European Mechanical Science 2017, Vol. 1(3): 104-110
Research Paper

Design of a Dual Operated Cassava Chipper

M. G.Yisa[1], A. Fadeyibi[2*], K.P. Alabi[3]

[1,2,3] Department of Agricultural and Biological Engineering, Kwara State University Malete, P.M.B. 1530, Ilorin, Nigeria

Abstract

Size reduction of agricultural products is an essential requirement for their processing and transportation. This research designed and fabricated a manually operated and motorised cassava chipping machine, which is adaptable to the local farmers at the cottage level. The design was carried out by empirically computing the threshold force required for cutting the cassava tubers, with a prior knowledge of the length (350 mm) and thickness (1.5 mm) of the cutting blades as influencing indexes. Also, the capacity of the machine was evaluated using six different cutting forces above and below the cutting threshold force (68.99 N). The results show that the cutting force increased exponentially with the length and diameter of the tuber. Also, less force was required to chip cassava tuber with longer length and shorter diameter probably due to the presence of inner and central crack defects, which is capable of forming easy crack initiation points with the slightest blade effort. The size of the electric motor required was a single phase 1 hp (4500 rpm), which is capable of powering the machine to an approximate capacity of 225 kg/h and comparable to the required human effort. The machine was also found effective in chipping cassava tuber to average size of 30 mm.

Key words: Chipper, Performance, Design, Cassava, Cottage

1. INTRODUCTION

The processing and storage of cassava tuber (*Musa esculanta crantz*) are required for the extension of the storage life and transportation of the product. The high amount of moisture contained in the cassava tuber [1-2] might be responsible for its deterioration in just few days after harvest. The size reduction of the product is therefore a way of value addition, which is capable of curtailing or minimising the deterioration and the postharvest loss involved, and this can be achieved either by the manual or mechanised chipping techniques. The manual cassava chipping technique is usually time consuming, wasteful and the uniformity of the chips are difficult to achieve. Besides, the increasing versatility of the cassava tubers as an industrial raw material makes manual chipping inadequate for the future chipping need of the cassava processing industry [3]. The mechanised techniques are an improvement on the manual method since the issues of drudgery and none uniformity of the sizes of chips have, to a large extent, been addressed in their designs.

There have been a number of attempts in designing appropriate mechanised techniques and systems of reducing the size of the cassava tubers for the purpose of storage, particularly in minimising the huge cost involved in transporting the products to the end-users [4-5]. For instance, the chipping machine used in Malaysia consists of rotating circular plate, which is about 12 mm thick and 1 m in diameter. The circular plates have fixed steel blades which are corrugated at the cutting edge. The machine produces strips of about 6 mm wide and 3-6 mm thick. The blades can be replaced and may be adjusted to produce strips of the required dimensions. The machine also involves two operators one feeding and the other pedaling [6]. In Thailand, petal chipper usually consists of thin circular plate which has been cut and formed to produce cutting element across the whole surface. Chips up to 0.03 m in diameter can be obtained from the Thai chipper [6].

However, not much work has been done in mechanising the cassava tubers in Nigeria even though the country is the second largest producer of the commodity in the world [5,7]. The few cases sighted have been reported by the International Institute of Tropical Agriculture (IITA, Nigeria), which has worked on cassava mechanisation and its various applications [8-9]. The institute has already developed two cassava chipping machines. The first one was powered by a 3.5hp petrol engine and 0.5hp electric motor. It has a capacity of chipping up to 1.2 t/h and fuel consumption rate of 0.8 l/h together with an operating speed of about 260 rpm. The second one was manually operated with a chipping capacity of about 200 kg/h at an operating speed of 60 rpm. However, one major challenge of the motorised system was that it depends on electricity and petrol for its power operation, and these are not readily available in the rural settings where the crops are

*Corresponding authour
Email: adeshina.fadeyibi@kwasu.edu.ng (A. Fadeyibi)

mostly grown. The manual type was produced with wood thus limiting its useful life and the production capacity of the machine was quite low compared to the amount of energy expended during its operation. Additionally, the designed a pedal operated cassava chipping machine, which is made from a bicycle attachment connected to a chipping plate, have been described [10]. The chipping late carried the knives which adapted the machine for both slicing and chipping operations. The machine was operated by two operators with one pedaling and the other feeding the crop through the cute. A motorised cassava chipper was used to chip cassava tubers after washing the tubers with a mechanical washer-peeler. The machine consists essentially of an assembly of knives, which rotates clockwise at 375 rpm and are driving by a 0.75 kW electric motor, are mounted on rotating discs, supporting cylinder rotated in a counter clockwise direction at 95 rpm by direct gearing to the rotating discs, and a hopper holding the peeled tubers. The peeled tubers were cut into slices as they pass through the machine, which has an average output of 225 kg/h [6].

Despite the numerous success stories about the already existing cassava chipping machines, their application especially at the small scale is a huge challenge. Besides, the machines are cumbersome and some required high technology and degree of literacy to operate, thus limiting their overall acceptability by the local farmers. There is therefore the need for an alternative design that can accommodate and address these deficiencies to increase productivity of the product. Information on the design and fabrication of the new machine has not been reported in the open literature. Thus, the objective of this study was to design and fabricate a manually operated and motorised cassava chipping machine for increasing the productivity of the chipping process at the cottage level.

2. MATERIALS AND METHODS

2.1 Materials Selection and Specification

The materials used in the fabrication of the cassava chipping machine were sourced locally. Galvanized metal sheet of 1 mm thickness together with 10 x 10 x 200 mm mild steel square rod, 45 mm x 45mm angle bar and 25 mm x 25 mm iron rod were used for the construction of the cassava chipping machine. The fabrication of the machine, whose model is shown in Fig. 1, was carried out at the Central Engineering Workshop, Federal University of Technology Minna, Nigeria.

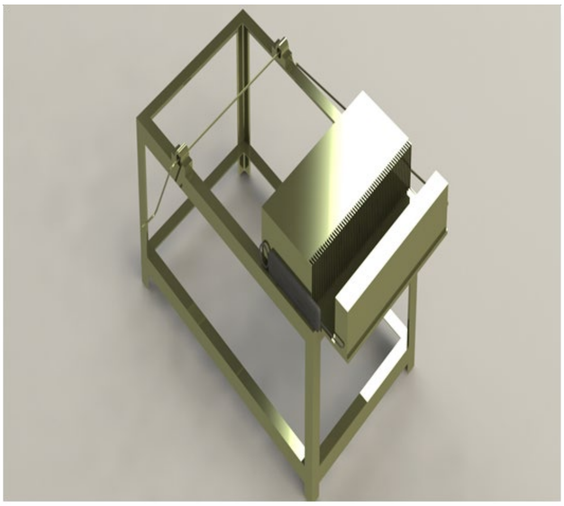

Fig. 1. Model of the cassava chipping machine

2.2 Design of Component Parts

2.2.1 Design Considerations

The design of the machine was based on the following considerations.

i. Twenty four (24) blades spanning 20 mm from each other were considered to ensure uniform cut size.
ii. A standard average table with a height of 760 mm was used to ensure systematic standing posture of the operator at rest (Berme *et al.*, 1990).
iii. Aluminium steel was used as the material of construction to ensure no contamination of products by the cutting blades. Also, cutting force on each blade was assumed 100 N.

iv. The machine was designed to be manually and electrically operated.

2.2.2 Design Analysis

In choosing the various parameters for the designs calculations of the machine, average values were chosen to accommodate for the efficient performance of the chipping machine, especially the cutting force to give room for fibrous species.

(a) Stress acting on connecting rod

The stress acting on the connecting rod was computed using Equation (1). This was done by assuming the length and width of the rod as 700 mm and 50 mm, respectively [11-12].

$$S_t = \frac{F}{A} \tag{1}$$

$S_t = \frac{F}{A}$where, S_tS_t= Stress (N/mm^2), F= Force (N), A= Area (L x W) (mm^2), L = Length (mm),

W= Width (mm)

$$S_t = \frac{F}{A}$$

$$= \frac{100\text{N}}{(700\text{x}50)}$$

$$= \frac{100 \quad 100}{35000\,35000}$$

= 0.0028 N/mm^2

The calculated tensile stress for mild steel connecting bar is 0.0028 N/mm^2 which is less than 2.8kN/m^2 permissible tensile stresses for mild steel therefore the member cannot fail. The crank drive arrangement of the connecting bar is shown in Fig. 2.

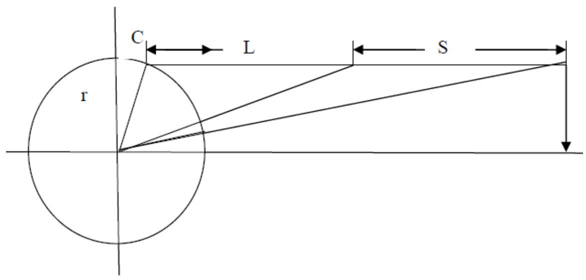

Fig. 2. Crank drive arrangement of the connecting bar (C = Crank pin, L = Length of connecting rod, R = Crank radius, S = Stroke length).

(b) Design of blades

Number of cuting blade was computed from the expression in Equation (2). Length 220 mm and width 70 mm was considered as shown in Fig. 3. The area provided for the blades was computed as length x width (220 x 70) mm = 15400 mm^2. Also, blade of 3 mm thickness was used for the machine and separated by a distance of 5 mm to each other.

$$\text{N. blades} = \frac{\text{Length}}{\text{Thickness} + \text{Spacing}} \tag{2}$$

$$\frac{220}{3\ mm + 5\ mm} = 28 \text{ blades}$$

Thus, 28 blades were vertically arranged to fill the whole length. Also, the total forces acting on blades was calculated as 28 blades x 100 N (based on the initial assumption) = 2800 N.

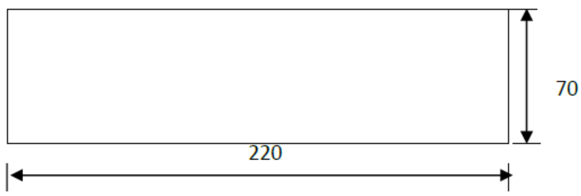

Fig. 3. Cuting blade (c) Design of prime over

The torque generated on the connecting rod was computed from the expression in Equation (3) (McCormick and Sanders, 1982).

$$\tau = \frac{\gamma F}{g\rho} \quad (3)$$

where, $\gamma\gamma$ = shear stress acting on the connecting rod (2.8kN/m^2), F = Total cutting force on 28 blades (2800 N), g = 9.81 m/s, $\rho\rho$ = density of mild steel material (7850 kg/m^3).

$$\tau = \frac{\gamma F}{g\rho}$$

$$\tau = \frac{2800\times 2800}{9.81\times 7850}$$

$$\tau = 101.81 \text{ Nm}$$

Thus, the output of the prime mover was computed from Equation (4) (Kachiru *et al.,* 1993),

where, PP = Power (watt), $\tau\tau$ = Torque (101.81 Nm),

$$P = \omega\tau P = \omega\tau \quad (4)$$

$\omega = \frac{2\pi N}{60}\omega = \frac{2\pi N}{60}$ = Angular speed (rad/s)

but, $\omega\omega = \frac{2\pi N}{60} = \frac{2\pi \times 60}{60}$ = 6.284

P = $101.81 \times 6.284 = 639.45$ W

Since, 746 W = 1 hp

639.45 W = X hp

So, X = 0.8572 hp

Therefore, a single phase 1 hp electric motor with a speed of 4500 rpm was elected to power the cassava chipping machine.

2.3 Drawing of the Cassava Chipping Machine

The isometric drawing, machine drawing of parts and the projected drawing of the cassava chipping machine are shown in Fig. 4, Fig. 5 and Fig. 6, respectively.

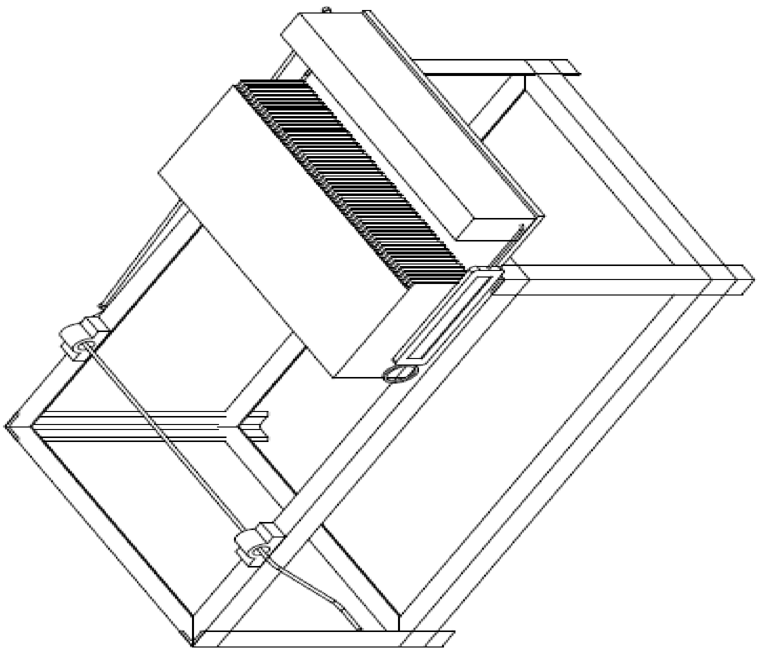

Fig. 4. Isometric view of the machine

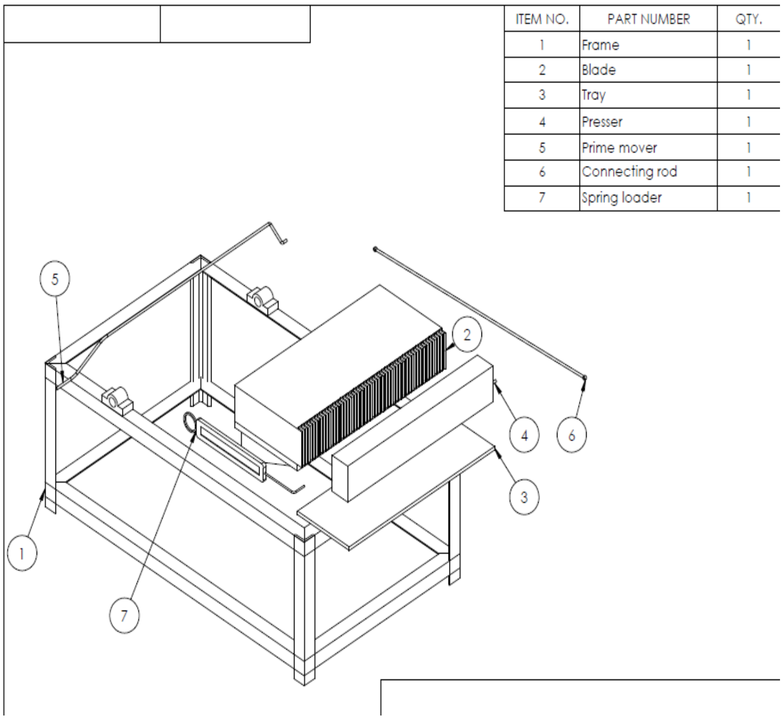

Fig. 5. Machine diagram showing parts (1- Frame, 2- Blade, 3-Tray, 4-Presser, 5- Prime mover, 6- Connecting rod, 7-Spring loader)

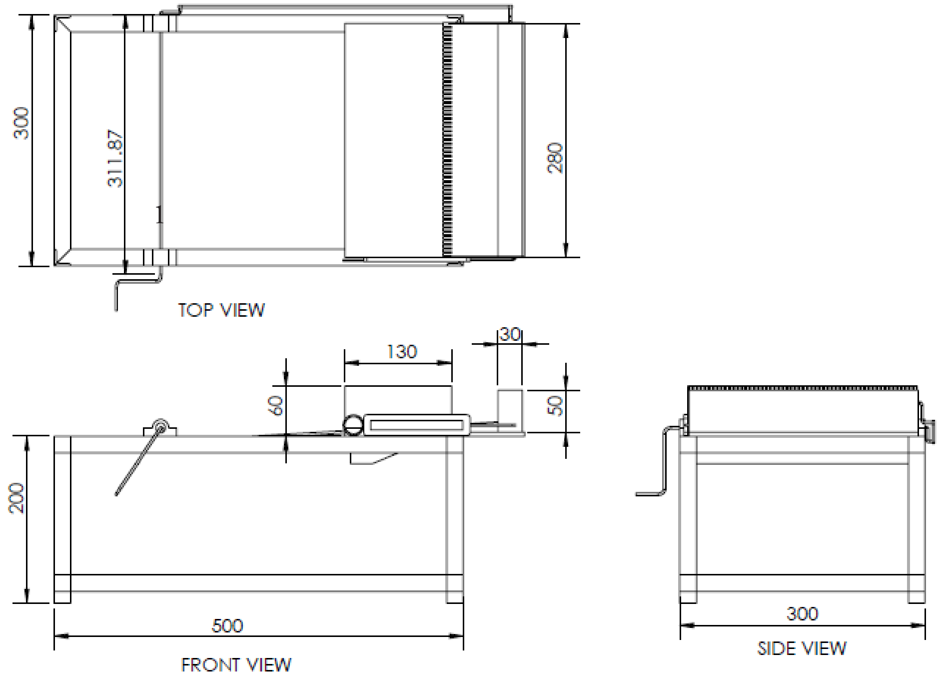

Fig. 6. Third angle projection of the machine

2.4 Performance Evaluation and Determination of Cutting Force

The cassava tubers were bought from Kasuwan Gwari market in Minna, Niger State. The tubers were cleaned with water and sorted manually into different categories of length (100-130mm, 131-150 mm, 151-160 mm, 161- 190 mm and 191-220 mm). Each size category was manually pealed and bagged for the chipping operation. The major components of the chipping machine included the frame, tray, blade through a crank mechanism. The stand carries the blade while a tray allows samples to be placed on it (Fig. 7). The blade has a hole of 5 mm thickness which allowed the attachment of the spring balance to the blade system. The chipping machine was design for manual operation, but can as well be powered by an electric motor in the event of fatigue from the operator.

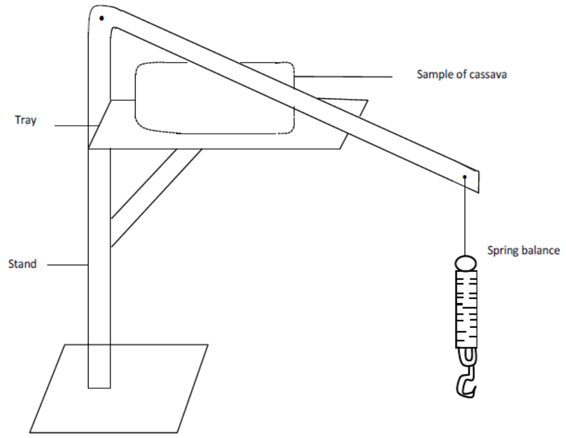

Fig. 7. Schematic diagram of chipping section of the machine

The cutting forces of the cassava tubers were determined by placing the samples on the machine tray and the blade lifted and brought down to initiate cutting. The force required for achieving the cutting was read directly from the spring balance attached. The procedure was replicated six times for the six categories of the cassava tubers and the average values of their respective cutting force recorded.

3. RESULTS AND DISCUSSION

3.1 Effect of the cassava tuber size on the average cutting force

The effect of the size of the cassava tuber on the required cutting force of the machine is shown in Figure 8. It can be seen that the average cutting force increased exponentially with an increase in the length and diameter of the tuber.This is expected because with longer and wider tuber, the relative cutting force resisting area presented by the tuber to the effort imposed by the blade on it will be larger. The increase in the required cutting force with increasing length and diameter of the tuber might be associated with the increased cross sectional area of the tuber which requires higher load to deform. For instance, the cassava sample with 160 mm length and 61.5 mm diameter required a cutting force of 88.30 N to deform compared with another sample with 100 mm length and 37 mm diameter which required only 51.99 N (Fig. 8).

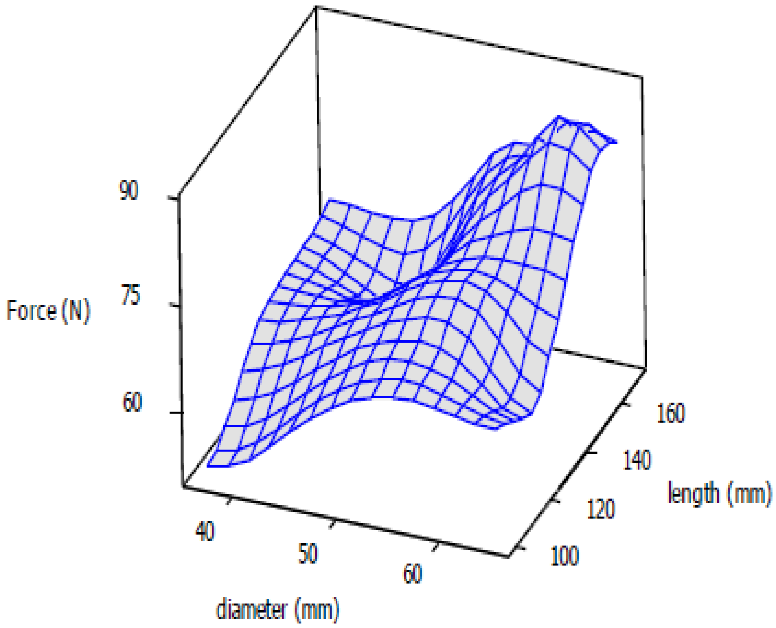

Fig. 8. Effect of the size of cassava tuber on the cutting force

It was however further observed that the sensitivity of the average cutting force to the axial dimension of the tuber was more pronounced at the length than it is at the diameter. Previous research results have shown that tuber strength properties increased with tuber length. In a similar investigation conducted to determine the radial compressive cracking force on two cassava varieties, Ilori and Adetan [3] reported that the average cutting force in radial compression of the tubers was more sensitive to variation in the length than it is to variation in the tuber diameter. The response of a tuber sample, irrespective of its size, to the blade effort of the chipping machine, no matter how small, will be high enough to cause rupture in the direction of its length than in the diameter. The degrees of maturity and tenderness together with likely inner and central cracks, capable of forming easy crack initiation points during compression, of some of the cassava samples might be responsible for the rupture experienced with the slightest blade effort.

The effort exerted on the blade handle in cutting the tubers during the machine operation was comparable to the motor powered spring response on the blade. According to Surya *et al.* [13] the average power a human being can generate is 500 W for steady work and 750 W for unsteady work. The maximum torque a human being can generate is 200 Nm [13]. However, since torque calculated (101.81 Nm) is less than the maximum torque a human being can produce, the machine would be able complement human effort. This means that in the event of fatigue from the operator, the machine can still be motorised with the 1 hp electric motor to give approximately the same output. The research results of McCormick and Sanders [14] in their work on human factor in engineering design revealed that the 1 hp electric motor is capable of powering cassava chipping machine to an approximate capacity of 225 kg/h. This implies that the longer and bigger the cassava tubers, the higher the effective cutting force required for chipping.

2. CONCLUSION

This study designed and fabricated a manually operated and motorised cassava chipper adaptable to local processors at the cottage level. The research also investigated the effects of the length and diameter of cassava tuber on the cutting force required for effective chipping operation. It was observed that the average cutting force increased with an increase in the length and diameter of the tuber. Also, the sensitivity of the average cutting force to the axial dimension of the tuber was more pronounced at the length than it is at the diameter. The size of the electric motor required was a single phase 1 hp (4500 rpm), which is capable of powering the machine to an approximate capacity of 225 kg/h and comparable to the required human effort. The average size of the chips obtained was 30 mm.

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