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Design, Development, and Performance Evaluation of a Motorized Cassava Peeling Machine

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ABSTRACT

This study focuses on the design, development, and performance evaluation of a motorized cassava peeling machine, constructed using locally sourced materials. The machine features an abrasive peeling drum, a hopper, a mild steel frame, and a pulley system, all powered by a 2 hp single-phase induction motor. During performance tests, the machine demonstrated an average throughput capacity of 75.54 kg/hr. and a peeling efficiency of 88.33%. Statistical analyses using factorial experimental designs revealed that machine speed and day after harvest had significant impacts on peeling efficiency ($p = 0.0199$) and throughput capacity. The optimal performance was observed when cassava tubers were processed 1 day after harvest using a 2 mm grater, maximizing throughput. While the interaction between the day after harvest and grater size significantly affected throughput capacity ($p = 0.0213$), the interaction between machine speed and grater size was insignificant. ANOVA results confirmed the reliability of the regression models, with model validation ensuring normality and constant variance. This locally fabricated machine offers an affordable and efficient solution for small to medium-scale cassava peeling, improving productivity and reducing manual labor.

INTRODUCTION

Cassava, a crucial staple crop, was introduced to Africa over 300 years ago by Portuguese traders from Brazil, significantly influencing the agricultural landscape of the continent. Originating near the Congo River, it has since spread across sub-Saharan Africa, becoming a primary source of carbohydrates and replacing traditional staples such as millet and yam in many regions. The adaptability of cassava to various farming systems and its role as a famine-reserve crop has made it indispensable, particularly in times of drought and food scarcity (Nweke *et al*., 2002; Otekunrin & Sawicka, 2019). Cassava's rise to widespread awareness in African agriculture can be attributed to its resilience and versatility. The crop thrives on poor soils with minimal inputs, making it accessible to millions of smallholder farmers, particularly women, who often cultivate it on marginal lands. Its ability to remain in the soil for extended periods without spoilage provides a reliable food source during adverse conditions when other crops fail, thus playing a vital role in food security (Nweke *et al*., 2002). Today, Africa accounts for about half of the world's cassava production, with Nigeria, the Democratic Republic of Congo, Ghana, Tanzania, and Mozambique being the top producers. In Nigeria, cassava has transitioned from a famine-prevention crop to a significant cash crop, driven by rapid population growth, market availability, and governmental efforts to promote its cultivation as a means of poverty alleviation (Onyediako & Adiele, 2022). The Nigerian government, recognizing cassava's potential, has implemented programs to diversify its uses, including its development as a primary industrial raw material and livestock feed. Despite the importance of cassava and the efforts towards maximizing its potentials, cassava production faces several challenges, one of them being the devastating African cassava mosaic virus, which can reduce yields by up to 75%. The virus, prevalent due to the lack of natural resistance in African cassava varieties, has caused localized famine in central Africa. Additionally, all cassava varieties contain cyanogenic glycosides, which can be toxic if not properly processed, posing health risks such as konzo, a neurological disorder. Moreover, the processing and handling of cassava often result in poor-quality products, which is worsened by labor-intensive and unsanitary conditions in rural areas where women primarily undertake processing. These inefficiencies not only reduce the nutritional value of cassava products but also limit their marketability and profitability. Better-designed equipment and improved processing techniques could enhance the quality and safety of cassava products, potentially leading to increased economic benefits for producers and processors (Kolawole & Agbetoye, 2007).

Cassava's industrial potential remains largely untapped, despite its numerous applications. Its leaves, rich in vitamins A and C, iron, calcium, and protein, are consumed in many African countries as a supplement

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to the root, which is deficient in certain nutrients. In addition, cassava is used in animal feed production, with its high energy content making it a cost-effective option for livestock industries. Further, cassava has potential applications in the food, beverage, and pharmaceutical industries, including the production of alcohol, syrups, monosodium glutamate, and even oil extracted from cassava seeds, though much of this potential remains underdeveloped (Tonukari *et al.*, 2015). The shift from a subsistence crop to one with broader economic value underscores the importance of modernizing cassava processing methods to meet both domestic and international market demands. In this regard, traditional methods of processing cassava to remove cyanide, such as fermenting in community ponds or spitting on the ground tubers, highlights one of the innovative ways in which indigenous communities have adapted to effectively process the crop while eliminating its toxic characteristics. Additionally, the traditional processing methods, particularly peeling, are labor-intensive and inefficient, often resulting in inconsistent product quality and limited export opportunities. This study seeks to address these challenges by developing a cassava peeling machine built to the needs of small-scale farmers in Nigeria. Such innovation is essential to enhance processing efficiency, reduce labor costs, and improve the quality and safety of cassava products. This technology can increase the economic prospects of cassava farmers, help reduce poverty and improve food security by increasing soil fertility, simplifying the transport and ensure compliance with international food standards for cassava products. Lastly, this study to develop a cassava peeling machine, supports the broader goal of integrating Nigeria into the global food market by enabling the exportation of high-quality cassava products.

LITERATURE REVIEW

The processing of cassava, particularly peeling, has been the subject of extensive research due to its critical importance in enhancing the efficiency, quality, and safety of cassava-based products. Traditional methods of cassava processing are often labor-intensive and time-consuming and yield products of inconsistent quality. Consequently, numerous studies have focused on developing and improving cassava peeling and processing technologies to address these challenges and meet both local and international standards. Historically, cassava processing has relied heavily on manual techniques, which involve peeling the tubers using simple tools such as knives. These methods, while accessible and low-cost, are characterized by low productivity and significant drudgery, particularly affecting women who constitute the majority of labor in cassava processing (Afoakwa *et al.*, 2021). Manual peeling also leads to substantial raw material losses and exposes processors to occupational hazards, including cuts and repetitive strain injuries. Additionally, the hygiene conditions in traditional processing are often suboptimal, contributing to the contamination and reduced shelf life of cassava products (Bechoff, 2017; Ray & Sivakumar, 2009). In response to the limitations of manual peeling, researchers have explored various mechanical peeling solutions aimed at increasing efficiency and reducing labor intensity. Early designs of mechanical cassava peelers emerged in the late 20th century, utilizing abrasive and cutting mechanisms to remove the peel. For instance, Ihekeronye and Ngoddy developed a prototype abrasive peeler that employed rotating drums lined with abrasive materials to strip off cassava skins. While this design demonstrated increased throughput compared to manual methods, it faced challenges related to excessive flesh loss and damage to the tuber surfaces (Ihekoronye & Ngoddy, 1985). Further advancements in engineering have led to more sophisticated peeling machines that incorporate improved mechanisms and materials. Adegoke *et al.* (2020) designed a cassava peeler utilizing blade assemblies arranged to mimic the manual peeling action, resulting in better peel removal efficiency and reduced flesh loss (Adegoke *et al.*, 2020). Similarly, Jimoh & Olukunle developed a rotary drum peeler with adjustable blade settings to accommodate varying tuber sizes and skin thicknesses, achieving higher peeling efficiency and product quality (Jimoh & Olukunle, 2012). Despite these innovations, widespread adoption of mechanical cassava peelers has been limited in many developing regions due to factors such as high initial costs, complexity of operation, maintenance requirements, and inadequate access to spare parts (Amanor & Bobobee, 2021). Additionally, variations in cassava tuber sizes, shapes, and skin characteristics pose significant challenges in designing universally effective peeling machines (Ajibola & Babarinde, 2016). Recent studies have focused on addressing the shortcomings of earlier mechanical peelers through the incorporation of automation, improved materials, and ergonomic designs. Alexander *et al.* (2020) introduced an automated cassava peeling machine equipped with sensors to detect tuber dimensions and adjust peeling parameters accordingly. This innovation resulted in enhanced peeling precision, minimized wastage, and improved processing speed (Alexander *et al.*, 2020).

Furthermore, researchers have explored the use of pneumatic and hydraulic systems to control peeling mechanisms, offering smoother operations and reduced mechanical stress on the tubers. The integration of food-grade stainless steel and corrosion-resistant components has also improved the hygiene and durability of peeling machines, making them more suitable for meeting international food safety standards. Energy efficiency and sustainability have become important considerations in recent developments. Solar-powered cassava peelers have been designed to cater to off-grid rural communities, reducing reliance on fossil fuels and lowering operational costs (Amanor & Bobobee, 2021; Chima Kalu & Musbau Oluwe, 2023). Additionally, designs have been proposed to allow for easy assembly, disassembly, and scalability based on processing needs. The adoption of improved cassava peeling and processing technologies has significant implications for food security, economic development, and poverty alleviation. Enhanced processing efficiency leads to higher product yields and quality, facilitating access to broader markets and better prices for farmers and processors (Victor Uzochukwu *et al*., 2021). Improved technologies also reduced processing time and labor requirements, allowing households to diversify their income-generating activities and improve their livelihoods. Moreover, efficient processing contributes to reduced post-harvest losses and extended shelf life of cassava products, which is crucial for stabilizing food supplies and prices, especially in periods of scarcity. High-quality processed products such as flour, starch, and ethanol meet industrial demands and open avenues for export, generating foreign exchange and contributing to national economies (Adeleye *et al*., 2021; Kolawole *et al*., 2010). Having said these, several challenges persist in the development and dissemination of efficient cassava processing technologies. For instance, limited access to financing, inadequate technical skills, and poor infrastructure hinders the widespread adoption of these technologies, particularly among smallholder farmers (Mbanjo *et al*., 2021). To address these issues, collaborative efforts involving government agencies, research institutions, and private sector stakeholders are essential. Also, future research should focus on developing cost-effective, user-friendly, and adaptable processing technologies that cater to the diverse needs of cassava producers across different regions, with emphasis placed on participatory design approaches that involve end users in the development process to ensure relevance and acceptability.

Experimental Design and Methodology

This section presents the conceptualization, design, and construction of the cassava peeling machine. The methodology and design were crafted to meet agricultural needs, focusing on enhancing efficiency, affordability, and ease of operation. The primary aim was to develop a machine capable of addressing the challenges faced in manual cassava peeling, with the added benefit of reducing labor and increasing output capacity. The approach involved selecting appropriate materials, ensuring the machine was simple yet effective, and designing the machine with locally available materials to cater to small and medium-scale farmers.

The cassava peeling machine operates by employing a reverse-rotation mechanism. The cylindrical peeling drum, which is covered in an abrasive material, spins in the opposite direction of the cassava tubers placed inside the chamber. This counter-rotation action facilitates the removal of the outer layer of the cassava tubers. The process occurs in batches, allowing for a more controlled and efficient peeling process. The operation begins with the cassava tubers being placed inside the chamber through the hopper. Once inside, the abrasive drum rotates at a speed determined by the motor and belt drive system. As the drum rotates, the abrasive material on its surface comes into contact with the cassava, peeling off the outer layer. The machine is powered by a single-phase induction motor connected to the drum via a belt and pulley system. The motor provides rotational energy, allowing the drum to reach the necessary speeds for effective peeling. The machine is designed to handle multiple tubers at once, with a capacity of up to 1.5 kg per batch.

MATERIALS AND METHODS

Durability, resistance to corrosion, and structural rigidity were key criteria used in the material selection process. While not exhaustive, Table 1 shows a summary of the materials used in the development and design of the chosen were readily available and cost-effective, ensuring that the machine could be easily manufactured and maintained by local farmers. Each part was designed based on desired production rates and other factors. Galvanized plate was selected for the peeling drum due to its high resistance to corrosion, ensuring a longer lifespan of the machine in contact with moist cassava tubers. To serve as the structure for the machine, 38.1 mm angle bar was used in the frame ensuring structural rigidity, while the shaft is made from steel to support the rotational forces and withstand the bending and torsional stresses encountered during operation. The prime mover consists of a single-phase induction motor, selected to provide consistent power at a speed of 1500 rpm, sufficient for the peeling process. To reduce friction and vibration, pillow block bearings and an aluminum pulley system were used to support the drum and transmit torque efficiently.

Table 1: Materials Used in the Design and Construction Process

SN	Item Description	Material	Quantity
1	Peeling drum	Galvanized plate	1
2	Machine frame	38.1 mm angle bar	1
3	Shaft	Steel	1
4	Bearings	Pillow block	2
5	Motor	Single-phase induction	1
6	Pulley system	Aluminum	1
7	Hopper	Mild steel	1
8	Belt	Rubber	1

Machine Specifications

The machine is designed to meet the requirements of small to medium-scale cassava processing operations. Below are the key specifications of the machine:

i. Machine Capacity: 1.5 kg per batch.
ii. Type of Motor: Single-phase induction motor.
iii. Pulley Ratios: 23:4, 23:7, 23:10 (in cm).
iv. Motor Speed: 1500 rpm.
v. Drum Dimensions: 90 cm in length and 16 cm in diameter.

Design Calculations

Pulley Design and Speed Calculation

The pulley design for speed and sizes were calculated to ensure optimal peeling performance using the equation for pulley systems (Equation 1). This equation was used to determine the machine's speed at different pulley ratios, with the maximum speed of 652 rpm requiring the highest power.

$$D_r/N_m = D_m/N_r \quad (1)$$

Where:

N_m = Speed of the motor (driver pulley) in rpm
D_m = Diameter of the driver pulley
D_r = Diameter of the machine's drive pulley
N_r = Speed of the machine's drive shaft

Power Requirement

The power needed to operate the peeling drum was calculated using Eqn 2. On computation, maximum power requirement of 745 watts was achieved. A factor of safety of 2 was applied, and a 2-horsepower motor was selected to ensure the machine's smooth operation under load.

$$P = T \times \omega \quad (2)$$

Where:

P = Power required (watts)
T = Torque opposing rotation (Nm)
w = Angular speed of the shaft (rad/s)

Peeling Drum Design

The peeling drum, a cylindrical design, with diameter of 170 mm and a length of 940 mm is wrapped with an abrasive material to remove the outer skin of the cassava tubers. It is designed to hold up to 1.5 kg of cassava per batch. Its effective abrasive action is generated by the rotation of the drum, which peels the cassava tubers as they rotate in the opposite direction within the chamber. Also related to the drum is the machine's shaft which supports both the peeling drum and the pulley system, transmitting torque from the motor to the drum. As in real world applications, the shaft was designed to withstand both torsional and bending stresses and the diameter determined using the Equation 3:

$$D = \sqrt{\frac{16}{\pi \cdot Su} \times (Kt \cdot Mt^2 + Kb \cdot M_b^2)} \quad (3)$$

Where:

S_u = Ultimate tensile strength of steel
K_t = Shock and fatigue factor for torsion
K_b = Shock and fatigue factor for bending
M_t = Maximum torsional moment
M_b = Maximum bending moment

The final calculated shaft diameter was 8.1 cm, ensuring sufficient strength to handle the forces during operation.

Fabrication of Components and Performance Evaluation

We proceed to present a thorough evaluation of the performance and fabrication process for the device the cassava peeling machine. As discussed in the introductory section, the design is aimed to achieve optimal peeling efficiency and throughput capacity, while using locally sourced materials and components. Additionally, a performance assessment was conducted to determine the machine's efficiency under various operating conditions, considering key factors such as machine speed, day after harvest, and grater size. These three major factors were put into focus through the use of the factorial design methodology. It comprised two levels of each factor, a useful way to determine the effects of the factors on peeling efficiency and throughput capacity. It also allowed for the analysis of both main effects and interaction effects between the variables. Tests were carried out at three different speeds: 261 rpm, 457 rpm, and 652 rpm. Descriptive statistical analysis using the ANOVA was employed to summarize the data before further modeling. Subsequently, a regression model was developed to predict peeling efficiency and throughput capacity based on the influencing factors. The general form of the regression equation is depicted in Equation 4 capturing the response and independent variable while also putting into consideration the constants such as motor speed.

$$Y = B_0 + \sum B_n X_n \quad (4)$$

Where:

Y represents the response variable (peeling efficiency or throughput capacity),
B_0 is the constant of the model,
B_n represents the coefficients of the independent variables,
X_n represents the independent variables (such as machine speed, day after harvest, and grater size).

Performance evaluation in terms of peeling efficiency and throughput capacity were found to be dependent variables which when analyzed in relation to the crop (day after harvest) and machine variables (machine speed and grater size) show useful insight in the overall efficiency and viability of the machine. To get qualitative samples, the evaluation experiment involved peeling batches of cassava tubers with five samples per batch. The time taken to peel each batch was recorded, and the peeling efficiency was calculated using Equation 5:

$$\eta = (M_{po}/(M_c+M_{po})) \times 100 \quad (5)$$

Where:

η represents peeling efficiency,
M_{po} is the mass of the peel collected,
M_c is the mass of the completely peeled cassava tuber.

Throughput capacity was calculated using:

$$T_c = W_t/T$$

Where:
T_c is the throughput capacity (kg/h),
W_t is the weight of cassava fed into the machine (kg),
T is the time taken to complete the peeling process (h).

RESULTS AND DISCUSSION

The evaluation of the cassava peeling machine was based on two primary metrics: peeling efficiency and throughput capacity. These were analyzed under various operational conditions to assess the machine's performance in real-world applications. Factors such as machine speed, day after harvest, and grater size were examined to determine their impact on the machine's overall effectiveness. Table 2 and 3 show data recorded during the experimentation and test of the machine showing machine speed, grater size for different runs and their resulting throughput and efficiency.

Table 2: Coded Randomized Experimental Runs

Run	Day After Harvest (days)	Machine Speed (rpm)	Grater Size (mm)	Peeling Efficiency (%)	Throughput Capacity (kg/h)
1	0	456.5	3.5	90	55.714
2	-1	261	5	80	128.999
3	1	261	2	80	67.768
4	-1	652	5	95	168.000
5	1	456.5	3.5	90	88.836
6	5	652	5	95	25.714
7	3	456.5	2	90	68.764
8	3	652	2	95	47.755
9	3	261	5	90	30.612
10	5	261	2	90	27.857

Table 3: Design Layout of Process Factors and Values

Run	Day After Harvest (days)	Grater Size (mm)	Machine Speed (rpm)	Peeling Efficiency (%)	Throughput Capacity (kg/h)
1	1	5	261	80	128.999
2	-1	5	652	90	168.000
3	5	2	261	90	27.857
4	3	3.5	652	95	47.755
5	3	456.5	3.5	90	88.836
6	0	2	456.5	90	55.714
7	1	5	652	90	125.455
8	5	3.5	652	95	25.714
9	1	2	261	90	67.768
10	3	5	261	90	30.612

Peeling Efficiency

Using the cassava weight before and after peeling provided a high level of accuracy when recording the efficiency of the machine. Since the weight of the entire cassava and the peel could be measured, it thus served as a crucial metric to indicates how well the machine removes the cassava's outer skin. In this setup, higher peeling efficiency means more of the peel is removed, leaving behind a clean tuber with minimal wastage. An analysis of variance (ANOVA) Table 4 revealed significant effects of two factors: day after harvest and machine speed. The p-values associated with these factors were less than 0.05, indicating their significance in affecting the machine's peeling efficiency. Of the two, the day after harvest p-value was 0.0199 while machine speed was 0.0199. The first value indicates that the moisture content in cassava tubers, which is related to the number of days after harvest, directly affects how easily the outer skin can be removed. Freshly harvested tubers with higher moisture content proved easier to peel, leading to higher efficiency. As the cassava tubers lose moisture over time, the peel becomes harder to remove, reducing the machine's efficiency. This is supported by the significant p-value, showing that day after harvest has a direct influence on the machine's performance. Similarly, the speed of the machine appeared to play a critical role in determining peeling efficiency. Higher machine speeds increase the interaction between the abrasive drum and the cassava tuber, improving the removal of the outer layer. The results show that as speed increases from 261 rpm to 652 rpm, peeling efficiency improves significantly.

Table 4: ANOVA Results for Peeling Efficiency

Source	**Sum of Squares**	**df**	**Mean Square**	**F-Value**	**p-Value**
Model	225.00	3	75.00	6.00	0.0239
Day After Harvest	112.50	1	112.50	9.00	0.0199
Machine Speed	112.50	1	112.50	9.00	0.0199
Grater Size	0.00	1	0.00	0.00	1.0000
Curvature	4.17	1	4.17	0.33	0.5818
Residual	87.50	7	12.50		
Lack of Fit	12.50	4	3.125	0.125	0.9636
Pure Error	75.00	3	25.00		
Total	316.67	11			

In contrast, the third parameter grater size was found to have no significant effect on peeling efficiency, with a p-value of 1.0000. This suggests that the size of the abrasive grater does not influence how effectively the machine removes the cassava peel. Figure 1 shows the Pareto chart for the peel efficiency. It clearly shows the relationship between the three factors considered and how they influence peel efficiency. Figure 1 depicts a Pareto chart, which visually ranks the influence of the tested factors on peeling efficiency. Both day after harvest and machine speed surpass the threshold for statistical significance, indicating that these factors are the primary determinants of peeling efficiency. The fact that grater size does not exceed the t-value limit confirms its negligible effect.

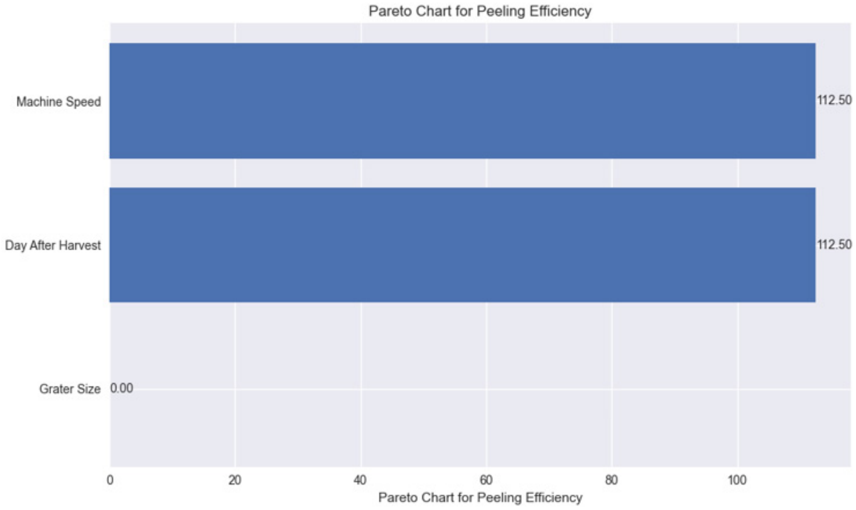

Figure 1: Pareto Chart for Peel Efficiency

Graphical Analysis of Peeling Efficiency

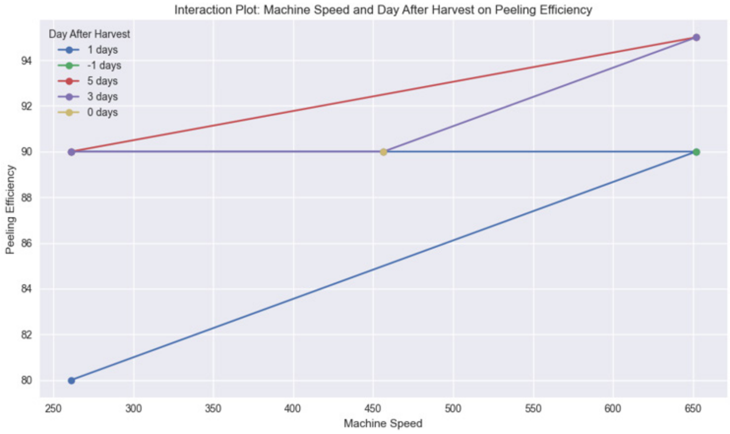

Figure 2: Interaction Plot: Machine Speed and Day After Harvest on Peeling Efficiency

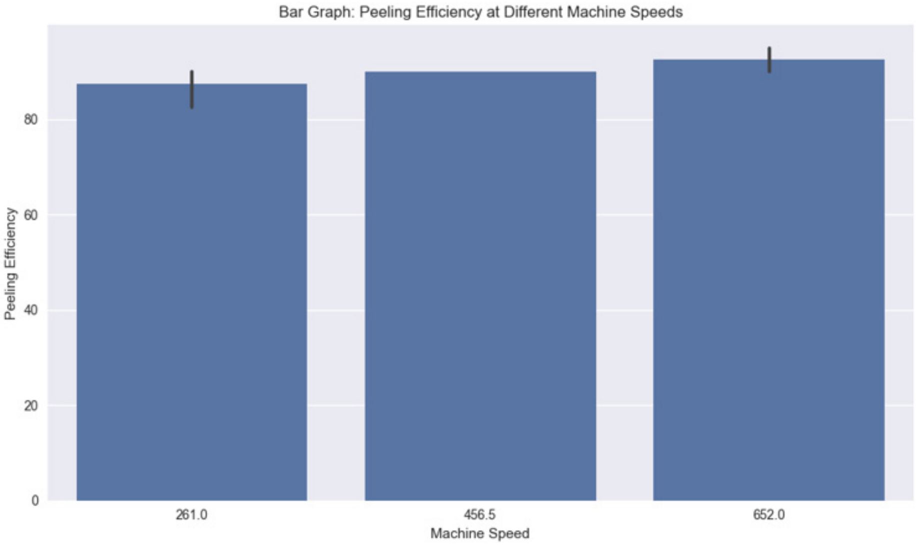

Figure 3: Bar Graph: Peeling Efficiency at Different Machine Speeds

Figures 2 and 3 further illustrate the relationship between peeling efficiency and the key factors. As shown in Figure 2, there is a clear linear relationship between day after harvest and peeling efficiency, with efficiency decreasing as the number of days post-harvest increases. This emphasizes the importance of peeling cassava shortly after harvest for maximum efficiency.

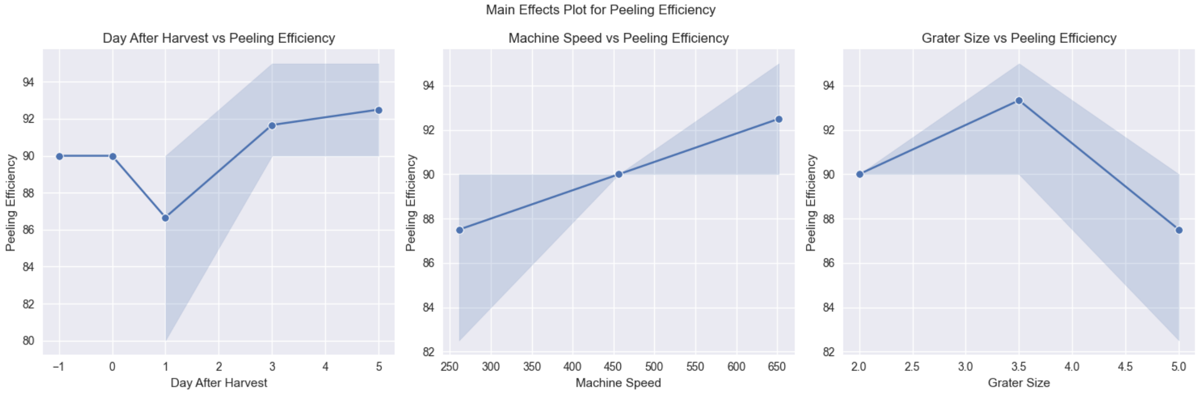

Figure 4: Main Effects Plot for Peeling Efficiency

In Figure 4, the linear relationship between machine speed and peeling efficiency is evident. As speed increases, so does peeling efficiency, confirming the findings of the ANOVA analysis. The grater size is also shown to lead to a reduction in the efficiency after a threshold of 3.5 mm. For further analysis, a regression equation was developed to predict peeling efficiency is while emphasizing the effect of each variable.

$$\text{Peeling Efficiency} = 74.368 + 1.875 \times \text{Day After Harvest} + 0.0191 \times \text{Speed} \qquad (6)$$

Equation 6 can further be used to estimate the peeling efficiency under various operating conditions, providing valuable insight into how adjusting the machine speed or time post-harvest can improve performance. Figure 5 shows the graphical representation of the regression datapoints.

Throughput Capacity

Throughput capacity is the amount of cassava that can be peeled by the machine in a given period (kg/h). Essential for understanding the machine's productivity in practical settings, this metric will prove the scalability and operational effectiveness of the machine. Higher throughput indicates that the machine can handle larger quantities of cassava in less time, which is critical for scaling operations. The results from Table 5 show that day after harvest, machine speed, and the interaction between day after harvest and grater size have significant effects on throughput capacity. Similar to its effect on peeling efficiency, the day after harvest had a p-value of 0.0004. This further showed that the moisture content of the cassava tubers influences the throughput capacity. Fresh tubers with higher moisture content are processed

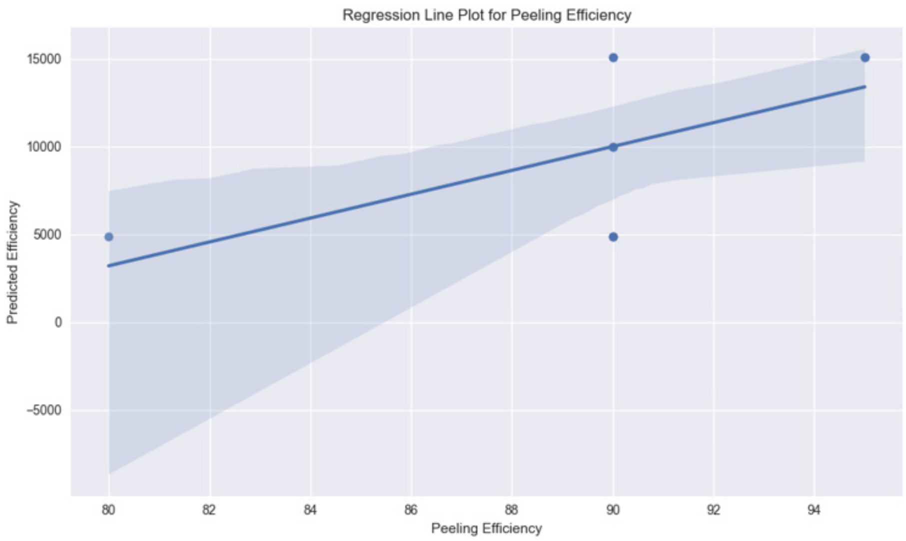

Figure 5: Regression Line Plot for Peeling Efficiency

more quickly, leading to higher throughput. As the tubers dry out over time, the machine takes longer to remove the peel, resulting in a lower throughput. This significant p-value underscores the importance of processing cassava shortly after harvest to maximize throughput. The speed of the machine with p-value: 0.0290 proved to be directly proportional to throughput capacity. As the machine's speed increases, more cassava can be processed in a shorter amount of time, resulting in higher throughput.

An interaction between day after Harvest and Grater Size showed p-value: 0.0213. This indicates that while grater size alone may not significantly affect peeling efficiency, its interaction with the moisture content of the cassava tubers does influence throughput capacity. This suggests that, depending on the day after harvest, certain grater sizes may perform better than others in terms of processing speed. Figure 6 – 8 show visual representation of these factors.

Table 5: ANOVA Results for Throughput Capacity

Source	Sum of Squares	df	Mean Square	F-Value	p-Value
Model	21461.01	6	3576.83	25.484	0.0038
Day After Harvest	16045.93	1	16045.93	114.32	0.0004
Machine Speed	1559.28	1	1559.28	11.109	0.0290
Grater Size	892.32	1	892.32	6.358	0.0653
Day After Harvest Grater Size	1893.03	1	1893.03	13.487	0.0213
Curvature	119.53	1	119.53	0.851	0.4083
Residual	561.43	4	140.36		
Total	22141.96	11			

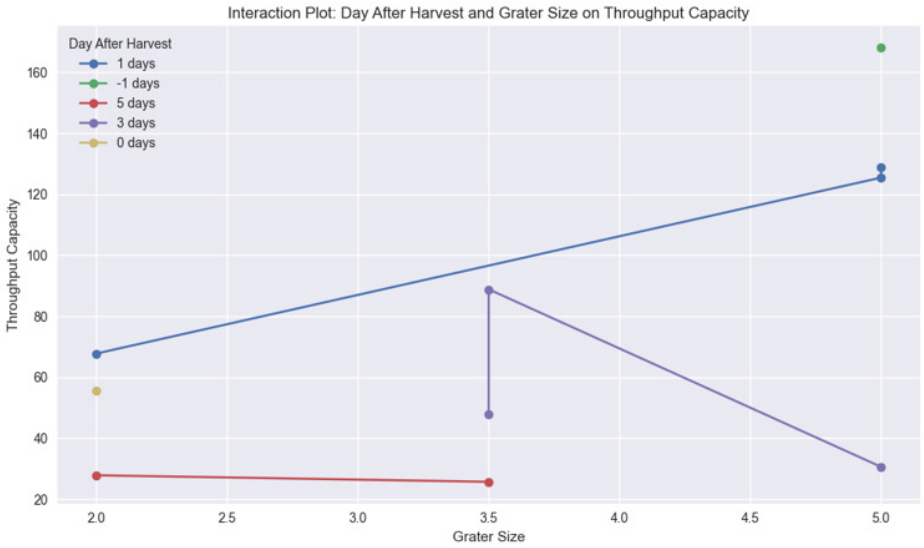

Figure 6: Interaction Plot: Day After Harvest and Grater Size on Throughput Capacity

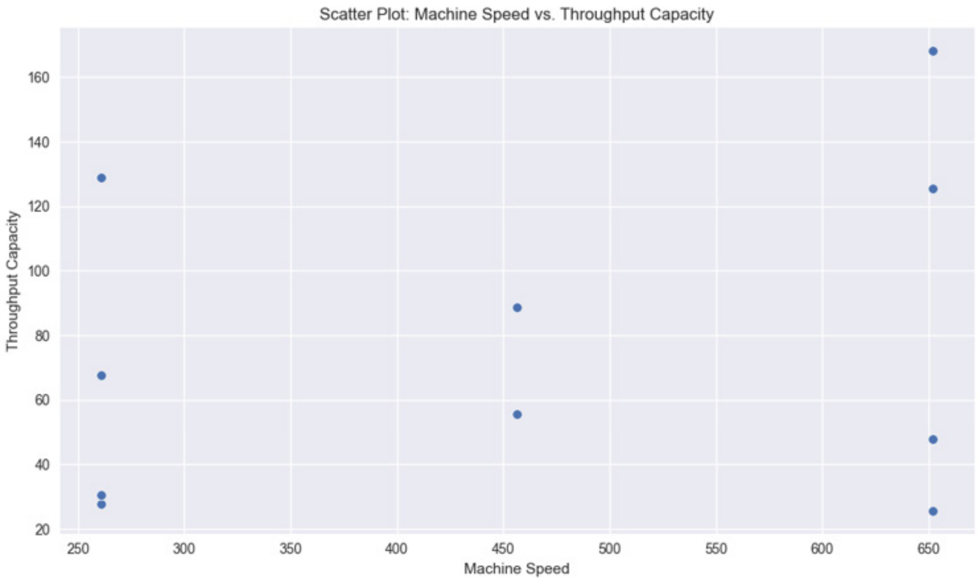

Figure 7: Scatter Plot: Machine Speed vs. Throughput Capacity

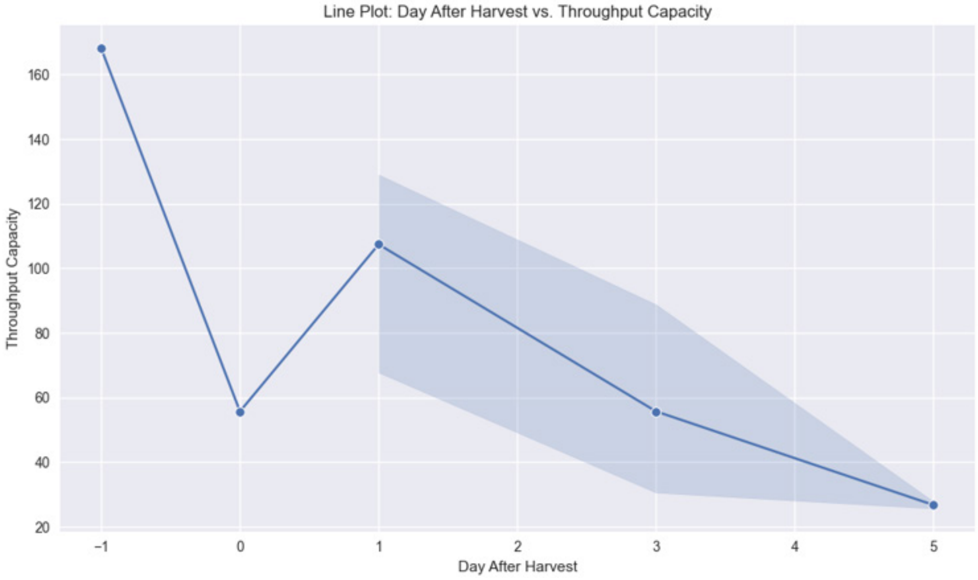

Figure 8: Line Plot: Day After Harvest vs. Throughput Capacity

Figure 6 illustrates the interaction effect between day after harvest and grater size on throughput capacity. The highest throughput capacity values (92 kg/h and 150 kg/h) were achieved with cassava tubers processed one day after harvest and using a 2 mm grater size. This interaction highlights the importance of considering multiple factors simultaneously to optimize machine performance. Figure 7 shows a clear positive correlation between machine speed and throughput capacity. As the machine speed increases, throughput capacity also rises, with the highest value recorded at 652 rpm. In Figure 8, the effect of day after harvest on throughput capacity is further analyzed. As expected, throughput capacity decreases from 130 kg/h on day 1 to 25 kg/h on day 5. This decline is due to the reduced moisture content of the tubers over time, making the peeling process more difficult and time-consuming.

A regression equation for predicting throughput capacity, based on the experimental factors, is presented by Equation 7:

$$\text{Throughput Capacity} = -31.51192 + 7.47533 \times \text{Day After Harvest} + 30.88459 \times \text{Grater Size} + 0.21463 \times \text{Machine Speed} \quad (7)$$

This equation was used to estimate the machine's throughput under different conditions, allowing operators to make informed decisions about optimizing machine speed, grater size, and the timing of cassava processing. Figure 9 shows a trend of predicted efficiencies for a large dataset of runs and indicates significant possible potentials and drawdowns of the machine.

The performance evaluation reveals that day after harvest and machine speed are the most influential factors on both peeling efficiency and throughput capacity. For optimal performance, freshly harvested cassava should

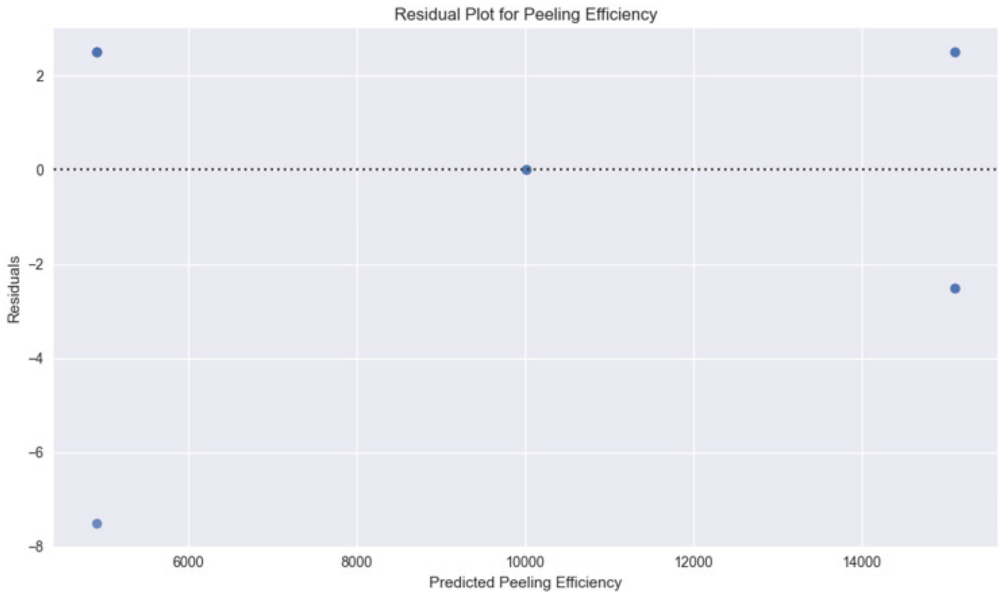

Figure 9: Residual plot for peeling efficiency

be peeled as soon as possible to maximize efficiency and throughput. Also, higher machine speeds improve both metrics, but care must be taken to avoid damaging the cassava tubers at excessive speeds. Finally, grater size alone does not significantly affect peeling efficiency but can influence throughput capacity when combined with other factors.

CONCLUSIONS

We developed an electrically powered cassava peeling machine which demonstrated an average throughput capacity of 75.54 kg/hr and a peeling efficiency of 88.33%. The experimental results highlighted that two key factors—machine speed and day after harvest—had a significant impact on both throughput capacity and peeling efficiency. The data collected from the randomized experimental runs indicated that an optimal combination of day after harvest and grater size can notably enhance throughput capacity. Specifically, the analysis showed that operating the machine with a smaller grater size of 2 mm and processing cassava tubers 1 day after harvest maximized the throughput. The ANOVA results confirmed that the interaction between these factors (day after harvest and grater size) plays a significant role in achieving optimal performance. However, the interaction effect between machine speed and grater size was found to be insignificant and can be disregarded. This means that while both machine speed and grater size independently influence performance, their combined effect does not contribute meaningfully to throughput capacity.

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