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Harpreet Kaur Jambh
Senior Research Fellow, Food Grains and Oilseeds Processing Division, ICAR-Central Institute of Post-Harvest Engineering & Technology, Ludhiana, Punjab, India

Kshitiz Kumar
Assistant Professor, Department of Food Processing Technology, A. D. Patel Institute of Technology, New Vidynagar, Gujrat, India

Corresponding Author:
Harpreet Kaur Jambh Senior Research Fellow, Food Grains and Oilseeds Processing Division, ICAR-Central Institute of Post-Harvest Engineering & Technology, Ludhiana, Punjab, India

Design and development of mango stone decorticator

Harpreet Kaur Jambh and Kshitiz Kumar

Abstract
A machine for removal of kernel from mango stones was designed, fabricated and tested. The major component includes jaw assembly, cutter and pneumatic cylinders. The stones are fed into jaw assembly manually and then cutter cuts the stones into two pieces transversely. The positioning of jaw assembly and movement of cutter is done by use of pneumatic cylinder. Before feeding, stones were dried to 12-15% moisture content so that shell gets detached from the kernel. Machine has been fabricated for cutting 18 mangoes stone in a batch. Machine was tested to cut the stones by applying 6-8 bar pressure on cutter. The results showed that machine cuts the stones into two pieces at low temperature and high pressure more efficiently.

Keywords: Mango stone, decorticator, cutting, pneumatic cylinder

1. Introduction

Mango (*Mangifera indica* L.) is one of the most important fruit crops grown in the tropical regions of the world and is currently ranked first in total world production among the major fruit crop. It is consumed worldwide in its raw as well as ripened form. In raw form it is consumed in form of pickle, mango powder, chutney, and beverage while the ripe fruit is a delicious table fruit and its pulp can be processed into juice, nector, squash, leather, slices etc. Befittingly it is called "King of Fruits" in south Asia (Thind *et al*., 2002) [1]. Mangoes are available in different sizes, ranging from 10 to 25 cm in length and 7 to 12 cm in width. Mango fruit has a flat, oblong stone (seed) in the centre, which is covered by the sweet edible pulp. Mango stone is composed of outer hard fibrous shell and inner nutritive kernel. Mango stone constitute 10-25% weight of the whole fruit. The nutritive kernel present inside mango stone form 20% of the whole fruit and 45-75% of the mango stone (Mirghani *et al*., 2009) [2].
Processing of mango yields 40–60% waste product, out of which peel (12–15%) and kernel (15–20%) constitute the major chunk (Kaur *et al*., 2004) [3]. Mango seed kernel contains high level of carbohydrates and oil (Kittiphoom, 2012) [4]. It also contains crude protein, ash, crude fibre and is rich in vitamins. The oil extracted from kernel is of good quality and could be used in cosmetics and soap industries. The kernel flour (starch) after mixing with the wheat or maize flour can be used for making chapaties. Ethiraj and Suresh (1992) [5] investigated that alcohol and the enzyme amylase can also be obtained from mango kernel. Mango seed kernel is rich in bioactive components such as antioxidant and phenolic compound (Soong *et al*. 2004) [6]. Kittiphoom, (2012) [4] studied the protein content of kernel which is low but contains most of the essential amino acids with highest values of leucine, valine and lysine. Further, the isolated active component can be used in food fortification. Processing of mango by-products reduces waste disposal problem and adds value to the product for food and other industrial uses. For the utilization of mango kernel it needs to be removed from the mango stone. The fibrous nature of shell covering the kernel makes the decortication a very tedious process. Various types of decorticator have been developed for nuts and seeds which work on the principle of centrifugal force, impact, abrasion, shear, and compression. Dehulling of sunflower seeds has been achieved using centrifugal sheller (Gupta and Das 1999) [7], melon seeds and bambra groundnut have been dehulled using centrifugal force and impact force (Makanjuola, 1975, Oluwole *et al*., 2007) [8, 9]. A mechanical cashew nut sheller on the principle of compression and shear (Jain and Kumar, 1997) [10], manually operated sheller using abrasion between rotating shelling disc for maize (Nkakini *et al*., 2007) [11] has been developed. The study on decortications of mango stone are far and few.

Mango stone decorticator has developed on the principle of impact and shear (Kumar *et al*. 2014) [12]. The main objective of this paper is to present a simple alternative method for the separation of the kernel from the mango stone. The design, fabrication and performance analysis of the developed machine has also been discussed.

2. Materials and Methods

2.1 Raw Material

The "Safeda" variety of mango samples to be used in the study was collected from the local market of Azadpur, New Delhi, India. Mangoes were cut to remove the stones. The mango stones were cleaned in tap water to remove traces of pulp and then dried in tray dryer at 60 °C until desired moisture content was achieved.

2.2 Moisture content

Moisture content of mango stone and kernel were determined by the hot air oven method. Randomly selected five mango stones were oven dried at 105 °C until they stopped losing weight. The moisture content is then calculated as:

$$M_w = \frac{W_W - W_d}{W_w} \times 100$$

$W_{b\,\%} = [(W_w - W_d) / W_w] \times 100$

Where;
M_w= moisture content (%wb)
W_w= weight of stones before drying
W_d = weight of stones after drying

After cleaning, mango stones were dried to the desired moisture content at which the kernel was detached from the shell and was easily removed and at the same time without affecting the nutritional content of kernel.

2.3 Axial dimensions

Axial dimensions include length, width and thickness of the mango stone and kernel. These were measured by using vernier calliper and maximum and minimum dimension from randomly selected samples were taken for designing a machine parts.

2.4 Methodology

Before designing the machine and reaching to the conclusion for the principle to be adopted for the development of machine few alternatives were tested for the removal of the kernel from mango stone. The result has been presented here as no such literature on such study was found.

2.4.1 Breakage by impact force

Mango stones were dried to different moisture content (10 to 20 % w.b.) and trials were performed to break them by impact force.

2.4.2 Roasting

In order to weaken and easily break apart the shell, the mango stones at three different moisture content (15, 25 and 35% w.b.) were roasted at three different temperatures (180, 200 and 225 ^{0}C) at two time interval (5 and 15 min).

2.4.3 Cutting

Mango stones were dried at four different moisture content (14, 17, 20 and 25% w.b.) and cut into two pieces transversely. Cutting mechanism was finalised and machine for the same was designed and developed.

2.5 Fabrication of machine

The schematic diagram of mango stone decorticator machine developed is shown in Fig 1. The basic principle of working of machine is based on cutting and impact force. The designed machine components include:

a. Jaw assembly
I. Upper jaw
II. Lower jaw
III. Backside jaw

b. Cutter
c. Double Acting Pneumatic Cylinder

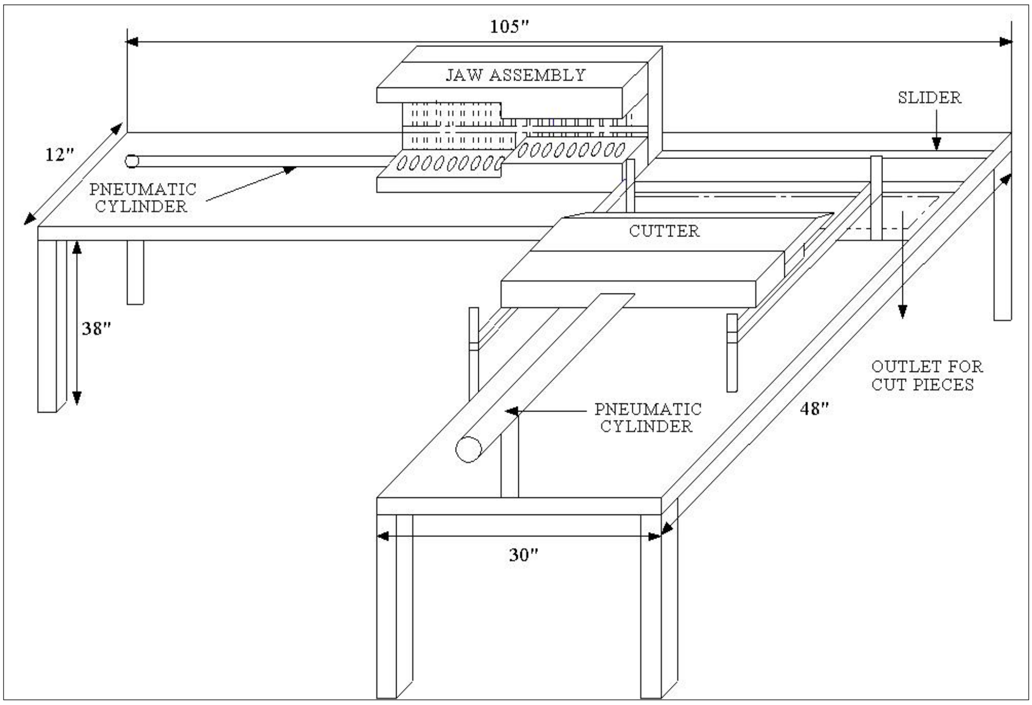

Fig 1: Schematic diagram of mango stone decorticator

2.5.1 Jaw assembly
It is the part where mango stones are placed vertically in between the jaws. Jaw assembly is made of mild steel. It has three parts; upper jaw, lower jaw and backside jaw. The whole assembly is designed in such a way that large size stones having maximum length 100 mm and small size stones having minimum length 70 mm are placed in between jaws. So the distance between upper and lower jaw is not same throughout its length. The distance between upper and lower jaw on left side is 80mm and on right side is 50 mm as shown in Fig 2. All three jaws i.e. upper, lower and backside contain grooves to hold the mango stone properly.

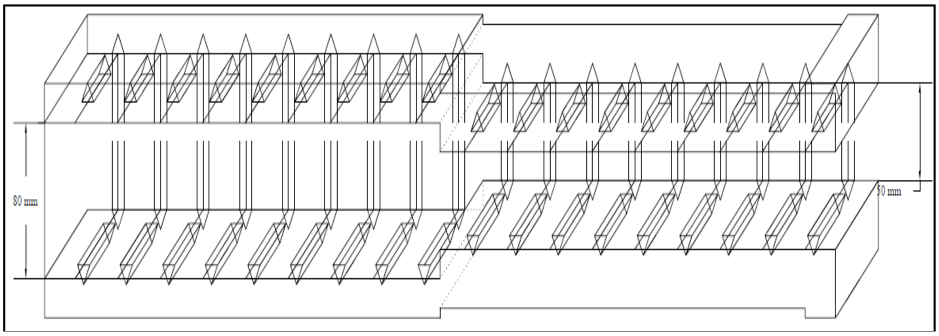

Fig 2: Schematic diagram of jaw assembly

2.5.2 Upper jaw
The length and width of upper jaw is 650 mm and 50 mm respectively. It has 18 grooves. The length, thickness and depth of each groove are 20 mm, 10 mm and 10 mm, respectively. The distance between each groove is 25mm. The right side is 15mm downwards than left side to hold the small size stones (Fig 3). There are 9 grooves on the right side and same number of grooves on left side. The milling of grooves has been done in such a way that these are in centre of the width of the jaw leaving 15mm on both sides along the width.

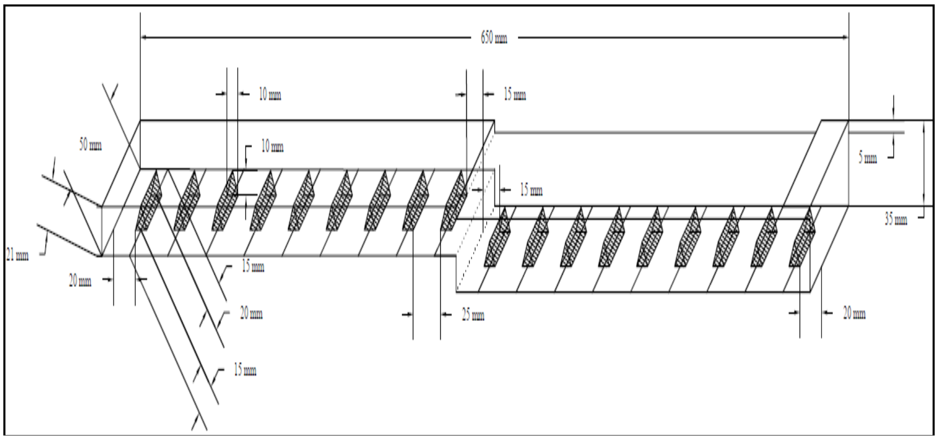

Fig 3: Schematic diagram of Upper Jaw

2.5.3 Lower jaw
The length and width of lower jaw is 650 mm and 50 mm, respectively. It has 18 grooves. The length, thickness and depth of each groove are 30mm, 10mm and 10 mm, respectively. The distances between grooves are 25mm. The left side of jaw is 15 mm upwards than right side to hold the small size stones (Fig 4). There are 9 grooves on the right side and same number of grooves on the left side. The milling of grooves has been done in such a way that these are in centre of the width of the jaw leaving 10mm on both sides along the width.

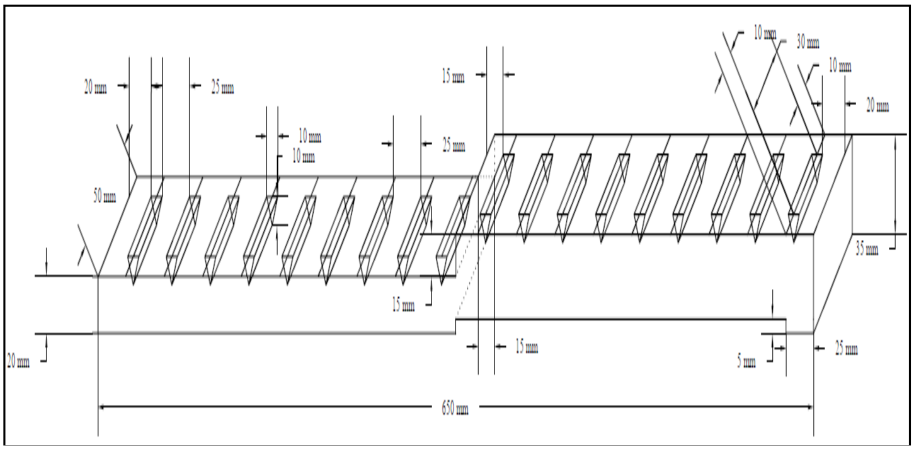

Fig 4: Schematic diagram of Lower Jaw

2.5.3.1 Backside jaw

The length, width and height of backside jaw is 650mm, 20mm and 100mm respectively. As large size stones are placed on left side, so length, width and depth of 9 vertical grooves on left side are 100mm, 10mm and 10mm respectively. Similarly, right side is for small sized stones, so length, width and depth of 9 vertical grooves on right side is 50mm, 10mm and 10mm respectively. There is one groove of length, width and depth of 650mm, 10mm and 10mm respectively along the length of jaw in the centre as shown in Fig 5. The cutter cuts the stone from the centre, so this groove along the length is for the safety of cutter and also to ensure that the cutter completely cuts the stones.

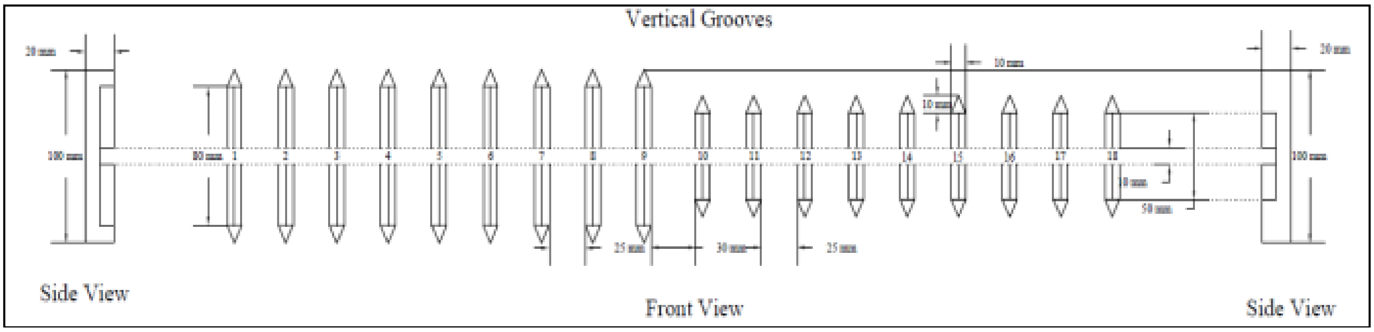

Fig 5: Schematic diagram of Back-side Jaw

2.5.3.2 Cutter

A blade made of SS having length, width and thickness of 650 mm, 100 mm and 8 mm, respectively is used to cut the mango stones into two pieces. The blade is attached to a frame having length same as that of the cutter, width 120 mm and thickness 12 mm as shown in Fig 6. The cutter is moved forward and backward by pneumatic cylinder.

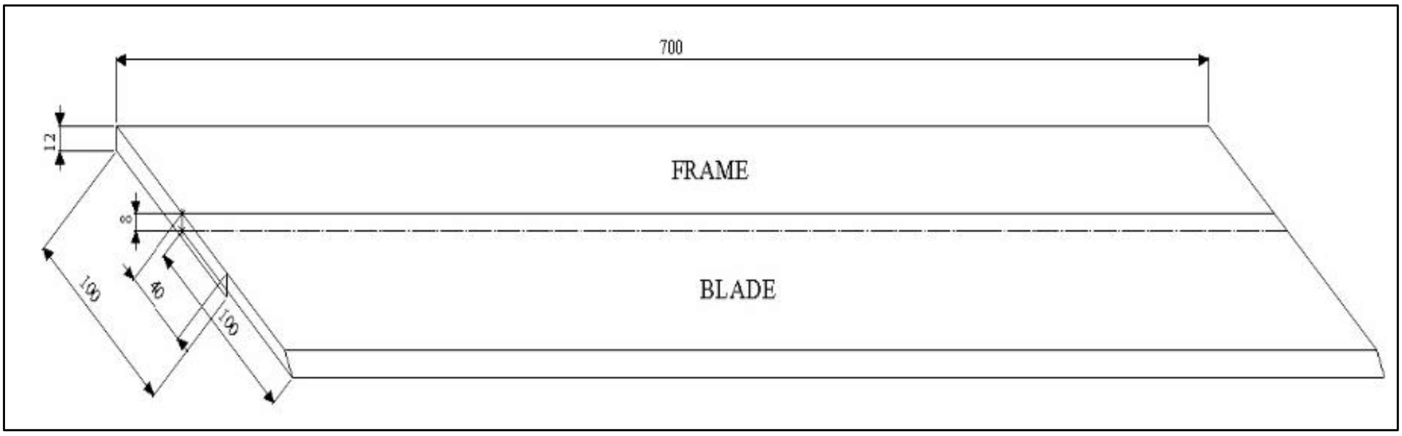

Fig 6: Schematic diagram of Cutter with frame

2.5.3.3 Double acting pneumatic cylinder

Two double acting pneumatic cylinders are used for the movement of jaw assembly and cutter. The pneumatic cylinder is a machine that changes and directs the force created by pressurized air in the system. The cylinder uses that force to accomplish useful work i.e. forward and backward movement of jaw assembly and cutter. Work is accomplished when the piston and rod are extended or retracted by the pressurized air acting on the surface of piston. In double acting cylinder the force of pressurized air can be used to create both- a pushing and pulling force. Two pneumatic cylinder are used, one for movement of jaw assembly and second for movement of cutter. Bore diameter, stroke length and maximum volume of pneumatic cylinder for movement of jaw assembly is 50 mm, 800 mm and 3.14 L, respectively while that for movement of cutter is 63 mm, 250 mm and 1.56 L, respectively.

A schematic diagram of double acting pneumatic cylinder is shown in Fig 7 where‘d’ is bore diameter and ‘L’ is stroke length.

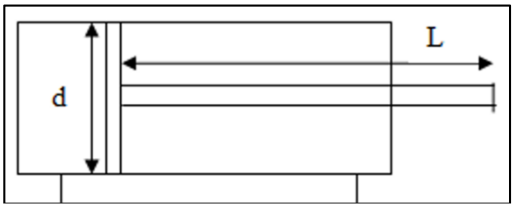

Fig 7: Schematic diagram of double acting pneumatic cylinder

2.6 Material Selection

The selection of adequate materials for the fabrication was done based upon functionality, durability, ability to withstand vibration and the cost of such materials. In the choice of material, their physical properties and behaviour are considered such that when subjected to the machine running condition should be able to withstand the service condition. Considering all this is mind, the jaw assembly is made up of mild steel; cutter is made up of stainless steel. The frame, on which jaw assembly, pneumatic cylinders and cutter mounted, is made of mild steel.

2.7 Testing of machine
The following variables selected for carrying out performance analysis of the developed machine are moisture content of the mango stone, pressure of pneumatic cylinder and breakage efficiency. The moisture content were varied at three level 12%, 15%, 18% while the pressure of the pneumatic cylinder were varied at 6, 7 and 8 bar.

After removal of kernel, performance indicator was calculated as below:

$$\text{Efficiency } (\%) = \frac{Q_2}{Q_1} \times 100,$$

Where

Q_2 = no. of whole stone

Q_1 = no. of cut stones

3. Results and Discussion
3.1 Engineering properties of mango stone and kernel
The average initial moisture content of mango stone and kernel was found to be 47.58% (w.b.) and 45.22% (w.b.) respectively. Previous study shows that the mango can be easily broken by drying it to 12-15% moisture content. Further drying can damage the chemical composition of kernel. An advantage of drying the kernel to moisture content of 12-15% detaches the kernel from the shell making it easier to separate and remove. When stones were dried to 12-15% (w.b.) moisture content the value of moisture content of kernel after drying was 17.37% (w.b.). The engineering properties of mango stone and kernel are shown in Table 1.

Table 1: Physical properties of Mango stone and kernel

Properties	Stone	Kernel
Length (mm)	82.20±4.77	53.35±6.11
Width (mm)	39.9±2.28	25.8±4.15
Thickness (mm)	19.9±2.81	14.25±0.81

Values are mean plus standard deviation of 20 samples

3.2 Breakage feasibility
3.2.1 By impact force at different moisture content
Breakage feasibility of mango stones dried to different moisture content by impact force is given in Table 2. The study showed that cracks could not be developed in the stone by impact force till the moisture content was reduced below 12%. Even at low moisture content i.e. 10%, only a small crack developed at weak point of stone by impact force and kernel could not be removed through this small crack. By drying to this low moisture content the nutritional properties of kernel also deteriorated. Hence this was not accepted for the design of machine for removal of kernel from the stone.

Table 2: Breakage feasibility at different moisture content by using impact force

S. No.	Moisture content (wb)	Observations	Breakage feasibility
1.	20%	▪ Kernel is in good condition	Didn't break
2.	17%	▪ Kernel is in good condition	Didn't break
3.	14%	▪ Kernel is in good condition	Didn't break
4.	10%	▪ Crack developed at weak point ▪ Quality of kernel was damaged	Kernel could not be removed from the crack developed in the mango stone

3.2.2 By roasting
Breakage feasibility of mango stone by roasting them at different time temperature combination is given in Table 3. The cracks developed during roasting of stones dried to 15%-35% (wb) moisture content in all time temperature conditions. By roasting the stone was completely burnt. It was found that heating the mango stones at temperature 180 °C temperature for even 5 minutes burn the kernel and all its properties are destroyed. Hence this line of thinking for the design of mango decorticator was also rejected.

Table 3: Breakage feasibility by roasting

S.no.	Moisture content (wb)	Roasting conditions		Observations	Breakage feasibility
		Temp. (°C)	Time (min.)		
1.	35 %	235- 255	5	Mango stone gets burnt.	Didn't break
			15		
2.	35 %	200-225	5		
			15		
3.	35%	180-200	5		
			15		
4.	25 %	235- 255	5	Mango stone gets burnt.	Didn't break
			15		
5.	25%	200-225	5		
			15		
6.	25%	180-200	5		
			15		
7.	15%	235- 255	5	Mango stone gets burnt.	Crack developed at weak point
			15		
8.	15%	200-225	5		
			15		
9.	15%	180-200	5		
			15		

3.2.3 By cutting
Breakage feasibility by cutting at different moisture content is shown in Table 4. The force required to cut stones dried to 14% moisture content is less as compared to force required for cutting at 20% moisture content or more. By drying mango stones to 14% moisture content, the nutrient quality of

kernel was not affected and the kernel got detached from the shell due to which the separation of kernel from the shell was easy after it was cut into two pieces.

Table 4: Breakage by cutting at different moisture content

S. No.	Moisture content (wb)	Observation s
1.	25 %	▪ Difficult to cut ▪ Kernel didn't separated from shell
2.	20 %	▪ Difficult to cut ▪ Kernel didn't separated from shell
3.	17 %	▪ Less difficult to cut ▪ Kernel didn't separated from shell
4.	14 %	▪ Less difficult to cut ▪ Kernel was separated from shell

3.3 Principle of operation

The mango stone decorticator has been designed for the removal of kernel from mango stone in small scale operation. Mango stones contain inner kernel and outer shell. This decorticator has two sections; first section is for holding the mango stones and second is for cutting the stones. Process flow chart is shown in Fig 8. The mango stones are cleaned under tap water and then dried in sun or in tray drier to moisture content less than 15% (wb). The dried mango stones are fed into the jaw assembly manually. The jaw assembly is allowed to slide to the left side by pneumatic cylinder so that stones are fed into the jaw. The upper jaw is moved in upward direction and the stones are placed in the grooves provided on the lower jaw. The upper jaw is then allowed to move downward so that stones can fit into the grooves. Now the jaw assembly containing mango stones is pushed forward to right side by pneumatic cylinder in front of the cutter. The blade is moved by pneumatic cylinder which cuts the stones into two halves. The cut pieces of stones are allowed to fall down and are collected. The kernels are separated from the shell manually.

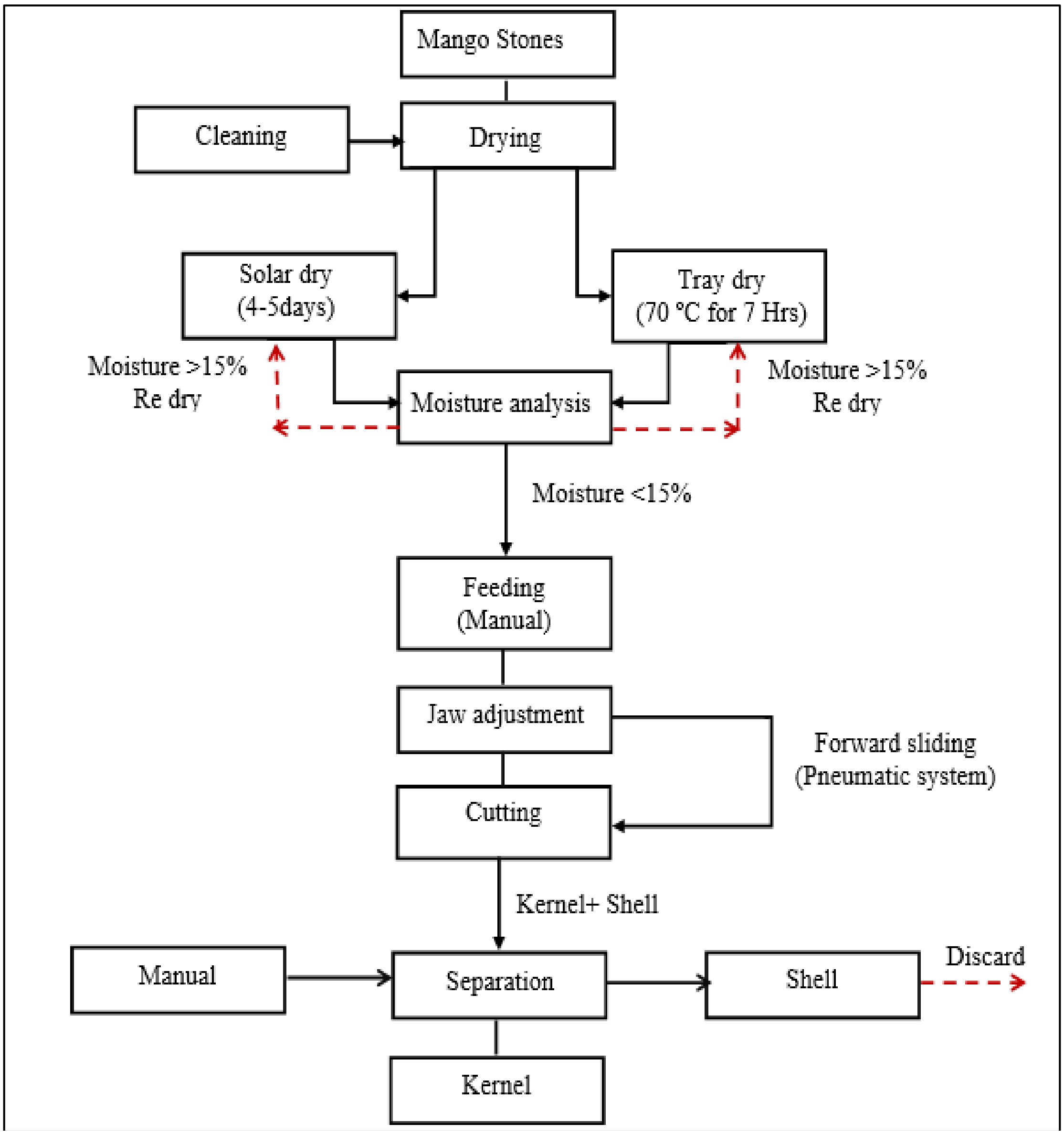

Fig 8: The mango stones are cleaned under tap water and then dried in sun or in tray drier to moisture content less than 15% (wb).

3.4 Performance analysis of the machine
It was observed that when the moisture content of mango stones increased from 12 to 18% (wb) the efficiency of the decorticator decreased at all the working pressure (Fig 9).

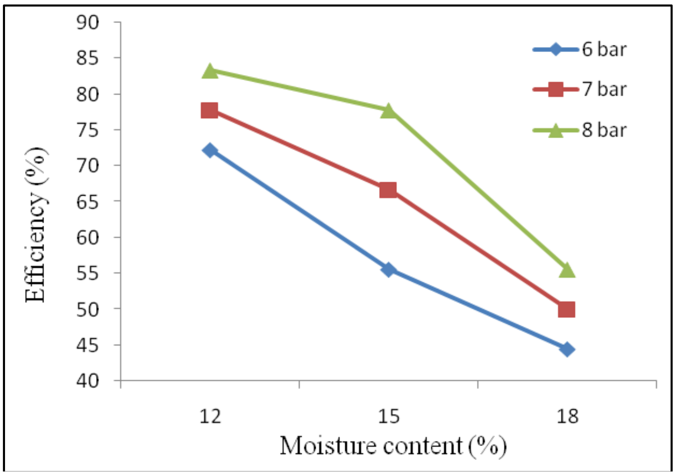

Fig 9: Effect of moisture content and pressure on efficiency

At moisture content 12-15% (wb) all the mango stones placed in the jaw slot got cut in single stroke and thereafter the kernel could easily be removed from the shell. When the moisture content was more than 15% it required more than one stroke to completely cut the mango stone, nevertheless all the mango stone were cut.

Increasing the pneumatic pressure had a positive effect on the efficiency at all level of the moisture content. The maximum efficiency was observed at 15% moisture content at 8 bar pneumatic pressure.

4. Conclusion
The simple and easy to operate machine for removal of kernel from mango stone has been designed, fabricated and tested. The dried stones are fed manually into jaw assembly and then cutter cuts the stones into two pieces. Pneumatic cylinders are used to move the jaw assembly and the cutter blade. Machine has been fabricated for cutting 18 mango stones in a batch. Other methodologies were also adopted for removal of kernel like breakage of shell by impact force and roasting. In both cases shell did not break. The separated kernels can be used for its various applications.

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