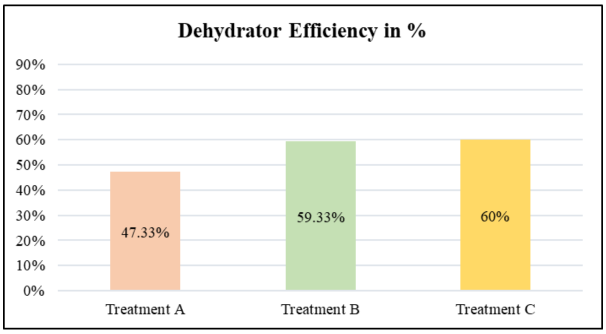

Fig. 6. Dehydrator Efficiency

To determine the significance of each treatment, a Completely Randomized Design (CRD) revealed a highly significant (p-value < .001) with an F-statistic of 156.800, indicating a substantial effect of treatment on dehydrator efficiency. This suggests that the different treatments likely have a real impact on dehydrator performance. To further analyze the significant differences identified by the ANOVA test, Duncan's Multiple Range Test was employed. Based on the results, The Duncan Grouping shows that Treatment B and C belong to the same subset (a), indicating no statistical difference in their means. Treatment A belongs to a different subset (b), signifying a statistically lower efficiency compared to Treatment B and C. Overall, the results suggest that Treatment A has a statistically lower dehydrator efficiency than Treatment B and C, which have similar efficiencies.

3.4.2 Milling capacity

An evaluation of milling capacity was conducted throughout the experiment by monitoring the weight of dehydrated banana samples from multiple replicates within each treatment group. Analysis of the results shown in Figure 7 revealed a trend of increasing average milling capacity with advancing treatment designations (A, B, and C). Treatment C exhibited the highest average milling capacity (1.43 kg/hr), while Treatment A displayed the lowest (1.40 kg/hr). This observed correlation can be attributed to the direct relationship between milling capacity and hammer mill rotational speed (RPM). As RPM increases, the hammer mill operates at a faster pace, enabling it to process a greater quantity of material within a fixed timeframe, ultimately leading to an enhanced milling capacity [12].

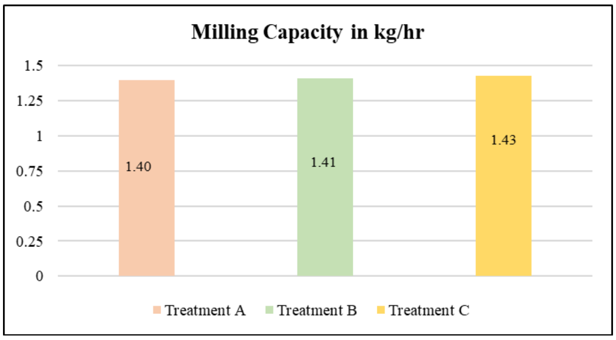

Fig. 7. Milling Capacity.

3.4.3 Milling efficiency

The weight of banana flour was obtained at different rotational speeds (495, 582, 670) and three replications were recorded. The average weight of banana flour across the three replications for treatment A is 370 g, for treatment B is 338.3 g, and for treatment C is 303.3 g. It can be observed that the weight of banana flour appears to decrease as the rotational speed (treatment) increases. Treatment A has the highest average weight (370g), and Treatment C has the lowest (303.3g) as depicted in Figure 8.

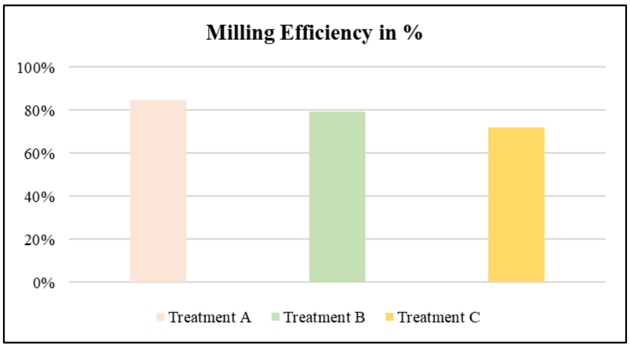

Fig. 8. Milling Efficiency.

Subsequently, it was also observed that the weight of residual flour appears to increase as the treatment designation increases. Treatment C has the highest average residual banana flour weight (133.33g) and Treatment A has the lowest (71.67g). This observation suggests that at higher rotational speeds, the hammer mill might not provide sufficient dwell time for the hammers to effectively impact and fragment the banana slices. This could lead to the slices deflecting off the hammers rather than undergoing proper milling, thereby reducing the overall milling efficiency and consequently, the yield of banana flour [13, 14].

3.4.4 Particle size analysis of Saba banana flour

Sieve size analysis, widely used across industries, separates particles by passing material through a series of sieves with progressively smaller openings, measuring the weight retained on each sieve, and plotting it against sieve size to generate a particle size distribution curve. For the Saba banana flour samples, a mechanical sieve with mesh sizes from 1.6 mm to 0.15 mm was used. The weight of flour retained on each sieve was recorded in three replicates for treatments A, B, and C. The results showed a diverse range of particle sizes, with significant amounts in the 0.3-0.15 mm range, as illustrated in Figure 9.

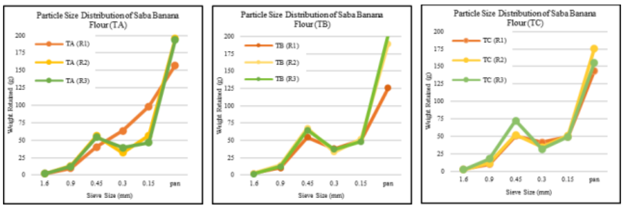

Fig.9.c Fig.9.b Fig.9.c

Figure 9. Weight Retained in each Treatment (a,b,c) for each Sieve Size.

The produced Saba Banana Flour from the Small-Scale Integrated Saba Banana Flour Mill of three (3) treatments and three (3) replications of each is depicted in Figure 10.

Fig. 10. Saba Banana Flour.

3.4.5 Economic analysis

This study examined the economic feasibility of a small-scale integrated Saba banana flour mill. The analysis centers on key financial indicators to assess the investment's potential profitability. Table 1 presents the basic assumption for the economic evaluation of the small-scale integrated Saba banana flour mill.

Table 1. Basic Assumption for Economic Evaluation of the Machine.

Items	Value
Dehydrator Output Capacity	400g (12hrs./day) = 400g /day
Milling Output Capacity	1.43kg/hr/day
Saba Banana Flour Production	343.2 kg/yr
Capital Investment	Php 25,000.00
Electricity Rate	Php 9.2792 /kWh
Daily Electric Consumption (Dehydrator)	2.4 kWh
Electricity Cost (Dehydrator)	Php22.27/day
Daily Electric Consumption (Miller)	0.5 kWh
Electricity Cost (Miller)	Php 4.64/day
Saba Banana Cost	Php 28.00/kg
Labor Cost	Php 250.00/day
Saba Banana Flour Price	Php 160.00/500 grams
Interest Rate	10%
Estimated Life Span	5 years
Maintenance Cost (10% of IC)	Php 2,500.00
Salvage Value (10% of IC)	Php 2,500.00
Tax and Insurance (10% of IC)	Php 2,500.00
Average Annual Income	Php 109,824.00

The initial capital expenditure for acquiring and installing the machine is Php 25,000. The mill's projected average annual income is Php 109,824.00. Key assumptions underpinning the financial analysis include a 10% annual interest rate, a 5-year equipment lifespan, and maintenance and salvage values equivalent to 10% of the initial investment cost. Reference to a journal publication:

3.4.6 Rate of return

Rate of return (ROR) is a critical metric in investment analysis. It quantifies the annualized percentage profit earned on an investment relative to its initial cost. Table 2 details the cost and profit of a small-scale integrated Saba banana flour mill, which will be used to calculate its ROR.

Table 2. Cost and Profit of the Small-scale Saba Banana Flour Mill.

Items	Value
Capital Investment	Php 25,000.00
Fixed Costs	
Depreciation	Php 2,300.00
Operation and Maintenance	Php 2,500.00
Taxes and Insurance	Php 2,500.00
Total Fixed Cost	
Variable Costs	
Wages	Php 60,000/yr
Electric Consumption	Php 6,458.40/yr
Total Variable Cost	Php 66,458.40
Total Annual Cost	Php 74, 258.40
Total Annual Income	Php 109,824.00
Net Annual Profit	Php 35, 565.60

ROR = (Net annual profit)/(Capital investment) x 100 = 35,565.60/25,000 x 100 = **142.26%**

The calculated Rate of Return (ROR) for the investment is 142.26%. This metric signifies the anticipated annualized return on investment associated with the small-scale Saba banana flour milling machine. This figure suggests a promising return, exceeding the project's cost of capital, which represents the minimum acceptable rate of return for the investment.

3.4.7 Payback period

The payback period is the time required to recuperate the initial investment in an integrated banana flour mill. It is a crucial indicator for determining the risk associated with purchasing such machinery. Table 3 depicts the annual cash flow created by the integrated banana flour mill for the first five years of its operating lifespan, providing a full overview of its financial performance.

Table 6. Cost and Income of Machine Until the End of Useful Life.

Yr	IC	FC	VC	TC	GI	NI
1	25,000.00	7,300.00	66,458.40	98,758.40	109,824.00	11,065.60
2		7,300.00	66,458.40	73,758.40	109,824.00	36,065.60
3		7,300.00	66,458.40	73,758.40	109,824.00	36,065.60
4		7,300.00	66,458.40	73,758.40	109,824.00	36,065.60
5		7,300.00	66,458.40	73,758.40	109,824.00	36,065.60
Salvage value at the end of 5 years					2,500.00	2,500.00
Total Income						155,328.00
Net Annual Cash Flow						31,065.60

Legend: Yr=Year, IC=Investment Cost, FC=Fixed Cost, VC=Variable Cost, TC=Total Cost, GI=Gross Income, NI=Net Income

Payback Period = (Initial Investment-Salvage value)/(Net annual cash flow) = (25,000-2,500)/31,065.60 = ***0.72 yr***

A payback period of 0.72 years indicates the timeframe required to recover the initial investment cost from the machine's generated income. This metric provides valuable insight into the investment's short-term financial viability.
In conclusion, the financial analysis reveals favorable indicators for the small-scale Saba banana flour mill. The projected high Rate of Return and relatively short Payback Period suggest the investment's potential for profitability.

4. CONCLUSION

In the study on a small-scale Saba banana flour mill, a significant correlation was found between dehydration time and efficiency. The highest efficiency of 60% was achieved with a 12-hour dehydration period, while a 6-hour period yielded only 47.33% efficiency. The dehydration process utilized a designed dehydrator with a capacity of 2.19 kg/m², spread across six trays, each with 0.16 m² of drying space.

The mill demonstrated a maximum capacity of 1.43 kg/hr and an efficiency of 84.56% at an optimal speed of 495 rpm. This indicates the small-scale Saba banana flour mill as a cost-effective, efficient solution for farmers, offering high revenue potential with minimal operating costs.

The mill's economic feasibility is highlighted by a high return rate of 142.26% and a short payback period of 0.72 years. Particle size analysis revealed that Saba banana flour predominantly falls within the 0.3 - 0.15 mm sieve range, with significant weight retained in this range.

These findings suggest that adopting this technology could enhance banana processing efficiency and economically empower farming communities.

4.1 RECOMMENDATION

To further enhance the study and provide a more comprehensive assessment of the machine's performance, the authors would like to recommend the following:

While the study identified a 12-hour dehydration period as the most efficient, further research should explore additional optimization strategies to achieve shorter dehydration times while maintaining high efficiency. Specifically, consider investigating alternative heat sources or methods, such as:

- **Alternative Heat Sources:** Evaluate the use of different heating mechanisms, such as infrared, microwave, or solar energy, to determine if they can reduce dehydration time while maintaining or improving efficiency.
- **Improved Heat Transfer Methods:** Explore advanced techniques for enhancing heat transfer within the dehydrator, such as improved air circulation or heat exchanger designs.
- **Hybrid Dehydration Techniques**: Assess the effectiveness of combining different dehydration methods (e.g., pre-drying using one method followed by final drying with another) to achieve faster processing times without compromising quality.
- **Energy source exploration**: While operating costs seem low, consider exploring alternative energy sources for powering the dehydrator and milling components. Options like solar power could further reduce operational costs and environmental impact.

Additionally, examine how these alternative methods impact the quality and consistency of the banana flour, ensuring that efficiency improvements do not adversely affect the final product.

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