Development and performance evaluation of a cocoa bean sheller cum winnower

Abstract: Cocoa (*Theobroma cacao* L.) is a commercial plantation crop in India. It is the main raw material in the production of chocolates, cosmetics, health drinks, pharmaceuticals etc. Shelling is one of the primary unit operation and critical step in the processing of chocolate. It affects the quality of the cocoa nibs in terms of flavor and purity. The present study focuses on the development of a cocoa bean sheller cum winnower and its performance evaluation in terms of percentage of cracked and uncracked beans, shelling efficiency, capacity, cleaning efficiency and energy requirement. Roasted cocoa beans were shelled using the developed cocoa bean sheller, which were further subjected to winnowing operation using cocoa bean winnower to separate the shells from the nibs. The shelling efficiency of the developed cocoa bean sheller and cleaning efficiency of the winnower were found to be 98 % and 90.38% respectively.

Keywords: Cocoa bean, Sheller, winnower, cocoa nib, primary processing of cocoa

Introduction

Cocoa, (*Theobroma cacao L.*) a native of Amazon region of South America is an important plantation crop in the world, belongs to *Malvaceae* family. The high polyphenol content of cocoa, coupled with its nutritional benefits, render this food of particular interest for all age groups of people (Beg et al., 2017). The three main varieties of cocoa are Forastero, Criollo, and Trinitario (Jahurul et al., 2012)

As of now, cocoa is one of the important commercial plantation crops in India and it is mainly cultivated in four major Southern States viz., Kerala, Karnataka, Andhra Pradesh and Tamil Nadu (Jayasekhar and Ndung'u, 2018, Jaganathan et al., 2015). The annual production of cocoa in India during 2019 was 26,000 MT from an area of 98,000 ha. The local requirements of

cocoa are met through imports, which constitutes about half of the total beans available in the country. Andhra Pradesh is the leading cocoa producer in India and Kerala is the second-largest producer with an annual production of 9180 MT during 2019.

Cocoa beans, the seeds of cocoa tree are processed to obtain chocolate liquor, cocoa powder and cocoa butter which are the main ingredients of chocolate and a vast range of products like cocoa beverages, ice cream and bakery products and impart a characteristic and distinctive flavour to its derived products (Beg et al., 2017). Chocolate is rich in antioxidants such as flavonoids and flavanols, responsible for destroying free radicals in the body (Praseptiangga *et al*., 2020). In addition to its confectionary use, cocoa also has cosmetic and pharmaceutical applications.

The post-harvest processing of cocoa comprises the steps of pod opening and beans removal from the pod, bean fermentation, drying, roasting, shelling and winnowing of beans, cocoa butter extraction, conching, tempering, moulding etc (Di Mattia *et al*., 2017). Out of these unit operation processes, the fermentation constitutes an essential critical step for the development of chocolate flavor, since it produces aroma precursors (Di Mattia *et al*., 2017). The dried seeds are roasted, cracked and ground to give a powdery mass from which fat is expressed. Cocoa nibs/cotyledons are the most important part of the beans (Febrianto *et al*., 2021).

The chocolate making process begins with roasting the cocoa beans. During roasting, the typical roasty and chocolate flavour and the specific texture (makes cocoa beans more brittle) of the beans are developed, undesired volatiles (acetic acid) are eliminated, and the moisture content is reduced to 1-2 percentage level (Aprotosoaie et al., 2016). Once the beans are roasted they must be dehulled and winnowed. Dehuling and winnowing separates the cocoa nibs (edible portion) from the outer hull or shell (Rojo-Poveda et al., 2020). The quality of chocolate or cocoa powder depends strongly on the purity of the nibs (Nguyen et al., 2019). The winnowing process in particular is one of the important unit operations in cocoa processing. Hand winnowing method is the practice performed in rural villages to separate cocoa nibs from roasted cocoa beans. It consists of a winnowing basket that is rounded at one end and open at the other to efficiently toss the cocoa beans into the air and catch them as they fall back to the basket. As the beans are repeatedly tossed, the brittle shells break apart and separate from the beans. The process is found effective if winnowing is to be done outside in windy conditions. The wind blows away the lighter shells as they are tossed into the air, separating them from the heavier beans that fall back into the basket. This is an arduous task, apart from the large labour requirement and time consumed during the operation.

Homemade chocolate industry cannot find a single small scale cocoa sheller cum winnower that is both efficient and affordable for small scale chocolate producers. Considering the above

facts, a Cocoa sheller cum winnower" was developed at this centre. The work was carried out under AICRP on PHET at Kelappaji College of Agricultural Engineering, Kerala Agricultural University, Tavanur.

MATERIAL AND METHODS

Raw materials

Fermented and dried cocoa beans were procured from a progressive farmer at Karuvarakund, Malappuram district. Materials for the construction of the machine were purchased from M/s Evergreen Engineering works, Coimbatore and M/s Pioneer gears, Thrissur. Good quality cocoa beans after being sorted out from cracked ones and beans having diseases were selected for the study. Dried beans were collected in gunny bags and transported to the laboratory with care. The dried cocoa beans were then roasted for 15 minutes at a temperature of 130°C using a cocoa roaster. The roasted beans were stored in stainless steel containers dry condition in the laboratory until the conduction of the experiment.

Determination of engineering properties of dried cocoa beans

Prior to the development of the cocoa bean sheller, the physical, optical and frictional properties of roasted cocoa beans were studied. Engineering properties of cocoa beans such as mass, size, shape, sphericity, density, specific gravity, porosity, colour and moisture content were determined using standard methods. Also the frictional parameters, such as the coefficient of friction and angle of repose were also determined.

Development of the cocoa bean sheller

The batch-type cocoa bean sheller consists of the following parts;

a) Feed Hopper
b) Metallic rollers
c) Chute
d) Motor
e) Frame assembly

Feed hopper: Feed hopper helps to feed the roasted cocoa beans to the roller assembly. It is rectangular in shape and is mounted over the roller assembly. The dimension of the hopper was optimized based on the bulk density and quantity of the cocoa beans fed to the machine. The length,

breadth and height of the hopper are 51 cm, 41 cm and 41 cm, respectively. It was made of 2 mm thick mild steel sheet with 45° inclination with horizontal surface to facilitate easy feeding.

Metallic rollers: The working element of the machine consists of a pair of rotating ribbed rollers and stationary flat plates. The rollers are rotating horizontally on its axis in opposite direction at same speed. Shelling of cocoa take place due to the shear force between the roller and flat plate. It was enclosed inside a concentric cylinder. Each roller is 31 cm in length with 15 straight ribbed strips were welded on the shaft. The diameter of the shaft as well as the roller is 3 cm and 6.7 cm, respectively. The clearance between the rollers and flat plate is 0.6cm. The rollers rotate at a speed of 40 rpm.

Chute: A chute is placed at the bottom end of the roller assembly to collect the shelled cocoa beans. It is made up of 2 mm thick MS sheet, with dimension 41×41 cm having an inclination of 40° with horizontal to facilitate easy discharge of products.

Motor: An electric motor of 0.5 hp having a speed of 1425 rpm was used as the prime mover for operation. The desired speed of the roller is 38 rpm and was attained using a drive gear assembly. The roller was powered from the motor with the help of a jaw coupling.

Frame assembly: The frame supports the entire machine component and was fabricated using GI square section. The components *viz.,* feed hopper, roller, chute etc. were mounted on the frame.

Working of cocoa bean sheller

Well matured, dried, roasted cocoa beans were selected for testing. Roasting of cocoa beans was performed at 130°C for 15 minutes using a cocoa roaster. Proper and slow roasting of the beans is required for effective shelling. Roasted cocoa beans were fed in to the machine through feed hopper. Uniform flow of cocoa beans was maintained by employing an adjustable sleeve which helped to distribute cocoa beans evenly in thin layers to the shelling chamber. The cocoa beans were fed in thin layers between the rotating rollers and flat plates. A combined action of compression and shearing force acts on the roasted cocoa beans, resulted in shelling action. A mixture of cocoa nibs and broken shells passed through the chute and was collected at the product outlet.

Cocoa bean winnower/ specific gravity separator

Winnowing is an agricultural operation to separate grain from chaff. Cocoa bean winnower is a machine used for separating cocoa nibs from the unwanted particles like cocoa shell, dust etc. A specific gravity separator present in college workshop was employed for winnowing operation. The main parts of cocoa bean winnower are triangular-shaped perforated deck, feed hopper, vibrating

feeder, deck movement controller and air flow controller. The triangular-shaped perforated deck is the main part of the machine. The bottom surface of the deck is properly baffled to ensure the uniform distribution of air over the deck. The feed hopper is the part which receives the mixture of the cocoa nibs and shells. The vibrating feeder below the hopper directs the fall of the mixture over the perforated deck. The deck leads to the discharge end where the separated particles are collected depending upon the difference in their densities. Cocoa shells being low density than cocoa nibs are collected at the low-density fraction outlet while the nibs are collected at the high-density fraction outlet. There are provisions to adjust the movement of the deck as well as the control of airflow into this deck. The inclination of the deck is optimised in such a way that it helps in floating the light material away from the heavier ones.

The working of the cocoa bean winnower is based on two principles: a) the characteristics of grains to flow down over an inclined surface and b) the floatation of the particle due to upward movement of air. It takes advantage of the difference in size, shape and specific gravity of particles. The working is based on the difference in density/specific gravity of the materials.

The cocoa beans after shelling turn into a mixture of nibs and shells. This mixture was fed into the cocoa bean winnower for separation of the nibs. The separation efficiency depends on two factors *i.e.*, vibrational motion of the deck and the air movement. The terminal velocity of the air is adjusted in such that it should not be greater than the terminal velocity of the cocoa nibs. The actual separation takes place in two steps. The first is in the vertical direction by stratification of the seeds and the second is in the horizontal direction by the table motion and gravity. Both of the separation takes place at the same time all across the deck of this separator to give a continuous grading of material until it leaves the table. The stratification of material is accomplished by air being blown through the porous deck and in effect floating the light material away from the heavier ones.

Performance evaluation of the cocoa bean sheller

Performance of the cocoa bean sheller was evaluated in terms of percentage of cracked and uncracked beans, shelling efficiency, energy requirement, time required for shelling and capacity of the sheller.

Determination of percentage of cracked and uncracked beans and shelling efficiency

The feed hopper was filled with roasted cocoa beans at optimum moisture content of 3-4 % (wb). The total number of beans (NT) fed to the machine was determined by counting. The beans were filled into the hopper and the power supply was switched on. With an adjustable sleeve, uniform flow of cocoa beans was maintained, which also spread the beans evenly to the gap

between the rotating rollers and flat plates along its length. The shelling was done due to the combined effect of compression and shear forces acted against the cocoa bean surface. The number of cracked beans (N1) and uncracked nuts (N2) were determined at the end of each run. The experiments were repeated 10 times and the average value was selected.

a) Percentage of cracked beans

$$\mu = \frac{N1}{NT} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

b) Percentage of uncracked beans

$$\mu 1 = \frac{N2}{NT} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

c) Shelling Efficiency (%)

$$\eta = \frac{w}{wt} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where,

w = total weight of shelled nibs

wt = total input weight

Determination of energy requirement of the sheller

The energy consumption of the sheller was determined based on the amount of electricity used per hour. A 0.5 hp motor was selected as the prime mover of this machine. The energy consumption was measured using an energy meter and was expressed in terms of kWh.

Determination of time required for shelling

The time required to shell 1 kg of cocoa beans was determined by using a stop watch and is expressed in seconds.

Determination of capacity of the sheller

Capacity is the quantity of cocoa beans shelled in 1 hour. It is expressed in kg/h.

Performance evaluation of the cocoa bean winnower

Winnowing of shelled cocoa beans was performed using a cocoa bean winnower/ specific gravity separator. The performance evaluation of the winnower was conducted in terms of its cleaning efficiency, capacity and time required for winnowing.

Determination of cleaning efficiency of the winnower

Cleaning efficiency was calculated based on the formulae suggested by Sahay and Singh (1994).

$$\text{Cleaning efficiency (\%)} = \frac{E(F-G)(E-F)(1-G)}{F(E-G)^2(1-F)}$$

Where,

E = Fraction of cocoa nibs at clean seed outlet

F = Fraction of cocoa nibs in feed

G = Fraction of cocoa nibs at foreign matter outlets

Determination of capacity of the winnower

Capacity is defined as the ratio of total weight of the cocoa bean taken for winnowing to the total time taken for winnowing. It is expressed in kg/h.

Determination of time required for winnowing

The total time taken to separate nibs from 1 kg of mixture of nibs and shells was noted using a stop watch and was expressed in seconds.

Cost economics

The operational cost of the cocoa bean sheller and the cocoa bean winnower was calculated by considering the fixed and variable cost.

RESULTS AND DISCUSSION

Engineering properties

Engineering properties of roasted cocoa beans viz. physical, optical and frictional properties of roasted cocoa beans were determined. The physical properties of roasted cocoa beans are presented in Table 1. Roasted cocoa beans had an initial moisture content of 5.30±0.13 (wb). The size of cocoa beans viz. length, width and thickness were found to be about 25±0.88 mm, 13.92±0.55 mm and 7.87±0.93 mm, respectively. The mass, geometric mean diameter and sphericity of roasted cocoa beans were found to be 1.60±0.12 g, 14.55±0.37 mm and 0.558±0.71 respectively. Bulk density, true density and porosity values of roasted cocoa beans were obtained as 614±10.32 kg/m^3, 858.54±11.32 kg/m^3 and 28.31±0.45% respectively. Terminal velocity of cocoa beans was obtained as 14±0.2 m/s and specific gravity as 0.848.

Table 1. Physical properties of roasted cocoa beans

Sl. No.	Properties	Mean Value ±SD
1	Moisture content, % wb	5.30±0.13
2	Length, mm	25.12±0.88
3	Width, mm	13.92±0.55

4	Thickness, mm	7.87±0.93
5	Geometric mean diameter, mm	14.55±0.37
6	Mass, g	1.60±0.12
7	Sphericity	0.558±0.71
8	Bulk density, kg/m^3	614±10.32
9	True density, kg/m^3	858.54±11.32
10	Porosity, %	28.31±0.45
11	Terminal velocity, m/s	14±0.2
12	Specific gravity	0.848

Optical Properties

The colour of the roasted cocoa bean are expressed in terms of L*, a* and b* values and arer illustrated in Table 2. The L*, a*, b* values were 25.75±0.01, 9.54±0.04 and 9.66±0.0, respectively.

Table 2 Optical properties of roasted cocoa beans

Sl. No.	Colour	Mean Value ±SD
1	L*	25.75±0.01
2	a*	9.54±0.04
3	b*	9.66±0.0

Frictional Properties: The frictional properties viz., angle of repose and coefficient of friction on four different surfaces *viz*., stainless steel, aluminium, GI and plywood were determined.

Table 3 represents the value of angle of repose which was found to be 22.37±0.13º and coefficient of friction on four different surfaces *viz*., stainless steel, aluminium, GI and plywood as 0.20±0.002, 0.2±0.001, 0.3±0.001 and 0.40±0.002, respectively.

Table 3. Frictional properties of roasted cocoa beans

SL. No.	Properties	Mean Value ± SD
1	Angle of repose	22.37±0.13°
2	Coefficient of friction	

i. Stainless steel	0.20±0.002
ii. Aluminium	0.2±0.001
iii. GI	0.3±0.001
iv. Plywood	0.40±0.002

Performance evaluation of the cocoa bean sheller: Performance of equipment is the basic criteria to evaluate its ability. The performance evaluation of the developed cocoa bean sheller is presented in Table 4.

Percentage of cracked and uncracked beans and shelling efficiency: One kilograms of cocoa beans were selected for shelling. From the experiment it was found that, out of 960 numbers of roasted cocoa beans (1kg approx.), 922 beans were completely shelled and 38 were unshelled. The percentage of cracked and uncracked beans was found to be 96.04% and 3.95%, respectively. The shelling efficiency of the developed cocoa bean sheller was 98 %. The cost of operation of the cocoa bean sheller was estimated as ₹ 83/h.

Energy Requirement of the Sheller: The energy consumption of the sheller was determined based on the amount of electricity used per hour. It was observed that the energy requirement for the sheller was 0.450 kWh.

Time Required for Shelling: The total time required to shell 1 kg of roasted cocoa beans was approximately 18 s.

Capacity of the Sheller: The capacity of the developed sheller was found to be 200 kg/hr.

Fig.1 Mixture of cocoa nibs and shells after the shelling process

Table 4. Performance evaluation of the cocoa bean sheller

Sl. No.	Parameters	Value
1	Capacity	200 kg/hr
2	Shelling efficiency	98-100%
3	Energy requirement	0.450 kWh
4	Time required for shelling	18s (1kg)
5	Cost of operation	₹ 83/h

Performance evaluation of the cocoa bean winnower: Performance of the cocoa bean winnower was evaluated in terms of cleaning efficiency, capacity and cost of operation.

Cleaning Efficiency of the Winnower: Cleaning efficiency measures how perfectly the cleaning process is done by the winnower, i.e. the rate at which cocoa shells are separated from cocoa nibs. The fractions of cocoa nibs at clean seed outlet (E), in feed (F) and at foreign matter outlet (G) were calculated as 0.994, 0.8128 and 0.2405, respectively. The cleaning efficiency of the cocoa bean winnower was found to be as 90.38%. The cost of operation of the cocoa bean winnower was found to be ₹ 88/h.

Capacity of the Winnower: Capacity of the cocoa bean winnower was found to be 200 kg/h.

Time Required for Winnowing: The time required to separate shell from the mixture of nibs and shell was found to be 18 s.

Fig.2 Cocoa nibs after winnowing process

Table 5. Performance of the cocoa bean winnower

Sl. No.	Parameters	Value

1	Cleaning efficiency	90.38%
2	Capacity	200 kg/h
3	Time required for winnowing	18 s(1kg)
4	Cost of operation	₹ 88/h

CONCLUSIONS

The main purpose of the cocoa bean sheller cum winnower is to facilitate value addition of cocoa at small-scale farm level thereby processing of cocoa and its value-added products could be produced at lower cost. The fabricated machine has paved a path to lift the processing of cocoa to an easier level which is accessible to any local farmer who runs a small-scale unit that produces chocolate or any other product from cocoa.

REFERENCES

Aprotosoaie A C, Luca S V, Miron A 2016. Flavor chemistry of cocoa and cocoa products- an overview. *Comprehensive Reviews in Food Science and Food Safety*, **15**: 73-91.

Beg M S, Ahmad S, Jan K, Bashir K 2017. Status, supply chain and processing of cocoa - a review, *Trends in Food Science & Technology*, **66**:108-116.

Cinar Z O, Atanassova M, Tumer T B, Caruso G, Antika G, Sharma S, Sharifi-Rad J, Pezzani R 2021. Cocoa and cocoa bean shells role in human health: an updated review. J*ournal of Food Composition and Analysis*, **103**: 104115.

Di Mattia C D, Sacchetti G, Mastrocola D Serafini M 2017. From cocoa to chocolate: the impact of processing on in vitro antioxidant activity and the effects of chocolate on antioxidant markers in vivo. *Front. Immunol*. **8**:1207.

Febrianto N A, Wang S, Zhu F 2021. Chemical and biological properties of cocoa beans affected by processing: a review. *Critical Reviews in Food Science and Nutrition*. **28**:1-32.

Jaganathan D, Thamban C, Jose C T, Jayasekhar S, Muralidharan K, Chandran K P 2015. Analysis of organic farming practices in cocoa in India. *Journal of Plantation Crops*, **43**(2):131-138.

Jahurul M H A, Zaidul I S M, Norulaini N A N, Sahena F, Jinap S, Azmir J, Sharif K M, Mohd Omar A K M 2012. Cocoa butter fats and possibilities of substitution in food products concerning cocoa varieties, alternative sources, extraction methods, composition, and characteristics. *Journal of Food Engineering*. **117**(4): 467-476 .

Jayasekhar S and Ndung'u I 2018. Review of on the breaking and winnowing machine for economic history of cocoa with special reference to India. *Journal of Plantation Crops*, **46**(2): 133-138.

Nguyen H, Pham D, Nguyen V 2019. A study of cocoa beans at small industrial scale in Vietnam. *International Journal on Advanced Science Engineering and Information Technology*, **9**(1): 329-335.

Praseptiangga D, Zambrano J M G, Sanjaya A P, Muhammad D R A 2020. Challenges in the development of the cocoa and chocolate industry in Indonesia: a case study in Madiun, East Java. *AIMS Agriculture and Food*, **5**(4): 920–937.

Rojo-Poveda O, Barbosa-Pereira L, Zeppa G, Stévigny C 2020. Cocoa bean shell- a by-product with nutritional properties and biofunctional potential. *Nutrients*, **12**(4), 1123.