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Design and development of a manually operated oil palm crusher

MR Islam[1], MA Awal[2*], CK Mistry[1]

[1]Minor Irrigation Division, Bangladesh Agricultural Development Corporation, Dhaka, Bangladesh; [2]Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh.

Abstract

Palm growers in Bangladesh are currently facing problems to extract crude palm oil from FFB. The traditional method of palm oil processing is time-consuming, laborious, hazardous, and inefficient resulting in the production of low-quality oil. Though mechanical processing is costly but produces good quality Crude Palm Oil (CPO) and the oil recovery rate is high. A low-cost mechanical (manually operated) oil palm crusher was designed and febricated in the workshop of the Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh. The crusher was designed by using Auto-Cad software. It was fabricated according to design parameters. It is fabricated by stainless steel (SS) shaft, stainless steel cylinder, mild steel (MS) hopper, (MS) hollow bars, MS pressure case cap & Bearing. It requires a very small rotating force. The cost of the crusher is only BDT 12000, which is within the buying capacity of the farmers of Bangladesh. Crusher was mounted on the table or bench. At first 500 gm fresh palm fruits were taken for experimentation. About 300 gm mesocarp and 200 gm oil palm kernel (nuts) were found from 500 gm oil palm fruits. Heating 300 gm mesocarp about 15 minutes and was weighted 280 gm mesocarp due to moisture loss. About 62 gm crude palm oil, 124 gm oil cake, 88 gm skum were collected from 280 gm mesocarp. The average m.c (wb) of fresh palm fruit was found 20.73%. The crushing capacity of the mesocarp of the crusher was o.84 kg/hr. The rotating speed of the screw was 26 rpm. Crude oil percentage was found 22.14%. The total time to extract 62 gm crude palm oil from 500 gm of fresh fruit was 1hr and 15 minutes. The weight of the crusher is 11 kg which is easy to operate by one man. The overall performance of the crusher was found quite satisfactory and could be useful for smallholder palm growers in Bangladesh.

Key words: Design, oil palm, crusher, manual, palm oil, performance

 ***Corresponding Author:** awalbau@gmail.com

Introduction

Palm oil is the second most important edible oil in the world after soybean. It is one of the two most important vegetable oils in the world's oil and fats market following soybean (Hartley,1988). The original home of oil palm (*Elaeis guineensis)* in West Africa. But it is now grown in several countries of Southeast Asia and America. Oil palm has been cultivated from ancient times in Africa between latitudes 130N and 120S (Kaul and Das, 1986). The oil palm fruit produces two distinct oils which are palm oil and palm kernel oil. Palm oil is obtained from the mesocarp while palm kernel oil is obtained from the seed or kernel. Palm oil is used mainly for the production of margarine and compounds in cooking fats and oils and also for the production of candles, detergents, soap, and cosmetic products. The annual requirement of oil and fats in Bangladesh is about 2.30 million tons, of which, on average, about 63% shares belong to palm oil and the average annual import quantity of palm oil is about 1 million tons which are about 66% of the total import of oils and fats (Alam, 2017). Bangladesh is a deficit in oils and fats for a long time. It produces only 10 percent of its requirement. To meet up the demand for palm oil, the cultivation of oil palm was introduced in 1978 through the import of Tenera seedlings from Nigeria and Malaysia.

The highly-rated commercial oil palm fruit is type Tenera, a hybrid of Durra and Pisifera (Baryeh, 2001 and Sundram *et al.,* 2003). Processing of palm oil categorized into various forms but basic processing stages are essentially the same including harvesting, sterilization, bunch stripping, digestion, crushing, clarification and drying. Most of the stages in the process are essentially the same, whether in a 60 t/h mill or a small-scale village process. The processing stages can be described as i) Bunch sterilization with high-pressure steam; this loosens the fruit from the bunch and inactivates the endogenous lipase, and any microorganisms, so that FFA build-up does not occur; ii) Bunch stripping, to separate the fruit from bunch stalk and spikelet's, iii) Fruit digestion to pulverize and disrupt the mesocarp, with heating to aid oil extraction; iv) Pressing or other treatment of the digested fruit to extract the oil; v) Separation, clarifying and drying the oil, vi) Separation of nuts from fiber, vii) Nut drying, grading, and cracking; viii) Separating kernels from shell and ix) Kernel drying and packing (Maycock, 1990).

Generally, the best quality of crude palm oil quality has an FFA percentage of less than 5% whereas the moisture content is less than 0.1% and the percentage of dirt is not more than 0.01%. In a palm oil mill, oil palm fresh fruit bunches (FFB) are processed to produce crude palm oil (CPO). Palm fiber, empty fruit bunches, sludge, decanter cake, and palm nuts are produced as byproducts. The standard crude oil percentage of oil palm is about 26-27% (FAO, 2002).

Alam *et.al*. (2020) develop a screw type manually operated oil palm crusher with extraction efficiency of 19%. The comparative performance of the digester–screw press (DSP) system and hand-operated hydraulic extraction system based on oil yield and quality, and operational economics for small-scale oil palm fruit processing. The results indicated that the throughput of the digester–screw press (DSP) system was four folds of that of the hydraulic system, whilst also operating at higher oil extraction efficiency (89.1%). However, the economic analysis of the systems indicates that at the throughput of 0.75 ton/hr and above, the digester–screw press (DSP) system was more economical in terms of equipment, labor, material, and floor space requirement and revenue accruing from the processing operation (Owolarafe *et al.* 2002).

Awal and Tabriz (2020) design and develop a motor oprated oil pal crusher. The crushing capacity of the crusher was 6.49kg/hr at a speed of 40 rpm and crude palm oil extraction percentage was 25.93%. Akinoso *et al.* (2011) investigated that compressive stress, feeding rate, and rotational speed of the expeller Influences the quality of expressed palm kernel oil. The lowest value of free fatty acid (FFA) content (1.09%) was produced at 10 Mpa compressive stress; 50 kg/h feeding rate and 110 rpm revolving worm speed. Optimum processing condition was achieved at a compressive stress of 18.3 Mpa, 61.1 kg/h feeding rate, and 76.7 rpm revolving worm speed. Amata and Ozuor (2013) researched comparing the quality of crude palm oil (CPO) produced by three different methods of oil palm processing in Delta North Agricultural Zone, which includes the scientific method, the semi-scientific method, and the traditional method. Parameters studied to assess quality were free fatty acid (FFA) content, peroxide value, and the carotene content. He also observed significant differences in per-oxide value except for free fatty acid (FFA) content and the carotene content.

Since 1978, a lots of oil palm were planted in different distric of Bangladesh, such as Chittagong, Barisal, Tangail, Jamalpur, Madhupur, Meherpur, Mymensingh, Rangpur, Comilla, Khagrachhari, Faridpur, Jessore, Khulna, Dinajpur & Sylhet. But, due to a lack of processing machine, every year, lots of oil palm fruits are wasted. At present palm oil is extracted in our country by traditional method. This method is laborious and time-consuming; on the other hand, oil extraction efficiency is very low. This method is not suitable; hence farmers are losing interest in palm cultivation. Yesmin and Rahman (2013) found from a survey, that 70% of the respondent, had asked at Phulpur Upazila from Mymensingh and Meherpur Sadar Upazila from Meherpur do not have machines that are used in palm oil extraction. They also founded that, some of the people are using the traditional method and boiling method to extract crude palm oil. Both methods are not suitable for the extraction of high-quality palm oil. Since, oil palm trees are already being spread all over the country and oil palm growers are facing serious problems with the processing of palm oil from fresh fruits bunch. Hence, it is necessary to design and develop an oil palm crusher for small holder farmers.

Materials and Methods

Design Consideration: The following factors were considered to design a manually operated oil palm crusher.

- ✓ Simple in construction
- ✓ The size of the cylinder
- ✓ The size of the shaft and handle.
- ✓ The clearance between the shaft and cylinder
- ✓ It should have a simple and easy adjustment
- ✓ It should have uniformity in the feeding rate
- ✓ It should be easy to repair and maintain
- ✓ The cost of a crusher will be affordable
- ✓ It should be light in weight and easy to operate
- ✓ Easily portable
- ✓ Low repair and maintenance cost.

The motor-operated oil palm crusher was designed and drawing was done with the help of Auto-Cad software. Then the crusher was fabricated accordingly and finally tested at the Workshop of Farm Power and Machinery Department, BAU, Mymensingh.

Design of different parts of manually operated oil palm crusher**:** The crusher consists of a pressure cage cylinder, frame, screw shaft, hopper, pressure case cap, a perforated strainer mounted inside the pressure cage cylinder, handle, adjustable terminal bolts, and these were designed and developed in the department of Farm Power & Machinery, Bangladesh Agricultural University.

Materials to fabricate the crusher**:** Materials required to construct the crusher were procured from the local market. The major materials required to fabricate the crusher were stainless steel (SS) shaft, stainless steel cylinder with SS strainer, mild steel (MS) hopper, M.S hollow bars, MS pressure case cap, Bearing (#6007).

Hopper: Hopper is the most important part of designing and developing the crusher. It was made by the M.S sheet. At first, a 12 cm diameter hopper was made which was welded with an MS hollow shaft. The hopper was supported by MS hollow shaft (feeding part). The feeding diameter of the hopper is 3 cm. When the round screw shaft rotates then prepared material enters the chamber from the hopper and then moves forward by the rotating pressing screw and is pressed (Figure 1 & 2).

Design and development of cylinder: A simply designed cylinder was introduced in the crusher. The cylinder was made of stainless steel. The length of the cylinder is 20 cm. The outer and inner diameter of the cylinder was 6 cm and 4 cm respectively. The cylinder was mounted with a bearing casing which is fixed to the frame. A perforated SS screen was mounted in the inner portion of the cylinder. The thickness of the perforated cylindrical screen was 5 mm. A pressure cage cap was fixed with a cylinder terminal which contains terminal adjustment bolts (Figure 3 & 4).

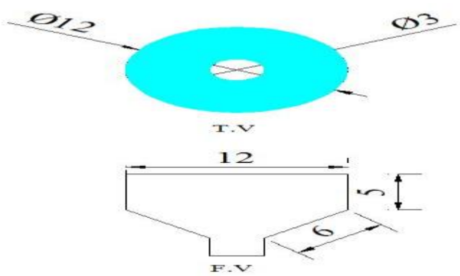

Figure 1. Different design views of the hopper (all dimensions are in cm).

Figure 2. Photographic view of the hopper.

Design of screw shaft: The screw shaft was fabricated of stainless steel. The total length of the screw shaft was 30 cm. The length of the helical screw portion was 20 cm. The root diameter of the screw is gradually increasing for developing high pressure. A small hole 1 cm dia was made in the bottom parts of the shaft for connecting the shaft with the handle (Figure 5 & 6).

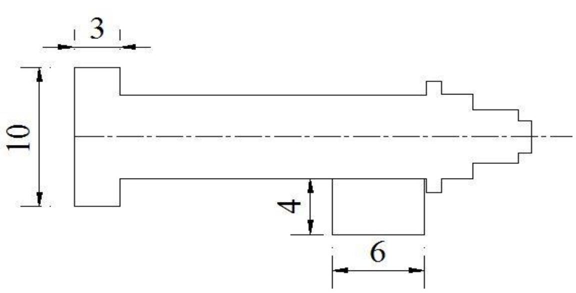

Figure 3. Design of pressure case cylinder (all dimensions are in cm).

Figure 4. Photographic view of pressure case cylinder.

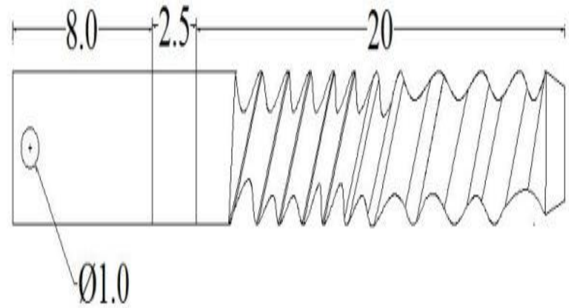

Figure 5. Design view of the screw shaft (all dimensions are in cm).

Figure 6. Photographic view of Screw shaft.

Design of pressure case cap: A pressure case cap was made of mild steel. It contains a terminal adjustment bolt. A borehole 1 cm dia was made on the outer part of the case cap that permits the flow of oil cake (Figure 7 & 8).

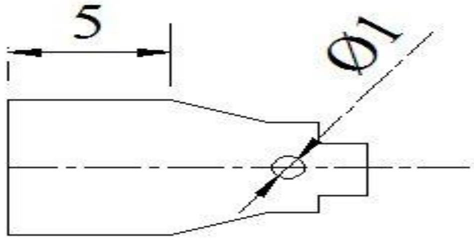

Figure 7. Design view of the pressure case cap (all dimensions are in cm).

Figure 8. Photographic view of pressure case cap.

Design of handle**:** The rotating handle of the crusher was made of M.S rod and attached to the main shaft. It was 30 cm long and 12 cm long gripping parts is shown in Figure 9. The rotating handle of the crusher was made by MS hollow bar. The rotating handle is connected with the screw shaft by nut and bolt. The rotation of the handle is always clockwise direction (Figure 9 & 10).

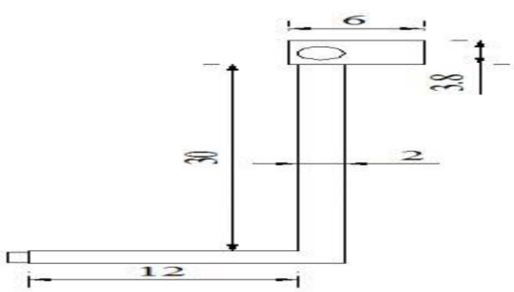

Figure 9. Design view of the handle (all dimensions are in cm).

Figure 10. Photographic view of the handle.

Design of perforated screen**:** The perforated screen was made of stainless steel and mounted inside the cylinder. The length of the screen 20 cm. Inner dia of the cylindrical screen 40 mm. The length of the perforated portion is 12 cm from the starting point of the screen. About 15 numbers of inclined slots are in the cylindrical screen.

Design of heating portion**:** A small cylindrical shape of the heating portion was made of stainless steel. The diameter of the cylinder is 6 cm and length 4 cm and attached vertically to the bottom part of the cylinder terminal (Figure 11). Spirit lamp or candle can be used for heating the pressure case cylinder and screw shaft through the heating portion for increasing oil extraction efficiency.

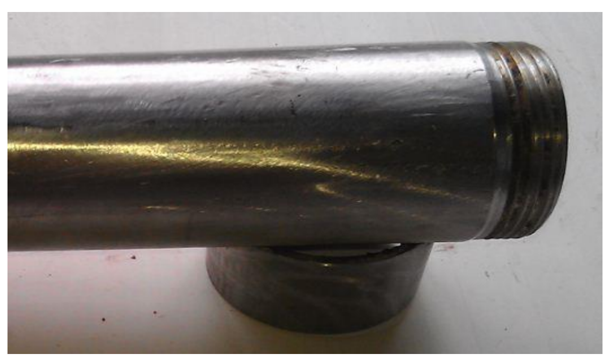

Figure 11. Photographic view of the heating portion below the cylinder case

Design of Frame**:** The crusher was mounted to the frame which was mounted to the table or bench. The frame is the supporting body of the crusher. Bolts and nuts were used for mounting the frame with a table (Figure 12 & 13).

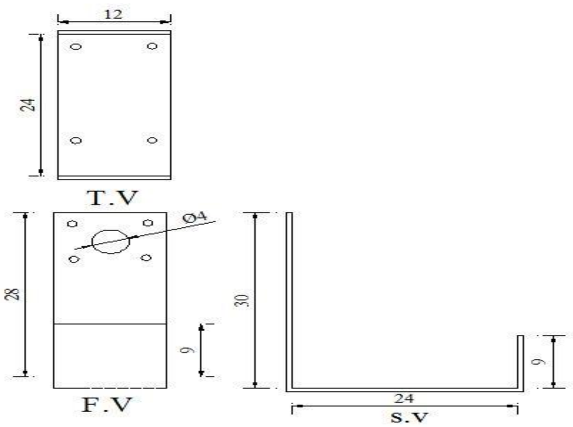

Figure 12. Different views of the frame (all dimensions are in cm).

Figure 13. Photographic view of the frame

Working principle of the manually operated oil palm crusher: When the oil press is operating, prepared material enters the chamber from the hopper and then moves forwards by the rotating pressing screw and is pressed. Under the high-pressure condition in the chamber, friction between material and screw, between material and chamber will be created, which also creates friction and relative movement among material particles. On the other hand, the root diameter of the pressing screw varies larger from one end to the other. Hence, when rotating, it not only pushes particles moving forwards but turns those outwards as well. Meanwhile, particles adjacent to the screw will rotate along with the screw's rotating, causing every particle inside the chamber to possess a different speed. Therefore, relative movement among particles creates heat which is necessary during manufacturing because of helping protein change property, damage colloid, and increase plasticity.

Determination method of crushing capacity (kg/hr) of the oil palm crusher: In a specific time, how much mesocarp is crushing by the crusher that is crushing capacity (kg/hr) of the oil palm crusher. It depends on the mesocarp slice. Before crushing, the mesocarp was weighted and time counted by the stopwatch.

So, the Crushing capacity = W/T

Where, W = Weight of mesocarp (kg) and

T = Total crushing time (hr.)

***Determination method of rpm of the screw shaft of the oil palm crusher*:** During crushing mesocarp by the crusher handle was rotated clockwise smoothly and the number of handle rotation was counted manually in 3 minutes, so that get average rpm of the oil palm crusher by the following formula.

Average, RPM = N/T

Where, N = Total number of rotations of the handle, and T = Total time

***Determination method of crude palm oil percentage in mesocarp*:** Crude palm oil was collected from crushing the mesocarp of the palm fruit. So, the crude palm oil percentage was calculated by the following formula.

Crude palm oil percentage = $(W_1/W_2) * 100$

Where W_1 = Weight of crude palm oil and

W_2 = Weight of mesocarp

Determination method of oil cake percentage in mesocarp: Oil cake was collected from crushing the mesocarp of the palm fruit. So, the oil cake percentage was calculated by the following formula.

Oil cake percentage = $(W_1/W_2) * 100$

Where, W_1 = Weight of oil cake,
and W_2 = Weight of mesocarp

Determination method of skum percentage in mesocarp: Skum was collected from crushing the mesocarp of the palm fruit. So, the skum percentage was calculated by the following formula

So, the Skum percentage = $(W_1/W_2) * 100$

Where, W_1 = weight of skum, and
W_2 = weight of mesocarp

Determination method of the amount of crude palm oil per kg of mesocarp: The amount of crude palm oil was divided by the amount of mesocarp thus obtained the amount of crude palm oil per kg of mesocarp.

Determination of oil extraction efficiency of the crusher: The standard crude oil percentage of oil palm is 26-27 % (FAO, 2002). For calculating oil extraction efficiency, the CPO percentage obtained by the motor-operated oil palm crusher is divided by this standard value.

Oil extraction efficiency = (Determined oil extraction %/oil expected % as standard value)

Results and Discussion

A manually operated oil palm crusher was fabricated at the engineering workshop in the Department of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh. The crusher was tested extensively in the laboratory. The crusher was a manually operated machine. It has one-hopper with 12 cm dia which contains fruits mesocarp. The feeding diameter of the hopper is 3 cm. It was made with a rotating screw shaft and cylinder. The clearance between the screw shaft and the pressure case cylinder is kept 2 mm to avoid friction. The weight of the crusher was only 11 kg so that the required small force to operate the crusher was within the capacity of a person (male or female). The crusher can be used in small-sized seeds.

Development of manually operated oil palm crusher: The design of the whole crusher is given below. After assembled its different parts, the complete crusher is presented here. Different parts of the crusher are shown in Figure 14. Isometric and photographic views of the crusher are shown in Figure 15 and Figure 16, respectively. The detail specification of the crusher is shown in Table 1.

Table 1. Specification of the manually operated oil palm crusher.

Particulars		Description
1	Name	Manually operated oil palm crusher.
2	Source of power	Manual
3	Source of power for driving	Rotating handle
4	Weight of the machine	11 kg
5	No. of hopper	1
6	No. of operator	One
7	Feeding system	Rotating screw shaft
8	Crushing mechanism	Rotation of the screw shaft developed high pressure
9	Recommended speed	26 rpm
10	Crushing capacity	0.84 kg/hr
11	Crude palm oil %	22.14%
12	Crushing efficiency	82%

Figure 14. Different parts of manually operated oil palm crusher (all dimensions are in cm).

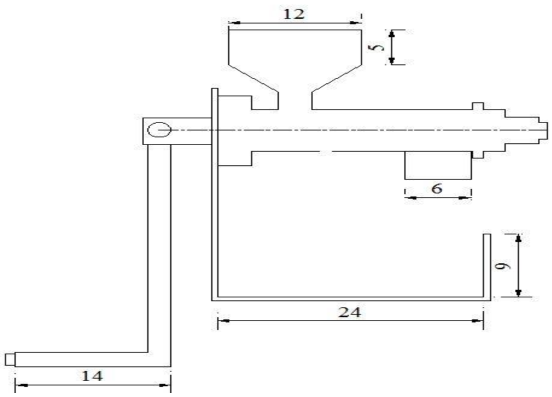

Figure 15. Isometric views of manually operated oil palm crusher.

Figure 16. Photographic view of manually operated oil palm crusher.

The moisture content of palm fruit: To determine the moisture content, palm fruits were placed in the electric oven at 105 oC for 24 hrs (Razavi and Taghizadeh, 2005). After 24 hrs the final weight was taken. By using the following formula moisture content of palm fruit was determined.

Moisture content (wb) = {(W1- W2)/ W1} * 100 Where, W1 = Initial weight of palm fruit, W2 = Final weight of palm fruit. The average moisture content was found at 20.73%.

Screw shaft rpm of the oil palm crusher: During crushing mesocarp by the crusher handle was *rotated* clockwise smoothly and the number of handle rotation was counted manually in 3 minutes, so that obtained average rpm of the oil palm crusher by the following formula.

Average, RPM = N/T

Where, N, Total number of handle rotation = 77

T, Total time = 3 minute

So, the average RPM of screw shaft = 77/3 = 25.66 = 26.

Amount of crude palm oil, skum, oil cake: At first 500 gm fresh palm fruit was taken for experimentation. After separation of 500 gm oil palm, weighted 300 gm mesocarp and 200 gm oil palm kernel (nut) with some mesocarp. Heating 300 gm mesocarp about 15 minutes and weighted 280 gm mesocarp due to moisture loss. Then 280 gm fruit mesocarp was taken in the hopper for crushing operation. About 62 gm crude palm oil, 124 gm oil cake, 88 gm skum were collected from 280 gm mesocarp as shown in Table 2.

Table 2. Amount of crude palm oil, skum, oil cake.

Serial no.	**Component**	**Amount (gm)**
1	Fresh fruit	500
2	Mesocarp	300
3	Oil palm kernel (nut) with some mesocarp	200
4	After heating mesocarp weight	280
5	Oil cake	124
6	Skum/sediment	88
7	Crude palm oil	62
8	Loss	6

Total time to get 62 gm crude palm oil from 500 gm fresh fruits: Time taken for separation of mesocarp and size reduction about 35 minutes. Then time is taken for heating the palm mesocarp slice for about 15 minute**s.** Time is taken for crushing 280 gm mesocarp about 20 minutes and others 5 minutes. Total time needed to get 62 gm crude palm oil from 500 gm fresh fruit as shown in Table 3.

Table 3. Total time to get 62 gm crude palm oil from 500 gm fresh fruits.

Serial no.	Component	Time (minute)
1.	Separation of mesocarp and size reduction.	35
2.	Heating the palm mesocarp slice	15
3.	Crushing operation	20
4.	Others	5
5.	Total time	1 hr and 15 minute

The crushing capacity of the crusher (kg/hr): 280 gm mesocarp was crushed in 20 minutes and was obtained crude palm oil about 62 gm. The crushing capacity of the crusher was found 0.84 kg/hr. The crude oil palm, skum, oil cake and mesocarp as a product after crushing operation is shown in Figure 17.

Figure 17. Crude palm oil, skum, oil cake, mesocarp respectively.

Crude palm oil percentage in mesocarp: After crushing operation 62 gm crude palm oil was extracted from 280 gm mesocarp. The percentage of CPO (Crude palm oil) was found 22.14%.

Amount of crude palm oil per kg of mesocarp: The amount of crude palm oil was divided by the amount of mesocarp thus obtained the amount of crude palm oil per kg of mesocarp. After crushing operation 62 gm crude palm oil was extracted from 280 gm mesocarp. The extraction oil (gm) per kg of mesocarp was found 221 gm/kg of mesocarp. The extraction oil (gm) per kg of oil palm fruits = 62 gm/500 gm = 124 gm/kg of palm fruits.

Oil cake percentage in mesocarp: About 124 gm oil cake was obtained from crushing the mesocarp of the palm fruit. The oil cake percentage was found 44.28%.

Sediment /skum percentage in mesocarp: About 88 gm skum was collected from crushing the mesocarp of the palm fruit. The skum percentage was found 31.42%.

Determination of feeding rate per minute: 280 gm mesocarp were crushed in 20 minutes and was obtained crude palm oil about 62 gm. The average feeding rate of mesocarp was found 0.84 kg/hr.

Percentages of crude palm oil, oil cake, skum in mesocarp: Percentages of crude palm oil, oil cake, skum in mesocarp is shown in Table 4.

Table 4. Percentages of crude palm oil, oil cake, and skum in the mesocarp.

Serial no.	Component	Percentages (%)
1.	Crude palm oil	22.14
2.	Oil cake	44.28
3.	Skum	31.42
4.	Loss	2.16

The oil extraction efficiency of the crusher: The percentage of crude palm oil in mesocarp was found 22.14% by the oil palm crusher. For calculating oil extraction efficiency, the CPO percentage obtained by the manually operated oil palm crusher is divided by the standard value and the oil extraction efficiency of the crusher was found (22.14/27)*100 = 82 %.

Conclusions

The design of a manually operated oil palm crusher is simple and its operation is also easy. It requires a small rotating force. The cost of the crusher was only BDT 12,000 which is within the buying capacity of the farmers of Bangladesh. Besides, if the machine is manufactured commercially then the price will be reduced to BDT 9,000. The crushing capacity of the mesocarp of the crusher was o.84 kg/hr at a speed of 26 rpm smoothly rotating and crude oil percentage was 22.14 %. That is 221 gm crude palm oil extracted from 1 kg of mesocarp.

The most advantageous feature of this machine is that it can provide us with crude palm oil within a few times at our home itself. It requires less storage space as well as less operational space. Being manually operated, it requires negligible maintenance cost except for some greasing. It is very easy to clean and can be comfortably washed with water in post-operation of the machine. The weight of the crusher is 11 kg which is easy to operate by one man. The overall performance of the crusher was found quite satisfactory. The extraction efficiency (without palm kernel) of the machine is 22.14 % which is very close to the reported average value and very higher than the traditional method (just by boiling). Moreover, many of the smallholder palm farmers don't have access to electricity in their locality so this machine is suitable for them. This machine might be introduced in Bangladesh and it will solve the burning need of smallholder palm farmers in Bangladesh.

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