Development and Performance Evaluation of a Multi-Crop Slicing Machine

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ABSTRACT

This study aims to develop an efficient, portable and ergonomically safe multi-crop slicing machine that can be affordable to small-scale entrepreneurs, evaluate its performance, and determine its slicing efficiency and throughput capacity at different operation speeds. Some of the machine's major components include the mainframe, outlet, hopper, slicing unit, slicing disc, pulley, electric motor base and bearing. The machine is powered by a single phase and 1hr electric motor. The performance of the machine was conducted with three selected crops (banana, cucumber and carrots); grouped into three categories, namely minimum-sized samples (35 – 54 mm), medium-sized samples (55 – 65mm) and maximum-sized (65 – 75mm); at five machine speeds of 26, 38, 42, 55 and 65rpm. The parameters determined were slicing efficiency and throughput capacity. Results showed that the highest mean slicing efficiency of 87% was attained by the machine when slicing minimum-size cucumbers at a rotational speed of 55 rpm, while the machine attained the lowest mean slicing efficiency of 58% for slicing maximum-sized cucumbers at a rotational speed of 65 rpm. The throughput capacities from the machine were affected by the slicing speeds, which ranged between 21.45 kg/hr to 42.90 kg/hr. The constructed machine demonstrated ability to slice all the selected crops satisfactorily.

Key words: Development; fabrication; variable speed; performance evaluation; Slicing efficiency; throughput capacity

INTRODUCTION

Vegetables, fruit and root crops (Cucumber, cassava, plantain, sweet potato, yam, cocoa yam, etc.) are among the most valuable staple food and fruit sources for tens of millions of people in West Africa. Increased production of these crops in Nigeria has brought about the need to develop appropriate processing technology. Most vegetable and fruit crops come large after harvest; therefore, size reduction is a preliminary stage for various food processing activities. The general term 'size reduction' includes cutting, crushing, grinding and milling. Such processes as cutting fruits and vegetables for canning, shredding sweet potatoes for drying, chopping of corn fodder, grinding limestone for fertiliser, grinding grain for livestock feed, and milling flour are all size reduction processes (Federick, 2008). Slicing denotes cutting materials into smaller sizes using a sharp blade or cutter.

The conventional method of slicing crops in rural areas involves placing them on a chopping board and cutting them into the desired thickness using a sharp knife. This method is injurious, laborious, unhygienic, and produces non–uniform slices, thereby giving poor end products. As a result of increased technological advancement, it has given rise to innovative discoveries and created awareness of the importance of using mechanical devices to slice agricultural produce. It is imperative to develop a multi-crop slicing machine for agricultural products in response to the escalating demand for both industrial and domestic usage. However, such machines are unavailable locally in Nigeria, and the imported ones are difficult to maintain.

The purpose of this study is to develop an efficient, portable and ergonomically safe slicing machine that can be affordable to small-scale entrepreneurs; the slicing efficiencies and throughput capacity at different speeds were analysed and reported

2.1 Some of the Reviewed work

There are previous studies in the literature relating to slicing machines for different crops.Ezeanya (2020) designed and evaluated a slicing machine equipped with two blades powered by a 0.25hp electric motor. The machine was tested with different crops and slicing speeds. The highest slicing efficiency of 87.6% was achieved when slicing small-sized Irish potatoes at 58 rpm, while the lowest efficiency of 60.7% was observed when slicing medium-sized onion bulbs at 69 rpm. Throughput capacity ranged from 20.52 to 44.28 kg/hr, and slice thicknesses of 5mm to 6mm were achieved. Agbetoye and Balogun (2009)presented a multi-crop slicing machine powered by a three-phase, 2 kW electric motor. The machine was tested with various crops and speeds. It performed best at 41 rpm for most crops, with high efficiencies and throughput capacities observed. For instance, carrot slicing had a throughput capacity of 48.9 kg/h and an efficiency of 95.4% at 41 rpm. Ehiem and Obetta (2011) developed a motorized yam slicer operated by a 1.5 hp motor, achieving a slicing efficiency of 52.3% and an average throughput capacity of 315 kg/hr. They also noted a percentage of non-uniform slices at 42.65%.Ukatu and Aboaba (1996) also presented a tuber slicing machine working at 45 rpm, allowing yam or cassava tubers to be cut into slices and fed into a conveyor system. Rajesh et al. (2016) also developed and evaluated a plantain peeler cum slicer, achieving an average slicing efficiency of 88.94% and throughput capacities ranging from 79.59 to 89.27 kg/hr. on their part, Kachru et al (1996) discussed the fundamental concept of cutting and how a cutting edge (knife) penetrates and separates materials during the cutting process. It emphasized the importance of cutting edge design and process kinematics. These studies primarily focus on the design, performance, and efficiency of slicing machines for various crops, providing insights into slicing techniques and machinery for different agricultural products

MATERIALS AND METHOD

Crops to be slides

Three vegetable crops are selected for this research work: cucumbers, plantains and carrots. These selected vegetables are very important as a food source for human consumption and raw materials for the industry. The cucumber (Cucumis sativus L.), is an annual deep-rooted crop, which is a member of the Cucurbitaceae and is an important vegetable crop with many health benefits (Elum, et al 2016). Cucumbers are long, cylindrical green fruits that contain about 95% water and areoften recommended as natural diuretics and helpful for bodybuilding.

Carrot (Daucus carota L.) is a root vegetable that comes in various colours and is rich in minerals and other health benefits. Carrots contain carotenoids, polyphenols and vitamins that act as antioxidants, anti carcinogens, and immune enhancers.

Bananas contain essential nutrients that may enhance heart health, help manage blood pressure, and boost a person’s mood, among other benefits. Eating bananas can help lower blood pressure and may reduce cancer risk. Bananas are high in potassium and contain good protein and dietary fibre levels.

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Design considerations

Basic considerations in designing the slicing machine are the affordability of the materials, comfort and ergonomics considerations for the user, portability, safety and corrosion resistance of the blade

Design Parameters

Radius of Slicing Disc

A primary design consideration was for the radius of the slicing disc to be greater than the diameter of the vegetables to be sliced (Saravacos & Kostaropoulos, 2002) The average diameter for the crops to be sliced was obtained from sampling as 5.92 cm. Therefore, 3×5.92 cm=17.76 cm. The disc radius of 18.0cm (0.18m) was chosen.

Volume of Slicing Disc

Volume (V) of slicing disc was determined using

$v = \pi r^2 h$ (Ezeanya, 2020) (1)

Where r = radius of slicing disc

h = thickness of slicing disc (2mm = 0.002m)

Therefore $v = \pi \times 0.18^2 \times 0.002$

$v = 2.03 \times 10^{-4} m^3$

2.3.3 Mass of Slicing Disc

Mass of slicing disc was determined from

$M = \rho \times V$ (2)

Where ρ = density of stainless steel = 7800 kgm^{-3}

Therefore M = 7800 ×2.03× 10^{-4} = 1.58 kg

Power Required to Drive the Machine

Force due to centrifugal action of the disc (F) is

$F = \frac{mv^2}{r}$ (3)

Where V= velocity = ωr

ω = angular velocity = $\frac{2\pi N}{6o}$

Therefore, angular velocity, ω = $\frac{2\times\pi\times 200}{60}$

= 20.94 rad s^{-1}

Velocity of slicing disc, V=20.94 ×0.18 =3.77m s^{-1}

Therefore, $F = \frac{1.58\times 3.77^2}{0.18}$

= 124.76 N

The total torque required (T) is given as equation 4

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$$T = F \times r \quad (4)$$

Therefore, $T = 124.76 \times 0.18 \quad = 22.46$ Nm

Power required to drive the machine is given as equation 5

$$P = \frac{2\pi NT}{60} \quad (5)$$

$$P = T \times \omega \quad = 20.94 \times 22.46$$

P = 470 watts = 0.63 horsepower

Considering the factor of safety of 1.5, therefore, 1.0 horsepower is recommended.

Hence, the following dimensions were obtained.

Height of the hopper = 55 mm

Length of the shaft = 300 mm

Diameter of the shaft = 30 mm

Speed of the shaft = 200 rpm

Thickness of the slicing disc = 2mm

Description of the machine

The isometric view of the constructed multi-crop slicing machine is shown in Figure 1. The machine consists of the following components, namely; hopper, upper housing, feed channel, conveying disc, slicer shaft, outlet, slicing unit, frame, idler shaft and idler frame, bearings and electric motor.

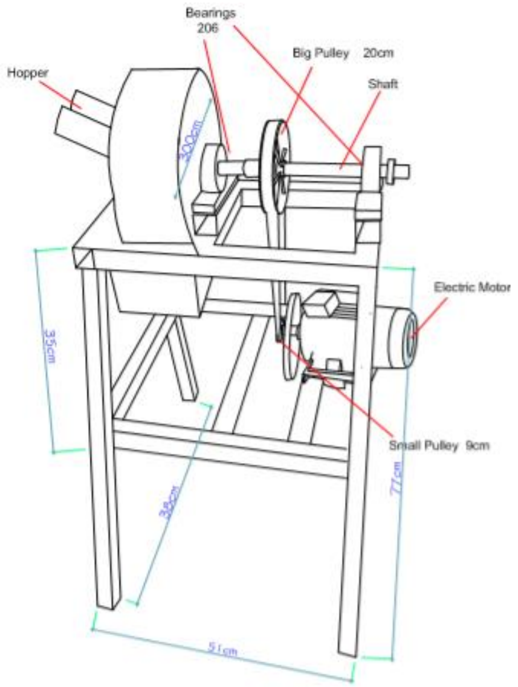

Figure 1: Isometric view of the constructed multi-crop slicing machine

Experimental procedure

The experiment was conducted using the following samples: cucumbers, carrots, and bananas bought in a local market in Binin kebbi, kebbi State. The experimental samples were peeled, washed, cut and separated into three different categories, namely minimum-sized samples (35– 54 mm), medium-sized samples (55 – 65mm) and maximum-sized (65 – 75mm). This was based on their measured physical properties. A vernier calliper was provided to measure the selected crops' major and minor diameters. Also, the masses and volumes of the selected crops were measured with an electronic weighing machine and volume displacement method. A no-load test was conducted to ascertain the functionality of the machine and its components. A tachometer of the model (UNI-T to UNI-T: UT – 373mini) was provided to ensure the correctness of operating speed as determined in the design calculation. At different mass, each of the samples was fed into the slicer at five different operating speeds of 26, 38, 42, 55, and 65 rpm according to The machine was operated for 4.6 minutes for each experimental test. Each experiment was repeated three times, and the average of the results was taken. Both the sliced and unsliced output materials from the machine outlet were collected and separated.

Analysis of operational parameters

Determination of slicing efficiency

The slicing efficiency (ηp) of the machine was determined using (6)

$$\eta p = \frac{M_{SS}}{M_S} \text{ (kg)} \quad (6)$$

Where

M_{SS} = mass of sliced materials (Kg)

M_s = total mass of sliced and damaged materials (Kg)

2.6.2 Determination of Throughput Capacity

The throughput capacity of the slicing machine was determined by equation (7)

$$T = \frac{M_{SS}}{t} \left(\frac{kg}{hr}\right) \quad (7)$$

Where: T= throughput capacity (kg/hr), t =time of slicing (hr)

RESULTS AND DISCUSSION

Tables 1,2, and 3 show the results of slicing efficiencies and throughput capacities at different speeds for bananas, cucumbers and carrots. The results show that the slicing machine could slice the selected crops according to the required size range of 4mm to 7mm thick at high efficiency. It was observed that the machine achieved maximum efficiency of 87% for slicing a minimum-sized cucumber sample at a rotational speed of 55 rpm, while the machine attained the least efficiency of 58% for slicing a maximum-sized cucumber at a rotational speed of 65 rpm. The results obtained during the test showed that the through put capacities range between 21.45 kg/hr to 42.90 kg/hr.

Also, as indicated from the results, it was observed that the machine pushed away the samples at a rotational speed of 65 rpm and beyond, leading to a higher percentage of damage and wastage.

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Table 1 Result of slicing efficiency and Throughput capacity for Banana

GROUP	Speed (rpm)	M_s (kg)	M_{ss} (kg)	M_d (kg)	T (kg/hr)	Time (mins)	Efficiency (%)
Minimum size	26	2.70	1.90	0.80	24.70	4.60	70
	38	2.90	2.10	0.80	27.30	4.60	72
	42	3.20	2.35	0.85	30.55	4.60	73
	55	3.60	2.99	0.80	40.30	4.60	86
	65	4.00	1.70	2.30	22.10	4.60	43
Medium size	26	2.90	1.80	1.10	23.40	4.60	62
	38	3.10	2.00	1.10	26.00	4.60	65
	42	3.40	2.39	1.01	31.07	4.60	70
	55	4.00	3.50	0.70	42.90	4.60	83
	65	4.50	2.00	2.50	26.00	4.60	45
Maximum size	26	3.20	1.90	1.30	24.70	4.60	59
	38	3.40	2.10	1.30	27.30	4.60	62
	42	3.60	2.40	1.20	31.20	4.60	67
	55	4.20	3.40	0.80	31.20	4.60	81
	65	4.60	1.92	2.68	24.96	4.60	42

M_S = mass of the sample, M_{SS} = mass of the sliced sample, M_d = mass of the damaged sample, T = Throughput capacity.

Table 2 Result of slicing efficiency and Throughput capacity for Cucumber

GROUP	Speed (rpm)	M_S (kg)	M_{SS} (kg)	M_d (kg)	T (kg/hr)	Time (mins)	Efficiency (%)
Minimum size	26	2.30	1.70	0.60	22.10	4.60	74
	38	2.60	2.00	0.60	26.00	4.60	77
	42	2.80	2.20	0.60	28.60	4.60	79
	55	3.10	2.70	0.40	35.10	4.60	87
	65	3.40	2.50	0.90	32.50	4.60	73
Medium size	26	2.50	1.80	0.70	23.40	4.60	72
	38	2.80	2.10	0.70	27.30	4.60	75
	42	3.00	2.30	0.70	29.90	4.60	77
	55	3.40	2.90	0.50	37.70	4.60	85
	65	3.70	2.50	1.20	32.50	4.60	68
Maximum size	26	2.90	1.85	1.05	24.05	4.60	63
	38	3.20	2.10	1.10	27.30	4.60	66
	42	3.40	2.40	1.00	31.20	4.60	70
	55	3,80	3.10	0.70	40.30	4.60	82
	65	4.00	2.30	1.70	29.90	4.60	58

MS = mass of sample, MSS = mass of sliced sample, Md = mass of damaged sample, T = Throughput capacity.

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Table 3 Result of slicing efficiency and Throughput capacity for Carrot

GROUP	Speed (rpm)	M_S (kg)	M_{SS} (kg)	M_d (kg)	T (kg/hr)	Time (mins)	Efficiency (%)
Minimum size	26	2.50	1.80	0.70	23.40	4.60	69
	38	2.82	2.00	0.82	26.00	4.60	71
	42	2.93	2.15	0.78	27.95	4.60	73
	55	3.21	2.70	0.51	35.10	4.60	84
	65	3.35	2.35	1.00	30.55	4.60	70
Medium size	26	2.65	1.80	0.85	23.50	4.60	68
	38	2.73	1.95	0.78	25.35	4.60	70
	42	2.87	2.05	0.82	26.65	4.60	71
	55	3.20	2.60	1.08	31.20	4.60	81
	65	3.68	2.60	1.08	33.80	4.60	71
Maximum size	26	2.71	1.65	1.06	21.45	4.60	61
	38	2.84	1.90	0.94	24.70	4.60	67
	42	2.92	2.20	0.72	28.60	4.60	75
	55	3.40	2.75	0.65	35.75	4.60	81
	65	3.80	2.90	0.90	37.70	4.60	71

M_S = mass of sample, M_{SS} = mass of sliced sample, M_d = mass of damaged sample, T = Throughput capacity.

Effect of Speed on Throughput Capacity

Figure 1, 2, and 3; shows the effect of variable speed on Throughput capacity for minimum, medium and maximum sized samples of the constructed machine. It was indicated from the results that the throughput capacity when slicing banana and cucumber was lowest at a speed of 26 rpm, and then increased to a maximum value at the speed of 55 rpm before dropping to a lower value at a speed of 65 rpm. A different observation was observed in the case of the carrot; it recorded a different trend by giving the highest throughput capacity value of 37.7 kg/hr at a speed of 65 rpm. This could be attributed to the structural difference between carrot and the two other samples tested along with it. This variation in throughput capacity with respect to slicing speed was also observed by previous research findings conducted for plantain, carrots, yam, onion, and banana (Ezeanya, 2020; Agbetoye and Balogun, 2009).

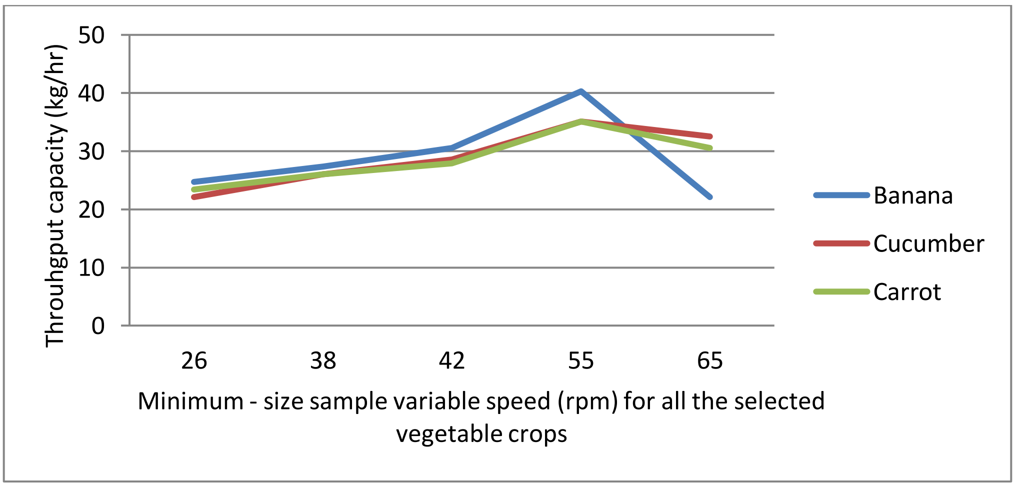

Figure 1: Showing the effect of variable speed on Throughput capacity for minimum sized sample

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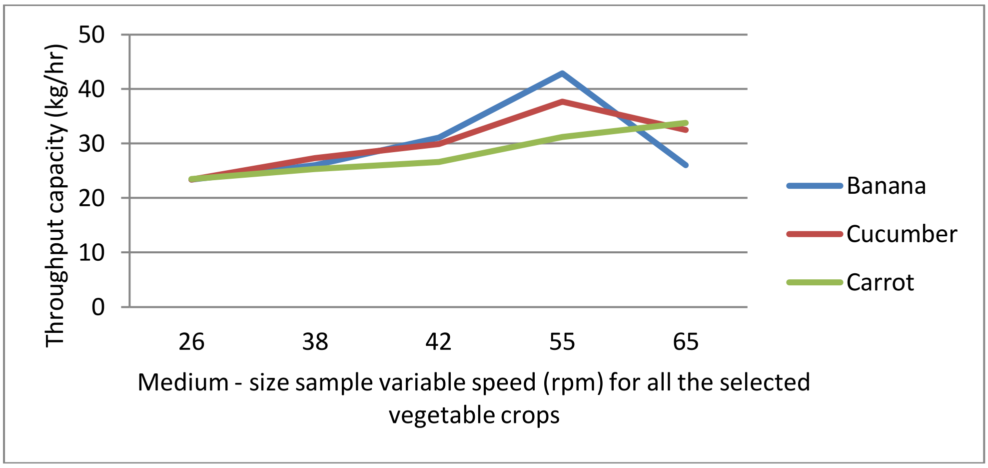

Figure 2: Showing the effect of variable speed on Throughput capacity for medium sized sample.

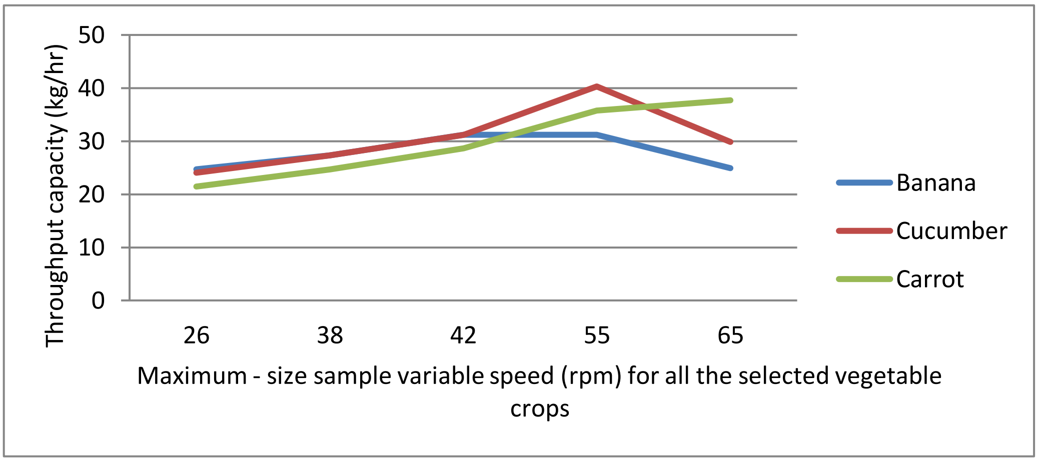

Figure 3: Showing the effect of variable speed on Throughput capacity for maximum sized sample.

Effect of speed on the slicing efficiency

This effect was observed from Tables 1, 2, 3; and Figure 4, 5, 6; it can be seen that the slicing efficiency of the machine varied with the variable speed of slicing disc for all the selected crops. These efficiencies increased from variable speed of 26 rpm, reaching highest values at speeds of 38 and 55 rpm, and then reduced slightly at speed of 65 rpm. It is worthy to note that speed of 55 rpm is recommended as the best slicing speed for the machine, for slicing the selected crops

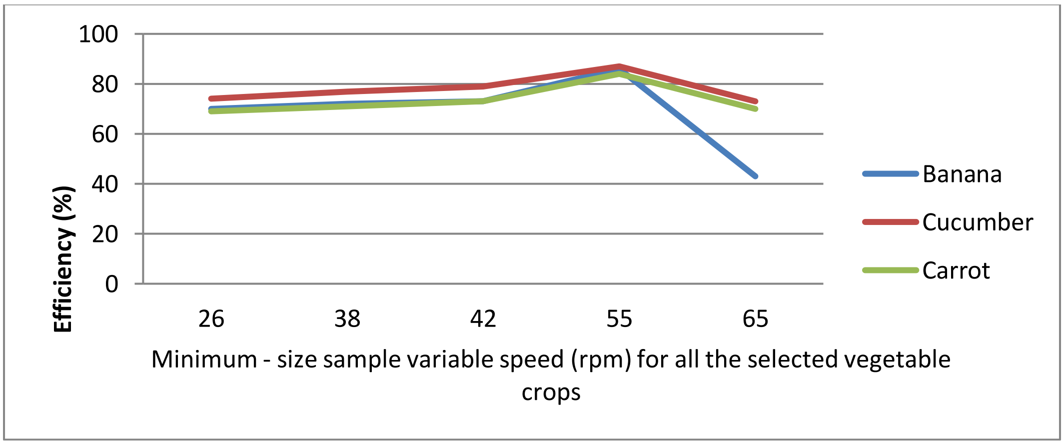

Figure 4: Showing minimum size variable speed for all selected samples and their efficiencies.

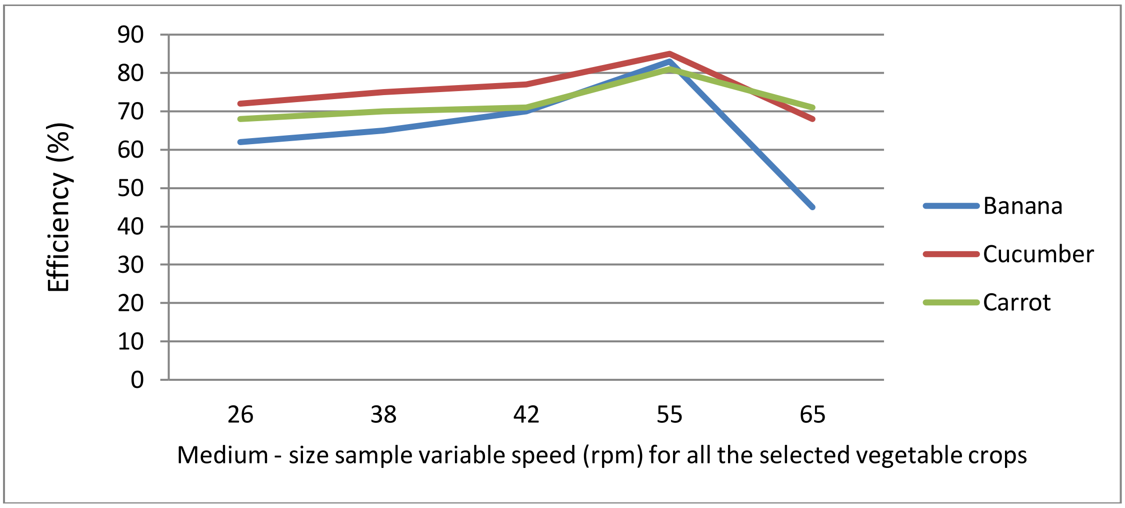

Figure 5: showing medium size variable speed for all selected crops with their efficiencies

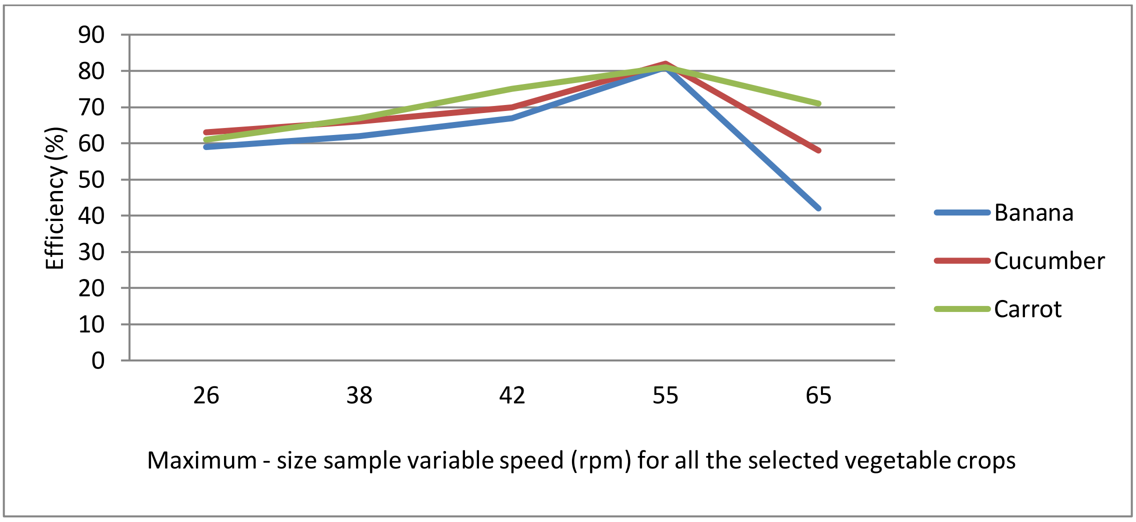

Figure 6: showing maximum size variable speed for all selected crops with their efficiencies

Effect of Size on Slicing Efficiency

The effect of size on slicing efficiency was presented in Figure 7; from the observation, the slicing efficiency varied with the sizes of the selected vegetable crops used for the experiment. This efficiency was observed to have reduced with the increased size of all the sliced and used samples. It was recorded from the results that the efficiency of the constructed slicing machine with a minimum sizeof all the selected samples increased and reached optimum value at speed of 55 rpm table (1, 2, and 3). After this speed, there was a reduction inits efficiency. This shows that above the speed of 55 rpm, the slicing blade tends to push the products back instead of slicing them. Thisbehaviour was equally observed for minimum-size bananas and carrots at 55 rpm. However, at the speed of 65 rpm there was an appreciable rise in efficiency of the carrot samplecompared to both banana and cucumber samples in each category table (1, 2, and 3). This behaviourexhibited by carrot samples could result fromits hard texture and fibre content, which resist the pressure from slicing blades of the machine at higher speeds. The differences in this slicing efficiency with speed and size of samples was previously observed during research findings conducted for carrots, banana,onion, plantain and yam (Rajesh et al., 2016; Agbetoye and Balogun, 2009;Ezeanya, 2020). Observation from Figure 4 indicated that efficiency varied with the different types of crop being sliced and also shows higher efficiency for cucumber and banana samples as against carrot samples

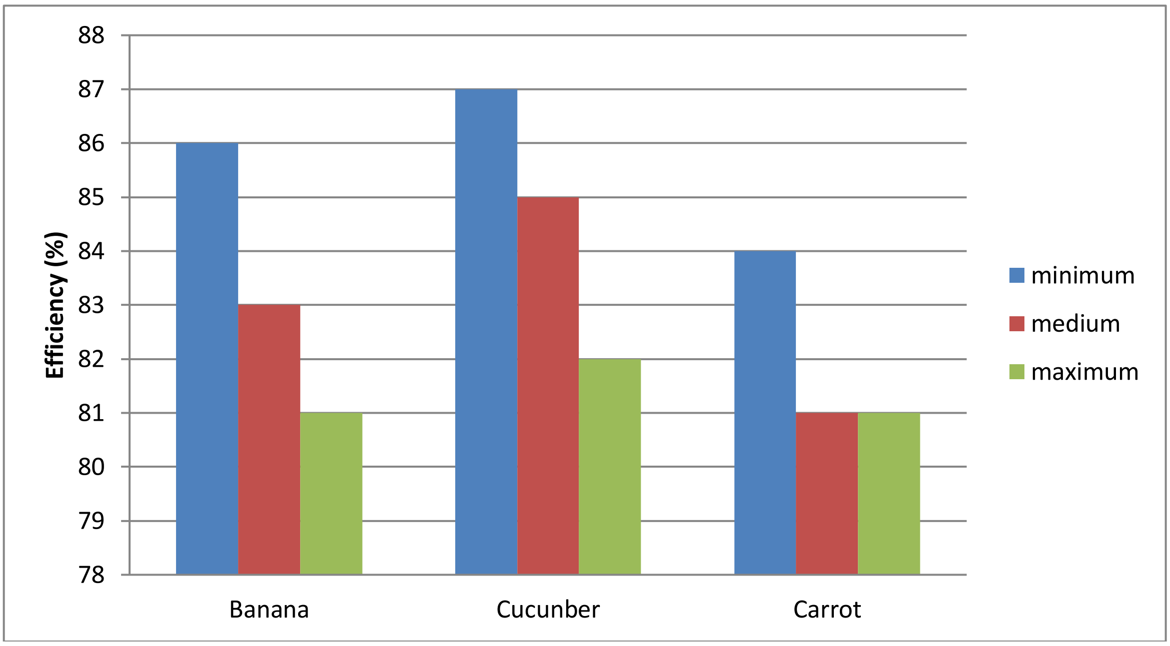

Figure 7: Showing the effect of size on the slicing efficiency for the selected crops

CONCLUSION

A portable slicing machine was developed capable for slicing banana, carrots and cucumber that can be affordable by local farmers for the purpose of drying, grinding, and processing their farms' produce. The developed machine was tested, and it was observed that it could slice the selected vegetable crop samples with high efficiency. The slicing efficiency and throughput capacity of the machine were observed to have been affected by the slicing disc and size of the selected samples. There was an increase in the slicing efficiency with an increase in rotational speeds of the slicing disc from speed of 26 to 55 rpm. Beyond this speed, the slicing efficiency reduces for all the samples. It was also noted that the slicing efficiency increased with decrease in size of the samples. Furthermore, the throughput capacity was reported to have increased with increase in rotational speeds of the slicing disc between thespeeds of 26 to 55 rpm. Above this speed, the throughput capacity decreased for most of the samples except for the all carrot samples.

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