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DEVELOPMENT AND PERFORMANCE EVALUATION OF A SLICING MACHINE

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ABSTRACT

Utilization of machinery reduces the time and drudgery of processing tubers. The high cost, energy consumption, and bulkiness can however render it unimportant for small-scale industrial applications. The study developed a two-feeder slicing machine to reduce the time-consuming and human-injurious labour involved in traditional crop processing. The slicing machine utilizes cold and hot working processes, with two conical-shaped hoppers and removable discs with diameters of 80-90 mm and lengths of 170 mm. Using discs, the product is sliced into a discharge chute where it falls due to gravity, secured with a bolt and nut, powered by a two-horsepower electric motor, allowing adjustable slice clearance. The machine was tested on Irish potatoes, sweet potatoes, and plantains, measuring geometric mean diameters and running at different speeds for two minutes. Materials were collected and categorized into sliced and unsliced forms. The machine achieved a maximum efficiency of 89% when slicing giant plantains at 412 rpm, while achieving the lowest efficiency of 60% when slicing little plantains at 224 rpm, with a slice rate range of 0.027 to 0.047 kg/sec. Cutting efficiency of the machine on small and large sizes of sweet potatoes were 64% and 69% at 224 rpm, while optimal efficiency was 84% at 477 rpm. The commercial and domestic two-feeder slicing machine efficiently sliced Irish potatoes (72%), plantains (88%), and sweet potatoes (75%), reducing manual labour, injury risk, and waste.

Keywords: Processing machine, slice-rate, slicing disc, efficiency, performance evaluation

INTRODUCTION

Potato, a high-quality vegetable with superior protein, high biological nutritional value, is widely used in over 100 recipes, supplementing meat and milk products, and reducing energy intake and food costs (Kartika and Arahanth, 2014). Potatoes are a nutritious vegetable with edible energy and protein, essential for breakfast, lunch, and dinner. As a short-duration crop, they produce more dry matter and edible energy than other roots and tubers. Potato nutritional content, include phosphorus, calcium, iron, and some vitamins (Pradhan et al., 2017; Chand et al., 2017; Rajesh *et al.*, 2016; Plaisier *et al.*., 2019). The mechanical way of processing potatoes uses machines and other devices to slice and chop potato tubers, whereas the conventional approach requires using a knife to cut, slash, and slice the potato into pieces (Birch *et al.*, 2012). The utilization of machinery reduces cutting time, but its high cost, energy consumption, and bulkiness render it unimportant for small-scale industry applications (Agbetoye and Balogun, 2009; Zimmerer, 2019). Several devices have been developed for slicing and chopping different crops. Gamble and Rice, (2018) developed an industrial slicer that was utilized to create chips of varying sizes and width from potato tubers. After evaluation, the slices were utilized to calculate the maximum thickness variability for each slice as well as the range of values that could be obtained at each thickness.

Owolarafe *et al.* (2017) devised a hand-held okra slicing system based on the engineering qualities of okra that was appropriate for usage on farms. The machine's slicing effectiveness was 76.4%. Mishra *et al.* (2020) built a slicer with better carriage design, streamlined controls, and improved geometry, among other advances that increased slice quality and ease of use. Neidhardt (2018) created the tomato slicer that has a package of detachable blades. Elements like the vertical grip, razor-sharp blades that cut with effortless accuracy and protective covers that increase user safety and convenience. Similarly, Aziz *et al.* (2011) created a spinning type operating slicing machinery for cutting fresh-cut pineapple. The machine could process 360 fruits in an hour.

A pedal-operated tuber scratching and slicing apparatus was created, built, and verified by Raji and Igbeka (2014). It was found that the equipment produced slices with a uniform thickness ranging from 1 to 13 mm and a throughput of about 376 kg/h at an efficiency of about 83%.

Hatwar *et al.* (2016) built a semi-automated potato chip maker that rotates and moves longitudinally, using an electric motor and leverage mechanism. The machine rotates the wheel and blades at different angles to produce different thicknesses of slices. Atul *et al.* 2013) also developed a twisted potato crisps maker using a technological concept that combined longitudinal and rotating motion generated by the handle, blade, and stud pitch to achieve the necessary thickness for their slices. With an average loss of 4.1%, the achieved slicing efficiency of the machine was 95.8–96.1%. The use of an automated plantain slicer lessened the tedious task associated with conventional large-scale plantain chip cutting (Atul *et al.,* 2013; Gegede, 2017). Slicing is the process of reducing materials into smaller sizes by means of a sharp blade or cutter. The conventional technique of slicing plantain with a knife is tedious, costly, susceptible to harm, and accompanied by minimal production (Kartika and Arahanth, 2014).

A two-feeder slicing machine was developed and evaluated to reduce labor and time in traditional agricultural crop processing, featuring cold and hot working processes, conical-shaped hoppers, detachable discs, and a two-horsepower electric motor for a rapid rate of slicing.

MATERIALS AND METHODS

Machine materials and description

The slicing system was conceptualized and constructed with portability and an easy-to-operate mode in mind. Corrosion-resistant slicing materials were also taken into consideration to avoid crop contamination while being sliced, and ergonomics helped to minimize operator fatigue. The machine was composed of an electric motor, a bearing, a shaft, an outlet chute, a disc blade, a frame, a belt and pulley, and an electric blade (Figures 1, 2, 3, and 4).

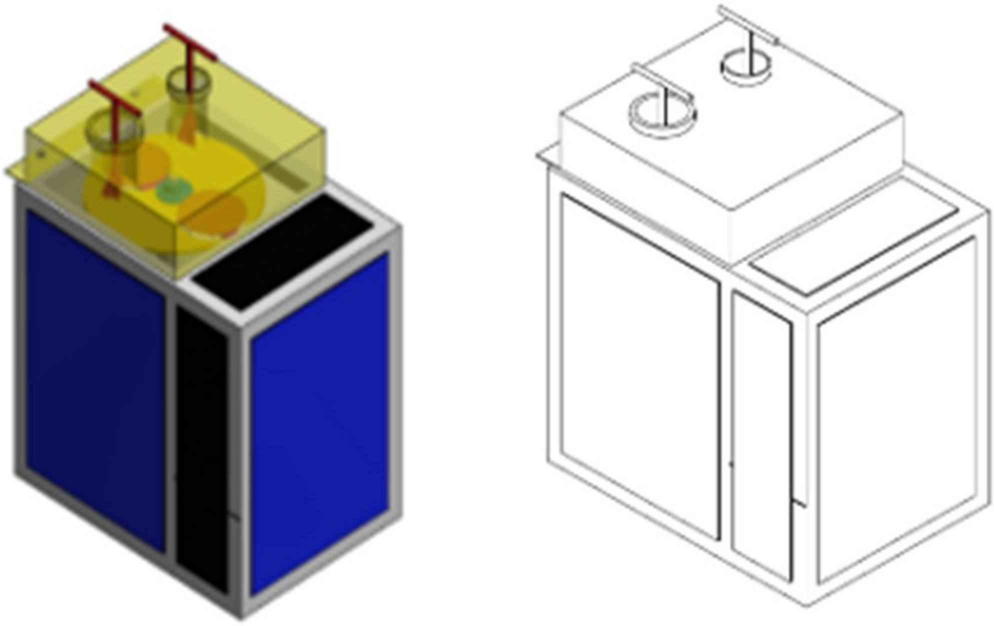
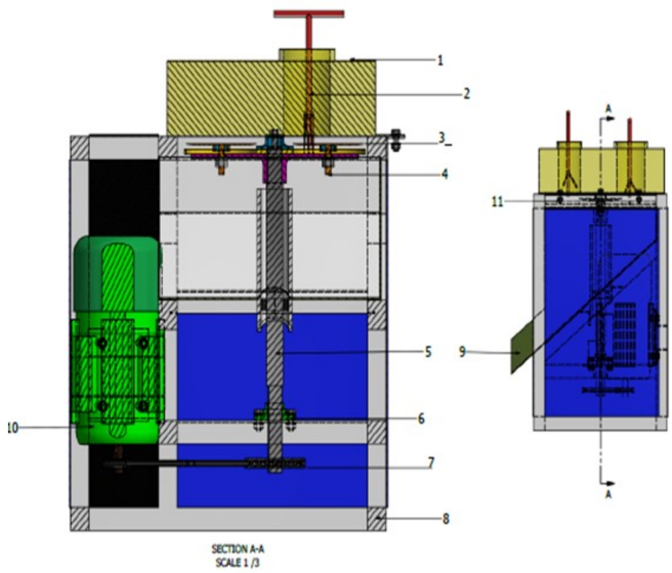


Figure 1: Isometric view of developed sclicier



PART LIST		
S/N	DESCRIPTION	QTY
1	HOPPER	2
2	FEEDER	2
3	DISC BLADE	2
4	SLICE THICKNESS ADJUSTER	2
5	SHAFT	1
6	BEARING	1
7	BELT AND PULLEY	1
8	FRAME	1
9	OUTLET CHUTE	1
10	ELECTRIC MOTOR	1
11	BOLT AND NUT	12

Figure 2: Isometric components view of the developed slicer

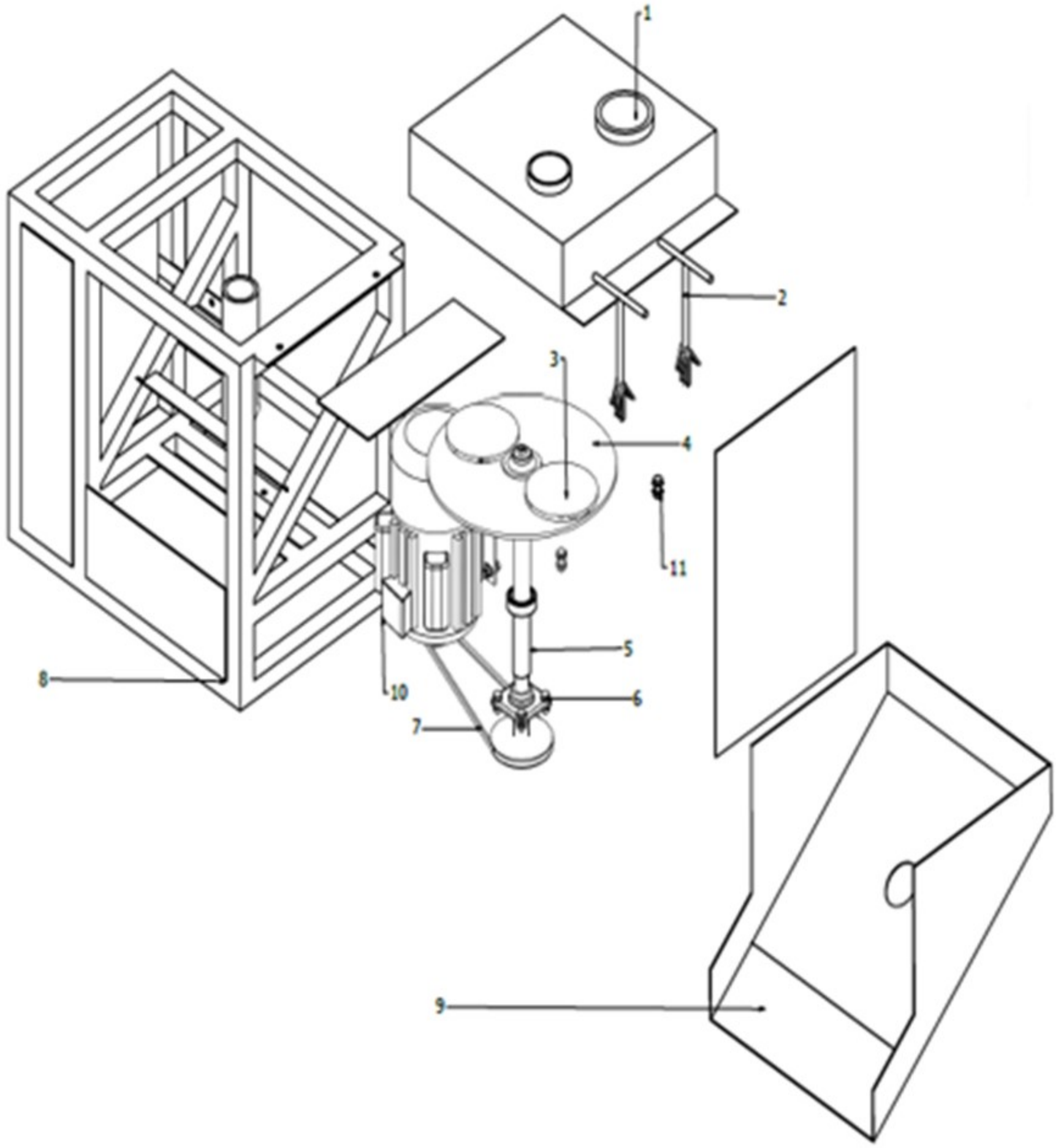


Figure 3: Exploded view of the slicing machine

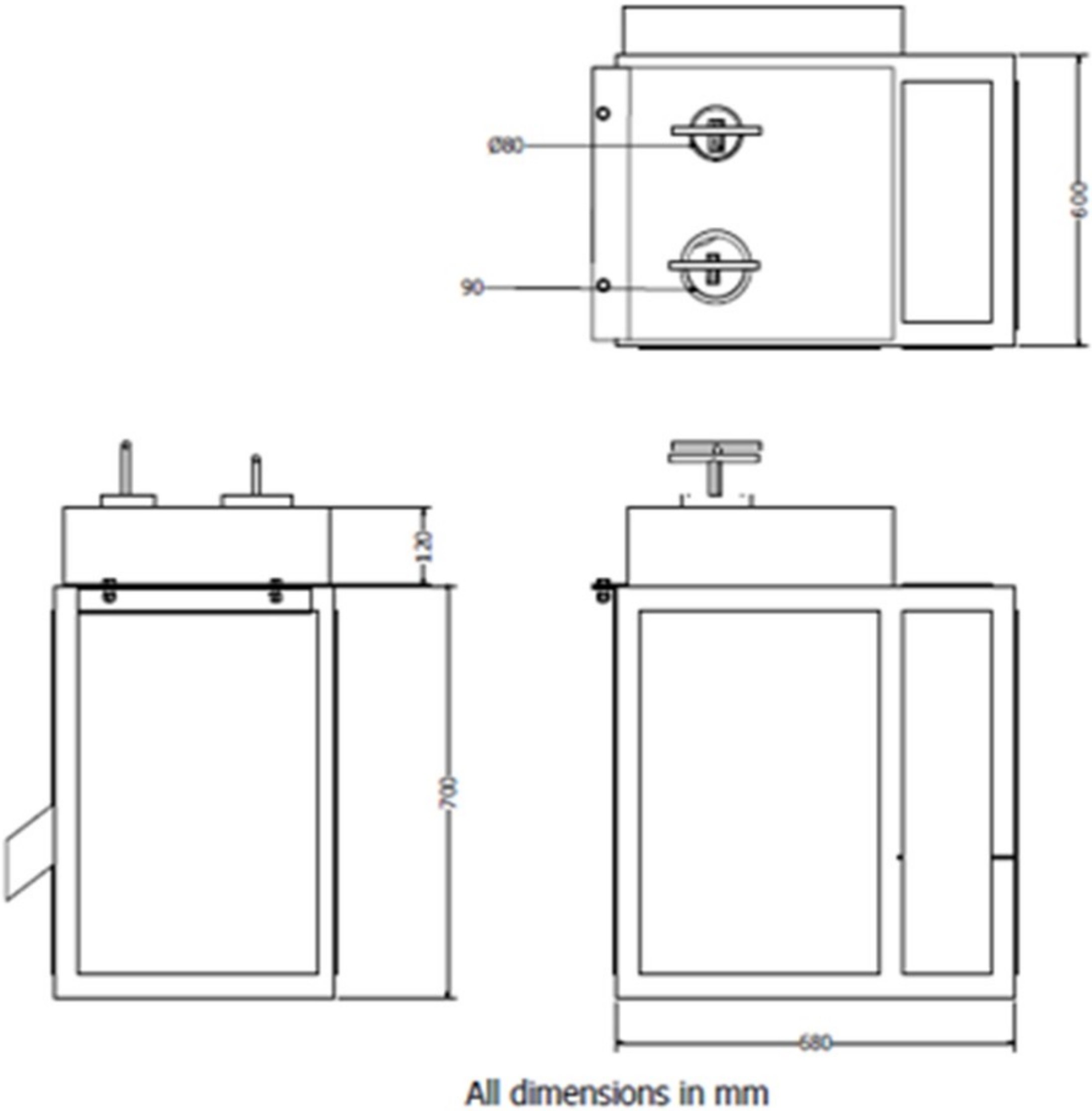


Figure 4: Orthographic projection of the developed slicer

System design calculations

The cutting equipment's slicing disc's radius was mm in diameter. Equations 1 and 2 were used to get the mass and volume (V) of the slicing disc (Khurmi and Gupta, 1917; Saraacos and Kostaropous, 2012).

$$V = \pi r^2 t \tag{1}$$

$$V = 3.142 \times (0.17)^2 \times 0.002 = 0.00018158 \text{ m}^3$$

$$m = \rho V \tag{2}$$

$$m = 7800 \times 0.00018158 = 1.42 \text{ kg}$$

Where, t is the thickness of the slicing disc (2mm = 0.002 m); The density of stainless steel was 7800 kg/m^3.

The electric motor's revolution per minute was 1410 rpm, with an angular velocity of 147.7 rad/s, driven by a drive outward centrifugal force of 52.63N as stated in equations 3, 4 and 5 (Hatwar *et al.* 2016).

$$w = \frac{2\pi N}{60} \tag{3}$$

$$w = \frac{2\times\pi\times1410}{60} = 147.7 \text{ rad/s}$$

$$V = wr$$

(4)

$$V = 147.7 \times 0.17 = 25.1 \text{m/s}$$

$$F = \frac{mv^2}{r} \tag{5}$$

$$F = \frac{1.42\times(25.1)^2}{0.17} = 52.63\text{N}$$

The machine requires a total toque (T) of 9Nm and approximately 2 horse power to slice the potato as contained in equations 6 and 7 (Spooner et al., 2015; Mishra *et al.,* 2020).

$$T = Fr \tag{6}$$

$$T = 52.63 \times 0.17 = 9\text{Nm}$$

$$P = \frac{2\pi NT}{60} \tag{7}$$

$$P = 147.7 \times 9$$

$$=1329.3 \text{ Watts} = 1.7 \text{ Hp}$$

Equation 8 shows that the electric motor speed (N) produced by the pulley diameters (D) of 31 mm, 54 mm, 57 mm, 66 mm, and 77 mm were 224, 390, 412, 477, and 556 rpm, respectively (Obeng 2014; Ukatu and Aboaba, 2016).

$$N_1D_1 = N_2D_2$$

(8)

For 31 mm diameter of the electric motor pulley;

$$N_2 = \frac{1410\times31}{195} = 224 \, rpm$$

For 54 mm diameter of the electric motor pulley;

$$N_2 = \frac{1410\times54}{195} = 390 \, rpm$$

For 57 mm diameter of the electric motor pulley;

$$N_2 = \frac{1410\times57}{195} = 412 \, rpm$$

For 66 mm diameter of the electric motor pulley;

$$N_2 = \frac{1410 \times 66}{195} = 477\ rpm$$

For 77 mm diameter of the electric motor pulley;

$$N_2 = \frac{1410 \times 77}{195} = 556\ rpm$$

The various implement components and the material selected are reported (Table 1); the most appropriate material and the available material used are also reported. The reasons for using the materials were also indicated (Table 1).

Table 1: Material Selection Criteria for Machine Component

S/N	Machine parts	Criteria for Selection	Suitable Material	Selected materials	Reason for Selection
1	Slicing Disc	Corrosion resistance, wear resistance, high tensile strength	Stainless steel	Stainless Steel	Corrosion resistance
2	The Frame	Malleability, availability, cost, weldability, rigidity	Mild steel	Mild steel	Readily available, low cost, easy to shape
3	Hoppers	Corrosion resistance, wear resistance, high tensile strength	Stainless steel	Stainless steel	Corrosion resistance and not brittle
4	Cutting table	Corrosion resistance, wear resistance, high tensile strength	Stainless steel	Stainless steel	Corrosion resistance
5	Shaft	High tensile strength, wear resistance	Medium high carbon steel	High carbon steel	High tensile strength, wear resistance
6	Pulley	Malleability, availability, welding ability	Mild steel	Mild steel	Readily available, low initial cost, easy to shape

Table 2: Machine Parts and Description

S/N	Components	Description	Quantity
1	Slicing disc	400mm by 400mm; Stainless steel	
2	Frame	1½ ×1½ angle iron 1½ ×1½ square pipe	1 Full length 1 Full length
3	Hopper	Round Stainless pipe: D 90mm × 110mm D 80mm ×110mm	1
4	Cutting table	Diameter 400mm ø Thickness 10mm Stainless steel	-
5	Shaft	Diameter 20mm ø Length 550mm High carbon steel	-
6	Pulley	Diameter – 250mm ø Mild steel	4
7	Electric motor	2HP	1
8	Paint	Silver colour	1lit.
9	Machining job		
10	Bolt & nuts	M -6; M -10; M -12	1, 2, 2 dozen
11	Bearing		2
12	Belt	Ball bearing	1

Machine description

The slicing machine was designed using cold and hot working processes, with cold working involving marking, cutting, rolling, and folding, and hot working involving heat -working metal operations, primarily from electricity. The device has two conical-shaped hoppers with diameters of 80 and 90 mm and lengths of 170 mm, and two removable discs with a radius of 170 mm and a thickness of 2 mm. As the product is sliced, the discs are designed to propel the cut piece down and into the discharge chute, where it falls due to gravity. A bolt and nut that secure blade to the cutting table allow clearance to be changed. A 5 mm slice clearance was intended for the output thicknesses. A single-phase, two-horsepower electric motor running at 1410 rpm powers the machine and transforms electrical energy into mechanical motion. The slicing discs use this rotating force, which is communicated through the shaft, to operate. Mild steel was used to build the system frame, which houses the electric motor and supports the machine. Its dimensions in terms of volume are 700 x 680 x 600 mm.

The two-way sweet potato slicing machine that was fabricated is shown (Figure 5).

Figure 5a: Cutting disc

Figure 5b: Machine shaft

Figure 5c: Slicer plan view

Figure 5d: Slicer couple

Figures: 5a-d: Machine assembly under construction

Figure 6: Slicing machine Assembly

Experimental procedure and performance evaluation

Irish potatoes, sweet potatoes, and plantains were the crop samples utilized in the test bought in Akure, Ondo State, Nigeria, at a neighborhood market. The crop samples were cleaned, peeled, and weighed in a sanitary manner. A vernier caliper was used to measure the major and minor measurements' geometric mean dimensions. The samples were divided into two sizes: small (measuring 22.62–33.14 mm) and big (measuring 33.35–49.9 mm). The geometric mean diameter range was 31.79–99.06 m for sweet potatoes, 34.01–63.33 m for Irish potato and 52.69–70.67 m for plantains (Table 3). For perfect operation, the machine was run for five minutes with no load. The slicer was fed samples with varying measured masses and was run at four different speeds: 224, 390, 412, 477, and 556 rpm. Each experimental test on the machine lasted for two minutes, and was replicated five times. The materials that came out of the machine's outlet were collected and divided into two groups: sliced and unsliced materials.

The types and sizes of each crop [length, width, geometric mean diameter (GMD), thickness and arithmetic mean diameter (AMD)] used are demonstrated as shown (Table 3).

Table 3: Classification of the sizes of the crop samples

Characteristics	Sweet potato	Irish potato	Plantain
Length (mm)	45.62 – 174.50	36.27 – 101.01	115.71 – 220.32
Thickness (mm)	25.33 – 78.89	31.76 - 51.10	35.32 – 37.05
Width (mm)	27.59 – 81.51	38.06 – 55.48	40.71 – 51.05
GMD (mm)	31.79 -99.06	34.01 – 63.33	52.69 – 70.67
AMD (mm)	34.42 – 111.02	35.35 – 69.40	63.81 – 102.24

GMD = Geometric Mean Diameter; AMD = Arithmetic Mean Diameter of crop samples.

RESULTS AND DISCUSSION

The chosen crops were sliced by the designed slicing machine to the size range of 5 mm to 6 mm thick (Figure 7). The cutting of small and large sizes of Irish potato at disc speed of 390 rpm gave the slicing efficiencies of 85% and 86% at different slice rates (Table 4). When the machine was used to slice giant plantains at 412 rpm, it achieved the maximum efficiency of 89% (Table 5), but when it was used to slice little plantains at 224 rpm, it achieved the lowest efficiency of 60% (Table 5). At 477 rpm disc speed, the slicing of sweet potato of 4.31 kg and 4.80 kg produced 84% and 88% slicing efficiency with difference of 0.02 kg/sec (Table 6). The range of the slice rate was 0.027 kg/sec to 0.047 kg/sec (Tables 5 and 6). It was inferred that, size of crops is directly proportional to slice rate as reported (Tables 4, 5 and 6).

Table 4: Slicing Efficiency of the machine and slice rate for Irish Potato

Category	Ds (rpm)	Mg (kg)	Mbu (kg)	Tm (kg)	T (Mins)	Eff (%)	Sr (Kg/sec)
Small	224	2.46	1.44	3.90	2.00	63	0.033
	390	2.72	0.48	3.20	2.00	85	0.027
	412	2.50	1.00	3.50	2.00	71	0.029
	477	2.56	1.14	3.70	2.00	69	0.031
	556	2.60	1.40	4.00	2.00	65	0.033
Large	224	2.70	1.50	4.20	2.00	64	0.035
	390	3.70	0.60	4.30	2.00	86	0.036
	412	3.30	1.22	4.52	2.00	73	0.038
	477	3.50	1.36	4.86	2.00	76	0.041
	556	3.80	1.48	5.28	2.00	72	0.044

Sr = Slice rate; Eff = efficiency; T = time; Ds = disc speed; Mg = mass of good slice; Mbu = mass of bad slice and unsliced; and Tm = total mass input

Table 5: Slicing efficiency of the machine and slice rate for plantain

Category	Ds (rpm)	Mg (kg)	Mbu (kg)	Tm (kg)	T (Mins)	Eff (%)	Sr (Kg/sec)
Small	224	2.30	0.90	3.20	2.00	71	0.027
	390	2.50	1.90	3.40	2.00	73	0.028
	412	3.26	0.44	3.70	2.00	88	0.031
	477	3.02	0.90	4.01	2.00	75	0.033
	556	2.80	1.46	4.26	2.00	66	0.036
Large	224	3.41	2.19	5.60	2.00	60	0.047
	390	3.51	1.59	5.10	2.00	69	0.043
	412	4.62	0.54	5.16	2.00	89	0.043
	477	3.70	1.19	4.89	2.00	75	0.041
	556	3.20	1.40	4.60	2.00	69	0.038

Sr = Slice rate; Eff = efficiency; T = time; Ds = disc speed; Mg = mass of good slice; Mbu = mass of bad slice and unsliced; and Tm = total mass input

Table 6: Slicing Efficiency of the machine and slice rate for Sweet Potato

Category	Ds (rpm)	Mg (kg)	Mbu (kg)	Tm (kg)	T (Mins)	Eff (%)	Sr (Kg/sec)
Small	224	2.50	1.40	3.90	2.00	64	0.033
	390	2.80	1.29	4.09	2.00	68	0.034
	412	3.00	1.30	4.30	2.00	70	0.036
	477	4.31	0.85	5.16	2.00	84	0.043
	556	3.91	1.40	5.31	2.00	74	0.044
Large	224	3.00	1.32	4.32	2.00	69	0.036
	390	3.40	1.22	4.62	2.00	73	0.039
	412	3.50	1.40	4.90	2.00	71	0.041
	477	4.80	0.62	5.42	2.00	88	0.045
	556	4.40	1.20	5.60	2.00	80	0.047

Sr = Slice rate; Eff = efficiency; T = time; Ds = disc speed; Mg = mass of good slice; Mbu = mass of bad slice and unsliced; and Tm = total mass input

Figure 7: Developed two-way slicing machine

Effect of speed on machine slicing efficiency

The slicing efficiency of the crops varied with the slicing disc speed (Figures 8 and 9). For Irish potatoes, the disc speed was first set at 224 rpm, producing a slicing efficiency of 63 and 64% for the small and big categories (Figures 8 and 9). This was then increased to 390 rpm, producing a slicing efficiency of 85 and 86% for both categories. For tiny Irish potatoes, the optimal speed obtained was 390 rpm (Figure 8). The plantain sample's slicing efficiencies increased by a rotational speed of 224 rpm, yielding efficiency values of 71 and 64% in the small and large plantain categories, respectively (Figures 8 and 9). At speeds of 412 rpm, the slicing efficiencies reached their highest values of 88% (small category) and 89% (large category) and then decreased at speeds of 477 rpm and 556 rpm. As a result, 412 rpm is the suggested speed for slicing plantains. When cutting sweet potatoes into small and big sample categories, slicing efficiencies of 64% and 69% were noted at a disc slicing speed of 224 rpm (Figures 8 and 9). The required speed of 477 rpm for slicing sweet potatoes yielded optimal efficiency of 84% and 84% for both categories (Figures 8 and 9). This showed that the machine's efficiency decreases at any speed over the suggested speed because of the quantity of poorly cut material.

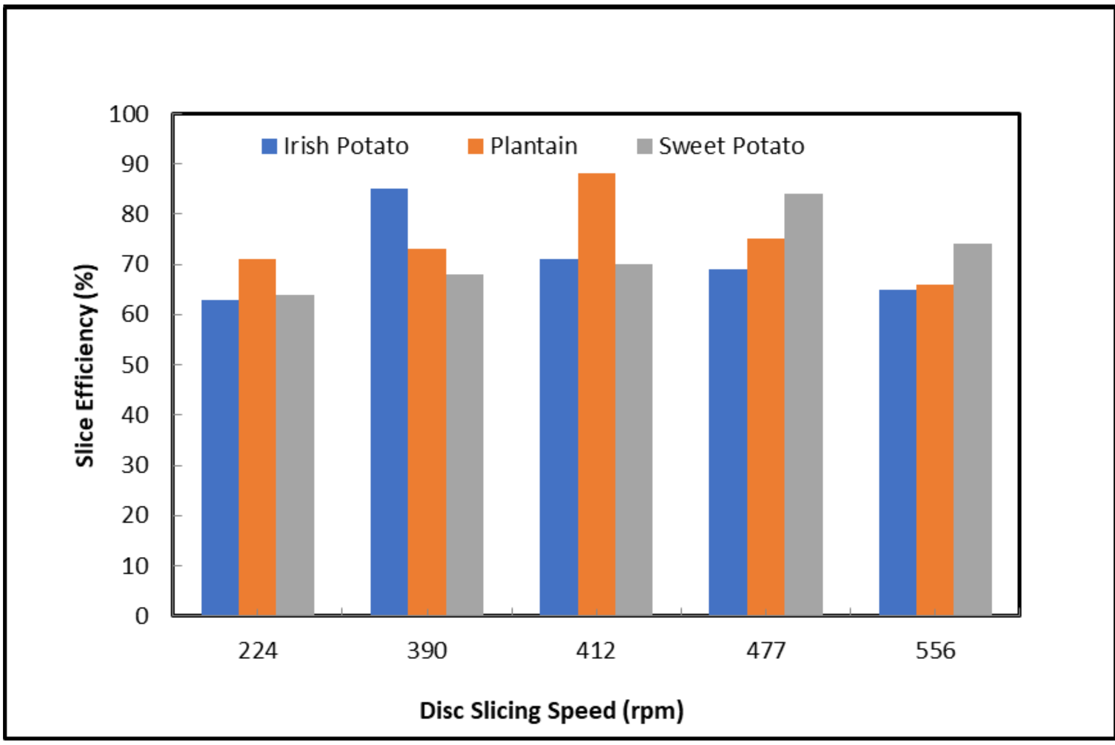


Figure 8: Impact of disc slicing speed on slice efficiency for small crop samples

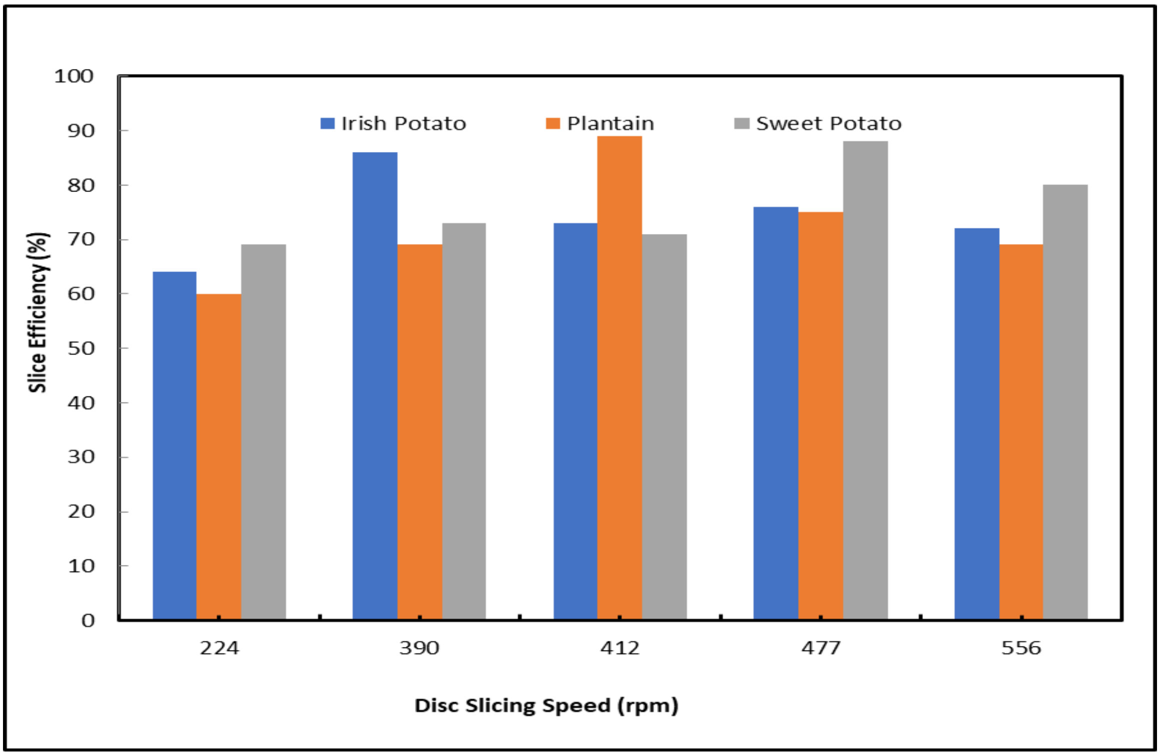


Figure 9: Impact of disc slicing speed on slice efficiency for large crop samples

Effect of the sizes of the samples on the slicing efficiency

As the size of each sample that is sliced increased, so did the slicing efficiency to a specific disc speed (Figure 10). With small-sized Irish potato, the slicing machine's efficiency grew and achieved its maximum of 85% value at speeds of 390 rpm for 2.72 kg of good slice. At same speed, a large-sized (3.70 kg) produced 86% slicing efficiency (Figure 10 and Table 4). After the peak efficiency at 390 rpm, efficiency began to fall (Table 4). The moderate moisture content and soft texture of the Irish potato samples may have contributed to their behavior, resulting in more damaged slices at faster rates. This indicates that, crop size slicing is indirectly proportion to slicing efficiency.

Small-sized plantain produced 88% slicing efficiency at disc speed of 412 rpm. When this slicing speed was exceeded, efficiency decreased. The maximum efficiency of 89% was achieved by large plantain potatoes at 412 rpm, after which the efficiency started to decline. The texture and fiber content of the crop, which tends to need such speed to slice, may be the cause of the plantain's behavior. This implies that, slicing efficiency could initially increase and later decreased as crop size increase as reported (Figure 10 and Table 5). This suggests that rather than slicing the crop samples or giving them an uneven slice, the slicing cutting disk pushed the samples back.

At speed 477 rpm, small and large-sized sweet potato produced 84% and 88% slicing efficiencies. After exceeding this disc speed, sweet potatoes with large sizes demand high-speed cutting due to their high texture and low water content in crop samples. The sweet potato's hardness determines the high-speed need for the slicing process (Figure 10 and Table 6).

Generally, slicing efficiency changed depending on which crop was being sliced (Figure 10). Slicing speeds had an impact on the slicing rate that the slicer produced, which varied from 0.027 to 0.047 kg/sec. Plantains had the highest efficiency, followed by sweet potatoes, while Irish potatoes had the lowest (Figure 10).

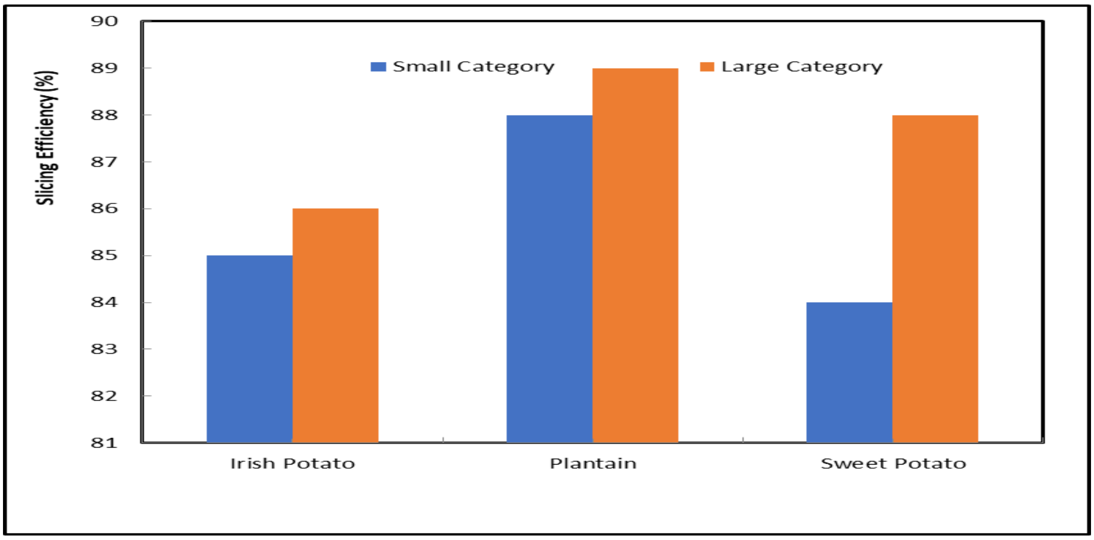


Figure 10: Size sample and Slicing Efficiency

Effect of disc cutting speed on slicing rate

For each crop, the machine's slicing rate increased from the small category to the big category when slicing the three crop samples (Tables 4, 5 and 6).

With the machine disc speed of 390 rpm, small-sized Irish potato produced optimal slicing efficiency of 85% at 0.027 kg/sec while, the highest efficiency of 86% was achieved at 0.036 kg/sec for large-sized. This means that, as crop size increases, the slicing efficiency rises as well as slice rate (Table 4).

3.26 kg of good plantains slice produced 88% efficiency at 412 rpm for slice rate of 0.031 kg/sec. With same speed, the cutting of 4.62 kg was achieved at 0.043 kg/sec slice rate and 89% efficiency. This implies that, the slice rate depends on crop sizes as reported (Table 5).

The cutting of 4.31 kg of sweet potato at 477 rpm for 84% efficiency was achieved at 0.043 kg/sec while, 4.80 kg at same speed but increased slice rate of 0.045 kg/sec resulted in 88%. This is a confirmation that, as crop size increases, the slice rate rises (Table 6).

The slicing rate increased as the disc speed increased until it reached the ideal speed suggested for each crop sample, at which point it fell (Tables 4, 5 and 6). The suggested disc speed for Irish potato and plantains (big and small categories) are 390 rpm and 412 rpm, respectively. In addition, for Irish potatoes (large and small samples), the recommended slicing rates are 0.036 and 0.027 kg/sec (Table 5). For sweet potatoes the recommended slicing rate is 0.045 and 0.043 kg/sec, respectively, at the suggested disc speed of 477 rpm (Table 6).

CONCLUSIONS

A portable slicing machine was developed and successfully sliced plantains, sweet potatoes, and Irish potatoes during performance evaluation. In the course of processing, the machine efficiently cut the crops into the prescribed slice. The machine's slicing rate and slicing efficiency are dependent on the speed of the slicing disk and sample size. At cutting speed rate of 0.047 kg/sec, the highest slicing efficiencies for both small and big categories of Irish potatoes was 86%, 87%, of sweet potatoes, and 89% of plantains, respectively. The result of the mean slicing efficiencies showed that, the machine was effective and efficient for a recommended disc speed of 390 rpm for Irish potato, 412 rpm for plantain and 477 rpm for potato. The machine is safe to use, solved the problems associated with manual labour and encouraged mass production of the selected crops chips

RECOMMENDATION

The vegetable holder should be converted from manual to mechanical, incorporating a gear and spring mechanism, to reduce human intervention and save time and energy.

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