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Development and Performance Evaluation of Coconut Dehusking Machine

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--ABSTRACT--
Contrary to the immense economic importance of coconut for both industrial and domestic uses, dehusking of the fruits after harvesting constitutes the most difficult and dangerous operations during processing. Performance evaluation of coconut dehusking machine was carried out. The machine was designed and fabricated using locally sourced materials. It consists of the supporting frame where the machine components were mounted. The de-husking unit consists of two galvanized steel pipe rollers with spikes and shafts. The driving and driven roller shafts are mild steel rods supported at both ends by ball bearings. Six spur gears were used with various pitch circle diameters and number of teeth respectively, and were attached proportionally to the driving and driven roller based on their functions in the machine. The flywheel is driven by a pinion which is attached to pulley and connected with a V-belt to the pulley of the electric motor, and rotates at the same speed with the driving gear. Two middle gears mounted on the same shaft with the flywheel were also incorporated to produce high torque. When the motor is switch on, power is transmitted through the gearing arrangement to the rollers with plurality of spikes and rotate them in opposite directions towards the center there by causing both the gripping and tearing of the husk when coconut is placed in between the rollers. While the rollers rotate, a feeding clamp welded to the frame is used to feed coconut fruit in the de-husking unit and a spring is attached to enable relative motion between the coconut fruit and the rollers during de-husking. Different sizes of coconut fruits were loaded at different times on the machine and the time taken for each fruit to be dehusked was recorded. A total of 80 fresh nuts were tested. The performance evaluation shows that the average efficiency of the machine was 92.50% while the average capacity is 120.6 coconuts per hour. On the other hand, the percentage number of distorted and broken coconuts were 7.5% and 3.75%. These figures are however infinitesimal Compare to the existing coconut dehusking machines. Hence it is recommended for use by farmers.
Keywords: *Performance, Evaluation, Coconut, De-husking, Machine*

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I. INTRODUCTION

Coconut (Cocos nucifera) isoneofthe world'smost usefulandimportant perennialplants with multiple uses for thousands of years. As coconut enters today's world, people over the world are becoming aware of its many health benefits and food uses in many facets of daily life, in some instances even as currency [1]. Coconuthasconsiderablesignificanceinthenationaleconomy of Nigeria inviewofrural employmentandincomegeneration ([2]. It belongs to the family arecaceae. Philippines are the world largest producers of coconut. It is found in the tropic and sub-tropic areas [3]. Coconuts are large, dry drupes, ovoid in shape, up to 381mm long and 305mm wide. The coconut is smooth on the outside greenish or yellowish in colour. Within the outer shell is a fibrous husk 25-50mm thick. The inner shell is brown and hard, surrounding the white coconut meat [4], [5], [6], [7].

The coconut husks (which are the rough exterior shells of the coconut) have to be removed for the usage of coconut. The coconut is known for its great versatility as seen in many domestic, commercial, and industrial uses of its different part. They are part of the daily diet for many people. Coconuts are different from any other fruits because they contain large quantity of water and when immature they are known as tender-nuts or jelly-nuts and may be harvested for drinking. When they mature they still contain some water and can be used as seed nuts or processed to obtain coconut oil, charcoal from hard shell and coir from fibrous husk. It could also be eaten in its raw form [8], [9], [10], [11], [12].

The husk is used for manufacturing variety of products such as nets, ropes, mats and carpets [7]. The coconut husk is made up of coir which is light weight, elastic, strong and has high durability. Coir fibre can be compared to waterproof because it cannot be damage by salt water and microbial degradation. By virtue of these qualities, the husk is very stressful to remove from the fresh fruit [13], [14], [15], and [16]. Almost every part of the coconut plant can be used by humans in one way or the other and for a significant economic value. Coconut versatility is sometimes noted for its naming. In Sanskrit, it is Kalpa vriksha (the tree which provides all the necessities of life); in the Philippines, the coconut is commonly called ″the tree of life″ [17]. The use of cutlass for coconut dehusking endangered the life of people involved, because during dehusking process, some may end up cutting their hands, and face as the cutlass bounces back on hitting husk.

As a means of resolving the problem associated with manual dehusking, [18] developed a coconut dehusking machine that is made up of three rollers in which one is in between the other two which rotate in opposite direction with some in built spikes which penetrates into the husk of the coconut and a base structure which provides support for the rollers. The interaction of the rollers in combination with the gripping action of the spikes causes tearing of the husk from the nut. However, this invention still left us with nut breakage and discharging problems. Apart from these problems, the machine can only dehusk dry coconut which leads to additional cost as a result of the search for appropriate drying methods for the fruit. During rainy season where over 95% of the fruit is produced in the rural area, the farmers still use the manual methods of dehusking by cutting with cutlass so as to avoid excess loss of the product. Therefore, a need arises for a machine that can dehusk both fresh and dry coconut without nut breakage. Hence the main objective of this work is the development and carryout a performance evaluation of a motorized coconut dehusking machine that would have higher capacity, efficiency, reduce drudgery and be more flexible in operation.

Coconut De-husking

Although coconut is of immense economic importance to both the industrialist and rural dwellers, dehusking of its fruit after harvesting constitutes the most difficult and dangerous operation in its processing. According to [19], the problem of separating the outer shell and husk of the fruit has been in existing for hundreds of years. [4], states that this problem of dehusking of coconut fruit started right from the time man planted coconut for stratification of his needs. According to [20], there are many farm equipment's and tools which are developed for the post harvesting operation of horticultural crops. The dehusking of a coconut is regarded as the most time-consuming, tiring, and difficult operation to perform and involves much human drudgery. Many attempts has been done to perform coconut dehusking manually as well as mechanized. There are two methods of dehusking coconut fruits:

1. Traditional method
2. Mechanical method

Traditional Coconut Dekusking Method

The traditional method of dehusking coconut fall under two major variant processes: Dehusking using matchet and dehusking using metal spike.

Manual Dehusking using Matchet

The very first process of extracting coconut meat involves splitting of the harvested fruit into two or three parts using matchet without removing the husk [2]. This method is very simple but concentrates only on the coconut meat thereby wasting other coconut by- products such as water/milk, shell and husk. However, this method poses a threat on human life as people cut their fingers hand during the operation. Also, the technique shortens the actual length of coir fibre extracts.

Manual Dehusking using Metal Spike

To tackle the irreversibility associated with the use of matched in dehusking coconut, the use of metal spike was later developed [16]. In this process, a metal spike is secured on the ground in a slightly slanting position with the point upwards. The nut is brought down with force on the spike, followed by twisting the fruit against the spike thereby loosening the husk. Although this process reduced the human injury, it also focuses on the extraction of coconut meat only and consumes both time and energy. The number of fruits one man can dehusk per day depends solely on the type of the coconut and the thickness of its husk [13]. Care is usually taken when the point of the spike enters the husk at the stalk end so as to avoid damaging of the shell which leads to nut breakage.

Mechanical Coconut Dehusking Method

[20] revealed that design and manufacturing of coconut de-husking machine consists of three operations, namely: Peeling of coconut fibers, that is de-husking of coconut In 1984, a coconut dehusking machine with a dehusking capacity of 800 hybrid coconut fruits per hour was developed in Malaysia [21]. The major components of this machine are; a rotating table, plunger, a circular saw, rotating cone and vertical knife. The machine is powered using a field tractor. In this machine, the coconut with its stalk end facing down is manually placed in the cavity of a rotating table after which the plunger pressing the coconut down to the pre-set

level. As the rotating advances, a circular saw slices off pieces of the husk at the stalk end of the coconut before the fruit is pushed into the dehusking section where vertical knife cut the husk into a vertical section. Thereafter, the plunger in the dehusking feeds the fruits into a rotating cone and where it is firmly gripped thereby, facilitating the tearing of the husk from the nut as the cones rotates. Though, this machine saves time, energy and also helps to recover all the coconut by-products, it cuts the husk into pieces and at times break the coconut during dehusking process. In recent innovation on fibre technology, it has been proved that the coir fibres can be used as effective reinforcement and bonded in polyster matrix. In the studies on mechanical performance and properties of fibre reinforced polymer composites, it was shown that both fibre length and orientation distribution play a very vital role in determining its mechanical properties. Consequently, dehusking of coconut with the full length of the extracted husk maintained becomes necessary [22]**.**

[19] developed a machine for removing the husk from the nut of a coconut fruit in a manner that leaves the nut intact and ensures that the husk is separated from the fruit without cutting into pieces. This machine comprises of a base or frame positioned on a supporting surface, two rollers (each having an elongated configuration and substantially parallel to one another). The rollers are interconnected to the drive such that they rotate in opposite directions relative to one another and in a preferred embodiment at relatively different speeds. The rotation of the rollers is such that a coconut placed on it will be forced into the space between the rollers. An important feature of this innovation is the existence of a penetrating means on each roller in the form of plurality of spikes. The spikes were arranged in a plurality of row having an elongated curvilinear configuration extending at least along a major portion of the roller's length. The spikes are sharpened and spaced from one another in a substantially whereby the patterned array in which the plurality of spikes of each roller were positioned facilitate the penetrating, gripping and tearing of the coconut husk. The husk once separated from the nut, passing through the spacing between the rollers to the supporting surface/collecting tray. This machine has discharging problem due to absence of conveyor. Also due to the shape of the spikes used, there is high rate of nut breakage and cutting of the husk in relative pieces even though it is aimed at producing a full-length husk.

In addition the machines are not popular among the small scale coconut producers due to the above deficiencies and high cost. Thus, separation of the husk using matchet remained the common means of dehusking coconut fruits among our rural dwellers in Nigeria despite the risk associated with this method. Therefore, a coconut dehusking machine that will enable the extraction of the coir fibre with its full length without any damage to the nut and also affordable by our low income earners is required in this sector for effective processing of coconut in our rural and urban communities [23].

Thus the existing coconut dehusking machine is associated with the following problems:

1. It has very low efficiency.
2. It operates with very low productivity.
3. It is not easy to use and ergonomic.
4. It is not safe to use and not environmentally friendly.
5. It consumes a lot of human energy.

II. MATERIALS AND METHODS

Design Consideration

The coconut dehusking machine was designed and fabricated based on the following considerations:

1. The availability of materials locally to reduce cost of production and maintenance of the machine.
2. The screw conveyor was placed in between the rollers for effective twisting of the coconut fruit during dehusking and also for appropriate discharging of dehusked nut.
3. Tapering of the roller by increasing the length of spikes along the roller accounts for reduction in the size of the fruit to enable proper gripping as tearing of the husk progresses across the length of the machine.
4. It is desired that there should be no husk on the nut, no nut breakage and the removed husk should have its full length intact. Hence, the electric motor, gears, pulley and speed reducer were carefully selected to meet the required speed of the dehusking and conveying units to achieve this objectives.

Design Analysis

Some data on the loads acting on the coconut to de-husk it are required. The husk is removed from the Machine through the shear force exerted by the fixed toothed rollers in the machine. In relation to that, the amount of shear load required to de-husk the coconuts has been determined. Both dry and mature coconuts of various sizes are tested experimentally in the Standard Universal Testing Machine (UTM) [14].

The shear yield strength of coconut fruit was determined using the equation,

$$\tau_{yt} = 0.577\,\sigma_{yt} \qquad (1)$$

Where: τ_{yt} is the shear yield strength.

σ_{yt} is the tensile yield strength $=175 N/mm^2$ for coconut fruit [24] and [23].

Since the orientation of the husk was not taken into consideration, a truncated cylindrical-shape spike was selected using the relation below [25].

$$A = (\times \frac{d}{2}\sqrt{\frac{d^2}{4}} + \frac{1}{4}(h_2 - h_1)) \qquad (2)$$

Therefore, the tangential force acting on the spikes during dehusking process was determined (Rajput, 2006).

$$F_t = \tau A \qquad (3)$$

Where: τ =shear stress of coconut fibre

F_t = the tangential force on the spikes

Determination of Power required by the machine

The power, P required for the dehusking of one coconut by this machine was determined as 0.75KW by [26]. Service factor for difficult drive = 1.8. From the following relation given below as:

∴ Design power = power to be transmitted $\times$ service factor

$$P = F \times V \qquad (4)$$

Where: F, is the force required to grip and tear the husk

V, the peripheral velocity of the driving gear

Hence, for a machine transmitting less than 3.75 kW, the design power is within the range of 0.7- 3.5 kW, [26]. For the purpose of this design, an electric motor of 2.2 kW was chosen to drive the machine.

Selection of belt and pulley

The machine requires two pulleys and a belt for its drives. Due to the availability, cost and performance, mild steel pulley with groove angle of 38^0 was selected. Type A V-belt with thickness (t) 8 mm was chosen, [26].

The minimum outside diameter of the driver pulley, D_0 =78 mm.

But pitch diameter of the driver pulley,

$D = D_0 - t$

But the pitch diameter of the driven pulley,

$D = D_0 + t$

D_A, pitch diameter of the driving pulley, and

D_B, pitch diameter of the driven pulley

Speed of electric motor, N_A

From the relation, [26].

$$N_A D_A = N_B D_B \qquad (5)$$

$$N_B = \frac{NA \times DA}{DB}$$

Speed ratio between the two pulleys

$= \frac{NA}{NB}$

The distance between the drive and the driven shaft can be estimated as

$$X = \left(\frac{3DA + DB}{2}\right) \qquad (6)$$

According to the Indian standard pitch length of V-belt, a type A V-belt with a standard pitch length of 747mm which is the closest value to 758.16mm was selected for the design, due to the power to be transmitted [26].

Belt tension;

The angle of lap for the smaller pulley (since both pulleys are made of the same material),

$$\theta = (180^0 - 2\alpha)\frac{\pi}{180} \text{ rad} \qquad (7)$$

Where: θ is the angle of lap (contact) and value for $\pi = 3.142$ [26].

$$\sin\alpha = \frac{D_B - D_A}{2x}$$

The centrifugal tension on the belt was determined using equation 8 according to [26]:

$T_C = MV^2$……………………………………………………………………… (8)

Where: T_C, is the centrifugal tension on the belt
M, is the mass of the belt $\frac{w}{g}$
V, is the peripheral velocity of the belt =?
Therefore, solving for the peripheral velocity we have,

$$V = \frac{\pi D_A N_A}{60}$$

From the dimensions of standard V-belts according to ISO: 2494-1974, [26] for a belt transmitting less than 3.75 kW.
Tension in the tight and slack side of the belt was determined using equation (9)

$P = (T_1 – T_2)\ V$………………………………………………………………… (9)

Where: P, is the power transmitted by the belt
T_1, is the tension in the tight side of the belt
T_2, is the tension in the slack side of the belt
V, is the peripheral velocity of the belt,

$P = T_1 (1 - T_2/T_1)\ V$

Also, $\frac{T1}{T2} = e^{\mu\theta}$

Therefore, $P = T_1 \{1 - \frac{1}{e^{\mu\theta}}\}\ V$

$\frac{T_1 - T_2}{T_2 - Tc} = e^{\mu\theta \operatorname{cosec} \beta}$……………………………………………………………… (10)

$T_2 = \frac{(T_1 + T_C e^{\mu\theta \operatorname{cosec} \beta})}{(1 + e^{\mu\theta \operatorname{cosec} \beta})}$

Determination of speed of the Driving Roller
Number of teeth on the speed reducer pinion, T_{SP}=9

$\frac{N_{Sp}}{Ns_g} = \frac{D_{Sg}}{Ds_p}$

$N_{Sp} D_{Sp} = N_{Sg} D_{Sg}$……………………………………………………………………… (11)

$N_{Sg} = \frac{N_{Sp} \times D_{Sp}}{Ds_g}$

$N_{g2} = = \frac{D_{g1} \times N_{g1}}{D_{g2}}$

$N_{g4} = \frac{D_{g3} \times N_{g3}}{D_{g4}}$

$N_{g4} = \frac{36 \times 56}{46}$

For the driving roller gear (gear 5);

$N_{g5} = \frac{T_{g4} \times N_{g4}}{D_{g5}}$

Design of the Shaft Diameter of Driving Roller
Due to the configuration of spur gear on the driving roller shaft, the tangential load acting on the gear teeth was computed using equation 12, [26].

$F_t = \frac{P}{V} \times C_s$……………………………………………………………………… (12)

Where: F_t, is the tangential load acting the driving gear teeth.

P, is the power transmitted by the driving roller shaft
V is the peripheral velocity of the driving gear =?
C_S is the service factor =1.8.
Assuming steady load conditions [26].

But $V = \frac{\pi D_{g5} \times N_{g5}}{60}$

But the normal force F_N, which is acting on the driving gear, was computed as;

$$F_N = \frac{F_t}{\cos \emptyset} \quad \ldots\ldots (13)$$

Where: $\emptyset$ is the pressure angle $=20^0$, [26].
The resultant load acting on the driving gear was computed using equation 4 by [26].
,

$$F_R = [(F_N)^2 + (W_G)^2 + 2F_N \times \cos \emptyset]^{\frac{1}{2}} \quad \ldots\ldots (14)$$

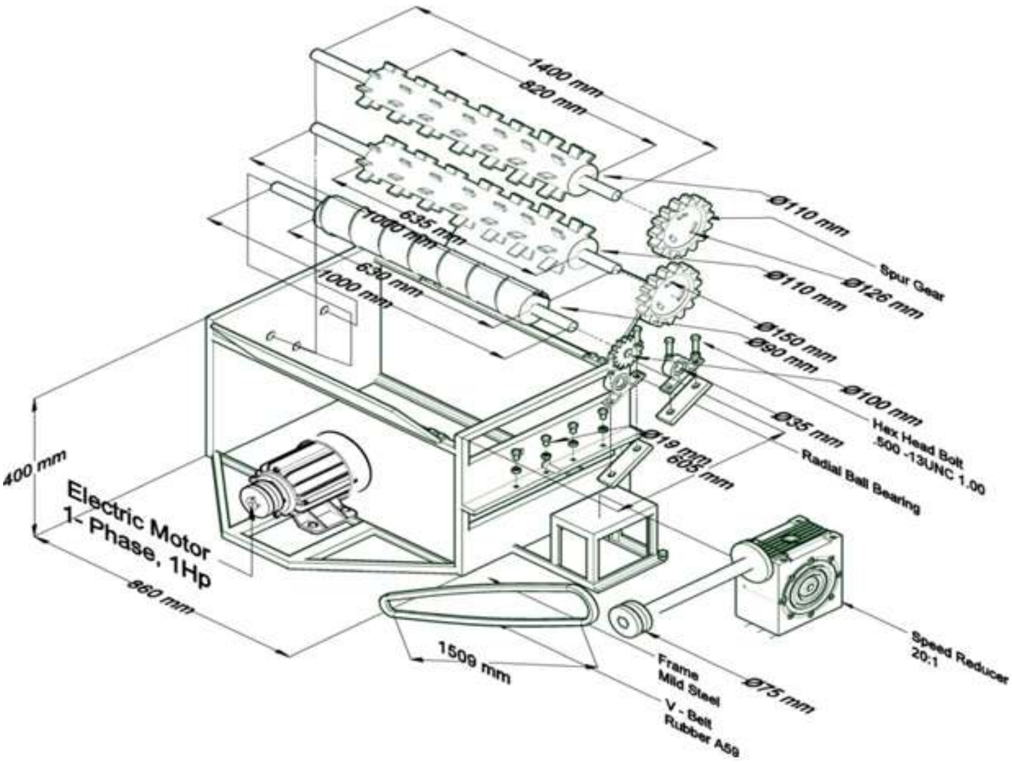

Figure 1. Exploded view of the mechanism coconut dehusking machine

FABRICATION AND DESCRIPTION OF THE MACHINE

As shows in figures 1-2 the coconut de-husking machine was fabricated in the department of Mechanical Engineering Workshop, Cross River University of Technology, Calabar. It consists of the frame which is the main supporting structure upon which other components of the machine were mounted. It is a welded structure constructed from mild steel angle iron. The de-husking unit consists of two rollers with spikes and shafts. Both rollers are galvanized steel pipe of known diameters. The spikes were formed by welding sharp mild steel rod on the rollers. The driving and driven roller shafts are mild steel rods supported by both ends by ball bearings. Six spur gears were used with various pitch circle diameters and number of teeth respectively, and were attached proportionally to the driving and driven roller based on their functions in the machine. The flywheel (speed reducer) is driven by a pinion which is attached to pulley and connected with a V-belt to the pulley of the electric motor, and rotates at the same speed with the driving gear. The purpose of the idler gear is to rotate the driven roller in the desired direction (clockwise direction), while the driving gear rotate the driving roller in the opposite direction (anti-clockwise direction). Two middle gears (gear 1 & 2) mounted on the same shaft with the flywheel were also incorporated to produce high torque. The barrier plates were constructed by cutting 4 mm mild steel plate, and were fastened on the frame before the rollers; the gear cover is constructed from an 18 gauge mild steel plate to protect the gears from getting damaged. The coconut de-husking machine requires the service of one operator. When the motor is switch on, power is transmitted through the gearing arrangement to the rollers with plurality of spikes and rotate them in opposite directions towards the center there by causing both the gripping and tearing of the husk when coconut is placed in between the rollers. While the rollers rotate, a feeding clamp welded to the frame is used to feed coconut fruit in the de-husking unit and a spring is attached to enable relative motion between the coconut fruit and the rollers during de-husking.

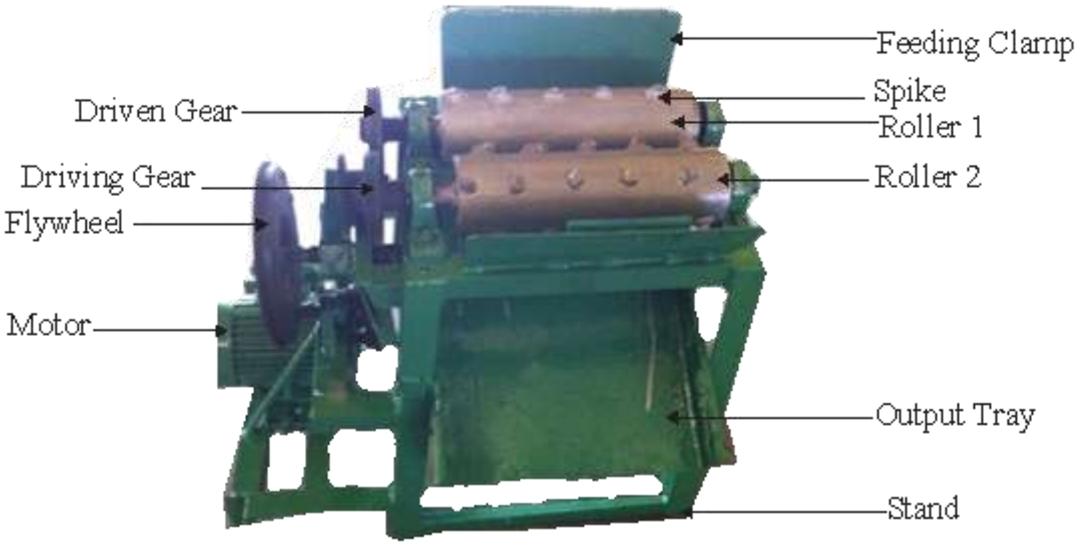

Figure 2. Showing the Mechanism of the Coconut Dehusking Machine

Performance Testing Procedure and Data Analysis

The objectives of this project can be actualized by the De-husking capacity and efficiency. It was determined by twenty experimental runs. Number of nuts (N_T) during the test with their respective de-husking timer, was recorded. The numbers of nut with full length of fiber W_{gf}, together with numbers of distorted fibre W_t, also was recorded. The de-husking time was measured using a stop watch. Thereafter, the efficiency, and capacity C of the machine was computed using the relations below:

$\eta(\%) = \frac{W_{gf}}{N_T}$………………………………………………………………….. 3.17

C (nuts/hr) = $\frac{N_T}{t}$………………………………………………………………… 3.18

III. RESULTS AND DISCUSSION

Performance Test results

The result of the performance test of the coconut dehusking machine is shown in Table 1.

Table 1: Performance Testing Result

S/N	No. of coconut dehusked, N_T	No. of broken nuts	No. of nuts dehusked with full length of fibre, W_{gf}	No. of dehusked nut with distorted fibre, W_t	Time, t (seconds)	Efficiency, η (%)	Capacity, C (nuts/hr)
1	4	0	4	0	125	100	115.2
2	4	0	3	1	120	75	120.0
3	4	0	4	0	112	100	128.6
4	4	0	4	0	108	100	133.3
5	4	0	4	0	124	100	116.1
6	4	0	3	1	121	75	119.0
7	4	0	4	0	126	100	114.3
8	4	0	4	0	118	100	122.0
9	4	0	4	0	120	100	120.0
10	4	0	4	0	120	100	120.0
11	4	0	3	1	115	75	125.2
12	4	0	4	0	117	100	123.1
13	4	0	4	0	114	100	126.3
14	4	0	3	1	119	75	121.0

15	4	0	4	0	120	100	120.0
16	4	0	3	1	121	75	119.0
17	4	0	4	0	122	100	118.0
18	4	0	4	0	125	100	115.2
19	4	0	3	1	117	75	123.1
20	4	0	4	0	128	100	112.5
Total	**80**	**3**	**74**	**6**	**2392**		
Average					**119.6**	**92.5**	**120.6**

Effect of the Modification on Efficiency of Machine

The spikes of the original machine were tapered to the discharge chute, and increase in length at every turning. This also contributes to the breakage of the coconuts as the sizes of this nuts where not properly considered before designing this machine.

Now, the spikes of this motorized machine and the size of the nuts were properly considered, so as to prevent the spikes from grabbing the endocarp of the nut, but only the husk were to be griped so as to have effective de-husking. Due to this reduction and size consideration, the nuts progressively undergo a very smooth de-husking. The modification has led to the following advantages over the existing Coconut de-husking machine; more efficient, saved time and energy, more productive, easy to operate, human and environmentally friendly.

Design of all the machine components are considered safe as far as the process is concerned. In order to validate the project aim, the de-husking capacity along with the efficiency of the machine has been evaluated. The test has been conducted in such a way that the machine has been operated by a different operator and the total number of the process time consumed has been measured using a stop watch. The capacity of the machine has increased to 120 nuts per hour.

The efficiency of the machine has increased from 92.5%. The operation of the machine is now easy and smooth and requires very small human effort. Hence, the introduced modification reduced drudgery.

1. The spiked roller gap of the coconut de-husking machine was adjustable either 2.5 cm ,3.0 cm, 4.0 or 5.1 cm by adjusting the positioning of the spiked rollers.
2. The rotational speed of the machine was determined using a digital tachometer (Stimpo Instruments USA). And a digital stop watch (Timex, Netherland) was used to measure the time taken to de-husk a coconut according to the different treatments. The de-husked coconuts were checked for damages or cracks.

IV. CONCLUSION

The modification and improvement of an existing coconut dehusking machine for farmers was carried out and tested. The performance evaluation shows that the average efficiency of the machine was 92.50% while the average capacity was 120.6 coconuts per hour. Whereas the percentage number of distorted and broken coconuts were 7.5% and 3.75%. These figures are however infinitesimal Compare to the existing coconut dehusking machines. Hence it is recommended for use by farmers.

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