Volume-6
Issue- II
December-2021

Rajarata University Journal

ISSN: 2362-0080
www.ruj.ac.lk/journals/

Category: Research Article

Nut Cracking Machine for *Terminalia catappa* (Tropical Almond/ *Kottamba*)

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ARTICLE DETAILS

Article History
Published Online: 31/12/2021

Keywords
Actual capacity, Mechanical cracking, Performance evaluation

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ABSTRACT

Tropical almond (*Terminalia catappa*) is an underutilized crop that belongs to *Combretacea* family. This plant has been identified as an important medicinal plant owing to its antioxidant and therapeutic properties against cancer and diabetes as proven in numerous pharmacological studies. In its processing, the adoption of manual cracking method results in damages of nuts with high risk of injuries to workers. Therefore, the aim of this study was to design, develop and evaluate a motorized tropical almond nut-cracking machine to minimize the damages on nuts. Major components of the machine are an electric motor as the power source, conveyor belt, fruit holders and impact hammer. Power is transmitted to the crankshaft from the electric motor by means of a belt and pulleys. The rotating crankshaft moves the hammer up and down to apply an impact on the fruit while the belt conveyor feeds fruits towards the hammer. After shattering, the nuts are separated from the shells through oscillatory action. At the performance evaluation of the machine, it was realized that damages caused to fruits and the operator were negligible. The machine weighs 62.5 kg and the total production cost of the machine was 65,000.00 LKR. Actual capacities of manual and mechanical cracking were 184 and 285 nuts/hr, respectively, while theoretical capacities were 225 and 327 nuts/hr, respectively. The comparative figures of the manual and mechanical cracking for field efficiencies were 82% and 87%, respectively. Therefore, this mechanical nut-cracking device could be recommended to replace laborious manual method of nut-cracking for tropical almond (*Kottamba*).

1. Introduction

Terminalia catappa L. is a large tropical tree in the family *Combretacea*, that grows mainly in tropical regions [1]. It is also known as *Kottamba*, Indian almond, tropical almond, country almond or sea-almond [2].The tropical almond fruit is 4-7 cm long, 2.5-3.8 cm wide, ellipsoid, more pointed at the apex than at the base, and slightly flattened. The nut is a hard-shelled stone and 3-4 cm long and 3-5 mm thick [3].The kernel within the nut is edible and can be eaten raw just after cracking the nut to take out the kernel from the fibrous shell. It is rich in protein, vitamin E, and many other nutritional values. The kernels of *T. catappa* are a good source of proteins, rich in essential amino acids, lipids, unsaturated fatty acids, fibre, antioxidants, and minerals such as potassium, calcium, and magnesium [4]. *T. catappa* is beneficial to control cholesterol in the body, blood pressure, body weight, and improve the immunity system, skin, brain health, and bones [5]. In addition to that, tropical almond consists of almost similar nutritional content and the taste of almond. Accordingly, this could be a prominent alternative choice to products like almond oil, roasted almond cosmetics, and beverages [2]. Although it has proven as an important plant encompassing numerous health benefits, it still remains an underutilized fruit tree in many countries.

A proper mechanical method for separating the kernel from the nut has not been ever thought of. The most popular method of cracking tropical almonds is crushing the nut using a hammering action with a stone or a hammer [5]. Many problems such as injuries sustained by crackers, causing damages to nuts, and high time consumption can be associated with this domestic method [6]. Therefore, it is obvious that developing a nut-cracking machine will address the above difficulties and popularize tropical almond processing among villagers/farmers by increasing the chances of value addition. In view of these potentials, it is timely to promote processing and consumption of this underutilized fruit. Making these seeds easily available in the market may uplift the demand for tropical almond and thus satisfy consumers with a cheaper alternative to the high priced almonds. Therefore, the objective of this study was to introduce a proper mechanical solution for cracking, in order to popularize a highly nutritious and an underutilized fruit in many tropical countries.

2. Material and Methods

Many factors such as availability of materials, simplicity, ease of operation, and the maintenance efficiency were considered in the designing process, to fabricate an affordable, durable and efficient machine that is suitable at village level.

2.1. Design Concept

The tropical almond cracking machine works on the principle of conversion of electrical energy from the electrical motor into mechanical energy in terms of rotation of the centrally mounted iron shaft, and conversion of angular motion to linear motion in terms of a crankshaft. The power is transmitted to the rotating crankshaft from the electric motor, using a belt and pulleys. Rotating crankshaft moves the hammer up and down to apply an impact on the tropical almond fruit. The belt conveyor carries the fruit with the support of fruit holders. The operator has to place fruits in the holders and operate the conveyor at a suitable rotating speed using an operating handle in order to feed the fruits to the hammer. After cracking the nuts, the collecting peg removes the fruits from the holder and puts them in the separating tray. The separating tray vibrates at a suitable vibrating speed to separate kernels from husks. The required power to operate the separation tray is supplied by the motor. At the end of the process, the kernels are collected in a separate collector, and the husks are separated.

2.2. Major Components of the Machine

Although the machine is complicated with several components to fulfil several tasks, some components such as power source, belt conveyor, fruit holders, reciprocating hammer, acentric shaft, and operating handle can be identified as the major components, based on their specific functions. The synchronization of several functions such as feeding, delivery at the hammer, cracking with the hammer, separation of husks are expected operations of this machine. Figure 1 shows the major components of the machine.

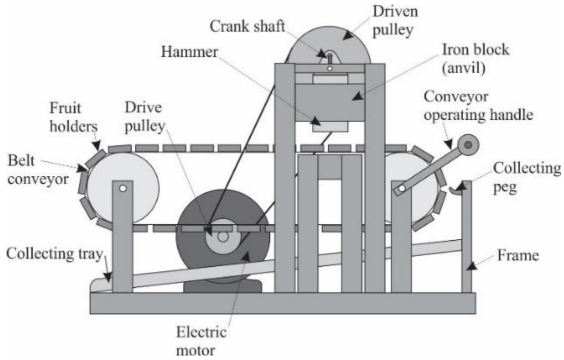

Figure 1: Major components of the tropical almond nut cracking machine

Material for the fabrication of the component parts of the machine was affected based on several factors such as local availability, durability, strength, workability, corrosion resistance, and the costs of material with the idea of facilitation of repairs and maintenance at the village level. Iron box bars, iron rods, L iron bars, flat iron bars, roller bearings with casings, rubber belts, and sheet metals have been used for the fabrication of the machine.

Impact type hammer connected to the crankshaft is the major element of this. A cylindrical shaped iron block is used as the hammer. After conducting a series of nut cracking experiments by using hammers of various masses, 0.3 kg was selected as the most appropriate mass of the hammer with adequate strength. A belt conveyor helps to supply tropical almond nuts at a preferred feeding rate to the hammer. It operates on two rotating drums. This belt is made of rubber and is strong enough to bear the impact force. Fruit holders made with sheet metal and small pins are fitted onto the belt in order to facilitate the conveyance of tropical almond fruits. At this initial stage, the conveyor was designed to operate manually on a compromised feeding rate, but there is a possibility to synchronize the conveyor with the hammer to automate this feeding operation in future. The operating handle helps to operate the conveyor with a suitable speed decided by the operator. A crankshaft was used to convert the angular motion of the motor (electric) into the linear motion of the hammer. Belt and pulley were used as the power transmission method from the motor to the crankshaft of the hammer as it is flexible and acts as a shock absorber. As a high reaction load is exerted by the hammer, it could create a reactive impact on the motor, which can be badly affect its coil. In this instance the belt and pulley allow slippage when a high reaction load is exerted. The expected impact force on a nut was worked out as 30 N, hence the required linear and angular velocities of the hammer were determined using the following equations.

$$F = mv^2/(2d) \text{\_\_\_\_\_\_\_\_\_\_(Equation 01)}$$

Where F is the average impact force, m is the mass of the hammer, V is the initial speed of the hammer, and d is the distance travelled during the collision.

$$V = r\omega \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_(Equation 02)}$$

Where V is the linear velocity of the crankshaft, ω is the angular velocity and r is the radius of the circular path of the crankshaft.

$$1\, rad\, s^{-1} \quad = \; 60/2\pi\, rpm$$

As the radius of the crankshaft was 0.02 m, the mass of the hammer was 0.3 kg, and the expected distance of travel during collision is 0.01m, the required linear velocity, and angular velocity to achieve 30 N impact force was 1.41 ms^{-1}, and 70.71 rad s^{-1} (674.96 rpm). The diameters of the drive and driven pulleys were determined using the following equation 03 [7].

$$\frac{N1}{N2} = \frac{D2}{D1} \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_(Equation 03)}$$

Where N1 is the rotating speed (rpm) of the drive pulley, N2 is the rotating speed (rpm) of the driven pulley, while D1 is the diameter of the drive pulley and D2 is the diameter of the driven pulley. As the rated rpm value of the motor is 1400 and the desired speed of the crankshaft is 675 rpm, the ratio between the diameters of the drive and driven pulleys is 1:2. According to [8] , the length of an open belt is given by the following equation 04.

$$L = \frac{\pi}{2}(D_1+D_2) + 2C + \frac{1}{4C}(D_1+D_2)^2 \text{—— (Equation 04)}$$

Where L is the length of the belt in inches, C is the centre length between two pulleys in inches, D_2 is the pitch diameter of the first pulley in inches and D_1 is the pitch diameter of the second pulley in inches. As the diameters of drive and driven pulleys were 2 and 4 inches, respectively and the centre distance of pulleys was 12 inches, the total length of the belt was 35 inches. The frame of the machine, which is made of mild steel was used to support all the component parts together in one assembly. The weight of the frame is supposed to reduce unnecessary vibrations when in operation. Therefore, L iron bars and iron rods were used to make the frame. Assembling the parts without disturbing all its expected tasks is very important and which received serious consideration in designing the frame.

Collecting Peg helps to remove the cracked *Kottamba* nuts from the holders and into the collecting tray. The collecting peg is permanently fitted to the frame and it removes all nuts from fruit holders continuously.

2.3. Measuring the dimensions of fruits

A sample of 100 tropical almond fruits (Figure 2) collected from 05 different locations of the country was measured to determine the average length, width, and thickness, a mandatory requirement in order to design important corresponding components of the machine. 0-300 mm auto power off digital Vernier Caliper, with reading accuracies of 0 -200 mm measuring range 0.03 mm and 200 – 300 mm measuring range 0.04 mm was used to measure each parameter.

Figure 2: Dried tropical almond fruits

2.3. Performance evaluation of the machine

The machine was tested for its performance compared with the traditional (manual) nut-cracking method using a hammer. Five male and five female workers were employed in the evaluation process with three repeats (replicates). Randomly collected tropical almond nuts from 05 different locations of Sri Lanka were dried properly (to the desired feel) before the evaluation. Moisture content was determined by the oven-dry method on wet basis. Five samples of dried fruits were taken randomly for moisture content determination. A metal hammer with a wooden handle which is nearly equal to the weight of the hammer of the machine and a metal base on which to keep the fruits were provided for the manual cracking.

During each trial, time taken to crack one fruit/nut, the total number of cracked nuts within 1 hour, number of completely cracked nuts, number of incompletely cracked nuts, number of damaged nuts, injuries caused to the operator, and breakdown time of the machine were recorded. The performance of each method was determined in terms of theoretical cracking capacity, actual cracking capacity, cracking percentage, nut damage percentage, and cracking efficiency. The actual cracking capacity of manual and mechanical methods with gender was statistically analysed with two-factor factorial design with SPSS software. The cracking percentage, nut damage percentage, and efficiencies of both methods were analysed with t test.

$$Theoretical\ Cracking\ capacity\ \left(\frac{nuts}{h}\right) = \frac{3600}{Time\ taken\ to\ crack\ 1\ fruit\ (seconds)}\ x\ 100 \quad \text{(Equation 05)}$$

$$\text{Actual Cracking capacity}\ \left(\frac{\text{nuts}}{\text{h}}\right) = \frac{\text{Number of fruits cracked by the machine}}{\text{Time taken (h)}}\ \text{x}\ 100 \quad \text{(Equation 06)}$$

$$\textbf{Cracking percentage}\ (\%) = \frac{\text{No. of completely cracked nuts within unit time}}{\text{Total number of cracked nuts within unit time}} \text{x}100 \quad \text{(Equation 07)}$$

$$\textbf{Nut damage Percentage}\ (\%) = \frac{\text{Number of damaged nuts}}{\text{Number of fruits fed to the machine}} \text{x}100 \quad \text{(Equation 08)}$$

$$\text{Cracking efficiency} = \frac{\text{Actucal cracking capacity}}{\text{Theoretical cracking capacity}}\ \text{x}\ 100 \quad \text{(Equation 09)}$$

3. Results and Discussion

The prototype of the machine was developed after a series of trials and modifications and then evaluated. The total production cost including material and labour for the prototype was 65000.00 LKR. As there is no nut-cracking machine for tropical almonds is commercially available, this prototype machine could be introduced at a very nominal price. The Plate 1 (a, b, c and d) show the fabricated phototype of the machine. Table 1 provides some specifications of the machine.

Table 1: Specifications of the tropical almond cracking machine

Parameter	Specification
Weight	62.5 kg
Length	0.75 m
Width	0.60 m
Height	0.50 m
Speed of the motor	1400 rpm
Drive pulley	0.0508 m
Driven pulley	0.254 m

a. Front view of the Tropical almond cracking machine

b. Electric motor, belt conveyor and hammer of the machine

c. Power transmission from motor to hammer

d. Operating handle of the conveyor

Plate 1: Different component parts of the nut-cracking machine

3.1 Moisture content of samples

The moisture content is the most important factor to be considered in the designing of a cracking machine for the extraction of the kernel from its nut [9]. The average moisture content of dried tropical almond fruits, which was used for evaluation, was 21% on a wet basis. Very low moisture content will make the kernel to be brittle and high moisture content will make it stick to the shell of the nut in almonds [6].

3.2 Important dimensions of the tropical almond fruit for designing

The average length, width, and thickness of tropical almond fruits were used in designing fruit holders of the cracking machine. The average length, width, and thickness were 487 mm, 323 mm, and 212 mm, respectively. These are in agreement with Morton (2019) where he measured length and width of the tropical almond fruit to be 4-7 cm and 2.5-3.8 cm, respectively. Table 2 shows the dimensions of measured fruits in this experiment.

Table 2: Dimensions of tropical almond fruits

	Length (mm)	Width (mm)	Thickness (mm)
Mean	487	323	212
Max.	526	343	221
Min.	420	208	192
Std. Dev.	35.25	30.82	5.69
Range	106	135	20

3.3 Performance of the nut-cracking machine

The theoretical cracking capacity, actual cracking capacity, cracking efficiency, damaged nut percentage, and cracking percentage with male and female workers were used to elaborate the performance of the nut-cracking machine. Theoretical capacity means the number of nuts cracked by either method without taking the time wastage into account. Here it is assumed that the operator continuously working at the maximum capacity and with no time wastage. It is the maximum capacity that can be achieved under a particular condition and something which cannot be achieved in practical situation, but which could be used to compare a method with its potential maximum level. The average theoretical capacity of the manual nut cracking method for males and females were 225 nuts/hr and 200 nuts/hr, respectively. The corresponding figure for mechanical nut cracking was 327 nuts/hr for both male and female operators. Actual cracking capacity means the number of nuts cracked by any method within a unit of time. In here, time utilized for resting, adjustments and various reasons were taken into account. Table 3 shows the actual nut cracking capacities of males and females in manual and mechanical nut cracking.

Table 3: Actual nut cracking capacity

	Manual cracking (nuts/hr)		Mechanical cracking (nuts/hr)	
	Male	**Female**	**Male**	**Female**
Mean	183.98	165.53	285.21	283.88
Std. Div.	2.49	2.91	2.04	2.02
Max.	187	169	289	286
Min.	178	160	282	280

The main effects of method and gender on actual cracking capacity were statistically significant (*p<0.05*). The actual manual cracking capacity was significantly higher in the male in comparison to females (*p<0.05*). Moreover, actual cracking capacity was significantly higher in the mechanical method compared to the manual method (*p<0.05*). The interaction effect of method and gender too were statistically significant (Figure 3). Under manual methods, the performance of males was higher in comparison to females. However, the performance of males and females was similar under the mechanical method. This means the actual capacity of the machine was not affected by the physical strength of the operator.

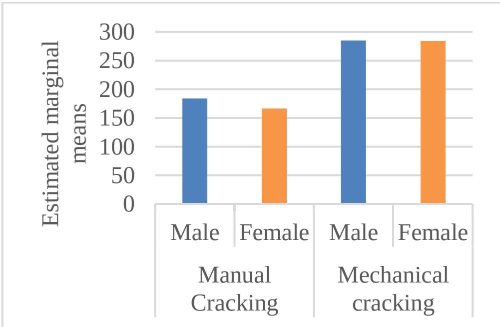

Figure 3: Interaction plot of actual capacities of manual and mechanical methods with gender

Table 4 shows the theoretical capacities, actual capacities, and efficiencies of both methods with gender.

Table 4: Mechanical performances with gender

	Manual		Machine	
	Male	**Female**	**Male**	**Female**
Actual capacity (nuts/hr)	184	166	285	284
Theoretical capacity (nuts/hr)	225	200	327	327
Efficiency (%)	82	83	87	87

The average efficiencies of the manual and mechanical methods were recorded as 82% and 87%, respectively. The lower efficiency of the manual method reflects that the associated time wastage in the manual method is higher than in the mechanical method.

Table 5 shows the damage nut percentage of both mechanical and manual cracking methods. In manual cracking damaged nut percentage was 7.2% while in the mechanical method it was only 1.3%. Even and controlled impact action of the hammer of the machine could be cited as the reason for this less damage. If the orientation of the nut can be addressed well when the nut is placed in the fruit holder, the damaged nut percentage can be further reduced. In addition to the injuries caused to the operator, the damage caused on the machine too could be an important factor to consider. This was given due consideration, during the evaluation and comparison process. There was no damage recorded during the process of this operation. However, this may prove to be different under longer operational conditions.

Table 5: Damaged nut percentage

	Manual cracking	Mechanical cracking
Mean	7.22	1.36
Std. Div.	1.94	0.72
Max.	11.2	3.21
Min.	4.3	0
P(T<=t) one-tail	3.10E-14	
P(T<=t) two-tail	6.21E-14	

4. Conclusions

The motorized tropical almond nut-cracking machine showed satisfactory results at a capacity of 285 nuts/hr with 87% efficiency. Although the capacity and efficiency of the manual nut-cracking were influenced by gender, both of them were not affected due to gender in the mechanical method under investigation .It implies that the operation of the mechanical method is easier and does not depend on the physical strength of the operator. As the total production cost of the machine at the research level was LKR 65000.00, it would be affordable for the low-income people who wish to start a new enterprise using tropical almonds with some value-addition. The machine did not result in much damage on the kernels and did not cause any injuries on the operators. In future, it would be possible to couple the conveyor of the machine with the hammer for increased efficiency.

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