Review Article

The technological developments in power operated coconut (*Cocos nucifera L.*) dehusking and deshelling machines: A Review

Abstract

The aim of this paper is to present recent developments related to power operated coconut dehusking and deshelling machines. Coconut is a fruit of great value as every part of the fruit is commercially viable. To utilize coconut fruit and its parts, it is necessary to remove the coconut husk and to break the coconut shell. Coconut husking and shell breaking are traditionally labour-intensive operations. Both the mentioned operations are tedious, require skills and prone to harm the worker. There are many attempts to reduce the human drudgery involved in coconut processing operations by making machines which can dehusk and deshell the coconuts. The paper simply explains working mechanisms, features and capacity of recently developed machineries in the field of coconut dehusking and deshelling. The different types of working mechanisms used for coconut dehusking and deshelling can be overviewed from this review, which can be helpful for further developments in this field.

Key Words: C*oconut, Coconut Dehusking, Coconut Deshelling, Coconut Processing*

Introduction

Coconut (*Cocos nucifera* L.) is tree of family Arecaceae which is also known as Palm family and of subfamily Cocoideae. Coconut is named with some unique adjectives like Tree of life, world's most useful plant, Tree of Heaven and so forth, because each and every part of coconut tree is useful for some purpose. Coconut is thought to be native to coastal areas of Southeast Asia (Malaysia, Indonesia, Philippines etc.) and Melanesia (Fiji, Vanuatu, the Solomon Islands, and Papua New Guinea). Wild types of coconut (niukafa) were believed to have been carried towards eastward on ocean currents to the tropical Pacific islands (Melanesia, Polynesia, and Micronesia) and westward to coastal India, Sri Lanka, East Africa, and tropical islands (e.g., Seychelles, Andaman, Mauritius) in the Indian Ocean. It plays an important role the lives and economies of people in regions like Indian subcontinent, Southeast Asia, Africa, Central America/Caribbean, Melanesia, Polynesia and Micronesia.

The coconut fruit is a fibrous drupe. From outside in, the coconut consists of a thin hard skin (exocarp), a thicker layer of fibrous mesocarp (husk), the hard endocarp (shell), the white endosperm (kernel), and a large cavity filled with liquid (water). When immature, the exocarp or outer skin is usually green or sometimes bronze. Wide variation in fruit shape and size exists within types and populations. Fruit shapes vary from elongated to almost spherical. Coconut tree can produce fruits throughout the year and one tree may yield around 50-80 fruits per year. (Chan and Elevitch, 2006; Orwa *et al.*, 2009; Asha Monicka *et al*., 2021).

It is well known that coconut fruit can be used for versatile purposes. This includes use of coconut as food, fodder, fuel, in apiculture and for fiber, in construction works, lipids, alcohol, for creation ornamental products etc. Coconut uses as food include copra, edible cooking oil, coconut chips, coconut honey, coconut jam from tender coconut, coconut candy, coconut milk, vergin coconut oil, milk and coconut sweet, defatted coconut meat as animal feed etc. There are many industrial uses of coconut fruit like fibres of coconut husk are used in making ropes and many kinds of useful articles, coconut oil can be used in soaps, detergents, shampoos, cosmetics, pharmaceuticals and explosives, coconut-shell charcoal's activated carbon can be used in general water purification, crystalline sugar preparation and gold purification (Orwa *et al.*, 2009; Agarwal and Bosco, 2014; Singh *et al.*, 2017; Shahanas *et al*., 2019)

The whole coconut fruit is composed of several different layers, mesocarp. husk, shell, peel and coconut meat. Coconut meat and coconut water are financially important part of coconut fruit. Coconut meat and coconut water are found at centremost part of the fruit. To obtain these important parts the coconut husk and coconut shell must be removed. Coconut husk is composed of many fibrous layers and are woven tightly with each other. On the other hand, coconut shell is single hard sphere covering coconut meat. Removal of husk and shell are most time consuming, repetitive, labour intensive, fatiguing, tedious and dangerous works in coconut processing. Traditionally and also till date, removal of husk and shell are performed largely by manual force with little help of tools. The workers had faced with minor/ major injury resulting slash or wound in hand, palm, thigh and upper body. The bending posture they adopt during local method of dehusking was tiresome and prone to be hazardous. This job was not very popular as it was often difficult to find labour for this operation due to every possibility of accidents. The manual coconut processing involves a lot of drudgery and

requires precaution against injury. The average dehusking capacity in traditional practices was observed 60-70 nuts/h (Mishra and Mohanty, 2016).

The power operated coconut dehusking and deshelling machines have numerous advantages over manual dehusking and deshelling. Power operated dehusking and deshelling machines reduces human drudgery, makes dehusking and deshelling easier, improves quality of operation, improves capacity of operation, makes dehusking and deshelling safer and power operated dehusking machines and deshelling machines are economical in long term (Singh and Udhayakumar, 2006; Jacob and Rajesh, 2012; Deo *et al.*, 2020; Varghese *et al.*, 2021). Although there are many tools and machines invented to perform these operations, still dehusking and deshelling of coconut is the labour-intensive task. Most of the available machines are for dehusking operations and very few are available for deshelling operation (Titmas and Hickish, 1929; Chan and Elevitch, 2006; Orwa *et al*., 2009; Vargheser and Jacob, 2014).

This review discusses the earliest documented machines related to husk removal and shell breaking to the most recent development in the field. The equipment and machines that are used to remove husk and break the coconut shell are discussed in separate sub sections. Both types of machines are further classified and briefly discussed in following subsections with appropriate representative figures or images. The machines discussed in further subsections may have similar names or generic names and the names are kept such as reported in their respective literatures.

1. Coconut dehusking machines: Majority of power operated dehusking machines make use of a rotating mechanism to remove the husk. Yet some machines employ different mechanisms like cam and follower and hydraulic expanding arms. A variety of machines, unique in operating mechanisms are discussed hereunder. The power operated dehusking and deshelling machines discussed in following section and overview of all the machines in terms of working mechanism and capacity is given in Table 1.

Table 1 Overview of power operated coconut dehusking machines

Sr no	Machine name	Dehusking Mechanism	Capacity (coconuts/hour)	Reference
1	Coconut dehusking machine (1987)	Rotating spike rolls	-	Dinanath (1987)

2	Hydraulically operated coconut dehusking machine	Hydraulic expanding arms	-	Kwangwaropas (1991)
3	General purpose coconut dehusking machine	Rotating spike rolls	-	Kwangwaropas (1998)
4	Power operated coconut dehusker (2008)	Rotating spike rolls	220-225	Gajakos *et al.*, (2008)
5	Twin-blade type powered-coconut husking machine	Cam and follower	-	Chandran *et al.*, (2012)
6	Power operated coconut dehusker (2011)	Cam and follower	-	Ghoshal and Mohanty (2011)
7	Coconut dehusking machine (2012)	Rotating spike rolls	120-150	Jacob and Kumar (2012)
8	Hydraulic coconut dehusking machine	Hydraulic expanding arms	300	Sakhare *et al.*, (2014)
9	Rotary coconut dehusker	Rotating drum and stationary concave	-	Vargheser and Jacob, (2014)
10	Mechanical coconut husking machine	Rotating spike rolls	-	Vargheser and Jacob, (2014)
11	Continuous power operated coconut husking machine	Rotating drum and stationary concave	356	Chandran, (2012)
12	Coconut dehusking machine (2014)	Rotating spike rolls	-	Taufik and Akhir, (2014)
13	Automated coconut dehusking and crown removal machine	Rotating spike rolls	210	Venkataramanan *et al.*, (2014)
14	Power operated dehusker (2015)	cam and follower	115-130	Patil *et al*., (2015)
15	Coconut de-husking, cutting and grating machine	Rotating spike rolls	-	Deokar *et al.*, (2017)
16	Coconut dehusking machine (2018)	Rotating spike rolls	220	Amal *et al*., (2018)

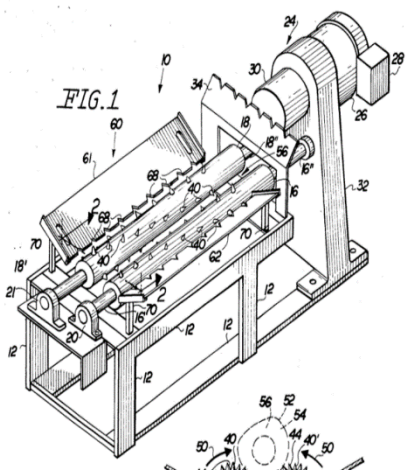
17	Economical coconut dehusking machine	Rotating spike rolls	70	Krishnan *et al*., (2018)
18	Coconut dehusking machine (2019)	Rotating spike rolls	120.6	Ovat and odey (2019)
19	Coconut dehusker machine for small scale industry	Rotating spike rolls	100	Herdian *et al.*, (2019)
20	Electric coconut husk remover	Rotating spike rolls	250-390	Andanappa *et al.*, (2020)
21	Coconut dehusking machine (2020)	Rotating spike rolls	45 (60.40% mc) 97 (30.02% mc) 175 (5.08% mc)	Chukwu *et al*., (2020)
22	Auger-assisted semiautomatic coconut husking machine	Augur assisted cam and follower	242 (green coconut) 229 (dry coconut)	Varghese *et al.*, (2021)
23	TNAU Power operated coconut dehusker	Rotating drum and stationary concave	-	Anonymous, 2021
24	Coconut dehusking machine model:COM11	Hydraulic expanding arms	-	Anonymous, 2021a

Table 2. Overview of power operated coconut deshelling machines

Sr no	**Machine name**	**Deshelling Mechanism**	**Efficiency**	**Capacity**	**Reference**
1	Coconut shelling machine	Impaling of blade on stationary shell	-	-	Mix (1995)
2	Coconut deshelling machine	Impaling of blade on stationary shell	90%	195 coconuts/hour	Tonpe *et al*., (2014)
3	Batch type coconut deshelling machine	Mutual impact in rotating drum	92%	200 coconuts/batch	Singh and Udhayakumar, (2006)

4	Electric motor powered low cost coconut deshelling machine	Impaling of blade on stationary shell	95%	24 coconuts/hour	Mondal and Kumar (2016)
5	Power Operated Coconut de-shelling machine	Impaling of blade on stationary shell	89-82%	141-144 coconuts/hour	Deo *et al.*, (2020)
6	Coconut deshelling machine model:COM20	Impaling of blade on stationary shell	-	360 coconuts/hour	(Anonymous. 2021b)

Figures of power operated dehusking machines



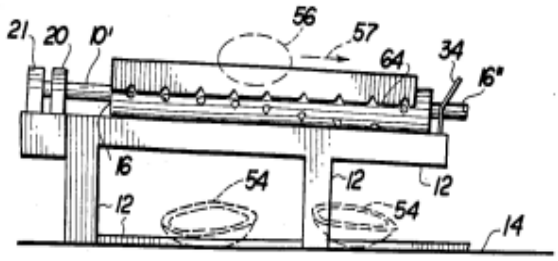


Fig. 1.1 Twin roller coconut dehusking machine

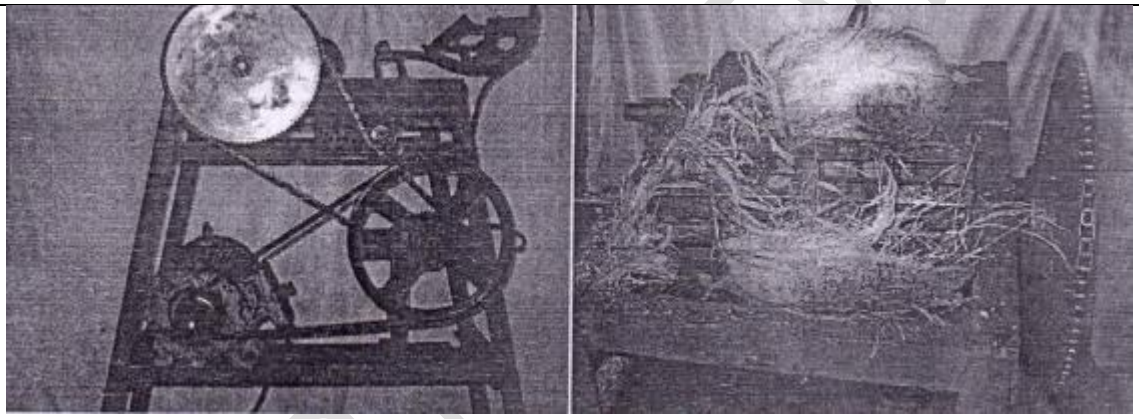


Fig. 1.2 Triangular teeth roller coconut dehusker

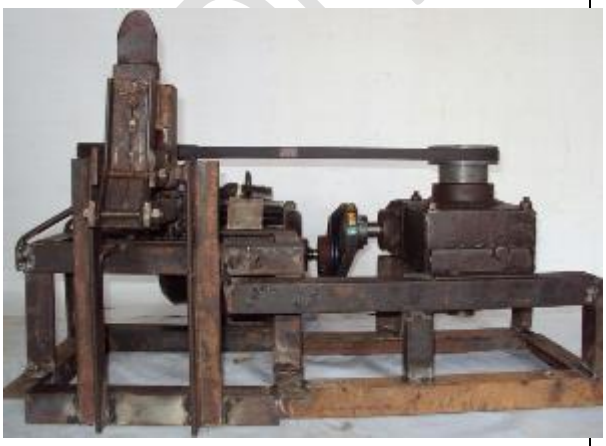


Fig. 1.3 Twin blade type powered coconut husking machine

Fig. 1.4 Cam and follower type coconut dehusker

Fig. 1.5 Coconut dehusking machine (Two spiked rolls)

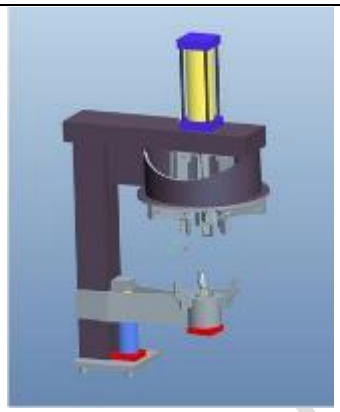


Fig. 1.6 Hydraulic coconut dehusking machine.

Fig. 1.7 Rotary coconut dehusker

Fig. 1.8 Mechanical coconut husking machine

Fig. 1.9 Continuous power operated coconut husking machine with its husk loosening mechanism(a) and husk removing mechanism (b).

Fig. 1.10 Petrol engine powered coconut dehusking machine

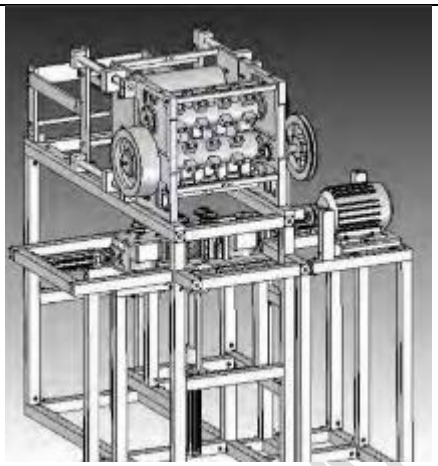


Fig. 1.11 Automated coconut dehusking and crown removal machine

Fig. 1.12 Power operated dehusker

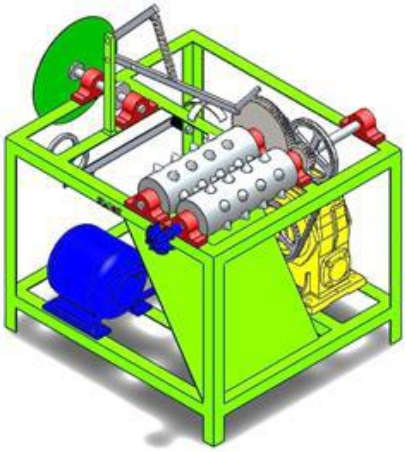


Fig. 1.13 Coconut De-Husking, Cutting and Grating Machine

Fig. 1.14 Single spiked roll type coconut dehusking machine

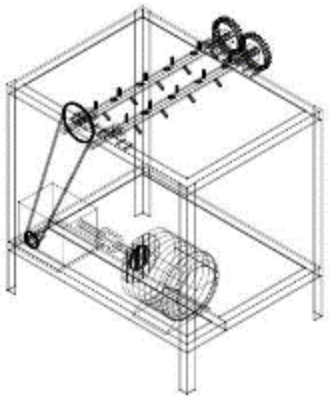


Fig. 1.15 Economical coconut dehusking machine

Fig. 1.16 Coconut dehusking machine with flywheel

Fig. 1.17 Coconut dehusker machine for small scale industry

Fig. 1.18 Electric coconut husk remover

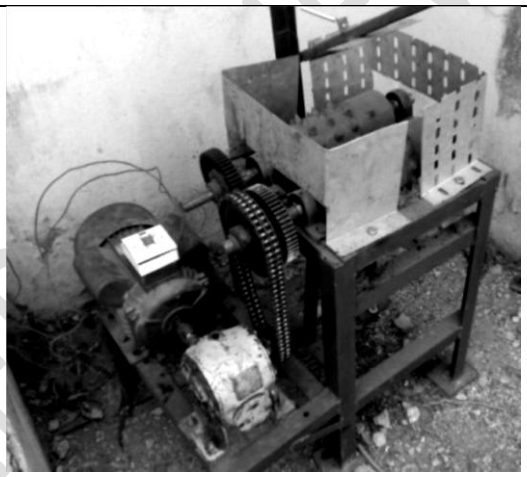


Fig. 1.19 Spiked and rollers type coconut dehusking machine

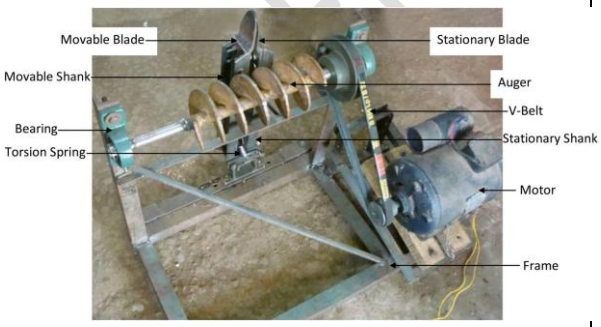


Fig. 1.20 Auger-assisted semiautomatic coconut husking machine

1.21 TNAU Power operated coconut dehusker

Fig. 1.22 Coconut dehusking machine (model:COM11)

1.1 Twin roller coconut dehusking machine: This machine (Fig. 1.1) was developed by Dinanath (1987). It was the first machine to use twin roller to dehusk the coconut. This machine consisted of two rollers rotating in opposite directions with each roller having a number of penetrating spikes at roller's peripheral surface. The rolls were kept inclined to facilitate passage of coconut by means of gravity. The spikes on roll were sharpened to penetrate the husk and the rotating action of rolls would tear away the husk from the shell of the nut.

1.2 Hydraulically operated coconut dehusking machine: The machine developed by Kwangwaropas (1991) consisted of three major parts, frame, power unit (1.5 kW electric motor) with hydraulic system and the dehusking mechanism. Two operators were required simultaneously to perform the dehusking operation. One person was required to operate the machine to loosen the husk and the other one removes small amount remaining husk from the shell. The average time required to dehusk the coconut was 10-12 seconds/coconut.

1.3 General purpose coconut dehusking machine: The machine was designed and developed by Kwangwaropas (1998). The machine consisted of the following major components: a frame, a power transmission unit (2 hp electric motor), a dehusking mechanism, a polishing mechanism and a husk conveying mechanism. The machine consisted of two rolls rotating in opposite directions and having six fins fixed on the periphery. The dehusking process concluded in two steps, 1) dehusking of coconut by pressing it down on dehusking rolls and 2) polishing already dehusked coconut on two

revolving brush sets. The time required to dehusk both dry and green was almost similar averaging 4.77 seconds.

1.4 Triangular teeth roller coconut dehusker: The machine was developed by Gajakos *et al.* (2008). The machine (Figure 1.2) consisted of a frame, electric motor (5 hp), speed reduction unit and dehusking unit. The dehusking unit un power operated dehusker consisted of two rolls, among them one was powered and the other was idle, the powered roll had triangular teeth on periphery. The triangular shaped teeth pierce the husk and tear it away from the coconut shell. The average time required to dehusk the coconut was found to be 16.56 second with dehusking efficiency and damage percent 82% and 18 % respectively. The capacity of the machine was found to be 200-225 coconuts per hour.

1.5 Twin blade type powered coconut husking machine: The machine comprised of a cam and a follower which was connected to a hinged movable-blade for separating the movable blade from the stationary blade (Fig. 1.3). The cam and follower mechanism was intended to allow dwelling of the two blades in the juxtaposed position for 280° and separation of the blades for the remaining 80°. The average time required to dehusk green coconut was 14.1s (second) and for dry coconut 15.1s. The husk was split into 3 to 5 pieces for complete removal of husk (Chandran *et al.*, 2009).

1.6 Cam and follower type coconut dehusker: Ghoshal and Mohanty (2011) conducted an ergonomically study and performance evaluation of manual and power operated dehusking machines. The power operated machine (Figure 1.4) consisted of a power source (1 hp electric motor), speed reduction unit, belt and pulley mechanism, cam, lever and knife/finger, hand protecting cover and a concave chute. The machine works on cam and follower mechanism, the power transmitted from the motor to reciprocating finger/knife, a similar finger is kept stationary. The reciprocating knife mimics the action of expanding and contraction action done in a manual dehusking machine. When both fingers are in a closed position the coconut is pressed on it. During reciprocating motion, the movable fingers are pulled away and the husk is torn from the shell. The whole action is to be repeated 3-4 times to complete loosening of the husk. Then a separate person removes the loosened husk from the coconut.

1.7 Coconut dehusking machine (Two spiked rolls): The machine was developed by Jacob and Kumar (2012) with a view to minimize drawbacks of manual dehusking methods. The machine was designed on the basis of various coconut properties such as, coconut shape, coconut dimensions, thickness of coconut husk, and weight of coconut. Force required to

dehusk was determined using an UTM machine and was used to determine the power requirement to dehusk the coconut. As seen from Figure 1.5, the machine consisted of an

Figures of power operated deshelling machines

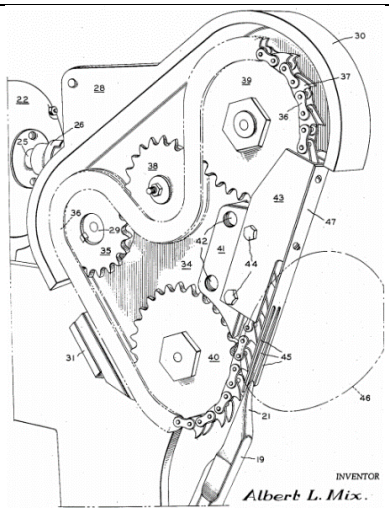


Fig. 2.1 Chain and teeth type coconut shelling machine

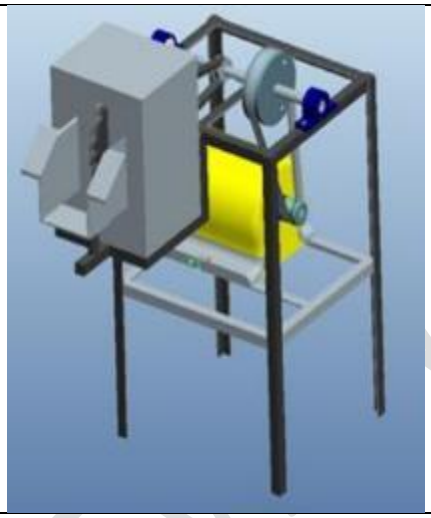


Fig. 2.2 Coconut deshelling machine (Belt and pulley drive)

Fig. 2.3 CPCRI batch type coconut deshelling machine

Fig. 2.4 Electric motor powered low cost coconut deshelling machine

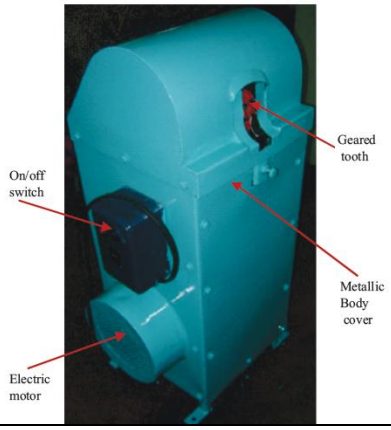


Fig. 2.5 ICAR-CPCRI power operated coconut de-shelling machine

Fig. 2.6 Coconut deshelling machine (Model:COM20)

electric motor (1 hp) as power source, a combination of belt and pulleys, spur gears for power transmission and a set of two spiked rolls to dehusk the coconuts. The capacity of the machine was found to be 120-150 coconuts per hour and the dehusking time per coconut ranged from 20-45 seconds.

1.8 Hydraulic coconut dehusking machine: The machine consisted of a hydraulic power unit, hydraulic cylinders, valves and gripping mechanism (Fig. 1.6). During the operation of the machine, the coconut was lifted by a gripping mechanism to height which could reach the working radius of the dehusking mechanism. The dehusking mechanism consisted of knifed links, which was used for opening coconut husks. The expansion of knifed links causes the removal of coconut husk by expansion. The capacity of the machine was found to be 300 coconuts per hour (Sakhare *et al*., 2014).

1.9 Rotary coconut dehusker: The rotary coconut dehusker was developed at KCAET, Tavanur for large-scale use. Dehusker consisted of a feeding inlet, a husking unit comprised of rotating drum and stationary concave assembly, a husk separation unit and power transmission unit (Fig.1.7). The concave and drum assembly was designed such that the inlet would allow whole coconut, while the outlet was contracted. Many small blades/spikes were welded on the periphery surface of the drum and the inner surface of the concave. The coconut was fed at the inlet and into the clearance between the inlet and the drum which reduces slightly by the system and forces the coconut to rotate. During this process, the blades/spikes penetrate the husk and puncture the surface. The shear force exerted upon the coconut by the blades of the rotating drum and the concave cause it to rip open the husk along different planes. (Vargheser and Jacob, 2014).

1.10 Mechanical coconut husking machine: The mechanical coconut husker consisted of three major components- an inlet throat, a husking mechanism, and an outlet (Fig. 1.6). The husking mechanism consisted of two rollers powered electrical motor (1.5 hp) with integral speed reduction and a gear box the whole set mounted almost vertically at the top of the machine. There were two kinds of rollers, the one on the right side were powered and other was spring loaded for pushing the coconut. The outermost roll had a series of slightly curved sharp hook-like knives that penetrate the husk when coconuts are fed from the mouth of the

throat. The whole coconut was fed through the converging feed chute in vertical position by hand. In the process, the sharp right roll consisting of slightly curved hook-like knives engage with the husk and left spring-loaded rollers press the coconut towards the right spiked rollers. As the rollers rotated, the husk gets detached from the shell, effecting a complete dehusking of coconut. (Vargheser and Jacob, 2014).

1.11 Continuous power operated coconut husking machine: Continuous power operated coconut husking machine (Fig. 1.9). was developed at KCAET and has a similar working mechanism of a rotary type coconut husking machine. The machine consisted of a feeding inlet, a husking unit made of rotating drum and stationary concave assembly, a husk separation unit and power transmission unit. At the feeding inlet the clearance between the inlet and the drum was slightly reduced and thus during operation this arrangement forced the coconut to rotate. During the process, the blades penetrate the husk and puncture it on the surface. The shear force employed upon the coconut by the blades of the dehusking mechanism caused it to rip open the husk surface. There the softened and punctured husk is separated and the nut emerges at the outlet. The coconut with loosened husk then falls into a husk removal unit consisting of two cylinders with protruding bars fixed on them. The rolls rotate in opposite directions and peel away the loose husk. The capacity of the machine was found to be 356 nuts per hour and average time required to dehusk one green coconut was 11.6 s and 9.5 s for dry coconut. The major problem related to this machine was that it was bulky and had high power consumption (Chandran, 2012).

1.12 Petrol engine powered coconut dehusking machine: This machine (Fig. 1.10) works on the principle same as of the one developed by Dinanath (1987). There is change in inclination of the rollers, in this machine rollers were kept inclined in a vertical position. This may facilitate easy movement of coconut from inlet to outlet by the help of gravity. This machine consisted of a 4.1 kW (5.5 hp) petrol engine that generated power to operate a hydraulic system, which controlled the movement of the double spike rollers by moving forward, reverse or stop using an operation lever. A hydraulic motor connected to the double spiked rollers using a pair of chain and sprockets. Coconuts were fed between the spiked rollers to start-off the dehusking process. An experiment was conducted to evaluate the effects of machine settings on dehusking time and the damages of coconuts. The machine setting variables were different roller spike gaps (2.5 cm and 5.1 cm), different coconut orientation and different rotational speeds (300 rpm, 350 rpm and 390 rpm). Three coconut

varieties were used, namely Malayan Tall, MAWA and MATAG. The MAWA variety produced the fastest dehusking time of 5.39 seconds using the smallest spiked roller gap of 2.5 cm. There was statistical evidence that rotational speed influenced MAWA dehusking time. Significant differences were obtained in dehusking time across coconut orientation for Malayan Tall. All varieties sustained no damages while dehusking, except for MAWA when the largest spiked roller gap of 5.1 cm was used (Taufik and Akhir, 2014).

1.13 Automated coconut dehusking and crown removal machine: The machine (Fig. 1.11) developed by Venkataramanan *et al.* (2014) aimed to eliminate the skilled operator involved in de-husking the coconut and to completely automate the dehusking and crown removing process. According to the authors, operation of the machine was simple and the maintenance of the machine was also not expensive. The machine could produce an average of 210 nuts per hour. It was also emphasised that introducing this machine in the farm areas could reduce the risk involved in the use of spikes in dehusking the coconut and also eliminates the skilled manpower required for dehusking the coconuts. The machine could also be integrated along with the further processing steps of the nuts such as the production of copra.

1.14 Power operated dehusker: Patil *et al.* (2015) developed a power operated coconut dehusking machine whose dehusking mechanism worked on principle of cam and follower mechanism. The machine (Figure 1.12) consisted of a main frame, electric motor, gear box, cam and follower, lifter, holding mechanism and splitting mechanism etc. during the dehusking operation the coconut is held horizontally by holding jaws. The cam and follower mechanism did two actions simultaneously, lifting and penetration of movable blades and splitting of coconut husk. The action was repeated 3-4 times to complete the loosening of the whole coconut husk. The dehusking time ranged from 28.28 seconds to 30.58 seconds and the capacity was found to be 115-130 coconuts per hour.

1.15 Coconut de-husking, cutting and grating machine: The machine developed by Deokar *et al*. (2017) can perform three operations viz. dehusking, cutting and grating (Figure. 1.13). Two toothed shafts rotating in opposite directions were used to dehusk coconut. The next operation which can be performed on this machine was cutting the coconut in half by rotating circular blade, before that if required coconut water can be extracted by punching coconut with a punching tool on the machine. The final operation which can be performed on this machine was grating of coconut meat on cut coconut halves. The average time for

coconut dehusking was 23 seconds, for cutting 11 seconds and for grating 19 seconds. The operation time was dependent on the quality of coconut in terms of maturity, a brown mature coconut was found to be giving best results

1.16 Single spiked roll type coconut dehusking machine: Amal *et al.*,(2018) developed a coconut dehusking machine to eliminate drawbacks regarding human drudgery, long time required by labours and to minimize difficulties related to it. The machine consisted of two rotating cylinders having tines (cutting pins) on one cylinder on its surface and another simple cylinder. The rolls rotated in opposite directions with different speeds to penetrate the husk and tear it away from the coconut shell. The unique feature about this machine was that the machine had tines attached to the cylinder with fasteners, this might help in replacing the tines easily. As it can be seen from Figure 1.14, the machine consisted of an electric motor as power source, combination of worm gear and spur gear as power transmitting mechanism, spiked and simple rolls and a frame to support all components. The machine performance was found to be 220 coconuts dehusked per hour.

1.17 Economical coconut dehusking machine: Krishnan *et al.* (2018) developed a coconut dehusking machine which worked on the principle of rotating spike rolls. The machine (Figure 1.15) consisted of an electric motor (740 watts), gear box (48:1) for speed reduction, chain and sprocket mechanism, gears and spiked dehusking rolls. The machine could dehusk 70 coconuts per hour.

1.18 Coconut dehusking machine with flywheel: This machine was developed by Ovat and Odey (2019) for coconut dehusking. The husk removal operation was carried out by two spiked galvanized steel pipe rollers rotating in opposite directions (Figure 1.16). Combination of spur gears, flywheel, pulley and belt was used to transfer power from 2.2 kW electric motor to rolls. The husk removal was performed by gripping and tearing of husk by spiked rolls. The performance evaluation showed that the average efficiency of the machine was 92.50% while the average capacity was 120.6 coconuts per hour. On the other hand, the percentage number of distorted and broken coconuts were 7.5% and 3.75%.

1.19 Coconut dehusker machine for small scale industry: The machine developed by Herdian *et al.* (2019) to dehusk coconut by means of two nails embedded rollers rotating at different speeds in opposite directions. They remove the husk from coconut by tearing action (Figure 1.17). The power transmitting mechanism consisted of a combination of two speed

reducers of ratios 1:20 and 1:30 with 2 hp motor. The machine had the capacity of dehusking 100 coconuts per hour.

1.20 Electric coconut husk remover: Andanappa *et al.* (2020) design and developed the electric husk remover for coconut fruits. The machine peeled coconut husk with the help of blades formed from iron bars which are attached on two cylinders rotating in opposite directions (Figure1.18). The machine was powered by a three phase 1 horsepower motor having 1440 rpm and the power transferred to rolls from the motor by a combination of belt, pulley, 40:1 ratio gearbox and two spur gears. The dehusking time of coconut was 11-22 seconds with an average of 15 seconds and dehusking capacity was varied from 250-390 nuts per sour with an average of 320 nuts per hour.

1.21 Spiked and rollers type coconut dehusking machine: The machine developed by Chukwu *et al.* (2020) comprised of rollers with spikes, chain drive, gears, electric motor, bearings, shaft, speed reduction gear box of 36:1 and sprockets (Figure 1.19). During operation coconut is to be placed between spiked rollers and the spikes penetrate the husk and tears it off leaving the coconut shell. The performance evaluation of coconut was performed on coconuts having three levels of moisture content (mc) 60.40% (d.b.), 30.02% (d.b.) and 5.08%. The average machine capacity was found to be 45 nuts per hour, 97 nuts per hour and 175 nuts per hour respectively.

1.22 Auger-assisted semiautomatic coconut husking machine: This machine is upgradation to manual coconut husking machines like Keramithra coconut husking machine. The machine is developed by Varghese *et al.* (2021). The machine comprised of a pair of upright blades; held juxtaposed for manual impaling, and an auger which is driven by belt, pulley and electric motor (Figure 1.20). The auger helps in movement of movable blade which in earlier machines was done by hand. The coconut is impaled on pair of blades and the auger pushes movable blade till one complete rotation. This helps in expansion and tearing of coconut husk. The mean time required for complete husking of green coconut and dry coconut have been found to be 12.6 s and 13.6 s respectively. The husking efficiency of ASCHM (Auger-assisted semiautomatic coconut husking machine) was found as 100% with no nut breaking with a capacity of 242 nuts/hr for green coconuts and 229 nuts/hr for dry coconuts.

1.23 TNAU developed power operated coconut dehusker: The machine (Figure 1.21) consisted of semi-circular stationary concave and rotating drum with knives, an electric motor (3hp), speed reduction unit (10:1), husk removal rolls, belt and pully system, chain and sprocket system. During dehusking operation, the small knives on drum penetrate the coconut husk fed through the inlet. The coconut emerges out from concave with loose husk, the loose husk is further pulled away from coconut with the help of two rolls (Anonymous, 2021).

1.24 coconut dehusking machine (Model: COM11): The machine was developed by a private firm based in Kuala Lumpur, Malaysia. The machine worked on bases of hydraulic mechanism. As seen from Figure. 1.22. The machine consisted hydraulically expanding arms to dehusk the coconuts. The operations were carried out in two main stages, 1) loosening of coconut husk by machine and 2) removal of loose husk manually. In first stage, the coconut was placed on coconut holder and the expanding arm (also called gripper) was penetrated around half inch depth, the expanding arms expand around angle of 45°, this action expands the husk and tears it away from the shell. After that the coconut is taken out of the machine and the loose husk can be removed from shell by hands (Anonymous, 2021a).

2 COCONUT DESHELLING MACHINE: Various deshelling machines which have been developed by various researchers are discussed hereunder and overview of all the machines in terms of working mechanism, efficiency and capacity is given in Table 2.

2.1 Chain and teeth type coconut shelling machine: The machine was invented by Mix (1995) with a view to remove the hard shell of the coconut adjacent to the meat after dehusking (Fig. 2.1). An endless chain and teeth mechanism was used to move the coconut about the knife to break the shell. The chain containing teeth was rotated by a motor. Eye of coconut was impelled on point of knife and shell of coconut was then engaged by teeth and the coconut was moved downwards continuously breaking the shell of coconut away from meat. The same process would be repeated by operator on the unshelled sides of coconut.

2.2 Coconut deshelling machine (Belt and pulley drive): A coconut de-shelling machine was developed by Tonpe *et al.* (2014). The machine consisted cutter with belt drive to deshell the coconut (Fig. 2.2). Performances test analysis showed that the machine deshelled the fruits without nut breakage and also that its average deshelling efficiency and capacity were 90% and 195 coconuts per hour. This machine was of the type which removes coconut shell in small portions. The coconut had supported on the extruded metal part, the

rotating cutter's edges would push the coconut shell against the metal part and when this reassured would exceed the strength of coconut shell, it would break. This process would be repeated with other unshelled patches of coconut for complete removal of shell.

2.3 CPCRI batch type coconut deshelling machine: The machine was developed at CPCRI, Kasrgod, India. The machine was developed to deshell partially-dried spilt coconuts (Fig. 2.3). The capacity of the machine was 200 nuts or 400 cups per batch. Partially dried copra were loaded into deshelling chamber manually. The deshelling chamber was allowed to rotate at a speed of 10 rpm for different periods and the deshelling efficiency was found best at 4 min. the optimum average moisture content for maximum deshelling efficiency (92%) was at 35% (d.b.) The time saved by using the deshelling machine was four times as compared to the manual method. (Singh and Udhayakumar, 2006).

2.4 Electric motor powered low cost coconut deshelling machine: The authors Mondal and Kumar (2016) developed this machine as alternative and cheaper option for commercially available machines. It consisted of toothed wheel and a deshelling rod to break the coconut shell (Figure 2.4). The power transmission system consisted of an electric motor and compound chain drive. The toothed wheel speed was kept around 34 rpm for deshelling operation. During shell removing operation the operator had to rotate the coconut around 6-9 times for complete removal of shell from kernel. During performance evaluation the deshelling capacity was found to be 24 coconuts per hour with efficiency of 95% shell removal

2.5 ICAR-CPCRI power operated coconut de-shelling machine: Deo *et al*. (2020) evaluated performance of the power operated coconut de-shelling machine developed by ICAR-CPCRI, Kasaragod, Kerala, India (Figure. 2.5). The machine consisted of an electric motor of 1 hp, chain and sprocket mechanism, two concentrical circular blades and stationary shaft. The chain and sprocket mechanism reduced motor rpm from 1440 to 24 rpm. The breaking of the coconut shell happens due to impact force of rotating blade. The coconut is to be placed firmly on stationary shaft, the rotating blade impacts on coconut shell, so the portion of shell between stationary shaft and rotating blade gets broken up. This process is to be repeated multiple times till the whole shell is removed. The deshelling capacity of the machine is about 141-144 shells per hour and the deshelling efficiency was found to be about 89-92%.

2.6 Coconut deshelling machine (Model:COM20): The machine was developed by a private firm, Method Machine Works which is based in Kuala Lumpur, Malaysia. The machine works on principle of impaling blade on stationary coconut shell. On this machine two workers can deshell coconut simultaneously. The power source was 1hp electric motor. The machine is of portable type and can be easily transported. The first part to be removed in the coconut shell is portion around coconut eye, as the eye can provide simple support to hold the dehusked coconut. During proceeding steps coconut must be rotated several times to completely remove the coconut shell. The firm reported deshelling of 360 coconuts per hour (Anonymous. 2021b).

Conclusion

The above-mentioned review suggests that there are numerous coconut husk removing machines developed but comparatively less work is done on shell breaking or shell removing machines. Most of the coconut husking or husk removal machines works on similar mechanism of two spiked cylinders/rolls rotating in opposite directions. The size, speed and types of spikes on periphery of rolls varies from each other. Also, there are some unique mechanisms too, like cam and follower, auger, hydraulics and use of force to loosen the husk before peeling it away. The similar trend is also seen in deshelling/shell breaking machines. Most of the machines use combination of blade and stationary support system to break the shell in small portions. Only one example of impact force can be seen which uses impact of coconuts among themselves to break the coconut shell. Also, there is not any known record of machine which can perform both the husk removal and shell breaking operation.

Reference

Agarwal, R. K., and S.J.D. Bosco, (2014). Optimization of Viscozyme-L assisted extraction of coconut milk and virgin coconut oil. *Asian Journal of Dairy and Food Research*. 33(4): 276. https://doi.org/10.5958/0976-0563.2014.00617.4

Amal, P., S. Sebastian, A. Babu, A.J. Saibu, and S. Kuriakose, (2018). DESIGN AND FABRICATION OF COCONUT DEHUSKING MACHINE. *International Research Journal of Engineering and Technology (IRJET)*. 5(4): 4485–4489. https://doi.org/10.14419/ijet.v7i2.8.10526

Andanappa, S., B. Suprit, G. Sridhar, F. Virupaxagouda, B. Prathiba, and S. C. Sajjan, (2020). Electric Coconut Husk Remover Design and Development. *Journals of Mechatronics Machine Design and Manufacturing*, 2(2): 18–25. https://doi.org/10.46610/jmmdm.2020.v02i02.004

Anonymous. 2021. Power operated coconut dehusker. Available at https://agritech.tnau.ac.in/agricultural_engineering/agriengg_fmp_commercial_po_coconut_dehusker.html Accessed on. 5. July. 2021.

Anonymous. 2021a. CoCoMaN Coconut Processing Machine, Operation Instructions, Coconut Dehusking Machine Model: COM11. Method Machine Works, Kuala Lumpur, Malaysia.

Anonymous. 2021b. CoCoMaN Coconut Processing Machine, Operation Instructions, Coconut Deshelling Machine Model: COM20. Method Machine Works, Kuala Lumpur, Malaysia.

Asha Monicka, A., T. Pandiarajan, and S. Ganapathy. 2021. "Determination of Key Parameters for Grading Dehusked Coconut Using Principal Component Analysis." Journal of Applied Horticulture 23 (1): 15–18. https://doi.org/10.37855/jah.2021.v23i01.03.

Chan, E. and C.R. Elevitch, (2006). *Cocos nucifera* (coconut), ver. 2.1. *In*: Elevitch, C.R. (ed.). Species profiles for pacific island agroforestry. Permanent agriculture resources (PAR), Holualoa, Hawai'i.

Chandran, A.S. 2012, *Development and testing of a continuous power operated coconut husker*. M. Tech. Thesis., Kerala Agricultural University, Tavanur, 2012.

Chandran, A. S., A. Mohan, and P.K. Shabeena 2009. *Development of a power-operated coconut husking machine*. B. Tech. Thesis., Kerala Agricultural University, Tavanur, 2012.

Chukwu, P. M.; B.A. Adewumi, I.A. Ola and O.D. Akinyemi, (2020). Development and Testing of a Coconut Dehusking Machine. *Agricultural Mechanization In Asia, Africa And Latin America*. 51(1): 29-33.

Deo, M. M., A.C. Mathew, M.R. Manikantan and K.B. Hebbar, (2020). Performance Evaluation of Power Operated Coconut de-shelling Machine for different Varieties of Coconut. *Journal of AgriSearch*, 7(03): 154–157. https://doi.org/10.21921/jas.v7i03.18690

Deokar, K., K. Malaviya, K. Mistry, P. Chaudhari and M. Dutta, 2017. Design and Manufacturing of Coconut De-Husking, Cutting and Grating Machine. *International Journal of Engineering Science and Computing*. 7(4): 6571–6574.

Dinanath, C. 1987. Coconut dehusking machine. US patent no. 4708056. Available at, https://patents.google.com/patent/US4708056A/

Gajakos. S.M., S.M. Nalawade, V.V. Aware, S.B. Patil and B.B Thakur. (2008). Development of power operated coconut dehusker. *Ag. Update*. 3(1&2):167-170.

Ghoshal, M. K. and S. K. Mohanty, 2011. Ergonomical study and performance evaluation of different types of coconut dehuskers. *Internat. J. Agric. Engg*. 4(1): 45-51.

Herdian, F., S.A. Novita, I. Laksmana, M.R. Nurtam and Z. Rildiwan, 2019. Development of Coconut Dehusker Machine for Small Scale Industry. *Journal of Applied Agricultural Science and Technology*. 3(2): 309–318.

Jacob, J., and K. S. Rajesh, 2012. Design and fabrication of coconut dehusking machine. *2012 International Conference on Green Technologies, ICGT 2012*. 155–159. https://doi.org/10.1109/ICGT.2012.6477964

Krishnan, R., P.P. Mahalingam, P.S. Samuel Ratna kumar and T. Babu, 2018. Design and fabrication of an economical coconut dehusking machine. *International Journal of Engineering and Technology(UAE)*. 7(2.8 Special Issue 8), 588–591. https://doi.org/10.14419/ijet.v7i2.8.10526

Kwangwaropas, M. 1991. Design, manufacturing and testing of the hydraulically operated coconut dehusking machine. *Witthayasan Kasetsart Sakha Witthayasat*. 25(2): 219-233.

Kwangwaropas, M. 1992. Development and improvement of the hydraulic coconut dehusking machine. *Witthayasan Kasetsart Sakha Witthayasat*. 25(4): 400-408.

Kwangwaropas, M. 1998. Research and development of a general purpose coconut dehusking machine. Research abstracts conducted by University's Lecturers in Thailand during 1995-1997, Office of the Permanent Secretary, Bangkok (Thailand). Bureau of Higher Education Standards.- Bangkok (Thailand), 1998.- p. 216-217.

Mishra, J. N. and S.K. Mohanty, 2016. Development of a coconut dehusker for reducing drudgery and injury. Department of industrial and production engineering, Dr, B, R, Ambedkar national institute of technology, Jalandhar-144011, Punjab, India, December 8-11, 2016. pp. 111-114. (*Proceeding of 14th International conference on humanizing work and work environment HWWE-2016*)

Mix, A.L. 1955. Coconut shelling machine. US patent no. 1783801. Available at, https://patents.google.com/patent/US2783801A/

Orwa, C., A. Mutua, R. Kindt, R. Jamnadass, and S. Anthony, 2009. Agroforestree database: a tree reference and selection guide version 4.0. Available at, http://www.worldagroforestry.org/sites/treedbs/treedatabases.asp Accessed on 17 May 2018.

Ovat, F. A. and, and S.O. Odey, 2019. Development and Performance Evaluation of Coconut Dehusking Machine. *The International Journal of Engineering and Science*. *8*(10 Series II): 15–22. https://doi.org/10.9790/1813-0810021523

Patil, S. R., P.U. Shahare, V.V. Aware, and Shirsat. 2015. Development of Power Operated Coconut Dehusker. *J. Indian Soc. Coastal agric. Res*. 33(1): 52-55.

Shahanas, E., S.T. Panjikkaran, K.T. Suman, E.R. Aneena, and C.L. Sharon, 2019. Standardisation and quality evaluation of jam using tender coconut pulp and fruit pulp. Asian Journal of Dairy and Food Research, 38: 31–40. https://doi.org/10.18805/ajdfr.dr-1427

Sakhare, V. P., K.K. Tonpe and N.C. Sakhale, 2014. Design and Development of Coconut De-husking Machine. *International Journal of Engineering Research and Technology (IJERT)*. 3(7): 670-674.

Singh, B., K. Khamrui, J. Lodh, A. Debnath and W. Prasad, 2017. Selection of levels of ingredients for the preparation of milk-coconut sweet based on sensory and

instrumental colour attributes. Asian Journal of Dairy and Food Research, 36(02): 106–111. https://doi.org/10.18805/ajdfr.v36i02.7952

Singh, T.V. and R. Udhayakumar, 2006. Development of a coconut de-shelling machine. Available at, https://www.pgia.ac.lk/files/Annual_congress/journel/v18/20.pdf Accessed on 15 May 2018.

Taufik, A.M. and H.M. Akhir, 2014. Performance evaluation of coconut dehusking machine. *Journal of Tropical Agriculture and Food Science*. 42 (2): 183-190.

Titmas, R.W. and R.S. Hickish, 1929. Coconut-husking machine. US patent no, 1724739. Available at, https://patents.google.com/patent/US1724739A

Tonpe, K.K., V.P. Sakhare, and C.N. Sakhale, 2014. Design and performances of coconut De-shelling machine. *International journal of engineering research and applications*. 4(7): 39-44.

Varghese, A., J. Jacob, and A.I. Rajan, 2021. Design, development and testing of an auger-assisted semi-automatic coconut husking machine. *Journal of Food Process Engineering*, *44*(3). https://doi.org/10.1111/jfpe.13638

Vargheser, A., and J. Jacob, 2014. A Review of Coconut Husking Machines. *International Journal Of Design And Manufacturing Technology (IDJMT). Proceedings of the International Conference on Emerging Trends in Engineering and Management (ICETEM14)*. 5(3): 68–78.

Venkataramanan, S., B.A. Ram and R. Rahul, 2014. Design and Development of Automated Coconut Dehusking and Crown Removal Machine. *International Journal of Sciences: Basic and Applied Research (IJSBAR)*.13(2): 183-219.