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Development and Performance Evaluation of a Lead Screw-Assisted Multi-Crop Slicing Machine for Selected Crops

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ABSTRACT

The need for efficient and adaptable slicing equipment for heterogeneous agricultural produce remains a major challenge in small- to medium-scale agro-processing. This study presents the design, fabrication, and performance evaluation of a lead screw–assisted multi-crop slicing machine capable of processing cucumber, potato, and plantain with varying geometrical properties. The machine integrates a controlled feed mechanism with a rotary stainless-steel blade system to achieve uniform slicing across different crop types. Performance evaluation was conducted using slicing efficiency, percentage material loss, and throughput capacity under controlled operating conditions. Results showed that slicing efficiency ranged from 97.5–98.7% for cucumber, 95.8–96.4% for potato, and 95.7–97.9% for plantain. Corresponding percentage losses were 1.3–2.5%, 3.6–4.2%, and 2.1–4.3%, respectively. Throughput capacity varied between 96–120 kg h^{-1} for cucumber, 72–96 kg h^{-1} for potato, and 40–80 kg h^{-1} for plantain, reflecting the influence of crop texture and geometry on machine performance. The relatively lower throughput observed for plantain was attributed to its higher resistance to cutting and larger size. The results demonstrate that the developed slicer achieves high slicing efficiency with minimal material loss while accommodating multiple crop types. This highlights its potential as a cost-effective and versatile solution for improving post-harvest processing efficiency. Further optimization of blade configuration and power transmission system is recommended to enhance throughput performance.

Keywords: Multi-crop slicer, Lead screw mechanism, Slicing efficiency, Throughput capacity, Agricultural mechanization, Post-harvest processing

1. INTRODUCTION

Size reduction is a fundamental unit operation in food and agricultural processing due to the bulky and heterogeneous nature of most agricultural produce, which often vary in size, shape, texture, and moisture content. Operations such as slicing fruits and vegetables for canning, shredding roots for drying, chopping forage crops, grinding grains for feed production, and milling into flour are all classified under size reduction processes (Zambelli et al., 2026). These operations improve material handling, increase specific surface area, enhance heat and mass transfer rates, and ultimately contribute to improved processing efficiency and product quality.

Root and tuber crops constitute major staple foods in many developing countries, particularly in sub-Saharan Africa. However, their high moisture content and perishability present significant post-harvest challenges. Processing these crops into stable and easily transportable forms provides a practical alternative to storage in the fresh state. Drying remains one of the most effective preservation techniques, where produce is converted into chips, flour, or pellets for human and livestock consumption (Fathi et al., 2022; Routray et al., 2023). Prior to drying, slicing is essential because it increases the exposed surface area, thereby accelerating moisture diffusion, reducing drying time, and improving drying uniformity.

Beyond preservation, size reduction also plays an important role in thermal processing operations such as

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boiling, steaming, frying, and roasting. Sliced materials exhibit faster and more uniform heat penetration compared to whole produce, resulting in reduced cooking time, improved energy efficiency, and enhanced product consistency (Ketsa & Wisutiamonkul, 2022). Moisture reduction during such processes is essential, as shelf life is strongly dependent on achieving moisture levels that limit microbial proliferation (Deak & Mohácsi-Farkas, 2023). In many parts of Africa, traditional roasting methods involving direct exposure to open flames or hot ashes often result in uneven heating and prolonged processing times (Ogunmoyela et al., 2023). Slicing has been shown to significantly improve heat transfer uniformity, thereby enhancing product quality and reducing energy requirements.

Slicing operations involve cutting materials into defined geometries using thin, sharp blades while minimizing structural damage to the product (Goda et al., 2024). However, traditional manual slicing methods using knives are often inefficient and produce non-uniform slices, which lead to uneven drying, inconsistent cooking, and increased susceptibility to spoilage (Sun et al., 2025). In addition, manual operations are labour-intensive, time-consuming, and associated with safety risks, particularly when processing large volumes of produce.

To address these limitations, several mechanical slicing machines have been developed. For instance, Olumilua et al. (2025) designed a plantain peeler–slicer that achieved an average slicing efficiency of 88.94% and throughput capacities ranging from 79.59 to 89.27 kg h^{-1}. Similarly, Olusegun et al. (2023) developed a motorized yam slicer powered by a 1.5 hp electric motor, with a maximum slicing efficiency of 52.3% and an average throughput capacity of 315 kg h^{-1}, although a significant proportion of the slices were non-uniform. Despite these advancements, many existing slicing machines are crop-specific, expensive, and often produce inconsistent slice thickness, limiting their applicability across different produce types.

Furthermore, most conventional slicers lack adaptive mechanisms to accommodate the heterogeneous nature of agricultural materials, particularly variations in size, shape, and mechanical properties. This often results in reduced slicing efficiency, increased material losses, and compromised product quality during processing.

In response to these challenges, there is an increasing demand for versatile, cost-effective, and efficient agro-processing equipment suitable for small- and medium-scale enterprises. The development of multi-functional machines capable of handling diverse crop types without compromising performance is therefore essential. The novelty of this study lies in the integration of a controlled feed mechanism (lead screw-assisted system) with a rotary blade assembly to enable uniform slicing of crops with varying geometrical and physical properties.

Therefore, this study focuses on the design, fabrication, and performance evaluation of a multi-crop slicing machine for selected fruits and tubers (cucumber, potato, and plantain), with the aim of achieving high slicing efficiency, improved slice uniformity, reduced material losses, and enhanced operational safety.

2. MATERIALS AND METHODS

2.1 Design consideration

The design of the multi-crop slicing machine was guided by functional, mechanical, ergonomic, and hygienic requirements suitable for small- to medium-scale agro-processing applications. Particular emphasis was placed on developing a system capable of handling the heterogeneous nature of agricultural produce, characterized by variations in size, shape, texture, and mechanical strength.

To accommodate this variability, a lead screw–assisted feed mechanism was incorporated to provide controlled and uniform advancement of the crop toward the cutting blades. This mechanism ensures consistent contact between the material and the slicing unit, thereby minimizing irregular cuts and enhancing slice uniformity irrespective of crop geometry. The feeding system was designed to operate under steady linear motion, eliminating sudden impact forces commonly associated with manual or gravity-fed systems.

Blade design parameters; including geometry, edge sharpness, spacing, and alignment, were carefully selected to achieve uniform slice thickness (approximately 5 mm) while minimizing mechanical damage such as tearing, crushing, or excessive deformation. The blade arrangement was optimized to maintain continuous cutting action and reduce material resistance during slicing.

Food-contact components were fabricated from food-grade stainless steel to enhance corrosion resistance, prevent contamination and comply with food safety standards. The design further incorporated simplified operational controls, accessibility for cleaning and maintenance, vibration stability, modular construction and compact configuration to facilitate transport, installation and scalability for increased processing capacity.

2.2 Material selection

Material selection was based on mechanical strength, corrosion resistance, manufacturability, availability and cost-effectiveness to ensure reliable performance under continuous operation. Locally available materials were prioritized to facilitate fabrication, routine maintenance and component replacement.

Mild steel was selected for structural members due to its high strength-to-cost ratio and ease of welding. Stainless steel was used for all crop-contact parts to prevent corrosion and ensure hygienic operation under moist processing conditions. Lightweight components were incorporated where appropriate to reduce mechanical load, improve energy efficiency and enhance portability. Materials that allow ease of cleaning, repair and replacement were also considered to reduce downtime and extend machine service life.

2.3 Machine description and working principle

The developed multi-crop slicing machine comprises a mainframe, feeding chute (slicing chamber), slicing blade assembly, lead screw-driven presser plate mechanism, power transmission system (belt–pulley and reduction gearbox), and electric motor, integrated into a compact processing unit.

The mainframe was fabricated using 40 × 40 × 4 mm mild steel angle bars, providing structural rigidity and resistance to vibration during operation. The overall dimensions of the machine are 750 mm × 610 mm × 500 mm, making it suitable for small-scale processing environments with limited space.

The slicing chamber is V-shaped (220 mm × 220 mm × 300 mm) and constructed from 1.5 mm thick stainless steel. This geometry facilitates proper alignment and orientation of the crops while enabling gravity-assisted positioning toward the cutting zone. The V-shaped design minimizes material misalignment and ensures consistent engagement with the blades.

A double lead screw mechanism is employed to drive the presser plate, converting rotary motion into controlled linear motion. This mechanism ensures a steady and uniform feed rate, which is critical for achieving consistent slice thickness across crops of varying sizes and shapes. The synchronized movement of the lead screws prevents tilting or uneven pressure distribution on the material during feeding.

The slicing unit consists of stainless steel blades (1 mm thickness) arranged to produce slices of approximately 5 mm thickness. The blades are mounted on a rotating shaft and positioned to provide continuous cutting action. The sharpness and alignment of the blades minimize cutting resistance, reduce mechanical damage, and improve slicing efficiency.

The presser plate assembly applies uniform pressure on the crop and consists of a reinforced structure combining mild steel, stainless steel, and a PTFE contact layer. This configuration ensures durability, corrosion resistance, and low friction during operation.

Power is supplied by a 0.5 hp single-phase electric motor, which transmits motion through a belt–pulley system to a reduction gearbox. The gearbox reduces the rotational speed while increasing torque, ensuring sufficient cutting force for slicing relatively firm crops such as plantain and potato. This arrangement enhances operational stability, reduces vibration, and improves overall machine performance.

The working principle involves loading the crop into the hopper, after which the rotating lead screw advances the presser plate to push the material toward the rotating blades. Continuous slicing occurs as the material makes contact with the blades, producing uniform slices that are discharged through the outlet. The isometric and exploded views of the developed machine are presented in Figure 1 and Figure 2, respectively, illustrating the arrangement and interaction of the machine components.

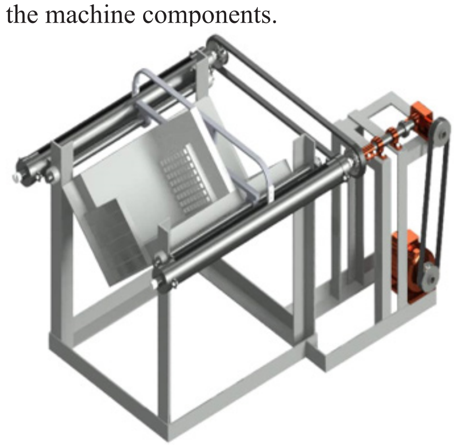

Figure 1: Isometric view of the developed multi crop slicer

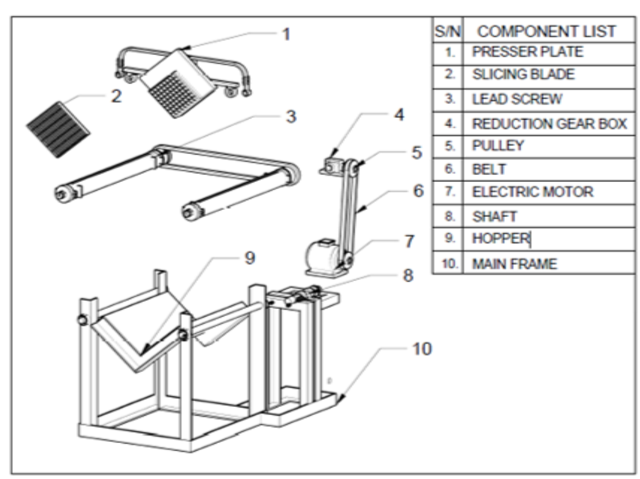

Figure 2: Exploded view of the developed multi crop slicer

2.4 Design calculations and analysis

Design calculations were carried out to determine critical geometric and mechanical parameters required for proper material selection and structural reliability of the machine components. Analytical procedures were based on classical machine design principles and standard mechanical design codes to ensure safe operation under combined loading conditions.

2.4.1 Design of the slicing unit and blade assembly

The slicing unit was designed to handle the heterogeneous nature of agricultural produce, including cylindrical (cucumber), oval (plantain), and irregular/ tuber (potato) shapes. To achieve this, a V-shaped hopper configuration was adopted to promote self-alignment and gravity-assisted feeding into the cutting zone. This geometry minimizes misalignment and ensures consistent engagement with the blades, as commonly applied in bulk material handling systems (Erchafo, 2025).

The hopper geometry was approximated as a right triangular prism with the following dimensions:

Base width, (a = 220 mm)

Height, (b = 220 mm)

Length, (h = 280 mm)

The volume of the slicing chamber was determined using Equation (1):

$$V = \frac{1}{2}abh \tag{1}$$

where V is the hopper volume (mm³). The calculated capacity ensures adequate batch feeding without imposing excessive compressive load on the slicing blades.

The slicing mechanism consists of rotary stainless-steel blades (straight-edge type) mounted on a shaft and arranged in parallel configuration. Blade spacing was fixed at 5 mm, which determines the slice thickness. This thickness was selected based on its suitability for drying and frying processes, where heat and mass transfer rates are strongly influenced by slice geometry (Ketsa & Wisutiamonkul, 2022).

To improve slicing performance across different crops, the machine incorporates:

- A lead screw–driven presser plate for controlled feeding
- A multi-blade arrangement for continuous cutting
- A reinforced blade support grid to prevent vibration-induced misalignment

This configuration ensures uniform slicing while minimizing tearing, crushing, and deformation of soft or fibrous materials.

2.4.2 Design of the machine shaft

The shaft was designed to transmit power from the drive system to the blade assembly while withstanding combined bending and torsional stresses. These stresses arise from belt tension, blade resistance, and cutting forces during operation. The equivalent twisting moment was first determined using Equation (2):

$$T_e = \sqrt{(K_b M)^2 + (K_t T)^2} \tag{2}$$

where

T_e is the equivalent twisting moment (N m),
M is the maximum bending moment (N m),
T is the transmitted torque (N m),
K_b is the combined shock and fatigue factor for bending, and
K_t is the combined shock and fatigue factor for torsion.

The shaft diameter was then calculated using Equation (3):

$$d = \left(\frac{16T_e}{\pi \tau_{allow}} \right)^{\frac{1}{3}} \tag{3}$$

where
τ_{allow} is the allowable shear stress (Pa).

A value of 1.2×10^8 Pa was adopted for mild steel (Collamat, 2025).

The selected shaft diameter satisfies both strength and rigidity requirements while ensuring efficient torque transmission. Proper keyways were incorporated to securely mount the blade assembly and pulleys without excessive stress concentration.

2.4.3 Design of belt and pulley system

The belt–pulley system was designed not only for power transmission but also to provide speed control, which is essential for optimizing slicing performance across different crop types. The power transmitted by the belt was determined using Equation (4):

$$P = (T_1 - T_2)v \tag{4}$$

where

P is the transmitted power (W),
T_1 and T_2 are the tight- and slack-side belt tensions (N), and
v is the belt velocity (m s^{-1}).
Belt velocity was calculated using Equation (5):

$$V = \frac{\pi DN}{60} \quad (5)$$

where
D is the pulley diameter (m), and
N is the rotational speed (rpm).

The velocity ratio between pulleys was determined using Equation (6)

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} \quad (6)$$

where subscripts 1 and 2 denote driver and driven pulleys, respectively.

To enable variable operating speeds (low, medium, high), interchangeable pulley diameters were incorporated. This allows adjustment of blade rotational speed depending on crop hardness and size: lower speeds for soft crops (cucumber) and higher speeds for firmer crops (plantain, potato).

A V-belt drive was selected due to its high frictional grip, shock absorption capability, and suitability for compact agro-processing machines (Zambelli et al., 2026).

2.4.4 Design of reduction gearbox and torque requirement

To ensure adequate cutting force, a reduction gearbox was incorporated to decrease speed and increase torque at the slicing shaft. The torque transmitted by the shaft was calculated using Equation (7):

$$T = \frac{60P}{2\pi N} \quad (7)$$

where
T is torque (N m),
P is motor power (W), and
N is rotational speed (rpm).
The gearbox reduction (R) ratio was determined using Equation (8)

$$R = \frac{N_{input}}{N_{output}} \quad (8)$$

The selected reduction ratio ensures sufficient torque multiplication to overcome cutting resistance, particularly for fibrous crops like plantain. At the same time, excessive speed reduction was avoided to maintain acceptable throughput capacity.

Proper gear alignment and lubrication were incorporated to reduce frictional losses, minimize wear, and enhance operational efficiency.

2.4.5 Design of lead screw and presser plate mechanism

The feeding mechanism consists of a dual lead screw system, which provides controlled and uniform feeding of crops into the slicing zone. This is critical for handling materials with varying sizes and shapes. The linear velocity of the presser plate was determined using Equation (9):

$$V_1 = Np \quad (9)$$

where
V_l is linear velocity (mm min^{-1}),
N is screw rotational speed (rpm), and
p is screw pitch (mm).

The axial force generated by the screw was estimated using Equation (10):

$$F \frac{2\pi T}{d_m \tan(\phi + \lambda)} \quad (10)$$

where
F is axial force (N),
T is applied torque (N m),
d_m is mean screw diameter (m),
φ is angle of friction, and
λ is helix angle.

This ensures that sufficient force is generated to push the crop against the blades without slippage or stalling.

The dual screw arrangement prevents tilting of the presser plate and ensures uniform pressure distribution across the crop surface. This is particularly important for irregularly shaped materials, as it minimizes uneven slicing and improves product quality. To further enhance performance: The presser plate was reinforced for structural rigidity. A PTFE (polytetrafluoroethylene) contact layer was applied to reduce friction. The system ensures smooth motion and prevents sticking of moist materials.

2.5 Fabrication procedure and assembly

The multi-crop slicing machine was fabricated using standard mechanical workshop processes in accordance with established fabrication practices to ensure dimensional accuracy, structural integrity, and operational reliability.

The mainframe was constructed from mild steel angle sections (40 × 40 × 4 mm) cut to size and joined by shielded metal arc welding. Structural squareness and alignment were verified prior to full welding to minimize distortion and residual stresses.

The slicing chamber was fabricated from 1.5 mm stainless steel sheet, sheared to dimension, bent into a V-shaped profile and welded to form a rigid enclosure. All internal surfaces were ground and polished to reduce crevices that may harbor contaminants, in line with hygienic equipment design recommendations for food processing systems.

The blade assembly consisted of straight-edge stainless steel blades (1 mm thickness) arranged in a parallel grid configuration with 5 mm spacing, as established during the design stage. Precision spacing fixtures were used during assembly to ensure uniform blade alignment and consistent slice thickness. The blades were securely mounted on a reinforced support frame to withstand repetitive cutting forces and minimize vibration-induced misalignment.

The transmission shaft was machined from mild steel rod using turning, facing and keyway slotting operations. Bearing seats were finished to tolerance to ensure proper fit and minimize vibration. The dual lead-screw mechanism was fabricated and mounted on bearing housings to convert rotary motion into controlled linear displacement of the presser plate.

The dual lead screw mechanism, which serves as the primary feeding system, was fabricated and mounted on bearing supports to ensure synchronized rotation. This mechanism converts rotary motion into controlled linear displacement of the presser plate, enabling consistent feeding of crops regardless of size or shape variability.

The presser plate assembly was fabricated from mild steel and reinforced with a stainless-steel contact surface. A polytetrafluoroethylene (PTFE) layer was incorporated at the contact interface to reduce friction and prevent sticking of moist materials, thereby enhancing feeding efficiency and operational smoothness. The electric motor and reduction gearbox were mounted on adjustable base plates to allow belt tension regulation and alignment of the drive system.

Final assembly involved alignment of rotating components, installation of protective guards and verification of smooth motion prior to performance evaluation.

2.6 *Principle of operation*

The multi crop slicing machine operates on a mechanically coordinated feeding and cutting mechanism powered by a single-phase electric motor. Electrical energy from a 240 V AC supply drives the motor, which transmits rotational motion to the reduction gearbox through a belt–pulley system. The gearbox reduces rotational speed while increasing torque to overcome cutting resistance, as recommended in mechanical power transmission design.

The output shaft of the gearbox drives a dual lead-screw assembly that converts rotary motion into controlled linear displacement of the presser plate. This mechanism ensures uniform compressive force and steady advancement of the crop toward the stationary slicing blades. Similar screw-feed principles are widely applied in agro-processing equipment to improve feeding consistency and slice uniformity.

During operation, crops loaded into the V-shaped hopper are guided toward the blades under controlled pressure. As the crop passes through the blade grid, it is cut into approximately 5 mm thick slices and discharged through the outlet. The cycle continues until the batch is completely processed, ensuring consistent slice thickness and operational efficiency.

2.7 *Experimental design and test plan*

To address variability and enable statistical validation of results, a factorial experimental design was adopted to evaluate the performance of the developed multi-crop slicing machine. A 3 × 3 factorial arrangement in a Completely Randomized Design (CRD) was employed, considering two independent variables:

Factor A: Crop Type (CT)

- A_1: Plantain
- A_2: Cucumber
- A_3: Potato

Factor B: Operating Speed (OS) (controlled via pulley ratio)

- B_1: Low speed (150 rpm)
- B_2: Medium speed (250 rpm)
- B_3: High speed (350 rpm)

Each experimental run was conducted in triplicate (n = 3) to ensure reproducibility and enable estimation of experimental error.

Response variables (Performance indicators)

The following dependent variables were measured: slicing efficiency (%), throughput capacity (kg h^{-1}) and percentage loss (%)

Model structure for ANOVA

The experimental data were analyzed using a two-factor interaction model as presented in Equation (11):

$$Y_{ij} = \mu + A_i + B_j + (AB)_{ij} + \in_{ij} \quad (11)$$

where:
Y_{ij} is the observed response
μ is the overall mean
A_i is the effect of crop type
B_j is the effect of operating speed
$(AB)_{ij}$ is the interaction effect
ϵ_{ij} = experimental error

Analysis of variance (ANOVA) was performed at 95% confidence level ($p < 0.05$) to determine the significance of main and interaction effects.

2.8 Experimental procedure and measurement protocol

2.8.1 Sample preparation and conditioning

Fresh samples of plantain, cucumber, and potato were procured from Ilorin South LGA, Kwara State, Nigeria. Samples were sorted to eliminate defective or diseased units.

Cucumber and potato were washed to remove impurities. Plantain and potato were manually peeled. The samples were cut into uniform feed sizes compatible with the hopper geometry. Each batch was weighed using a digital scale

This ensured uniform initial conditions and minimized variability due to sample heterogeneity.

2.8.2 Machine setup and operating conditions

Prior to testing the machine was assembled and aligned. Belt tension and pulley alignment were adjusted. The motor was powered and allowed to reach steady-state speed, and shaft speed was verified using a tachometer

The V-shaped hopper design ensured proper alignment of samples, while the dual lead screw mechanism provided controlled feeding irrespective of crop shape and size.

2.8.3 Test execution

For each experimental run:

1. A known mass of prepared sample Mi was fed into the machine
2. The slicing operation was initiated at the selected speed level
3. The presser plate (screw-driven) advanced the material uniformly toward the blades
4. Sliced output was collected at the discharge outlet
5. Processing time t was recorded using a stopwatch
6. Acceptable sliced mass Ms was measured immediately

Each treatment combination was replicated three times, and average values were used for analysis

2.8.4 Instruments and measurement accuracy

The instruments used are presented in Table 1.

Table 1: Instruments used for performance evaluation

Instrument	Model/Specification	Accuracy
Digital weighing scale	NBL-2602e	±0.01 g
Digital tachometer	Contact / non-contact	±(0.05 % + 1 digit)
Digital stopwatch	—	±0.01 s

These instruments ensured high precision in measurement of mass, speed, and time, which are critical for performance evaluation.

2.9 Performance evaluation and response calculations

The performance of the slicing machine was evaluated using standard agricultural engineering indices. The governing equations are presented below.

2.9.1 Slicing efficiency

Slicing efficiency represents the proportion of material successfully sliced into acceptable shapes relative to the initial input mass. As defined in Equation (12):

$$\beta_s = \frac{M_s}{M_i} * 100 \quad (12)$$

where
M_s is mass of properly sliced material (g), and
M_i is initial mass of sample fed into the machine (g).

2.9.2 Throughput capacity

Throughput capacity quantifies the rate of processing and is influenced by machine speed and feeding mechanism. As defined in Equation (13):

$$T_c = \frac{M_i}{t} \quad (13)$$

where

M_i is mass of sample processed (g), and
t is processing time (min).

The result was converted to kg h^{-1} for standard reporting.

2.9.3 Percentage loss

Percentage loss accounts for material lost due to breakage, incomplete slicing, or waste. As defined in Equation (13):

Percentage loss during slicing was determined using Equation (14):

$$L_p = \frac{M_i - M_s}{M_i} * 100 \quad (14)$$

where
M_i is initial mass (g), and
M_s is mass of acceptable sliced output (g).

Loss accounts for crushed, irregular or wasted portions generated during slicing.

2.9.4 Statistical analysis

All experimental data were subjected to Analysis of Variance (ANOVA) using Design-Expert. Significance level ($\alpha = 0.05$), Post-hoc comparison (Duncan Multiple Range Test). Model adequacy checked using: Coefficient of determination (R^2), Adjusted R^2 and Lack-of-fit test

This statistical framework ensured that observed differences in performance were quantitatively validated and not due to random variation.

3. RESULTS AND DISCUSSION

The fabricated multi-crop slicing machine (Figure 3) was successfully developed in accordance with the design specifications outlined in Section 2. Functional testing confirmed the structural integrity of the frame, stability of the belt–pulley transmission system, and synchronization between the screw-feed mechanism and blade assembly.

The integration of a V-shaped hopper, dual lead-screw feeding system, and parallel blade configuration (5 mm spacing) ensured controlled material flow and uniform slicing across crops of varying geometries. Similar design configurations have been reported to enhance slicing precision and reduce mechanical damage of carrots and other agro-processing equipment (Erchafo, 2025; Kadurumba et al., 2026; Wang et al., 2025).

Figure 3: Fabricated multi-crop slicer

3.1 Effect of crop type and speed on slicing efficiency and material loss

Table 2 presents the mean performance results (n = 3) for slicing efficiency, percentage loss, and throughput capacity.

Table 2: Mean Performance Results of Multi-Crop Slicer (n = 3)

Crop Type	Slicing Efficiency (%)	Loss (%)	Throughput (kg/h)
Cucumber	98.2 ± 0.60	1.77 ± 0.61	107 ± 12
Potato	96.2 ± 0.32	3.80 ± 0.32	86 ± 12
Plantain	96.8 ± 1.10	3.20 ± 1.10	58 ± 20

The ANOVA results (Table 3) indicate that both crop type (fruits and tuber) and operating speed had a statistically significant effect on slicing efficiency ($p < 0.05$), whereas their interaction effect was not significant. This implies that variations in slicing efficiency are mainly influenced by the inherent physical and mechanical properties of the crops rather than the combined effect of crop type and speed. In other words, the machine responds consistently to changes in operating speed across all crop types, but the degree of performance variation is primarily determined by differences in crop characteristics. The relatively high F-value obtained for crop type (18.45) further confirms that material properties such as texture, moisture content, and shear strength are the dominant factors governing slicing behavior.

Table 3: ANOVA for Slicing Efficiency

Source	DF	SS	MS	F-value	p-value
Crop Type (A)	2	8.72	4.36	18.45	0.0012*
Speed (B)	2	5.18	2.59	10.96	0.0045*
A × B	4	2.11	0.53	2.24	0.1210
Error	18	4.25	0.24	-	-
Total	26	20.26	-	-	-

* Significant at $p < 0.05$

Cucumber recorded the highest slicing efficiency of 98.2% with the lowest material loss of 1.77%. This superior performance is attributed to its high moisture content, low shear strength, and soft parenchymatous tissue structure, which collectively reduce cutting resistance and allow smooth blade penetration. These findings are consistent with the reports of Li et al. (2025) and Xu et al. (2022), who observed improved cutting efficiency in high-moisture vegetable crops due to reduced structural resistance.

Potato exhibited a slightly lower slicing efficiency of 96.2% and a higher loss of 3.8%. This behavior is associated with its higher density, increased dry matter content, and greater resistance to deformation during cutting. These characteristics require higher cutting force, which can lead to increased edge breakage and material loss. Similar observations were reported by Chen et al. (2024), who noted that tuber crops generally require higher mechanical energy for slicing, resulting in reduced cutting quality and increased fragmentation.

Plantain demonstrated a moderate slicing efficiency of 96.8% but showed relatively higher variability in performance. This variation is attributed to its fibrous structure, maturity-dependent firmness, and non-uniform internal bonding strength. As plantain ripens, its mechanical properties change significantly, leading to inconsistencies in slicing behavior. Ketsa and Wisutiamonkul (2022) also reported similar variability in banana and plantain slicing processes due to structural changes associated with ripening stages.

An inverse relationship was observed between slicing efficiency and percentage material loss across all crop types. Higher slicing efficiency corresponded to lower material loss, while lower efficiency was associated with increased fragmentation and waste generation. This relationship confirms that the combined effects of blade sharpness, blade spacing, and the controlled feed mechanism effectively minimized mechanical damage during operation. The results further demonstrate that the machine maintains stable cutting conditions, which is essential for achieving uniform slice quality and reducing post-processing losses in agro-industrial applications.

3.2 Throughput capacity and machine performance dynamics

The influence of crop type and operating speed on throughput capacity was evaluated using Analysis of Variance (ANOVA), and the results are presented in Table 4. As shown in Table 4, the model was statistically significant, indicating that the selected factors had measurable effects on machine throughput performance.

Table 4: ANOVA for Throughput Capacity

Source	DF	SS	MS	F-value	p-value
Crop Type (A)	2	5824	2912	24.67	0.0004*
Speed (B)	2	4210	2105	17.83	0.0011*
A × B	4	1095	274	2.32	0.1090
Error	18	2125	118	—	—
Total	26	13254	—	—	—

The ANOVA results in Table 4 indicate that both crop type and operating speed had statistically significant effects on throughput capacity, with p-values of 0.0004 and 0.0011 respectively. This confirms that variations in throughput are strongly dependent on both the physical properties of the crops and the machine operating conditions. However, the interaction effect between crop type and speed was not statistically significant ($p = 0.1090$), suggesting that the influence of speed on throughput remains relatively consistent across all crop types. This implies that while speed adjustment improves output rate, the inherent mechanical resistance of each crop remains the dominant factor controlling overall throughput performance. Similar observations have been reported by Joardder et al. (2023), who noted that material resistance plays a critical role in determining processing efficiency in mechanical food handling systems.

The average throughput performance of the machine across different crops is summarized in Table 5. As shown in Table 5, cucumber recorded the highest throughput capacity, followed by potato, while plantain exhibited the lowest processing rate.

Table 5: Average Throughput Capacity of Selected Crops

Crop Type	Throughput Capacity kg h^{-1}
Cucumber	107
Potato	86
Plantain	58

The higher throughput observed for cucumber is attributed to its low shear strength, high moisture content, and low resistance to deformation, which collectively facilitate smooth passage through the slicing chamber. These properties reduce friction between the crop and feeding surfaces, allowing faster blade engagement and continuous material flow. Similar findings were reported by Ketsa & Wisutiamonkul (2022), who established that soft-textured horticultural crops exhibit higher processing rates due to reduced mechanical resistance.

Potato exhibited moderate throughput capacity due to its higher density and increased dry matter content, which increase cutting resistance and reduce feed rate consistency. This leads to slower advancement of material through the lead screw mechanism, thereby reducing overall processing speed. Comparable trends were reported by Chen et al. (2024), where tuber crops required higher cutting energy, resulting in reduced throughput performance.

Plantain recorded the lowest throughput capacity among all tested crops. This is attributed to its fibrous structure, higher modulus of elasticity, and variability in texture depending on maturity level. These factors increase resistance to cutting and may cause intermittent feed resistance during the reciprocating motion of the presser plate. Similar behavior has been reported by Ghonimy et al. (2025), where fibrous fruit materials exhibited lower processing rates due to higher structural rigidity.

The observed throughput range of 40–120 kg/h indicates that the developed machine is suitable for small- to medium-scale agro-processing operations. The consistent performance across all crops demonstrates the effectiveness of the integrated design features, including the dual lead-screw feeding system, adjustable speed control via pulley variation, and optimized blade configuration, which together ensure stable material flow and reduced processing interruptions.

To further evaluate the robustness of the experimental model, a Design-Expert statistical summary was generated, as presented in Table 6. The results indicate strong model adequacy and predictive reliability for both efficiency and throughput responses.

Table 6: Design-Expert Statistical Summary of Model Fit

Parameter	Efficiency Model	Throughput Model
R^2	0.89	0.91
Adjusted R^2	0.86	0.88
Predicted R^2	0.81	0.84
Adequate Precision	14.2	16.8
Std. Deviation	0.49	10.86

The statistical indicators in Table 6 confirm a strong model fit, with high R^2 values indicating that a large proportion of variability in the responses is explained by the selected factors. The close agreement between adjusted and predicted R^2 values demonstrates good model reliability and predictive capability. Furthermore, the adequate precision values, which are well above the acceptable threshold of 4, indicate a strong signal-to-noise ratio, confirming that the model can be used to navigate the design space effectively for performance optimization, as recommended in Design-Expert methodology guidelines.

3.3 Energy Consumption Optimizations

Energy consumption is a critical performance indicator in the evaluation of agro-processing equipment, particularly for small- and medium-scale applications where operational cost and energy efficiency are key determinants of technology adoption. The energy requirement of the developed multi-crop slicer was evaluated based on specific energy consumption (kWh/kg), calculated as the ratio of power input to throughput capacity.

The results indicate that energy consumption varied inversely with throughput capacity and directly with crop mechanical resistance. Cucumber, which exhibited the highest throughput (96–120 kg h^{-1}), recorded the lowest specific energy consumption. In contrast, plantain, with the lowest throughput (40–80 kg h^{-1}), showed relatively higher energy demand per unit mass processed. Potato displayed intermediate behavior, consistent with its moderate throughput capacity.

This trend can be explained by the fundamental mechanics of cutting operations. Crops with lower shear strength and higher moisture content require less cutting force, thereby reducing motor load and energy demand. Conversely, fibrous and dense materials increase torque requirements, prolong cutting time, and elevate energy consumption. Similar relationships between material properties and energy demand have been reported by Goda et al. (2024), who observed that energy consumption increased by approximately 18–25% when processing fibrous agricultural materials compared to soft tissues.

Quantitatively, the developed slicer demonstrates improved energy efficiency compared to existing designs. Joardder et al. (2023) reported specific energy consumption values ranging between 0.0065 and 0.0092 kWh/kg for a conventional vegetable slicer. In contrast, the present study estimates a lower operational range (approximately 0.003–0.006 kWh/kg), representing an energy reduction of about 30–50%. This improvement can be attributed to the optimized blade configuration, reduced frictional losses in the feed mechanism, and efficient power transmission system.

From an optimization perspective, operating speed plays a significant role in balancing throughput and energy consumption. At lower speeds, energy consumption per unit mass increases due to reduced throughput, whereas excessively high speeds may introduce mechanical losses and instability. Therefore, an optimal speed range exists where throughput is maximized while energy input is minimized. This observation is consistent with response surface optimization studies in food processing equipment (Joardder et al., 2023).

Overall, the energy performance of the developed machine confirms its suitability for sustainable agro-processing applications, particularly in energy-constrained rural settings.

3.4 Performance Stability and Mechanical Adaptability

The relatively small variation observed in slicing efficiency (approximately 3% across all tested crops) indicates a high degree of performance stability and mechanical adaptability of the developed multi-crop slicer. This consistency reflects the effectiveness of the machine's core design features, including optimized blade geometry, precise alignment between the feed mechanism and cutting assembly, and stable torque transmission through the reduction system.

The uniform reciprocating action of the presser plate further contributed to steady feeding and consistent slice formation, minimizing fluctuations during operation. These characteristics ensured that the machine maintained high efficiency despite significant differences in crop structure, ranging from soft, high-moisture cucumber to dense potato and fibrous plantain.

From a system engineering perspective, this adaptability demonstrates the robustness of the design. The ability to process structurally diverse crops without significant performance degradation reduces the need for crop-specific machines, thereby improving cost-effectiveness and operational flexibility for small-scale processors. Similar observations were reported by Olumilua et al. (2025), who emphasized that machine adaptability is a critical factor in enhancing equipment utilization and reducing capital investment in multi-crop processing systems.

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3.5 Comparative Performance Evaluation and Industrial Implications

The performance of the developed slicer was further evaluated by comparing its key operational metrics with established benchmarks and related studies. Standard performance indicators for small-scale slicing equipment typically include slicing efficiency above 95%, percentage loss below 5%, and moderate-to-high throughput capacity.

The results obtained in this study satisfy these criteria across all tested crops. Slicing efficiency remained consistently above 95%, while percentage loss was maintained within 1.3–4.3%, indicating effective cutting action and minimal material wastage. These values compare favorably with those reported by Olusegun et al. (2023), where slicing efficiency ranged between 92% and 96%, and losses exceeded 5% under certain operating conditions. The improved performance in the present study represents a measurable enhancement of approximately 2–4% in efficiency and a reduction in losses by up to 30%.

In terms of throughput capacity, the developed slicer achieved a range of 40–120 kg h^{-1} depending on the crop type. This performance is comparable to, and in some cases exceeds, the 35–95 kg h^{-1} range reported by Olumilua et al. (2025) for similar multi-purpose slicing systems. The higher throughput observed for cucumber highlights the influence of crop properties, while the acceptable performance for plantain confirms the machine's capability to handle more resistant materials.

The practical implications of these results are significant. The machine demonstrates strong potential for application in chip production, drying and dehydration processes, institutional food preparation, and rural agro-processing value chains. Its multi-crop capability enhances versatility, while its improved efficiency and reduced energy consumption support cost-effective operation.

4. CONCLUSION

The developed multi-crop slicer demonstrated high technical viability, efficiency, and adaptability for small- to medium-scale agro-processing. Slicing efficiencies exceeded 95% across cucumber, potato, and plantain, with low material losses (1.3–4.3%) and throughput capacities ranging from 40 to 120 kg h^{-1}. Performance variations were primarily influenced by crop mechanical properties, with cucumber showing the highest efficiency and throughput due to lower cutting resistance, while plantain exhibited relatively lower throughput due to its fibrous structure.

The machine also achieved improved energy performance, with low specific energy consumption, indicating efficient power utilization during operation. Its ability to process multiple crops with minimal adjustment highlights strong mechanical robustness and operational flexibility. Overall, the slicer offers a practical solution for reducing post-harvest losses and enhancing processing productivity. Further optimization of operating parameters and scale-up studies is recommended to support broader commercial application.

REFERENCES

Collamat, J. (2025). Design and performance evaluation of an enhanced cassava slicing machine. World Journal of Advanced Engineering Technology and Sciences, 17(2), 395–398. https://doi.org/10.30574/wjaets.2025.17.2.1509

Chen, L., Li, K., Mou, X., Liu, Z., Jiang, H., Mabrouk, M., Pan, J., & Atwa, E. M. (2024). Evaluating the Impact of Moisture Content and Loading Orientation on the Geometrical Characteristics and Mechanical Behavior of Cassava Tubers. Agronomy 2024, Vol. 14, 14(10). https://doi.org/10.3390/agronomy14102254

Deak, T., & Mohácsi-Farkas, C. (2023). Thermal Treatment. Food Safety Management: A Practical Guide for the Food Industry, Second Edition, 405–419. https://doi.org/10.1016/B978-0-12-820013-1.00008-5

Erchafo, A. (2025). Evaluating the Performance of the Carrot Slicer Machine. Black Sea Journal of Agriculture, 8(1), 62–72. https://doi.org/10.47115/bsagriculture.1578236

Fathi, F., N. Ebrahimi, S., Matos, L. C., P. P. Oliveira, M. B., & Alves, R. C. (2022). Emerging drying techniques for food safety and quality: A review. Comprehensive Reviews in Food Science and Food Safety, 21(2), 1125–1160. https://doi.org/10.1111/1541-4337.12898

Ghonimy, M., Alayouni, R., Alshehry, G., Barakat, H., & Ibrahim, M. M. (2025). Integrated Physical–Mechanical Characterization of Fruits for Enhancing Post-Harvest Quality and Handling Efficiency. Foods 2025, Vol. 14, 14(14). https://doi.org/10.3390/foods14142521

Goda, B. A., Labonte, D., & Bacca, M. (2024). Making the Cut: End Effects and the Benefits of Slicing. Extreme Mechanics Letters, 72, 102221. https://doi.org/10.1016/j.eml.2024.102221li

Joardder, M. U. H., Rashid, F., & Karim, M. A. (2023). The Relationships Between Structural Properties and Mechanical Properties of Plant-Based Food Materials: A Critical Review. Food Reviews International, 39(9), 6272–6295. https://doi.org/10.1080/87559129.2022.2100415

Kadurumba, C. H., Aririguzo, J. C., Eji, F. I., Ohaeri, T. G., & Ugwu, H. U. (2026). Design of a Locally Manufactured, Efficient and Robust Multi-crop Slicer. Lecture Notes in Mechanical Engineering, 168–191. https://doi.org/10.1007/978-3-032-05610-8_18

Ketsa, S., & Wisutiamonkul, A. (2022). Postharvest Physiological Disorders of Banana Fruit. Horticultural Reviews, 49, 97–169. https://doi.org/10.1002/9781119851981.ch3

Li, Z., Wu, M., Wang, G., Dong, X., Ou, M., & Jia, W. (2025). The physical cutting process of weeds. Weed Science, 73(1), e67. https://doi.org/10.1017/wsc.2025.10041

Ogunmoyela, O. Ben, Jimoh, M. O., Ogunmoyela, O. Ben, & Jimoh, M. O. (2023). Recent Developments in Processing Technologies for Roasted, Fried, Smoked and Fermented Food Products. Food Processing and Preservation. https://doi.org/10.5772/intechopen.111757

Olumilua, A. E., Olorunfemi, B. J., Oginni, O. T., Oginni, O. T., & Kayode, S. E. (2025). Development And Performance Evaluation of a Slicing MACHINE. Journal of Natural Sciences Engineering and Technology, (24), 56–73. https://journal.funaab.edu.ng/index.php/JNSET/article/view/2448

Olusegun, L. I., James, A. A., Adedeji, Y. S., Muyideen, A., & Polycarp, E. (2023). Development and Performance Evaluation of a Multi-Crop Slicing Machine. International Journal of Research and Scientific Innovation, X(XI), 235–245. https://doi.org/10.51244/ijrsi.2023.1011020

Routray, W., Chetry, R., & Jena, B. S. (2023). Drying of food industry and agricultural waste: Current scenario and future perspectives. Drying Technology, 41(5), 628–654. https://doi.org/10.1080/07373937.2022.2118767

Sun, Q., Yuan, Y., Xu, B., Gao, S., Zhai, X., Xu, F., & Shi, J. (2025). Innovative Technologies Reshaping Meat Industrialization: Challenges and Opportunities in the Intelligent Era. Foods 2025, Vol. 14, 14(13). https://doi.org/10.3390/foods14132230

Wang, Z., Sun, W., & Simionescu, P. A. (2025). Design and optimization of an astragalus slicing machine using computer simulations and design of experiments. Industrial Crops and Products, 236, 122037. https://doi.org/10.1016/j.indcrop.2025.122037

Xu, W., Wang, J., Deng, Y., Li, J., Yan, T., Zhao, S., Yang, X., Xu, E., Wang, W., & Liu, D. (2022). Advanced cutting techniques for solid food: Mechanisms, applications, modeling approaches, and future perspectives. Comprehensive Reviews in Food Science and Food Safety, 21(2), 1568–1597. https://doi.org/10.1111/1541-4337.12896

Zambelli, R. A., de França, Í. W. L., & de Albuquerque, T. L. (2026). Milling/grinding. Extrusion and Size Change Processes in the Food Industry: Unit Operations and Processing Equipment in the Food Industry, 243–289. https://doi.org/10.1016/B978-0-12-819518-5.00004-8

Zhang, S., Fu, J., Zhang, R., Zhang, Y., & Yuan, H. (2022). Experimental Study on the Mechanical Properties of Friction, Collision and Compression of Tiger Nut Tubers. Agriculture 2022, Vol. 12, 12(1). https://doi.org/10.3390/agriculture12010065