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Design, Construction and Testing of a Motorized Tuber Chipping Machine

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ABSTRACT

A motorized tuber chipping machine was designed, constructed and tested for its efficiency using yam and cassava tubers. The purpose is to reduce the thickness and increase the surface area thereby improving drying. It consists of rotary blades, feeding chutes and electric motor. It is powered with the aid of a 2hp, 1800 rpm electric motor, using a pulley and belt. The device is manually fed with one tuber at a time. Performance of the device was evaluated using the following parameters: chipping efficiency, chipping capacity and percentage of non-uniform chips. The chipping efficiency, chipping capacity and percentage of non–uniform chips obtained was 78.19%, 6.6kg/min and 21.81% respectively. The chute is made adjustable to different tuber thickness so as to reduce vibration percentage of non–uniform chips.

Keywords: Tuber, Chipping Efficiency, Chipping Capacity

INTRODUCTION

Root and tuber crops (cassava, plantain, sweet potato, yam, cocoa yam, etc.) are among the most valuable staple food source for tens of millions of people in West Africa. Increased production of root crops in Nigeria has brought about the need for the development of appropriate processing technology. Cassava (Manihot esculenta crantz) is considered as an important source of energy diet in Nigeria, which plays a major role in alleviating food crises because of its efficient production of food energy, year round availability, tolerance to extreme stress conditions suitability to present farming and food system in Africa [1].

World consumption of cassava for food (fresh or processed) is concentrated in developing countries. The world production is about 84 million tonnes. Highest production is in Africa- 99.1, 51.5 and 33.2 million tonnes in Asia and Latin America respectively [2]. Nigeria has annual output potential for cassava production of 75.5 million tonnes [3]. In Asia over 40% of the cassava is for direct human consumption, with much of the remainder exported as chips. The major consumers are concentrated in India and Indonesia. In India, baked roots are converted into small chips and flour. In Indonesia, 57% of production is for human consumption while 43 percent are eaten boiled or processed into dried chips [2].

Nigeria is by far the world's largest producer of yam, accounting for over 70–76 percent of the world production. According to the Food and Agricultural Organization (FAO) report [2], Nigeria produced 18.3 million tonnes of yam from 1.5 million hectares, representing 73.8 percent of total yam production in Africa. According to 2008 figures, yam production in Nigeria has nearly doubled since 1985, with Nigeria producing 35.017 million metric tonnes with value equivalent of US$5.654 billion. In this perspective, the world's second and third largest producers of yams, Côte d'Ivoire and Ghana, only produced 6.9 and 4.8 tonnes of yams in 2008 respectively [2]. According to the International Institute of Tropical Agriculture, Nigeria accounted for about 70 percent of the world production amounting to 17 million tonnes from land area 2,837,000 hectares under yam cultivation. Yam, a tropical crop in the genus Dioscorea, has as many as 600 species out of which six are economically important staple species. These are: Dioscorea rotundata (white guinea yam), Dioscorea alata (yellow yam), Dioscorea bulbifera (aerial yam), Dioscorea esculant (Chinese yam) and Dioscorea dumetorum (trifoliate yam). Out of these, Dioscorea rotundata (white yam) and Dioscorea alata (water yam) are the most common species in Nigeria. Yams are grown in the coastal region in rain forests, wood savanna and southern savanna habitats. Yam is in the class of roots and tubers that is a staple of the Nigerian and West African diet, which provides some 200 calories of energy per capita daily. In Nigeria, many yam-producing areas refer to 'yam is food and food is yam'. It also has an important social status in gatherings and religious functions, which is assessed by the size of yam holdings one possesses [4].

Plantain and banana (Musa species) are important food crops in sub-Sahara Africa, providing more than 25% of the carbohydrate and 10% of the calorie for approximately 70 million people in the region [5]. Africa contributes about 50% of world production of plantain [6]. The major producing countries with an annual output exceeding a million tonnes include Nigeria, Ghana, Cote d'Ivoire and Cameroon. Nigeria is one of the major producers of plantain in West and Central Africa, but the per capita consumption for Nigeria is the lowest in the region, implying the existence of market potential for increased production in the country [2]. Plantain and banana can't stay for long days before it gets ripe and spoiled. This shows the need for fast and efficient drying to achieve good preservation [7].

In Nigeria manually operated chipper has been developed by Rural Agricultural. Industrial Development Service (RAIDS) and international Institute of Tropical Agriculture (IITA)'s post-harvest unit. The length of the chips depends on the angle of contact of the roots with the blade; the size of the chips varies. Generally, they are 36mm thick, 6-10mm wide and 100-250mm long. Also reported, is a motorized potato cutter designed by International Potato Centre (CIP) had a capacity up to 270kg/hr; pedal-operated cassava slicer up to 500kg/hr by P. T Kreta Laksana of Indonesia, a root crop slicer by the Department of Agricultural Chemistry and Food Science (DACFS) in the Philippines has 31-23kg/hr. The National Institute for Scientific and Industrial Research (NISIR), Malaysia developed a cassava chipping machine which consist of two blades and producing slices of 2-3mm thick [8]. Ajibola et al. developed a chipping machine which is made of circular plate with slicing blade and another set of stationary criss-cross blade. Both machines performance was found to be satisfactory. They observed that, the chipping machine with circular plate had a maximum throughput capacity of 258.76kg/hr with a chipping efficiency of 80% [9]. Akintunde and Akintunde reported a mobile cassava chipper. The machine has chipping output of 700kg/hr of fresh tuber, driven by 5hp petrol engine at speed of 900rpm [10]. Akintola evaluated a modified cassava chipping machine at the speed of 300,411 and 514rpm and obtained maximum machine capacity and chipping efficiency of 148kg/hr at the speed of 514rpm and 91.26 at a speed of 300rpm respectively [11]. In Nigeria apart from direct processing at local level and consumption, animal feed, the decision of the Federal Government for inclusion of cassava flour of 10% in bakery and cassava chips export project, increased the demand for cassava production [12]. Cassava tubers for example has high moisture content and cannot be stored for more than 2 to 3 days resulting in accumulation of toxic substances that make it unfit for consumption. Therefore, processing has been an integral part of the utilization. It has to be converted into some other form for low moisture storage. Yam tubers also have to be stored in a low moisture form for a longer period of use. The simplest mode of processing the tubers is conversion into chips and drying. Therefore, the aim of this work is to develop and evaluate the performance of a motorized tuber chipping machine.

MATERIALS AND METHODS

Components of a Universal Tuber Chipping Machine

The followings are the components of the universal tuber chipping machine as shown in Figure 1.

a) ***Feeding Chute*:** The chute serves as the hopper and provides means of feeding the tubers to the device. It is made of galvanized steel and inclined 40^0 to the horizontal, which is the angle of internal friction between the tuber and the material of construction. Its length and diameter were based on average length and diameter of the tuber. This helps to prevent wobbling. Its dimensions are large enough to take the biggest tuber.

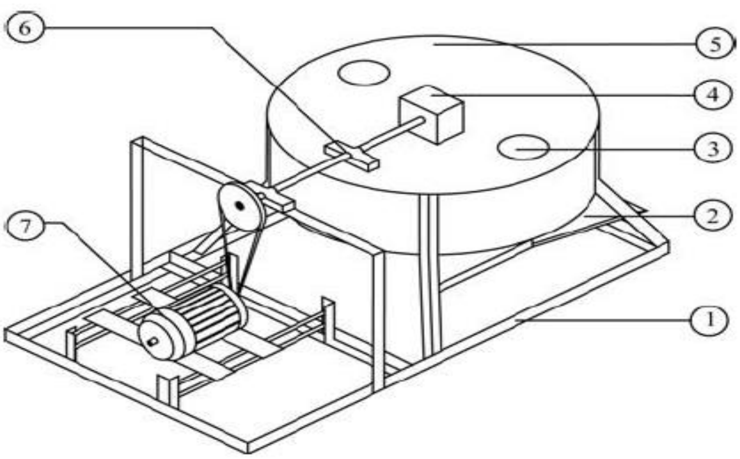

Fig. 1 A perspective view of the Universal Tuber Chipping Machine
[1 = Device Frame, 2 = Collector, 3 = Feeding Chute, 4 = Gear Box, 5 = Blade Housing, 6 = Bearing and 7 = Electric Motor]

b) ***Blades*****:** The blades are made of galvanized steels coated with aluminum. They are used for effecting chipping. To prevent tuber damage, easy maintenance and replacements, the blades were sharpened and bolted to the bearing shaft.
c) ***Blade Housing*****:** The blades housing shields the rotating blades during and after operation to prevent accident. A door way was provided to facilitate easy access to the blades by the side of the housing
d) ***Pulleys*****:** The pulley was designed to reduce electric motor speed in the design.
e) ***Bolts and Nuts Selection*****:** For all the attachments made, 5 mm bolts and nuts were used.

The lengths, weights and thicknesses of the uniform chips were averagely 60 mm, 15 mm and thickness 2 mm respectively. This is essential in determining the speed of the blades.

Experimental Procedure/Working Principle of the Tuber Chipping Machine

The tuber chipping machine reduces tubers into smaller thickness for faster drying. It consists of powered shaft, bevel gears, blades and feeding chutes. The powered shaft is of diameter 40 mm and 150 mm long with 8-tooth bevel gears (Ø 50 mm) at its end. The blades are 250 mm long and 50 mm wide. Each of the blades has holes of Ø 7 mm at one end to facilitate bolting it to the blade's bearing shaft of diameter 40 mm. Blade's bearing shaft with bevel gears at its end was angled, 90° to that of power shaft. The blade housing is of diameter 60 mm and 250 mm high. The mainframe base is 1,000 mm by 600 mm. The standing legs were angled at 65° to the base frame to ensure stability in operation. The assembly and isometric drawing of the chipping machine are shown in Figure 1. Feeding chute is Ø 90 mm and 280 mm long. It is opened through the top of the blades housing. The slicer is operated by a 2hp, 1800rpm electric motor and power transmitted to the blades through the shaft via the pulley's v-belt. It is manually fed with one tuber at a time through the chute. The whole tuber falls vertically as it is manually fed by the operator against the rotating blades and become chipped. The thickness of the slices is predetermined by the feed rate pressure on the tuber and this is greatly enhanced by the rotating speed of the blade. The chips are collected through the channel into the receptacle below the blades housing.

The Feeding Chute

Yam and cassava tubers were used for the experimentation. The weigh (W), length (L) and mean circumference (C) of different sizes of yam and cassava tubers were taken. The mean of their circumference were used to determine the average diameter (d) using equation (1).

$$\pi d = C \tag{1}$$

Where C= mean circumference of tubers, d= diameter of tubers The diameter $d,$ becomes the diameter of the chipping chute.

Performance evaluation of the machine was carried out on one variety of cassava (Manihot palmate), two types of chipping disc (knife and groove). Freshly harvested cassava were peeled manually and washed in clean water. Fairly regular size tubers were randomly selected and introduced into the machine that has been on idle speed for about a minute. The machine was switched off when the tuber is chipped and the operation timed. The chips from the chute were collected and manually separated and categorized as – uniformly chipped and non-uniformly chipped; and their weight noted. The experiment was repeated for other blade and speeds. The same experiment was repeated for yam tubers.

The machine speed was checked by tachometer and adjusted; chip thickness of 3-5mm was considered well chipped; constant mass, pressure of feeding tuber, water lost during chipping is negligible were assumption made. The machine was evaluated for chipping efficiency and machine capacity. The efficiency of the machine was found in accordance with the following definitions.

Determination of Dynamic Frictional Coefficients of Blades and Tubers

When two bodies in contact move relatively to one another, resistance occurs between them due to friction. Different sizes of tuber chips were individually placed on a neat weight-carrying pan. Weight (F) was added to the pan until the slices begin to move at uniform velocity. The thickness and weigh of each slice (R) were measured using micro–meter screw gauge and weighing balances respectively to determine the coefficient of dynamic friction (μ) as shown below:

$$\mu = \frac{F}{R} \tag{2}$$

The coefficient of dynamic friction is used to determine the frictional force which in turn helps in determining the shear force that must be applied to the blades in other to effect shearing of tubers.

Therefore, the shear force of the device is given by;

$$F_s = \tau_s \times A_s \tag{3}$$

Where F_s= shear force, τ_s= shear stress and A_s= cross sectional area of the shearing blades

Determination of the Number of Revolution of the Shaft (N)

We know that, linear velocity (V) is given by;

$$V = \omega r \quad (4)$$

And from third equation of motion,

$$V = \sqrt{2as} \quad (5)$$

But $$\omega = \frac{2\pi N}{60}$$

$$\therefore \sqrt{2as} = \frac{2\pi N r}{60} \quad (6)$$

Note that the radius of the circle, r = length of the blades, l

$$\therefore N = \sqrt{\frac{60^2 as}{2\pi^2 l^2}} \quad (7)$$

s = thickness of the tuber chips and a = acceleration due to gravity

Performance Evaluation

Chipping Efficiency (η_c): This is the weight of uniformly sliced tuber (W_u) to the weight of the tuber fed (W_T), that is;

$$\eta_c = \frac{W_u}{W_T} \times 100\% \quad (8)$$

Chipping Capacity (C_c): This is the total weight (W_T) of tuber in a given time, T, given by;

$$C_c = \frac{W_T}{T} \quad (9)$$

Percentage Non-Uniformity of the Chipped Tubers

This is the ratio of the weight (W_n) of non uniform slices to the total weight (W_T) fed into the slicer. That is;

$$\text{Percentage non-uniformity} = \frac{W_n}{W_T} \times 100\% \quad (10)$$

Table 1- Weight Measurements and Efficiencies of Chipped Tubers

	Diameter of tubers (mm)	Weight of tubers, W_T (kg)	Weight of uniform sliced tuber, W_u (kg)	Weight of non-uniformly sliced tuber, W_n (kg)	Time, T (s)	Chipping capacity, C_c (kg/min)	Chipping efficiency, η_c (%)	% of non-uniformly chipped tuber
Yam	80.7	1.06	0.94	0.12	10.04	6.33	88.68	11.32
	72	1.1	0.91	0.19	10.15	6.50	82.73	17.27
	67.2	1.14	0.86	0.28	10.29	6.65	75.44	24.56
	65	1.11	0.77	0.34	9.99	6.67	69.37	30.63
	62	1.1	0.91	0.19	9.54	6.92	82.73	17.27
Mean	69.38	1.102	0.878	0.224	10.002	6.61	79.79	20.21
Cassava	40.4	0.52	0.49	0.03	4.82	6.47	94.23	5.77
	32.5	0.56	0.46	0.1	5.14	6.53	82.14	17.86
	27.9	0.6	0.41	0.19	5.44	6.62	68.33	31.67
	25	0.57	0.32	0.25	5.16	6.63	56.14	43.86
	22.4	0.56	0.46	0.1	5.04	6.67	82.14	17.86
Mean	29.64	0.562	0.428	0.134	5.12	6.58	76.596	23.404
Mean of means						6.60	78.193	21.807

RESULTS AND DISCUSSION

Table 1 represents the performance parameters of the tuber chipping machine. From the table, the machine has an average chipping efficiency of 78.19 %, while the chipping capacity and percentage non–uniformity cutting of chips are 6.6 kg/min and 21.81 % respectively.

These parameters were tested with five tubers of yam and cassava with varying diameters. It was observed that, tubers of diameter close to the feeding chute have higher chipping efficiency than tubers of lower diameter. For instance, yam tubers with diameters of 80.7mm and 72mm have efficiencies of 88.68% and 82.73% respectively. The same behavior is noticed with tubers of cassava. Highest chipping efficiency of 88.68% and 94.23% were obtained for yam and cassava diameters of 80.7 and 40.4mm respectively. This could be due to reduced wobbling effect of the tubers with the chute walls as the tuber diameters are close to that of chute wall. The chipping efficiency progressively dropped as the diameters decrease except for diameters of 62 and 22.4mm for yam and cassava respectively which showed a slight increase that could be attributed to input error and irregular orientation of the tuber. This shows that, the larger the diameter, the better the chipping efficiency of the machine as the engagement between blades and tuber is maximum. From Table -1, it can be observed that the chipping capacity increases with decrease in the diameters of yam and cassava tubers which implies that, larger diameters take more time for chipping. It can also be observed that, tuber weight does not necessarily affect the chipping capacity and efficiency. The percentage of non- uniformly chipped tuber is largely affected by the size of the tubers as they increase with decrease in diameters. These could be as a result of rocking effect of the tubers and chute resulting in wobbling as chipping is in progress. This means that, more non uniform chips are produced at smaller diameters. The machine performance was found to be slightly lower than that of [10], but higher than that of [11] and [12] but generally followed the same trend. It can therefore be concluded that, the age, size, shape, orientation, feed rate and pressure of the tuber in contact with the chipping disc are factors affecting the chipping efficiency and uniformity of the chips.

CONCLUSION

A motorized yam and cassava tuber chipping machine have been designed, constructed and tested. It can be observed from Table 1 that the mean means chipping efficiency obtained from the chipping machine is 78.19% with an average chipping capacity of 6.6kg/min. The mean of means percentage of non-uniformly chipped tuber is also observed from the table to be 21.81%. The lengths, weights and thicknesses of the uniform chips were averagely 60 mm, 15 mm and thickness 2 mm respectively. The five tests carried out on both tubers show that, the chipping efficiency increases with reduced capacity as the diameters of tubers approach that of the feeding chute. This means, the higher the diameter of tuber, the better the efficiency. The simplicity of operation and maintenance of the machine, the performance and compactness make it adoptable to the small or medium scale farmer for tuber processing.

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