Design, Fabrication and Testing

Reduction Machine. *Gbabo A.*[1], *Oyebamiji S*[1], *Abdulraheem O*[1], *Gana I.M.*[2] *and V.A Thomas*[1]

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ABSTRACT

This research work was carried out to design, fabricate and test the performance of a manual and motorized ginger size reduction machine in order for the ginger to be dried easily for storage. This concept also aimed at reducing the processing cost, drudgery and time involved in drying ginger. The machine was designed to have a capacity of 900kg per day. The machine consists of hopper, cutting unit, press, cutting blade, frame, an electric motor, manually operated pulley and crank arm. The machine was designed and fabricated using locally sourced material of stainless steel for all part that made contact with the ginger. Three ginger cutting orifices size blades of 2.5 x 2.5cm, 2.0 x 2.0cm and 1.5 x 1.5cm were used in the design so as to enable testing to be carried out to ascertain the orifice size that achieved efficient drying. The machine was tested for its efficiency and capacity using varying speeds and blade sizes. Results show an increase in the cutting efficiency with increase in speed and blade size as the highest cutting efficiency of 93.3% was obtained at a speed of 80rpm and blade size of 2.5cm. Also machine capacity increases with increase in the speed of the machine and increase in blade size as the highest machine capacity of 28kg/h was recorded at a speed of 80rpm and a blade size of 2.5cm. The percentage uncut increased with decrease in speed and blade size as the highest percentage uncut of 28.3% was obtained at a speed of 40rpm and a blades size of 1.5cm. Conclusively the set aim and objectives of this project work were duly achieved and the equipment can be easily dismantled for ease of transportation and maintenance and reassembled when needed.

Keywords : Design, fabricate, size reduction, ginger

1. INTRODUCTION

Ginger (*Zingiber officinale*) is a flowering herbaceous perennial crop, grown as an annual crop for its spicy underground rhizomes, ginger root or simply ginger. It is scientifically known as Zingiber officinale ... in regions from the Indian subcontinent to southern Asia (Ravindran and Nirmal, 2005) ... perennial reed-like plant with annual leafy stems, about a meter (3 to 4 feet) tall. The young gingerrhizomes are juicy and fleshy with a mild taste. Traditionally, the rhizome is gathered when the stalk withers; it is immediately scalded, or washed and scraped, to kill it and prevent sprouting. Raw ginger is composed of79% water, 18% carbohydrates,2% protein, and 1% fat. In 100wgrams. it supplies Calories and contains moderate amounts of vitamin B6, dietary minerals, magnesium and manganese, but otherwise is low in nutrient content.

Averagely it takes about nine months from ginger planting to mature. If fresh ginger is required, it is harvested six months after planting. If mature ginger is required, it is harvested nine months after planting. The rhizomes can also be left in the ground for two years for propagation. Ginger harvesting starts from October until May, manually by hand or with machines. It is usually available in three different forms; fresh (green)ginger, preserved ginger in brine or syrup and dried ginger spice

Ginger is valued for its essential oils, mainly oleoresin and ginger ol, used in pharmaceutical, bakery and soft drink beverage industries as well as culinary and cosmetic preparation. The percentage composition of volatile oil and non volatile extract of ginger from Nigeria was given as 2.5% and 6.5% respectively (Akhila and Tewari,1984; Ravindran and Nirmal, 2005) which accounts for the high demand for Nigerian ginger in international market

Nigeria is one of the largest producers and exporters of ginger in the world, especially the split-dried ginger. Nigeria produced 156,000wMT of ginger in 2012, accounting for 7% in the world and ranking 4th globally. Ginger cultivation in Nigeria started in 1927 in the then southern Zaria (now Southern Kaduna) Plateau Gombe, Benue, Nassarawa, etc. Ginger farmed in Nigeria especially the type farmed in Kaduna, is the best and in demand throughout the world. In Nigeria, ginger is found in almost all the local markets across the country. Ginger is used as flavoring for recipes such as ginger bread, ginger biscuits, sweets, and ginger tea, ginger ale and ginger beer. It is used as a spice in much local cuisine, and also acts a constituent of herbal medicines. Ginger is an important export product which plays a major role in the total contribution of the agricultural sector to Nigeria economy. Freshly harvested ginger cannot last for a long period of time in its freshly harvested state, therefore there is need for further processing of the harvested ginger before it can be exported, the bulk of Nigerian ginger is marketed internationally in split-dried form, where the importing countries further process it into industrial products mainly ginger powder, essential oils, oleoresin and ginger ale concentrates. The amount of foreign exchange earned by exporting dry ginger is how ever very insignificant when compared with the amount spent on ... ginger products thereby substantiating the need for industrial processing of the Nigerian ginger within Nigeria (Yiljep et al., 2005).

Nigerian ginger is mostly cultivated by peasant farmers and processed by them as whole dry or split dry ginger. Splitting facilitates the drying process. Farmers traditionally use manual method of splitting ginger using a knife, which is slow and labour-intensive, not suitable for large-scale production. Splitting machine is scarce and cutting machine is not attractive.

Size reduction of ginger is an important unit operation in the dry ginger processing because it reduces the time consumption for drying and energy requirement. Cutting and dicing are the two main pulverizing types which has been practiced for ginger rhizomes. If the ginger is cut, only 5 to 6 hours are needed to dry in a cross-flow drier, compared to 16 to 18 hours for drying scraped whole ginger using the same equipment and conditions. Most of the time dried cut ginger is produced for the export market because there is a big demand in the international market for such value added products. Mechanization of cutting procedure is important due to the problems of labor shortage in the industry. Although various types of vegetable slicers are available in the market, due to some drawbacks, those machines cannot be introduced for the ginger cutting(Jayashree&Visvanathan2011). While considering the morphological characteristics of a ringer rhizomes, long and strong fibers can be found in the flesh which can withstand the cutting forces. Some machines have also been made to solve this problem of ginger cutting an example of which is turmeric slicer for ginger cutting. The turmeric slicer developed by All India Coordinated Research Project on Post-Harvest Engineering and Technology was tested for cutting of ginger. The machine/process parameters were optimized for better cutting efficiency. But these machines are not available to local farmers. They commonly make use of normal kitchen knives which cause injuries due to the hazardous cutting equipment and practices. Also the productivity and the efficiency of the cutting procedure is not at its optimum level. The quality of final products also not uniform due to this manual cutting practices. Mechanical cutting of ginger can solve the problems associated with the manual labour and transform into commercial production. This study is undertaken to design and develop a cost effective and efficient mechanical solution to slice the fresh ginger with high quality output.

2. METHODS

2.1 Machine Description

i. Hopper

This is where the ginger is feed into it is has the shape of a cone frustum.. It is designed in a way that it allows easy feeding of the material into the cutting chamber. The hopper was made of stainless steel because of its high strength, high resistance to corrosion and easy machinability.

ii. Cutting blade

Ginger in the base drum is being pushed forward against the cutting blade which slices the gingers as it is being pushed out. The cutting blades are made of straight knife crossed over each other to from smaller square unit and mounted on a hollow cylindrical frame. The blades and the blade frame were made of stainless steel due to its strength, resistance to corrosion and easy machinability

iii. Base drum (cutting unit)

This is where ginger from the hopper is fed the ginger is collected here before the press presses it against the cutting blade. The base drum is a hollow cylindrical structure made of stainless steel due to its ability to resist corrosion, ease of machining, and local availability.

iv. Press

This pushes the ginger collected in the base drum towards the cutting blade and eventually out of the machine the press consists of a cylindrical plate attached to a shaft. The press was made of stainless steel due to its high strength, corrosion resistance and machinability.

v. Crank arm

This is made of shaft bent at 90^{O} to form a cam. It converts the circular motion of the pulley to reciprocating motion delivered to the press to enable it push the material in the base frame a shaft made of mild steel was used because it can withstand the bending and shearing force, it is easily machined and it is relatively cheap

vi. Frame

This supports the whole machine and provides rigidity to the machine was made of mild steel due to its high load bearing capacity and it is cheap.

vii. Belt and pulley system

This is the machine part that transmits torque from the electric motor to the crank arm by means of belt attached to both the electric motor pulley and the shaft pulley.

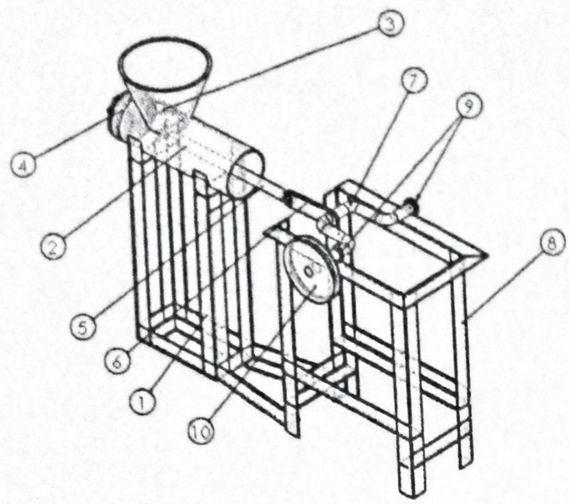

Fig. 1: Isometric view

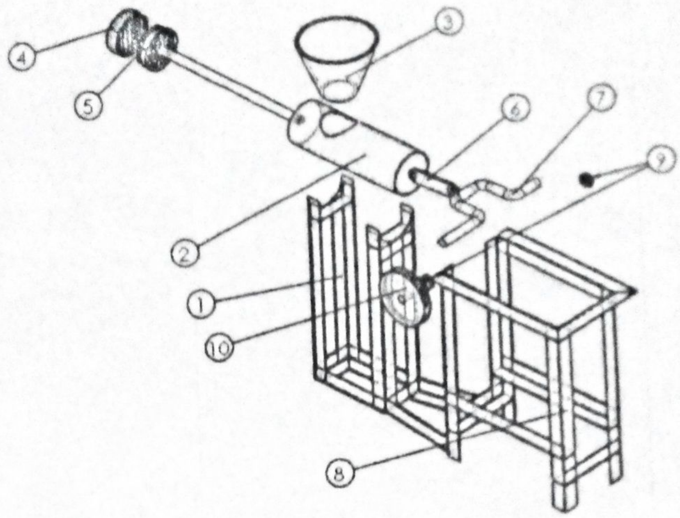

Fig. 2: Exploded view

2.2 Working mode of the machine

Ginger is fed into the machine through the hopper and slides down into the cutting unit where the press being move by the rotation of the electric motor through the crank arm pushes the ginger out of the machine through the cutting blades to where it is being collected.

2.3 Design of the major parts of machine

The following are the parameters and assumed parameters used for the design of the major parts of the machine. These parameters and assumed values made the design calculations possible as well as the fabrication. The implement was designed mainly for ginger size reduction machine.

LEGEND	
Key	**Name of parts**
1	Main frame
2	Cutting unit (Base drum)
3	Hopper
4	Cutting Blade
5	Press
6	Extension Arm
7	Crank Arm
8	Pulley Arrangement Support Frame
9	Bearing
10	Pulley

i. Determination of the volume of the hopper

The volume of the hopper was calculated in order to determine the weight of the hopper.

$$V_h = \left(\frac{1}{3}\pi h_1\left(r_1^2 - r_2^2\right)\right) - \left(\frac{1}{3}\pi h_2\left(r_3^2 - r_4^2\right)\right) \qquad (1)$$

Where, V_h is volume of the hopper (m), h_1 is the height of bigger cone (m), h_2 is the height of smaller cone (m), r_1 is the outer radius of bigger cone (m), r_2 is the inner radius of bigger cone, r_3 is the outer radius of smaller cone (m), r_4 is the inner radius of smaller cone (m).

ii. Determination of weight of the hopper

The weight of the hopper was calculated to know the total weight of the machine it is given by

$$\mathbf{W = \rho \times V \times g} \quad (2)$$

Where W is the weight of the hopper (N), **ρ** is the density of mild steel (Kg/m^3), V is volume of the hopper (m^3), g is the acceleration due to gravity.

iii. Determination of machine capacity

The machine capacity was obtained as follows

$$\mathbf{M_c = M \times w} \quad (3)$$

Where $\mathbf{M_c}$the machine capacity (kg/h), M is is the mass of ginger expelled (kg), w is the angular speed (rpm)

iv. Determination of force required to reduce the size of ginger.

This is done to know the force required to reduce the size of ginger to be able to determine the power required to reduce the size of ginger. It was obtained using the equation reported by Khurmi and Gupta (2005)

$$\mathbf{F = f \times N} \quad (4)$$

$$\mathbf{N = \frac{M}{m}} \quad (5)$$

Where F is total force required to cut the whole ginger (N), f is force required to cut 1 ginger (N), N is the total number of cut ginger, M is the total mass of ginger (kg), m is unit mass of ginger (kg).

v. Determination of required power to reduce the size of ginger

The power required to reduce the size of ginger was calculated to be able to determine the power requirement of the electric motor that can be used to drive the machine. The power required to reduce the size of ginger can be determined using the formula reported by Khurmi and Gupta (2005)

$$\mathbf{P = \frac{2\pi N\tau}{60}} \quad (6)$$

$N_1 = \frac{N_2}{V.R}$ (11)

Where N_1 is the output speed of the gear, N_2 is speed of the electric motor, V.R is the velocity ratio

xi. Determination of pulley diameter

The pulley diameter was determined to know the appropriate pulley to be selected for the fabrication of the machine. The pulley diameter was calculated as reported by reported by Khurmi and Gupta (2005), and is give as follows

$D_2 = \frac{N_1 D_1}{N_2}$ (12)

Where N_1 is speed of driving (gear) pulley, N_2 is speed of driven (machine) pulley, D_1 = diameter of driving (motor) pulley and D_2 is the diameter of driven (machine) pulley

xii. Determination of center distance

The center distance is the distance between the center of the driving and the driven pulley. It was calculated to know the minimum distance between the electric motor and the machine pulley. The center distance (x) is given as reported by Khurmi and Gupta (2005), and is given as

$X = \frac{D_2+D_1}{2} + D_1$ (13)

Where D_1 is diameter of driving (motor) pulley, D_2 is the diameter of driven (machine) pulley

xiii. Determination of length of belt

The length of the belt was calculated to be able to select the appropriate belt for the machine to function efficiently.The length of the belt can be obtained as reported by Khurmi and Gupta (2005), and is given as

Length of belt (L_b) = $\frac{\pi}{2}(D_1 + D_2) + 2x + \frac{D_1 - D_2}{4x}$

Where D_1 is diameter of driving (motor) pulley, D_2 is the diameter of driven (machine) pulley, X = center distance between pulleys

xiv. Determination of belt velocity

The velocity of the belt can be calculated using the formula reported by Khurmi and Gupta (2005), and is given as

$$V_b = \frac{\pi D_1 N_1}{60} \quad (15)$$

Where V_b is the velocity of the belt, D_1 is diameter of driving (motor) pulley, N_1 is speed of driving (gear) pulley.

xv. Determination of the angle of contact between the belt and pulley

The angle of wrap is the angle of contact between the belt and the pulley.The angle of wrap of the belt is given as reported by Khurmi and Gupta (2005), and is given as

$$\text{Angle of wrap } (\theta) = (180^0 - 2\propto) \times \frac{\pi}{180} \quad (16)$$

$$\text{Where } \propto = \sin^{-1}\frac{r_2 - r_1}{x} \quad (17)$$

Where r_1 is radius of driving (motor) pulley, r_2 is radius of driven (machine) pulley, X is center distance between pulleys.

xvi. Determination of belt tension

The tension developed in the belt was evaluated in order to know the power transmitted by the electric motor. It was determined as follows as reported by Khurmi and Gupta (2005), and is given as

$$K = 2.3 \log\frac{T_1}{T_2} = \mu \times \theta \times cosec\beta \quad (18)$$

Where, T_1 is tension in the tight side of the belt in N, T_2 is the tension in the slack side of the belt in N, β is average groove angle of the shaft pulley, θ is angle of constant or lap between the two pulleys, μ is coefficient of friction between the belt and the pulleys

xvii. Determination of torque generated in pulley

The torque generated in the pulley was determined as reported by Khurmi and Gupta (2005), and is given as

$$\tau = (T_1 - T_2)r \quad (19)$$

Where τ is the torque generated (Nm), T_1 is the tight side tension, T_2 is slack side tension, r is radius of pulley

xviii. Determination of power transmitted by the belt

This is done in order to know the amount of energy transmitted. Power transmitted by the belt was determined as reported by Khurmi and Gupta (2005), and is given as

$$P = (T_1 - T_2) \times V \quad (20)$$

Where, P is power transmitted by the belt, T_1 is the tight side tension, T_2 is slack side tension in N, V = velocity of the belt in m/s.

xivx. Determination of shaft diameter

This was evaluated to know the shaft that is appropriate for the design this was calculated using the equation reported by Khurmi and Gupta (2005), and is given as

$$d^3 = \frac{16 \times T}{\pi \times \tau} \quad (21)$$

$$T = \frac{P \times 60}{2\pi N_1} \quad (22)$$

Where, T is the torque in N.mm, P is the power transmitted to the shaft in Watts, N_1 is speed of shaft in rpm, τ is shear stress of the shaft in N/mm^2, d is the shaft diameter in mm

xx. Critical speed of the shaft

Critical speed is the speed at which the unbalanced mass of the rotating object causes deflection that will create resonant vibration. The critical speed was calculated to avoid issued such as noise and vibration. For machine efficiency the critical speed of the shaft is to be determined. It was determined as reported by reported by Khurmi and Gupta (2005), and is give as

$$\omega_S = \sqrt{\frac{48\varepsilon I}{ML}} \quad (23)$$

where $\omega_S$is the critical speed of the shaft, ε is the modulus of elasticity of steel, M is the mass of the shaft, L is ength of the shaft.

xxi. Torsional deflection of the shaft

To know the angle of deviation of the shaft in degrees and to make sure this angle of deviation is at its minimum. It was determined as reported by reported by Khurmi and Gupta (2005), and is give as

Thus,

$$\alpha = \frac{584\tau L}{D^4 G} \quad (24)$$

where, α is the angular shaft deflection in degrees, L is Length of the shaft, G is modulus of elasticity of steel, D = 2.26×4√τ

xxii. Determination of Maximum Working Stress of the Shaft

This is done in order to know the strength of the shaft and it behavior under working condition. It is determined as follows as was reported by reported by Khurmi and Gupta (2005), and is give as

$$\sigma = \frac{16Ts}{\pi d^3} \qquad (25)$$

Where σ is maximum permissible working stress, d is the shaft diameter, Ts is the torque of the shaft

2.3 Testing of the Machine

Fresh ginger of 54 kg was bought from farmers, washed and shared into equal parts of 2kg each for testing the fabricated machine. The machine was first run under no load condition to ascertain the parts are moving freely. This parts weighing 2kg were fed into the hopper while the machine was put on to run using a machine speed of 40rpm and a blade size of 1.5cm. This process was then replicated three times to get the average and the whole process was repeated for a blade of size 2cm and 2.5cm and speed of 60rpm and 80rpm. With this the ginger were cut to the size of the blade. The weight of the cut and uncut sample were recorded and the following parameter were calculated

i. Cutting efficiency: This is the effectiveness with which the machine cut the ginger to predetermined size according to the sizes of the blades. This was calculated using the formula below

$$\text{Cutting efficiency} = \frac{W-W_U}{W} \times 100 \qquad (26)$$

Where W is the initial weight of ginger, W_U is weight of uncut ginger

ii. Percentage uncut ginger: The percent uncut ginger is the percentage of ginger that escaped being cut by the machine during the process of its operation. It was computed by the equation below

$$\text{Percentage uncut} = \frac{W_U}{W} \times 100 \qquad (27)$$

Where W is initial weight of sample, W_U is the weight of uncut ginger

iii. Machine capacity: This is the average quantity of ginger that was cut by the machine in an hour. The quantity of ginger cut in an hour can then be obtained using the expression be

$$M_c = \frac{W - W_U}{t} \times 60 \quad (28)$$

Where W= initial weight of sample, WU= weight of uncut ginger, t = time of cutting the sample in min

3. RESULTS AND DISCUSSION

The result of testing of the machine using 2 kg of ginger at various speed of 40, 60 and 80 rpm is presented in Table 1. The cutting efficiency ranges from 71.67 to 93.33 %. The highest value 93.33 % was obtained from interaction between blade size of 2.5 cm and speed 40 rpm. The least value of cutting efficiency of 71.67 % was obtained from interaction between blade size of 1.5 cm and speed 40 rpm. The machine capacity ranges from 8.93 kg/h to 28 kgh. The highest value 28 kg/h was obtained from interaction between blade size of 2.5 cm and speed of 80 rpm. The least value of cutting efficiency of 8.93 kg/h was obtained from interaction between blade size of 1.5 cm and speed 40 rpm.

Table 1: Effects of Blade Size and Speed on Machine Efficiency and Capacity when 2 kg of Ginger was processed

Speed (rpm)	Blade size (cm)	Weight of cut ginger (kg)	Weight of uncut ginger (kg)	Time of cutting (min)	Percentage uncut (%)	Cutting efficiency (%)	Machine capacity (kg/h)
80	1.5	1.7	0.3	6.67	15	85	15.43
	2	1.80	0.2	4.67	10	90	24.16
	2.5	1.87	0.13	4	6.67	93.33	28.0
60	1.5	1.57	0.43	9.33	21.67	78.33	10.09
	2	1.73	0.27	8	13.33	86.67	13.12
	2.5	1.8	0.2	6.33	10	90	17.13
40	1.5	1.43	0.57	9.67	28.33	71.67	8.93
	2	1.57	0.43	9	21.67	74.33	10.51
	2.5	1.53	0.47	8.33	20.33	76.67	11.11

3.1 Machine capacity

From Figure 3, the highest values of machine capacity were obtained with blade size of 2.5 cm, while blade size of 1.5 cm produced the least machine capacity for all the speed. The machine capacity increases with increase in blade size for all the speed. This could be as result of more area of contact between the blade of 2.5 cm with the ginger. This resulted to more cutting of the ginger with that blade compared to the other blade with least size. The increase in the size of the blade also played a role as the bigger the blade sizes the less the resisting force that might be experienced when cutting the ginger. On the other hand machine capacity increases with increase with speed. This could be as result of more centrifugal force associated with higher speed which causes more segregation of the ginger with higher speed of cutting. Also at higher speed the strokes of the press are more which leads to increase in the machine capacity.

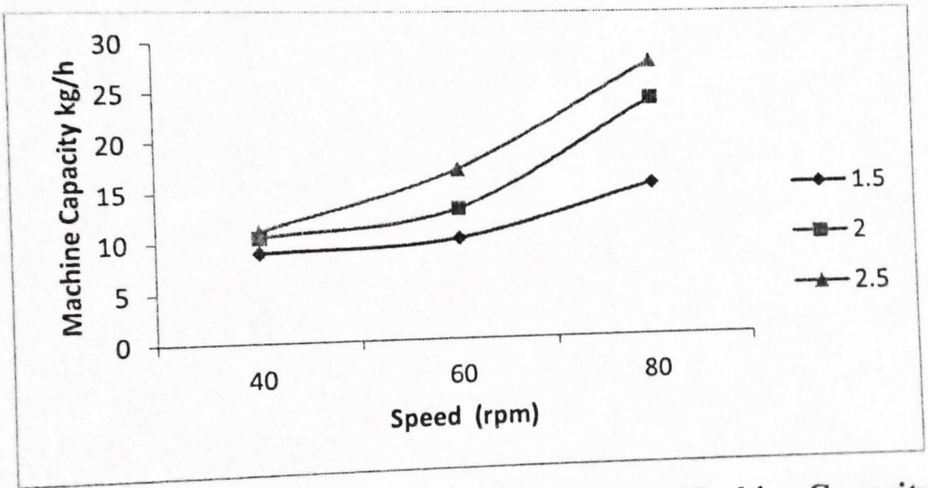

Figure 3: Effects of Speed and Blade Size on Machine Capacity

3.2 Effects of cutting speed and blade size on cutting efficiency

The effect of speed on cutting efficiency of the various blade sizes is presented in fig. 4. Cutting efficiency of the machine increased significantly with increasing speed from 40 rpm to 80 rpm but was almost constant at speeds of 60 rpm to 80 rpm for 2 cm and 2.5 cm blade sizes. However, cutting the ginger with speed of 80 r.p.m using 2.5 cm blade size had the highest cutting efficiency of 93.33 % while cutting at a speed of 40 r.p.m produced the least cutting efficiency of 71.67 % with blade size of 1.5 cm.

Generally, all the speeds produced their highest efficiency (85% to 93.33) with blade size of 2.5 cm while their least efficiency (71.67% to 76.67%) were obtained with blade size of 1.5 cm. Therefore, the machine cutting efficiency increased with increase in blade size. The high cutting efficiency observed with speed of 80 rpm could be as result of increased in centrifugal force which results to high shear force, more number of impacts, greater number of beating and cutting effect of ginger by the blade. This agreed with results of an earlier study by Jayesh (2009) were speed of cutting was reported to have a significant effect on size reduction of solid materials. Higher speed of cutting resulted to more yield of the material than lower speed of cutting. The higher efficiency observed with blade with greater size could be as result of increased in contact between the blade and the ginger with increased in size. This result agreed with the result of an earlier finding by Rachel (2007) where blade design was found to affect size reduction of materials. Both the blade size and cutting speed have significant effects ($p \leq 0.05$) on cutting efficiency of the machine.

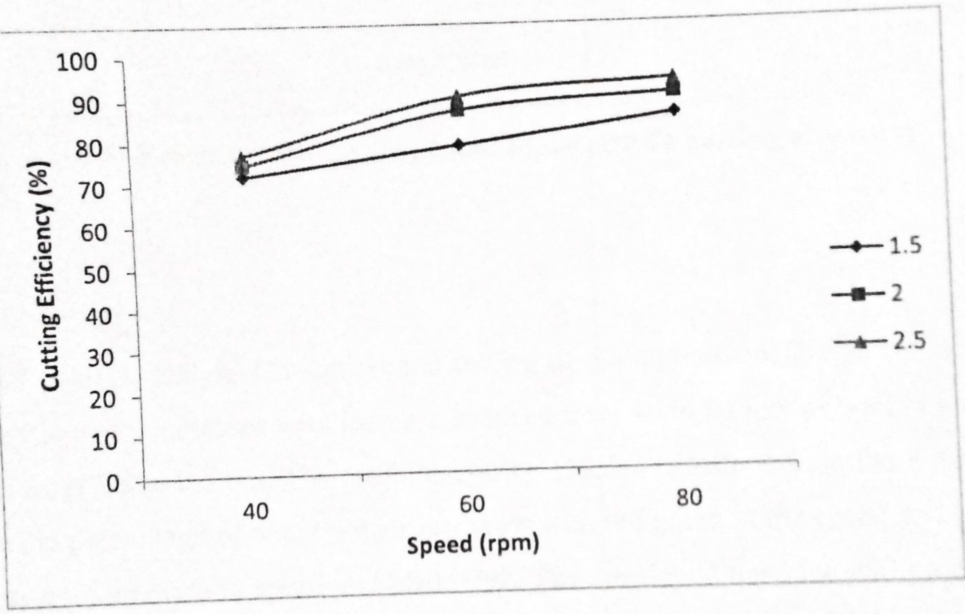

Figure 4: Effect of cutting speed and blade size on cutting efficiency

3.3 Effects of cutting speed and blade size on percentage uncut

The effects of cutting speed and blade size on percentage uncut presented in Figure 5. The percentage of the uncut ginger using blade size of 2.5 decreased from 23.33 % to 6.67 % with increased in speed of cutting 40 rpm to 80. This could be due to increase in impact, cutting and shearing actions of the blade with increased in speed of cutting which resulted to decrease in uncut ginger. This agreed with the findings report by Jayesh (2009) where rotational speed was found to be a key factor to size reduction of solid materials. Where, higher speed of cutting resulted to more segregation of materials than the lower speed. On the order hand the percentage of uncut ginger using speed of 80 rpm decreased from 15 % to 6.67 % with increased in blade size from 1.5 cm to 2.5 cm. This could be as result of increased in contact between the blade and the ginger with increased in size which caused more segregation of the materials. This result agreed with the result of an earlier finding by Gbabo et al. (2012) where blade design was found to affect segregation of materials.

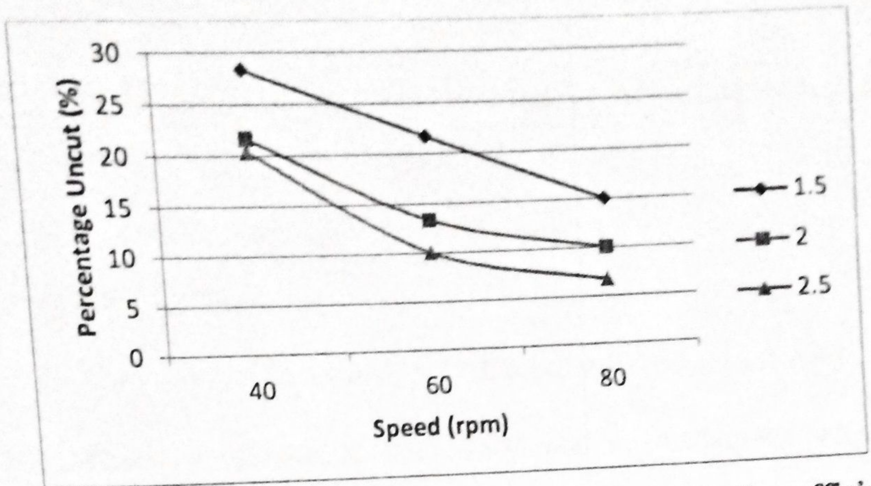

Figure 5: Effect of cutting speed and blade size on cutting efficiency

4. CONCLUSIONS

After the successive design, fabrication and testing of the equipment, it was concluded that the machine capacity increases with increase in speed from 40 to 80 rpm as well as increase in blade sizes from 1.5 to 2.5 cm. The machine cutting efficiency followed similar trend. On the other hand the percentage of uncut ginger increases with reduction in the speed and blade size and reduces with increase in speed and blade size. The developed machine will go along way in increasing processing and utilization of ginger

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