Design and Performance Evaluation of a Cashew Apple (*Anacardium occidentale* L.) Slicing Machine

Kay J. Jaranilla[1, 2*], Hellen F. Gavino[1], Romeo B. Gavino[1] and Carolyn Grace G. Somera[1]
[1]Department of Agricultural and Biosystems Engineering
[2]Philippine Center for Postharvest Development and Mechanization (PHilMech)
Central Luzon State University
Science City of Muñoz, Nueva Ecija 3199 Philippines
[*]*jaranillakay@gmail.com*

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Abstract

One challenge in cashew apple (CA) production is the absence of processing equipment, leading to manual operations. Cashew apple processors often resort to manual slicing, resulting in uneven thickness and increased manpower requirements. This study aimed to address these issues by developing a slicing machine that ensures uniform thickness and reduces the need for manual labor during the slicing process. The machine underwent evaluation at three different slicing speeds (28, 42, and 60 strokes per minute [spm]). The most efficient speed was found to be 60 spm, with a slicing capacity of 249.26 kg/h and a slicing efficiency of 86.66%. The corresponding rates for damaged sliced CAs and juice extraction during slicing were 4.93 and 22.33%, respectively. In comparison, manual slicing demonstrated a capacity of 32.21 kg/h and a slicing efficiency of 29.99%. The machine's capacity was almost eight times higher than that of manual slicing. The optimal slicing speed for CAs was determined to be 60 spm, which significantly reduced losses in terms of thickness, extraction, and physical damage of CA during the slicing process. Using the machine not only minimized the time required for slicing but also reduced labor costs, making it a more efficient and economically viable option for CA processing.

Keywords*:* capacity, cashew, efficiency, postharvest technology, slicing speed

1. Introduction

In the Philippines, there are 28,600 ha planted for cashews. Among the regions in the country, Mindoro, Marinduque, Romblon, and Palawan (MIMAROPA) is the leading producing region with a total production area of 25,978 ha, representing 91% of the national production areas and with 3,407,585 bearing trees. The average yield of nuts and cashew apples (CA) is 500 tons and 821,000 pieces per hectare, respectively (SunStar, 2010).

Cashew apples are considered an agricultural waste of cashew nut production; they are highly perishable and deteriorate easily if not processed within a day (Talasila and Shaik, 2013). However, they can be processed into human food products such as wine, prunes, vinegar, and others. In Palawan, cashew production is increasing due to the demand for nutritious food items and the expanding market for cashew-based products (Billdo and Paller, 2020).

One of the challenges faced by CA processors is the lack of technologies for CA production, resulting in low production and high investment costs in terms of labor and raw materials (Billdo and Paller, 2020; Domingo, 2023). Currently, the prevailing practice among CA processors is manual slicing – a task known for its tedious and time-consuming nature. According to the Department of Agriculture Palawan Agricultural Experiment Station (Fuertes, 2015), the process of handling CAs involves picking ripe CAs, floating, sorting, slicing, and soaking. Manual slicing is carried out using a knife and cutting board. Continuous slicing is avoided for the safety of the processors, as it can lead to muscle pain. According to Pawar *et al*. (2020), manual slicing is a relatively slow operation, deemed unhygienic and of low quality, necessitating special attention and the involvement of multiple processors, and taking a considerable amount of time. This method of slicing is most commonly followed but is characterized by being time-consuming, tedious, unhygienic, expensive, and sometimes hazardous (Nagaratna *et al*., 2022).

One crucial technology in CA production is the slicing machine, which is currently unavailable in the market. The absence of a slicing machine in the processing of CAs results in a significant volume of unprocessed CAs that primarily go to waste. This study aimed to develop a CA slicing machine to assist processors by producing sliced CAs with minimal manpower, efficiently processing bulk volumes during the peak season, and ensuring a uniform thickness of the sliced CAs.

2. Methodology

Figure 1 shows the schematic diagram of the CA slicing machine. It has five major components, namely (a) loading pan, (b) conveyor assembly, (c) slicer assembly, (d) incline and discharge chute, and (e) power transmission. The schematic diagram illustrates these major components to facilitate easy visualization of the machine. The loading pan accommodates the CAs, and the conveyor, composed of a chain and hollow stainless steel, conveys the CAs to the slicer. In the slicer assembly, the CAs are cut and then dropped onto the incline and discharge chute. The power transmission system, which consists of a reducer, chain, and sprocket, is connected to the conveyor.

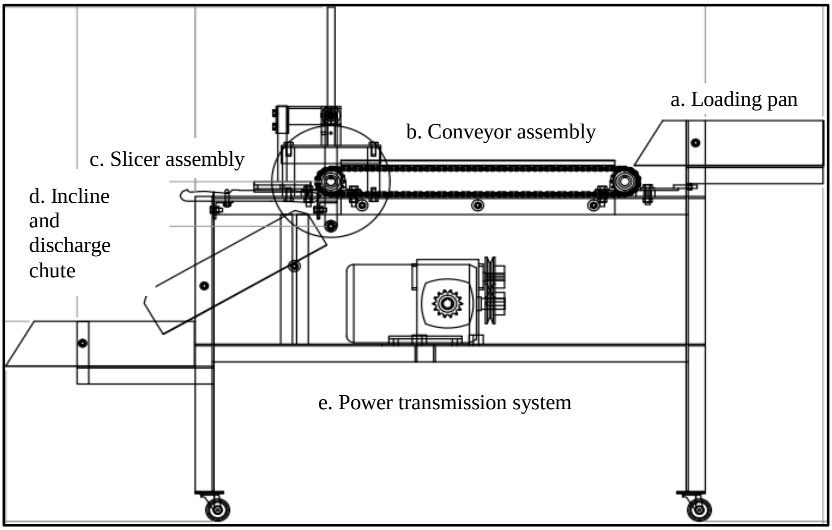


Figure 1. Schematic diagram of CA slicing machine (side view)

2.1 Conveyor Unit

The conveyor unit was composed of stainless cold-rolled steel, a transmission chain (extended pin), a shaft, and a sprocket. The conveyor was powered by a chain and sprocket (Philippine Agricultural Engineering Standard [PAES], 2000). The design of the stainless cold-rolled steel rod, which was fastened to the transmission chain, was based on the estimated weight of three CAs, approximately 0.318 kg, placed in a parallel position between two rods. The diameter of the cold-rolled steel for the conveyor was computed using Equation 1.

$$d = \sqrt[3]{\frac{16T}{\pi t}} \tag{1}$$

where d is the diameter (mm) of the shaft for the conveyor; T is the Torque (N·mm); and t is the Torsional shear stress.

The selection of belt and pulley sizes for the transfer of power from the electric motor to the reducer was computed using PAES (2000). The belt and pulley transmission efficiency was < 100%.

Moreover, the speed was determined using speed ratio (Equation 2).

$$N_L D_L = N_S D_S \tag{2}$$

where N_L is the number of revolutions (rpm) of the driven pulley; N_S is the number of revolutions (rpm) of the driver pulley; D_L is the diameter (mm) of the driven pulley; and D_S is the diameter (mm) of the driver pulley.

The belt speed/velocity of the machine was computed using Equation 3.

$$V = \frac{2\pi N_S}{60} \; Rs \tag{3}$$

where V is the belt speed/velocity (m/sec); W is the angular speed (rad/sec); N_S is the number of revolutions of driving (rpm); and R_S is the radius of the sprocket (m).

To determine the correct size of the motor for the machine, the required power of the CA slicing machine was computed using Equation 4.

$$Hp = \frac{TS}{5255} \tag{4}$$

where Hp is the horsepower of the motor (hp); T is the Torque (N·m); S is the speed (rpm).

The cycle time of the conveyor was identified using Equation 5.

$$C_T = \frac{2(0.690)}{0.085 msec^{-1}} \tag{5}$$

where C_T is the cycle time (sec); L is the length of conveyor (m); V is the belt speed (m/sec).

Figure 2 shows the top view of the conveyor unit of the CA slicing machine. The dimension indicated in Figure 2 is in millimeters.

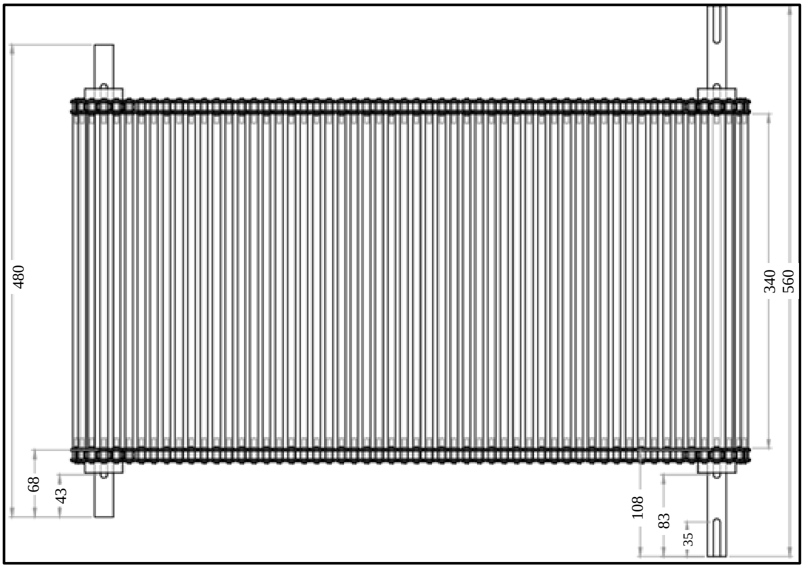


Figure 2. Conveyor unit of cashew of slicing machine

2.2 Chain and Sprocket

The selection of chain sprocket for the transfer of power from the reducer to the shaft of the conveyor was computed using PAES (2000) formulas. The chain and sprocket transmission efficiency was ≤ 100%. The length of the chain was determined using Equation 6.

$$L_P = 2C_P + \frac{N}{2} + \frac{n}{2} + \left(\frac{N\text{-}n}{2\pi}\right)^2 \left(\frac{1}{C_P}\right) \tag{6}$$

where L_P is the length of the chain, pitches; C_P is the center-to-center distance in pitches; N is the number of teeth in the large sprocket; n is the number of teeth in the small sprocket.

The number of teeth of the sprocket was computed using Equation 7.

$$T = \frac{t\,N_S}{N_L} \tag{7}$$

where T is the number of teeth of the large sprocket; t is the number of teeth of the small sprocket; N_S is the speed of the small sprocket (rpm); N_L is the speed of the large sprocket (rpm).

The correction of the center distance for a given length was computed using Equation 8.

$$C = \frac{P}{8}\left[2L_P - N - n + \sqrt{(2L_P - N - n)^2 - 0.810(N - n)^2}\;\right] \qquad (8)$$

where *C* is the center-to-center distance (mm); *P* is the pitch of the chain (pitches); *LP* is the length of the chain (pitches); *N* is the number of teeth of the large sprocket; and *n* is the number of teeth of the small sprocket.

2.3 Simulation of Machine Components

The design of the machine, including the slicing unit, conveying unit, and power transmission system, was drawn using AutoCAD (Autodesk, n.d.). The Ansys student software (Ansys, n.d.) was used to analyze components of the machine such as the conveying unit, shafting, and structure/frame to determine the applicable forces needed to prevent material deformation. Mechanical simulation was conducted to check the machine's capacity relative to the applied forces during operation. The yield strength of structural steel is 250 MPa, which is the maximum stress that can be applied to the machine without causing deformation.

Figure 3 shows the boundary conditions and force applied to the structure. The red-colored portions (right and left) indicate the areas experiencing the highest stress, while the blue-colored portions (right and left) signify areas experiencing the minimum stress. Since the highest stress was 7.4956 MPa, which is significantly lower than the yield strength of structural steel (250 MPa), the structure was considered safe with a small chance of failure. The overall dimensions of the machine's frame were 1,731 × 625 × 1,167 mm.

2.3.1 Conveyor Shaft Analysis

The shafts of the conveyor were also subjected to simulation given the rotational velocity of 30 rpm and a load of 30 N.

In Figure 4, force A was applied on both ends that hold the shaft in position during the slicing activity.

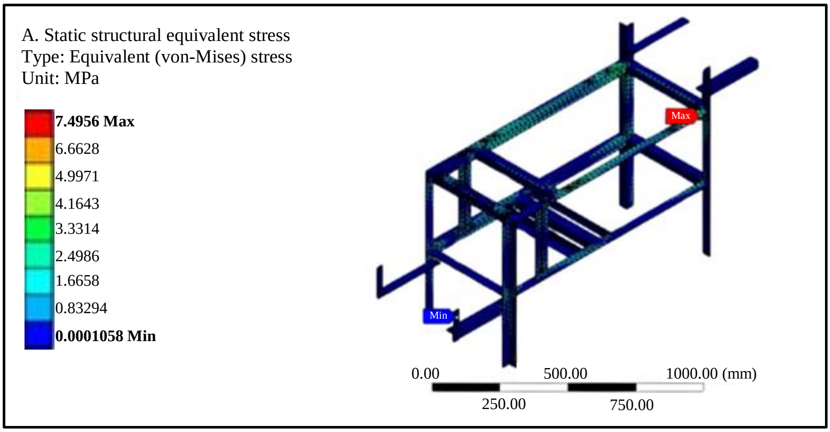


Figure 3. Frames of CA slicing machine

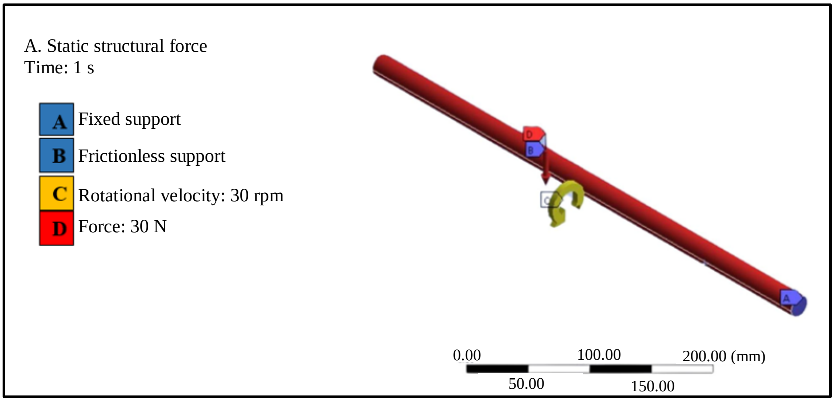


Figure 4. Conveyor shaft of CA slicing machine

Frictionless support (force B) was also applied to represent the pillow block bearing that held the rotating shaft and a rotational velocity was applied at 30 rpm which was used during the operation of the machine. Therefore, the shaft with diameter size and length of ¾" and 480 mm, respectively, was safe to use during operation.

Frictionless support (force B) was also applied to represent the pillow block bearing that held the rotating shaft, and a rotational velocity of 30 rpm was applied during the operation of the machine. Therefore, the shaft with a diameter of ¾ inch and a length of 480 mm was deemed safe to use during operation.

The conveyor unit in Figure 5 was composed of stainless cold-rolled steel, a transmission chain (extended pin), a shaft, and a sprocket. The conveyor was powered by a chain and sprocket (Muda *et al*., 2015). The design of the stainless cold-rolled steel rod fastened to the transmission chain was based on the weight of three CAs, approximately 0.318 kg, placed in a parallel position between two rods. The conveyor unit underwent a simulation process to determine its safe operating level. The maximum deformation was 1.0425×10^{-3} mm, which is within the safe level. The strain that occurred on the conveyor during operation was at a minimum value of 9.4527×10^{-5}, a negligible level of strain. The maximum stress that occurred on the conveyor was 10.418 MPa, which indicated it was safe since the ultimate tensile strength of structural steel is 480 MPa (Xometry, 2023).

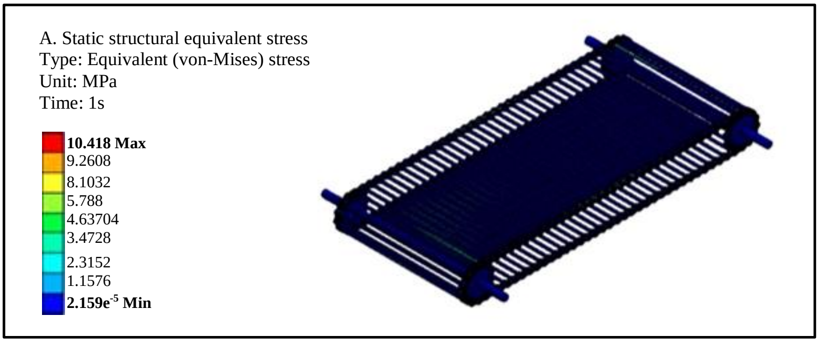


Figure 5. Conveyor of CA slicing machine

2.4 Fabrication of the Machine

Based on the design plan, an accredited local machinery fabricator was commissioned to do the fabrication of the machine. Simple and local manufacturing technologies were employed on most of the parts of the machine. The different activities during the fabrication and assembly process of the machine components (frames, conveyor assembly, slicing assembly, chute, and pan) were measuring, cutting, welding, grinding, bending, slitting, machining, fastening, and painting.

2.5 Performance Test and Evaluation

Based on the methods of testing agricultural machinery using PAES (2000), the evaluated parameters included slicing capacity, slicing efficiency, and percentage of damage (crush-sliced CA). Table 1 displays the treatments and combinations of pulleys in terms of rpm, millimeters per second, and strokes per minute (spm). These treatments were used during the performance testing of the machine.

Table 1. Pulley combination and treatment

Treatment	Slicer (rpm)	Slicer speed (mm/sec)	Slicer speed (spm)	Pulley combination (mm)
T_1	14	42	28	88.9 to 178
T_2	21	63	42	88.9 to 127
T_3	30	89.64	60	88.9 to 88.9

2.5.1 Parameters considered during Final Evaluation

The different parameters considered in the evaluation of the machine were the following: slicing capacity, slicing efficiency, and percentage damage.

Slicing capacity was computed using Equation 9, where the weight of the sliced CA over the operating time to slice the CA was used to get the capacity in kg/h.

$$S_C = \frac{W_i}{t} \tag{9}$$

where S_C is the slicing capacity of the machine (kg/h); W_i is the weight output (kg) of the CA; t is the operating time (h) of the machine.

Slicing efficiency was computed using Equation 10, which subtracts the weight of a sliced CA with a thickness other than 10 mm from the weight of a CA sliced to 10 mm, and divides this difference by the weight of the CA sliced to 10 mm.

$$S_E = \frac{W_i - W_C}{W_i} \times 100 \tag{10}$$

where S_E is the slicing efficiency of the machine (%); W_i is the weight of sliced sample kg; and W_C is the weight of sliced.
The percentage of damage was calculated to assess losses in terms of crush-sliced CAs and extracted juice during the slicing operation. Equation 11 was used to compute the percentage of damage.

$$\%D = 100 - S_E \tag{11}$$

where *%D* is the percentage damage (crush-sliced), and S_E is the slicing efficiency of the machine (%).

2.5.2 Size Uniformity of Slice

The uniformity of the sliced CA in terms of thickness was evaluated using random sampling. The sliced CA was randomly taken, and its thickness was measured using a digital caliper (Mitutoyo, Series 530, Japan).

2.6 Statistical Analysis

The data were analyzed statistically using a single factorial experiment arranged in a completely randomized design (CRD) with three replications. The treatments used were three different drive speeds. Analysis of variance (ANOVA) was used to determine whether the differences among the treatment means were significantly different using F-value (5 and 1%). Comparison of manual and mechanical slicing was evaluated using an independent t-Test using three replicates for each method.

2.7 Cost Analysis

The cost analysis included the calculations of the annual cost of operation: fixed and variable costs, break-even point, cost of slicing using the machine (Php/kg), and payback period, in case the machine shall be used for customer service operation. Table 2 shows the assumption of the machine. In particular, the annual use of the machine was 800 h. This is derived by considering the peak season of cashews from February to June (five months), 20 working days per month, and an operating time per day of 8 h as per Occupational Safety and Health Standards of Department of Labor and Employment (2016) for the safety of operator, with a noise level of 85.4 dB.

Table 2. Assumptions of the cost analysis

Assumptions	Values
Custom rate	1
Estimated life (year)	10
Capacity (kg/h)	249.26
Operation (h/day)	8
Annual use (h/year)	800
Manual cost of slicing (Php)	1.82

2.7.1 Machine Cost

The machine cost was computed considering the cost of materials (COM) and fabrication labor. The estimated fabrication labor was 40% of the cost of the material. The equation was used to calculate the total machine cost.

The total machine cost (TMC) was computed using Equation 12 to determine the total cost of the machine fabrication.

$$TMC = COM + Lf \tag{12}$$

where *TMC* is the total machine cost (Php); *COM* is the cost of materials (Php); and *Lf* is the fabrication cost (Php).

Equation 13 was used to determine the cost of slicing per kg.

$$CS = \frac{TFC}{V} + \frac{TVC}{SC} \tag{13}$$

where C_S is the cost of slicing (Php/kg); *TFC* is the total fixed cost (Php/h); *V* is the volume (kg/year); *TVC* is the total variable cost (Php/h); and *SC* is slicing capacity (kg/year).

The breakeven point (BEP) was calculated using Equation 14 to determine the point at which total cost equals total revenue, indicating neither profit nor loss for the machine.

$$BEP = \frac{TFC}{\left(CR\text{-}\left(\frac{TVC}{SC}\right)\right)} \tag{14}$$

where *BEP* is the breakeven point; *TFC* is the total fixed cost (Php/year); *CR* is the custom rate (Php/kg); *TVC* is the total cost variable (Php/h); and *SC* is the slicing capacity of the machine (kg/h).

The payback period (PBP) was calculated using Equation 15 to determine the number of years required to recover the total cost of the machine.

$$PBP = \frac{TMC}{NI} \tag{15}$$

where *PBP* is the payback period (year); *TMC* is the total machine cost; and *NI* is the net income.

The return on investment (ROI) (Equation 16) was calculated as the ratio of annual net income to the initial cost of the machine.

$$ROI = \frac{ANI}{IC} \tag{16}$$

where *ROI* is the return on investment; *ANI* is the annual net income; and *IC* is the initial cost.

3. Results and Discussion

3.1 Cashew Apple Slicing Machine

The machine was designed to slice CAs ranging from 9.50 to 10.5 mm in thickness and can be operated by one or two operators. The first operator manually loads the CAs into the loading pan, while the second operator unloads the sliced CAs from the discharge chute and removes the topped and tailed parts. The machine has a slicing capacity of 249.26 kg/h (see Table 2).

Figure 6 depicts the major components of the CA slicing machine: (a) loading pan, (b) conveyor assembly, (c) slicing assembly, (d) inclined chute, (e) discharge pan, and (f) power transmission system. During operation, CAs are placed in the loading pan. The first operator switches on the electric motor and arranges the CA pieces in parallel with the conveyor's direction. As the conveyor moves, the press block reciprocates, pressing the CAs downward onto the slicing knives to ensure uniform slicing. The movements of the conveyor and press block are synchronized such that as the press block descends, a CA piece is positioned over the slicers. Sliced CAs drop into the discharge chute and pan. The second operator removes the top and sliced-tailed portions of the CAs at the discharge chute.

3.2 Machine Slicing Performance

In Figure 7a, the slicing capacity reached its peak at a speed of 60 spm, achieving the highest value of 249.26 kg/h. Different slicer speeds significantly influenced the slicing capacity of the machine, indicating a direct proportionality between slicer speed and slicing capacity (Agbetoye and Balogun, 2009). Odior (2012) also noted in his study that increasing slicing speed results in higher capacity.

Figure 7b illustrates slicing efficiency, showing that the highest efficiency of 86.66% was attained at a speed of 60 spm, followed by 80.00% at 42 spm, with the lowest efficiency recorded at 76.66% for 28 spm.

Although the comparison was said to be statistically the same, 60 spm still provided the optimum slicer speed and gave the highest performance of the machine. Thus, 28- and 42 spm did not acquire the 10 mm as much as of 60 spm. This may be due to the gradual slicing operation due to the speed of the slicer which can create non-uniform thickness due to deformation during slicing. This is similar to Agbetoye and Balogun (2009), who found out that the lowest speed yielded a lower slicing efficiency.

The percentage of damage in sliced CAs is indicated in Figure7c. The result simply explained that, as the slicer speed increased, the percentage of sliced damage decreased. The damaged sliced CA was more acquired due slow speed of the slicer which resulted in a structural deformation during the slicing operation. This also confirmed that sliced CA from lower slicing speed produces more crumps sliced CA to be considered as a damaged product.

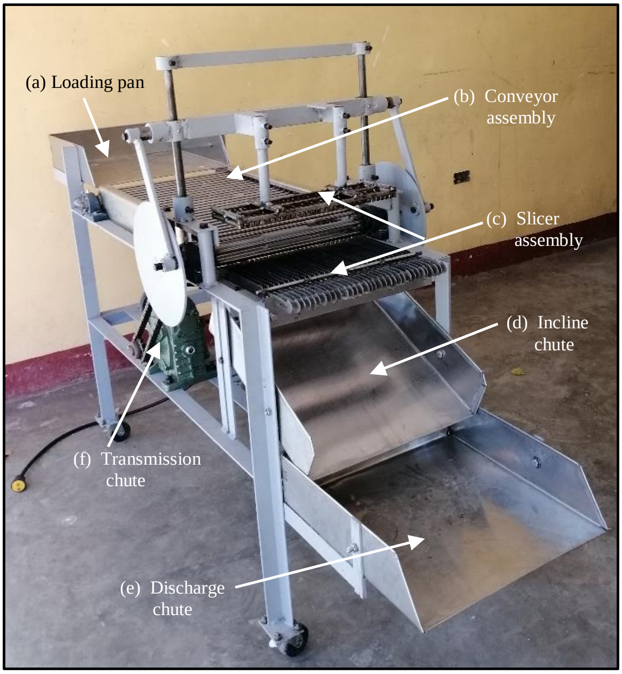
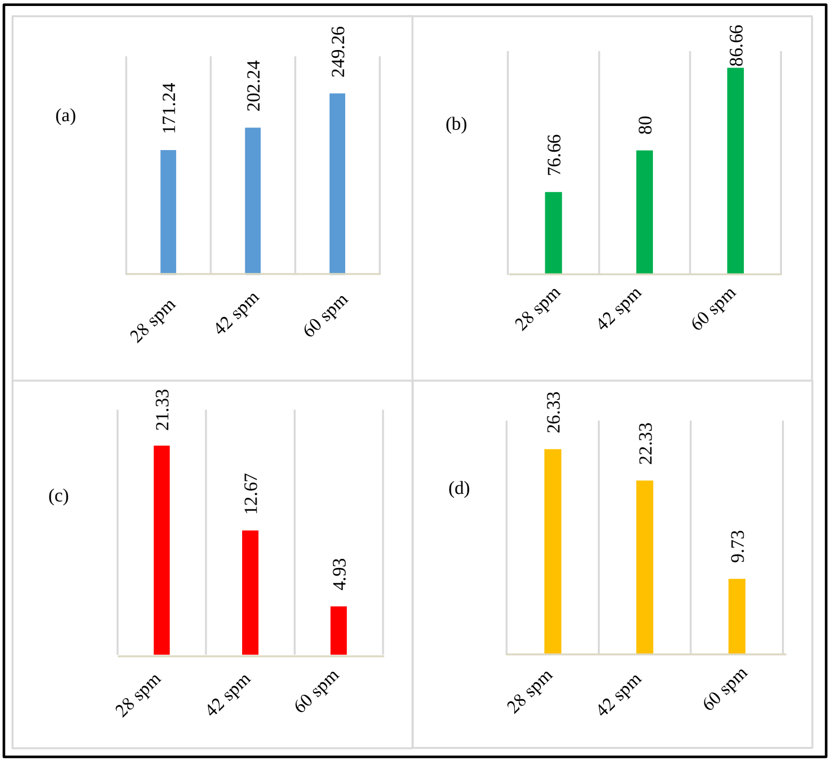


Figure 6. CA slicing machine



Slicing capacity (kg/h) (a); slicing efficiency (%) (b); damage slice (%) (c); and juice extracted during slicing (%) (d)

Figure 7. Machine performance parameters vis-à-vis different speed

The percentage of juice extracted during slicing is shown in Figure 7d revealing that the different slicer speed had a significant effect on juice extracted during slicing operation. This indicated that during slicing operations using different slicer speeds, different level of extraction occurred. Twenty-eight spm had the highest percentage of about 26.33% followed by 42 spm of about 22.33%, and 60 spm of about 9.73% as the lowest percentage of juice extracted during slicing. This means that 28 spm and 42 spm had higher percentages of crumpled sliced CAs which also gave the highest percent of extraction. High speed yielded lesser juice extract compared with low speed. Pawar *et al.* (2020) stated that during cutting, deformations occurred in the materials that caused losses. If the CA was not properly sliced, there was a tendency that the CA tended to be pressed due to gradual force. During operation, low speed produced the highest percentage of extracted juice because of slicing speed which is similar to the study of Kamaldeen and Awagu (2013).

3.3 Slicing Capacity

As shown in Table 3, the slicing speed of 60 spm gave the highest slicing capacity followed by 42 spm and 28 spm with 249.26 kg/h, 202.24 kg/h, and 171.24 kg/h capacity, respectively. It shows that the different speeds had a significant effect on the slicing capacity of the machine.

Table 3. Slicing capacity at different slicer speed

Slicer speed (stroke/min)	Slicing capacity (kg/h)
28	171.24[c]
42	202.24[b]
60	249.26[a]

The means side scored with a common letter are not significantly different by LSD at a 5% level.

Comparison among means on the slicing capacity at different slicer speeds revealed significant differences among all treatments. This indicated that slicer speed was directly proportional to the slicing capacity. Further, a higher slicing speed would result in a higher slicing capacity. These results agreed with Agbetoye and Balongon (2009), stating that the higher the slicing speed, the higher the percentage of sliced materials. Odior (2012) similarly stated in his study that an increase in slicing speed produces higher capacity.

Table 4 shows that mechanical slicing with a capacity of 249.26 kg/h was significantly different from manual operation with only 32.21 kg/h. This implied that any food processor may be able to produce sliced CAs eight times faster than manual slicing. This conformed with the result of Hoque and Saha (2017). This slicer can increase capacity, conserve energy, and time, and obtain high-quality of sliced materials.

Table 4. t-Test comparison on slicing capacity as influenced by manual and mechanical CA slicing capacity (kg/h) of the machine

Treatment	Mean	t	df	P-value*
Machine	249.26[a]	37.78	4	0.000
Manual	32.21[b]			

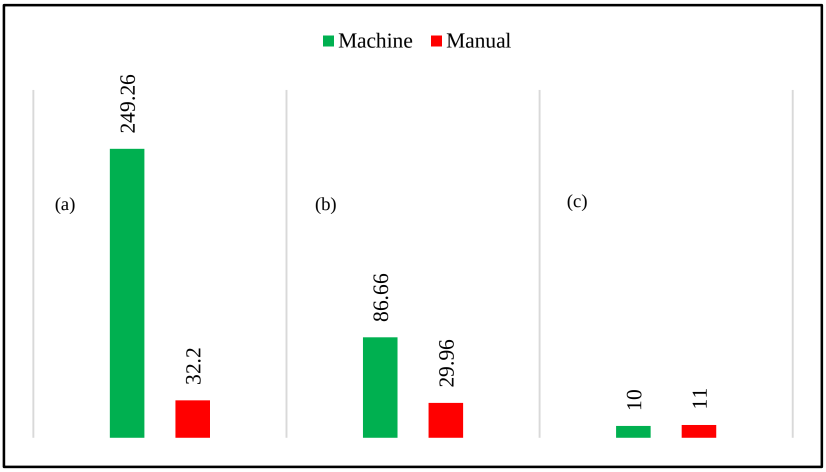
*Highly Significant at a 5% of the level of significance

3.4 Manual and Machine Slicing Performance

The mechanical slicing with a capacity of 249.26 kg/h was significantly different from manual operation with only 32.21 kg/h as shown in Figure 8a. The mechanical slicers can increase capacity, conserve energy, and time, and obtain high-quality sliced CAs. The slicing efficiencies (Figure 8b) for both machine and manual were 86.66 and 29.96%, respectively. CA slicing machine performed more efficiently than manual which is a good contributor to quality CA products. The optimum sliced CA thickness (Figure 8c) was 9.50 to 10.50 mm. Mechanical slicing machine produced apples of thickness 10 mm while manual operation recorded an average of 11 mm. The machine produced sliced CAs with a uniform thickness which would give a better quality of CA by-products (Figure 8c).

3.5 Cost Analysis

The machine had an annual fixed cost of Php 24,502.50 and a variable cost of Php 58.31/hour, respectively. It had an annual capacity of 199,408.00 kg and spent an amount of Php 71,786. The breakeven point was determined to be 31,984.77 kg/year. The cost curve in Figure 9 shows the decreasing cost for increasing production volume, with the shaded region representing annual profit. Furthermore, the cost analysis showed that an investment of Php 135,000.00 yielded an annual net income of Php 127,621.12, giving a 94.5% ROI and a payback period of just one year.



Slicing Capacity (kg/h) (a); slicing efficiency (%) (b); and thickness (mm) (c)

Figure 8. Manual and mechanical operation performance

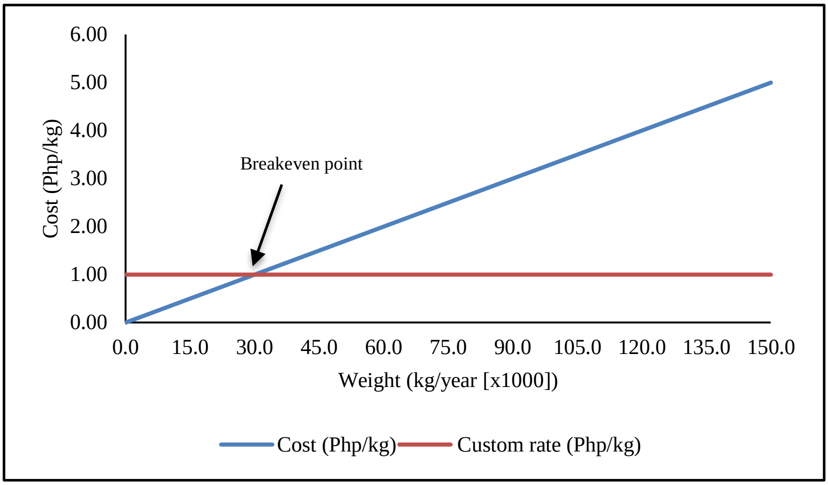


Figure 9. Breakeven point of CA slicing machine

In Table 5, the customs rate was determined at Php 1.0/kg of sliced CA after giving 178% markup from the cost of slicing of Php 0.36. This was lower compared with the Php 1.82 cost of manual operation.

Table 5. Comparison of cost of slicing between machine and manual

Operation	Cost of slicing (Php/kg)
Machine	1
Manual	1.82

4. Conclusion and Recommendation

This study successfully designed a CA slicing machine with overall dimensions of 1,731 × 625 × 1,167 mm for a CA processor. The machine can be fabricated using locally available materials such as structural steel, stainless plate, stainless steel, chain sprocket, and shaft. It operates optimally at 60 spm with a slicing capacity of 249.26 kg/h, an efficiency of 86.66%, and a thickness of 10 mm. The machine also achieved a low percentage of damage in sliced cashews (4.93%) and a juice extraction rate of 9.73%. The performance of the slicing machine significantly surpasses manual slicing in terms of capacity, efficiency, and thickness uniformity. Specifically, the machine's capacity was eight times higher than manual slicing, achieving 249.26 kg/h compared with 32.2 kg/h manually.

To further enhance the slicer's performance, it is recommended to adjust the thickness, length, and width of the knives, and to redesign the press block or implement an alternative mechanism in the slicing assembly.

5. Acknowledgment

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