DEVELOPMENT AND PERFORMANCE EVALUATION OF A COCOA BEAN SHELLER CUM WINNOWER

By

ANJALI PALAKKEEL (2016-06-003)

ANJANA NARAYANAN (2016-06-028)

APARNA SURESH (2016-06-006)

JASEERA NASRIN (2016-06-014)

SANJAY P (2016-06-019)

DEPARTMENT OF PROCESSING AND FOOD ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR-679573, MALAPPURAM KERALA, INDIA

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PROJECT REPORT

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DEPARTMENT OF PROCESSING AND FOOD ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR-679573, MALAPPURAM KERALA, INDIA

2020

DECLARATION

We, hereby declare that this thesis entitled ***"Development and Performance Evaluation of a Cocoa Bean Sheller cum Winnower"*** is a bonafide record of research work done by us concerning the research work and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar titles, of any other University or Society.

Place: Tavanur

Date:

Anjali Palakkeel (2016-06-003)

Anjana Narayanan (2016-06-028)

Aparna Suresh (2016-06-006)

Jaseera Nasrin (2016-06-014)

Sanjay P (2016-06-019)

CERTIFICATE

Certified that this thesis entitled **“ Development and Performance Evaluation of a Cocoa Bean Sheller cum Winnower”** is a record of research work done independently by **Ms Anjali Palakkeel (2016-06-003)**, **Ms Anjana Narayanan (2016-06-028)**, **Ms Aparna Suresh (2016-06-006)**, **Ms Jaseera Nasrin (2016-06-014)**, **Mr Sanjay P (2016-06-019)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to them.

Place: Tavanur

Date:

Guide:

Dr Rajesh G K

Assistant Professor
Department of P&FE

Kelappaji College of
Agricultural Engineering
& Technology, Tavanur

Co-guide:

Er. Nithya C

Assistant Professor (C)
Department of P&FE

Kelappaji College of
Agricultural Engineering
& Technology,Tavanur

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Anjali Palakkeel (2016-06-003)

Anjana Narayanan (2016-06-028)

Aparna Suresh (2016-06-006)

Jaseera Nasrin (2016-06-014)

Sanjay P (2016-06-019)

Dedicated to the farmers who thrive to serve us…

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SYMBOLS AND ABBREVIATIONS

% w/w	:	weight by weight
%	:	percentage
&	:	and
/	:	per
=	:	equal to
±	:	plus or minus
≈	:	approximate
ºC	:	degree Celsius
AOAC	:	Association of Official Analytical Chemists
cm	:	centimetre
d.b	:	dry basis
et al.	:	and others
etc.	:	et cetera
Fig.	:	figure
g	:	gram
GI	:	galvanized iron
h	:	hour
ha	:	hectare
hp	:	horse power
ICCO	:	International Office of Cocoa, Chocolate Sugar confectionery

KCAET	:	Kelappaji College of Agricultural Engineering and Technology
kg	:	kilogram
kg/h	:	kilogram per hour
kg/ha	:	kilogram per hectare
kg/m^3	:	kilogram per cubic metre
kJ/kg	:	kilojoule per kilogram
kW	:	kilowatt
kWh	:	kilowatt-hour
L	:	litre
min	:	minute
ml	:	millilitre
mm	:	millimetre
m/s	:	metre per second
MMT	:	million metric tonnes
MT	:	metric tonnes
N	:	Newton
No.	:	number
PVC	:	poly vinyl chloride
rpm	:	revolutions per minute
s	:	second
SD	:	standard deviation
SS	:	stainless steel

t	:	tonne
t/ha	:	tonnes per hectare
viz.	:	namely
w.b	:	wet basis
wt.	:	weight

INTRODUCTION

CHAPTER I

INTRODUCTION

Cocoa (*Theobroma cacao L.*), native to Amazon region of South America is an important plantation crop in the world and is used mainly in the production of chocolate. It is an important agricultural export commodity grown at an altitude of fewer than 1312 feet above sea level and has an optimal temperature range between 18ºC and 32ºC (Anon., 2008). The desired rainfall for the optimal growth of the crop is at least 100 cm but not more than 1000 cm per year (Anon., 2008).

Global production of cocoa in 2018-19 was 4.4 MMT, from across 10 million hectors, with an average yield of 0.44t/ha (Anon., 2020). Africa, Asia, and Latin America are the primary growing regions of Cocoa. Currently, Cote d'Ivoire is the leading producer of cocoa with an annual production of 2.15 MMT during 2017-18 (Anon., 2019). However, Ghana is recognized as the world leader in premium-quality cocoa production (S. Kolavalli,2001).

In India, cocoa is primarily grown as an intercrop in the states of Kerala, Karnataka, Andhra Pradesh and Tamil Nadu. In 2018-19, India harvested 23,981 MT of cocoa beans from an area of 94,008 ha, which is only about 1% of the yield produced by Ivory Coast (Anon., 2019a). 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 with an annual production of 9615 MT across an area of 32,949 ha during 2018-19 (Anon., 2019a). Kerala is the second-largest producer with an annual production of 8,507 MT across an area of 16,894 ha during 2018-19 (Anon., 2019b). India exported 27,603.77 MT of cocoa products to the world for the worth of 1,350.84 crores during the year of 2018-19 (Anon., 2019a).

Cocoa beans, the seeds of the cacao 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. They impart a characteristic and distinctive flavour to its derived products. In addition to its confectionary use, cocoa has cosmetic and pharmaceutical applications too. Cocoa husks can be hydrolysed to produce fermentable sugar. After the removal of theobromine, the cocoa cake is used as a feed ingredient for poultry, pig, sheep, goat, cattle and fish (Adeyanju *et al*., 1975). The cocoa pod is a good source of potassium and thus used in the production of potash fertilizer, local soap, biogas and particle boards (Adeyanju *et al*., 1975; Opeke, 1987).

The post-harvest processing of cocoa comprises of pod opening, removal of beans from the pod, bean fermentation, drying, roasting, shelling and winnowing of beans, cocoa butter extraction, conching, moulding etc. Of these, fermentation is the critical step in the development of flavour and quality attributes of the cocoa beans. The chocolate making process begins with roasting the dried cocoa beans which are then cracked and ground to give a powdery mass from which fat is expressed. Roasting is the key step in the production of chocolate liquor or cocoa powder as it helps in the removal of undesirable volatile compounds, provides desirable aroma and flavour which makes cocoa beans more brittle. Once the beans are roasted, they must be dehulled or shelled to obtain cocoa nibs (edible portion). The cocoa nibs are then processed into chocolate or other cocoa products.

The Shelling process is performed to break open the shell of the roasted cocoa bean, which encloses the cocoa nib. It is one of the primary processes that affects the quality of the cocoa nibs in terms of flavour and purity. This step is significant and crucial in determining the commercial acceptance of both the cocoa beans as well as the chocolate which is further to be processed from it.

Winnowing separates the cocoa nib (edible portion) from the outer hull. It is an important unit operation because if there is a high percentage of husk present along with the cocoa nibs, it will affect the quality of the chocolate. Hand winnowing is performed in rural villages to separate cocoa nibs from roasted cocoa shells. The assembly 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 get separated from the beans. This is an arduous task, apart from the large labour requirement and time consumed during the operation. Large industries thus rely upon mechanically operated cocoa bean shellers to perform this operation.

Homemade chocolate industries and small-scale chocolate producers find it difficult to purchase a sheller that is both efficient and affordable. The availability of such a sheller which also has provision to perform winnowing would flourish the production of cocoa products to higher levels. Considering the above fact, a study has been undertaken about the **“Development and Evaluation of a Cocoa Bean Sheller cum Winnower”.**

Objectives of the present study are:

- To study the engineering properties of roasted cocoa beans
- To develop an efficient cocoa bean sheller cum winnower
- To conduct the performance evaluation of the developed machine in terms of capacity, shelling efficiency, cleaning efficiency and energy requirement

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

This chapter deals with a comprehensive review of the research work done by various research workers related to the engineering properties of cocoa beans, cocoa processing machinery and its performance evaluation.

2.1. COCOA

The cacao tree, *Theobroma cacao L.*, originated in the tropical regions of South America. It proliferates in the tropical climate, 20° North and South of the equator. It grows in humid areas with average annual rainfall and relative humidity of 1250-3000 mm and 70-100%, respectively. Cacao trees are multiplied by vegetative propagation through budding or grafting. The trees are 12-15 m in height and are often grown as an intercrop. The cacao trees are fast-growing and start bearing pods after two to three years (Cook, 1982; Beckett, 2009). The fruit is fully grown in 143 days and the ripening starts afterwards. Maturity is attained after 170 days as indicated by the colour of the pod. Harvesting is done twice a year. On average, a fruit is 180-200 mm long and weighs about 400-500g.

Cocoa seeds contain about 40-50% fat and 14-18% protein depending on the time of harvest. Although cocoa is not an optimal vitamin source as a single food but on a per unit energy basis, cocoa is adequate. As a single source of food, however, cocoa is an excellent source of essential minerals. Cocoa fat is neutral in flavour. Of the caloric content in the typical whole bean, about 50-60% comes from cocoa butter. Freshly harvested cocoa beans contain about 12-14% potentially digestible carbohydrate and a considerable amount of non-digestible carbohydrate or fibre. The amounts of non-nutritive compounds (only in the sense that they do not provide energy or maybe classed as a traditional vitamin) contained in 100 g of cocoa powder are significant and may account for 20% of powder weight (Robert Rucker, 2009).

Table 2.1. Proximate composition of cocoa (*Theobroma cacao*)

Component	Average concentration (% w/w)	
	Pulp	Seed
Water	80-85	35-45
Lipid	<0.5	45-55
Sugars	6-10	0.5-2
Pectin	4-7	2
Organic acid	0.5-1	0.5-1
Polyphenols	<0.1	7-10
Alkaloids	<0.1	3-3.5

Source: Thompson *et al*. (2001); Ardhana and Fleet (2003); Schwan and Wheals (2004)

2.2 HISTORY

The cacao tree is native to South America. It may have originated in the foothills of the Andes in the Amazon and Orinoco basins of South America, current-day Venezuela, where even today, wild cocoa varieties can be found. Chocolate was introduced to Europe by the Spaniards and became a popular cocoa product by the mid-17th century. They also introduced the cacao tree into the West Indies and the Philippines. It was also introduced into the rest of Asia and West Africa by Europeans. In the Gold Coast, modern Ghana, cocoa was introduced by an African, Tetteh Quarshie. The cocoa plant was first given its botanical name by Swedish natural scientist Carl Linnaeus in his original classification of the plant kingdom, who called it *Theobroma cacao* ("Food of God") (Anon., 2015).

2.3 COCOA PRODUCTION

Fig. 2.1 shows the production status of cocoa during 2018-19, globally. The total world production of cocoa in 2018-19 was 4.4 MMT, from across 10 million hectors, with an average yield of 0.44t/ha.

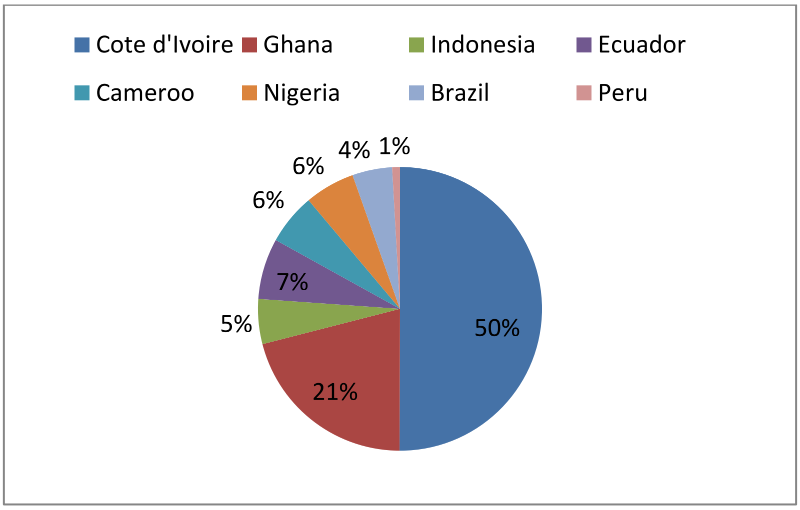

Fig. 2.1: World cocoa production (%) in 2018-19

Source: Anon., 2020

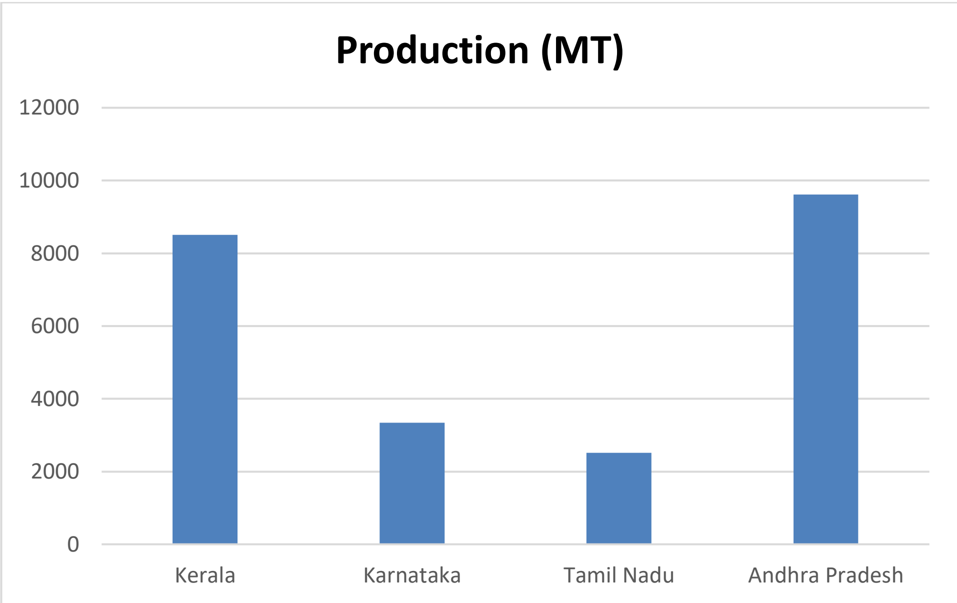

Fig. 2.2: State-wise production of cocoa in India (2018-19)

Source: Anon., 2019a

In India, cocoa is mainly grown in Kerala, Karnataka, Andhra Pradesh and Tamil Nadu in an area of 94,008 ha with a total production of 23,981 MT in the year 2018-19. Andhra Pradesh ranks first in production with an annual production of 9,615 MT during 2018-19 (Anon., 2019a). Kerala is the second-largest producer with an annual production of 8,507 MT across an area of 16,894 ha during 2018-19. The total productivity of cocoa in India is around 669 kg/ha (Anon., 2019b).

2.4 VARIETIES OF COCOA

The three large and distinct groups within the cocoa species are *Criollo*, *Forastero* and *Trinitario* (Adewumi, 1997).

2.4.1 *Criollo*

It is native to Central America and considered the best-flavoured cocoa. This variety has white to pale yellow cotyledon. The variety is also characterized by slender trees, green pods or pods coloured by anthocyanin pigments. Leaves are relatively smaller and more oval than the other types. The seed is cylindrical in cross-section. It weighs around one gram and is covered with sweet mucilage. Pods are soft, easy to break, and do not have the woody layer found in other varieties. Immature pod colour ranges from pale green to red. On fermentation and drying, the cotyledon colour turns light brown. It is very susceptible to most pests and diseases of cocoa. It produces the best quality of chocolate. With proper attention and care, the yield can be enhanced as high as 1.0-1.5 t/ha (Anon., 2008).

2.4.2 *Forastero*

Forastero is native to Venezuela and Northern Amazon Basin. It is commercially grown in Brazil, Central America, the Caribbean and West Africa. The group is characterized by green pods, absence of anthocyanin pigmentation, thick pericarp, strongly lignified mesocarp, plump but slightly flattened purple beans. The trees are vigorous, with leaves larger than those of *criollo*. *Forastero* is noted for its superior growth and high bean yields as well as appreciable tolerance to West African virus strains (Anon., 2008).

2.4.3 *Trinitario*

Trinitario is the product of hybridization between *Criollo* and *Forastero* and has its origin at Trinidad. It shows a range of characteristics possessed by both *Criollo* and *Forastero*.

The trees are generally vigorous with a variable reaction to pests and diseases. Pods are either green or pigmented. The bean colour varies from light to very dark purple (Anon., 2008).

2.5 STRUCTURE OF COCOA

The cocoa pod consists of cocoa beans, placenta and mucilaginous pulp. Cocoa pods are usually ovoid and can range from 20 to 32 cm in length. The colour ranges from yellow to red or violet. The surface texture of most cocoa pods is deeply grooved to nearly smooth. The cocoa bean is encompassed by mucilaginous pulp. The number of beans per pod ranges between 30 and 40. Bean consists of two convoluted cotyledons and a germ, all enclosed in the testa. The colour of the cotyledon varies from white to purple (Adzimah and Asian, 2010). The schematic diagram of the cocoa pod is shown in Fig. 2.3.

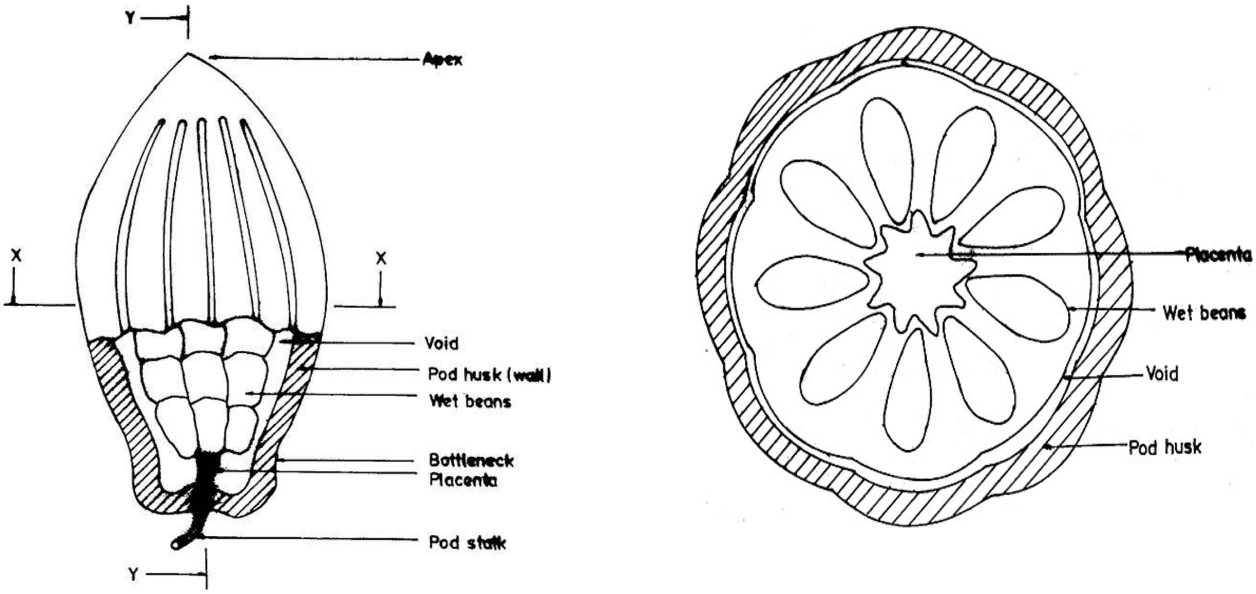

Fig. 2.3: Geometry of cocoa pod

Source: Fabunmi, 2004

2.5.1 Cocoa Beans

Cocoa beans, the base for making chocolate, are the seeds of the cacao tree. They are found inside the cocoa pods, encompassed by a white mucilaginous pulp. The number of beans per pod ranges between 30 and 40. Bean consists of 2-10 convoluted cotyledons and a germ, all enclosed in the testa. The colour of the cotyledon varies from white to purple.

The cotyledons store the food for the developing plant and become the first two leaves of the plant when the seed germinates. The food store consists of fat, known as cocoa butter, which amounts to about half the weight of the dry seed. The quantity of fat and its properties such as melting point and hardness depend on the variety of cocoa and the environmental conditions.

The seeds are fermented which causes many chemical changes in both the pulp surrounding the seeds and within the seeds themselves. These changes cause the chocolate flavour to develop and the seeds to change colour. The seeds are then dried and despatched to processors as the raw material for the production of cocoa mass, cocoa powder and cocoa butter. The first stage of processing includes roasting the beans to change the colour and flavour, followed by shell removal. After roasting and deshelling, an alkalising process can be done to alter flavour and colour.

2.6 PROCESSING OF COCOA

Processing of cocoa beans includes harvesting and pod breaking, fermentation, drying, cleaning, roasting, deshelling, winnowing, alkalization and finally grinding to liquor which can be pressed into cake and butter. The cake is further pulverized into powder. The processing steps were earlier performed by manual methods, but nowadays, cocoa processing industries are becoming highly automated with improved technologies and capital investments.

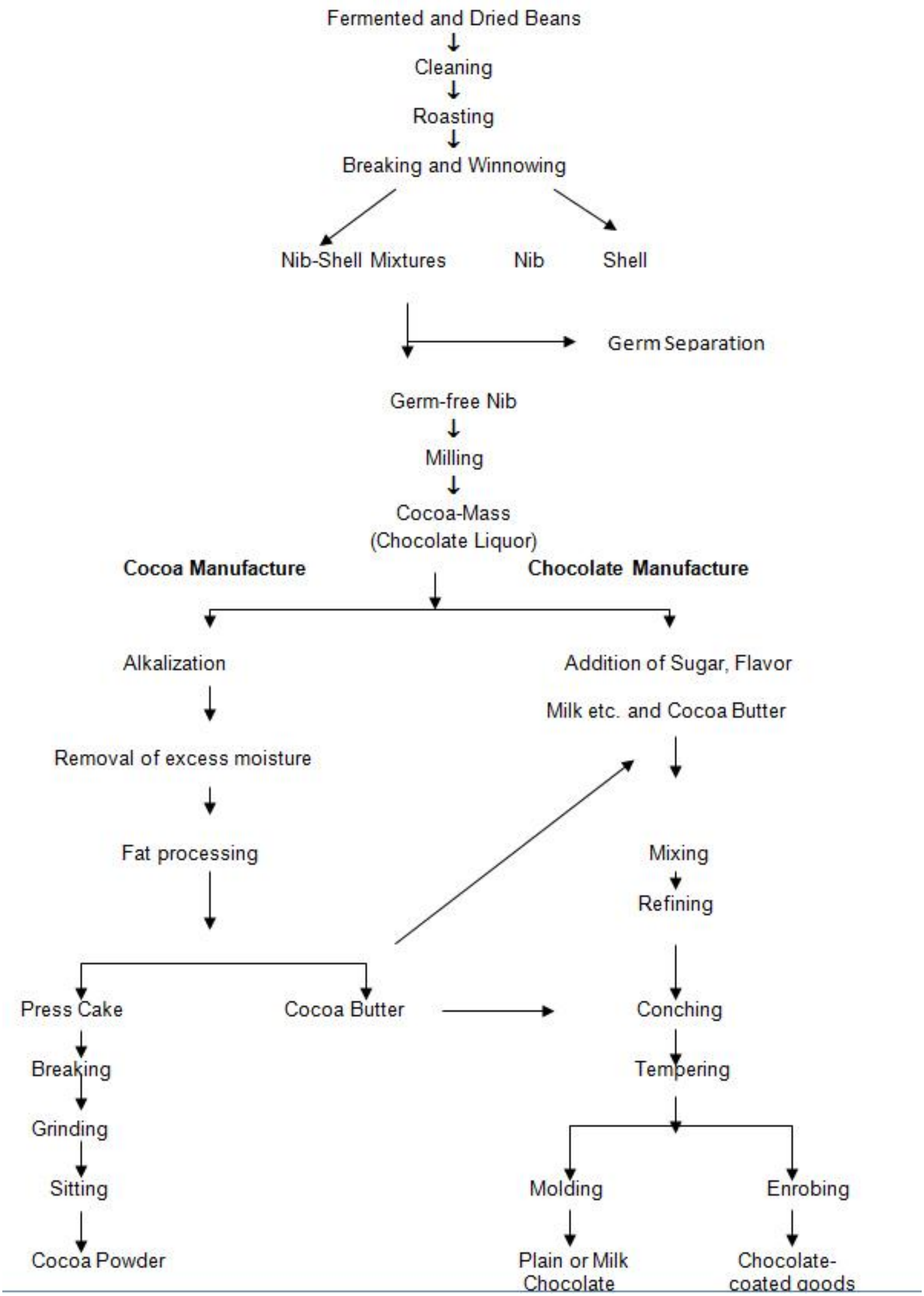

Fig.2.4: Flowchart of cocoa processing and chocolate making

Source: TNAU Agritech portal, 2020

2.6.1 Harvesting and Pod Breaking

Harvesting is done manually by cutlass or long knife to get a pod from the tree with a long handle steel tool. The beans are extracted from the cocoa pod by breaking the pods manually or mechanically. These pods can be opened with a hard stick to remove the beans from them.

Cocoa pod breaking machine built by M/s Christy and Norris limited of England was evaluated at M/s Cadbury brothers' cocoa plantation at Ikiliwindi, Cameranoon (Are and Jonnes, 1974). The machine was operated by two persons- one fed the cocoa pods into the machine, while the other collected the beans. The cocoa pods were fed into the hopper and directed to the shelling section by gravity. The cocoa pods were broken using a revolving wooden cone mounted vertically inside a ribbed cylindrical metal drum. The beans passed through the meshes and were collected in a wooden box. The shell fragments dropped out at the open end of the rotary sieve.

An environmentally friendly cocoa splitting machine was developed by Adzimah and Asiam (2010). It consisted of a frame, collecting containers for cocoa pods and beans and chopping off knives. The knives were actuated by positive displacement hydraulic pumps of 65 hp.

2.6.2 Fermentation

Fresh beans obtained from the pods can be packed into basket, boxes or heaped into piles that can be covered with banana leaves to start the anaerobic fermentation. This process lasts for 3-7 days to serve three main purposes *viz.,* liquefaction, removal of mucilaginous pulp and development of aroma, colour and flavour. The fermentation stage determines the quality of the cocoa powder.

Seeds of the ripe pod are microbiologically sterile. When the pod is opened with a knife, the pulp becomes contaminated with a variety of microorganisms, many of which contribute to the subsequent fermentation. Organisms come mainly from the hands of workers, knives and unwashed baskets used for transport of seeds and dried mucilage left on the balls of the boxes from previous fermentations (Schwan and Wheals, 2004).

During fermentation, microbial activity leads to the formation of a range of metabolic end products such as alcohols, acetic acid and other organic acids, which diffuse into the beans and cause their death. This induces biochemical transformations within the beans that lead to the formation of precursors of the characteristic aroma, flavour and colour, which are further developed during drying and finally obtained during roasting and further processing (Ardhana and Fleet, 2003).

Fermentation of cocoa is an important unit operation which results in the formation of flavour precursors and the development of the chocolate brown colour. Fermentation is carried out in different ways *viz.*, box method, heap method etc. depending on the variety of cocoa (Beckett, 2008).

At the time of cocoa bean extraction, beans are astringent and bitter with no chocolate flavour. Raw beans have slaty grey colour. During fermentation, due to the action of yeasts, acetic and lactic acid bacteria, the mucilaginous pulp enclosing the beans convert into ethyl alcohol, acetic acid and lactic acid, respectively. The formation of acid and heat keep the cell membrane permeable and develop flavour precursors *viz.*, amino acids, peptides and reducing sugars. (Gill *et al*., 1984; Hansen *et al*., 1998; Thompson *et al*., 2001; Schwan and Wheals, 2004; Nielsen *et al*., 2007).

When cocoa is adequately fermented, the seed coat is transformed from a soft, white, close-fitting skin to a pale brown, crisp and easily removable shell. In later stages of fermentation, the beans get swollen by absorption of moisture and the shell becomes fragile. The shell gains about 10% of its original weight during fermentation and it has been found that the shell becomes saturated with mucilage from the pulp (Potty, 1979).

After fermenting, the entire cotyledon is uniformly tinted by the pigment released from the pigment cells. The rise in temperature and formation of alcohol and acetic acid in the pulp during fermentation is responsible for killing the germ in the cotyledons. The germinating power of cocoa is destroyed at 43-44°C; especially, the Criollo germ is killed at lower temperatures in a shorter duration. Usually, the germs are killed on the third day and the cotyledon starts absorbing moisture on the fourth day of fermentation. The beans become rounded on the fifth day when the space between the cotyledons is filled with a brown gummy juice containing compounds of tannin with theobromine and caffeine (Potty, 1979).

2.6.3 Drying, Packing and Storage

After fermentation, cocoa beans are dried by solar drying in the open air or employing hot air oven dryer to prevent deterioration from bacteria. The dried beans are packed into sacks, plastic bags etc. for storage into warehouses (Beg *et al.*, 2017).

Once the fermentation process is over, the storage life of the beans is increased by the process of drying. The fermented beans have a moisture content of about 55%. Such high moisture content products have a low shelf life and are prone to putrefaction. For safe storage and transportation, the moisture content is reduced to 6-8% (db) by drying of beans. Generally, beans are dried within 24 h after fermentation to avoid mould growth. During the drying process, the beans undergo some biochemical reactions. Apart from the reduction in moisture content, the objective of drying is to remove bitterness, astringency, prevent off flavour produced due to excessive acidity. The rate of drying is very important for optimum quality of end products. When the process is too slow, it leads to mould growth while a faster process will prevent the essential oxidative changes and may lead to excess acid formation.

During the drying process of cocoa, a distinct constant rate and two falling rate period are seen (Bravo and McGraw, 1974). They reported that the critical moisture content lies at 40% (wb) and the first falling rate lies between 40% and 23% (wb) moisture content.

Drisya *et al. (2019)* developed a dryer that consisted of a cylindrical drying chamber, blower, heating coil, DC motor and agitator. Fermented cocoa beans were fed into the drying chamber manually. Fresh air was pumped into the machine by the blower. The blower pushes the air through the ball valve into a cylindrical horizontal pipe inside which the heating coil is placed. Heating coils heat air to the required temperature with the help of a thermostat. The heated air is then pushed into the drying chamber where the beans are placed above a mesh. The heat from the air decreases the moisture content in the cocoa beans thus, drying the beans. The agitator provides occasional turning of beans which helps in proper and uniform drying. The time required for drying at temperatures 40, 45 and 50ºC using the mechanical dryer was 10, 7 and 5.5 hours, respectively. The capacity of the dryer was 10 kg. The efficiency of the dryer at different drying temperatures *viz*., 40, 45 and 50ºC were 53.02, 48.47 and 36.80 per cent, respectively.

Ajala and Ojewande (2014) conducted a study on drying of fermented cocoa beans. In the study, cocoa beans were subjected to hot air drying in a tunnel dryer at 50, 55, 60, 65, 70, 75, 80 and 85ºC. The proximate, chemical and physical attributes of the samples were investigated. The results show that higher temperature of drying conferred higher drying rate on the samples; proximate, chemical and physical analyses were inversely related in most cases.

Komolafe *et al.* (2014) developed a batch type cocoa bean dryer. The dryer consists of a drying platform, drying chamber, heating duct (flue) and air holes. The heated air dryer was successful in drying 5 cm deep thin layer up to 25 kg capacity with 7 h of continuous drying.

2.6.4 Roasting

Roasting is the most important technological operation in cocoa beans processing, and the degree of chemical changes depends on the temperature applied during the process. Properties of roasted beans, such as formation of a characteristic brown color, texture of roasted beans, concentration of volatile flavor compounds, total acidity and fat content, depend on roasting conditions mainly temperature and processing time (Ramli *et al.*, 2006; Krysiak *et al.*, 2013; Owusu et al., 2013). The selection of process parameters has a decisive influence on the nature of chemical and physical changes occurring in the cocoa beans, which determines the quality of the final products.

During study on cocoa beans roasting, Ramli et al. (2006) also found that the burnt taste and odor increased with increasing time and roasting temperature (170 °C for 50 min left higher burnt flavor, bitter taste and astringency). ROCHA *et al*. (2017) indicated that roasting at 120 °C for 40 min produced greater cocoa flavor, lower astringency and sour taste.

2.6.5 Shelling

The roasted cocoa beans are shelled to remove the outer hard covering around the cocoa nib**.** The Shelling process is one of the primary processes and critical steps in the processing of chocolate or any product that is derived from cocoa beans. It affects the quality of the cocoa nibs in terms of flavour and purity. This step is significant and crucial in determining the commercial acceptance of both the cocoa beans as well as the chocolate which is further to be processed from it. After drying, the cocoa beans are subjected to roasting process at a temperature of 120^0c for about 20 min to incorporate desired characteristic flavour, aroma and brittleness. The shelled cocoa undergoes winnowing to separate the shells from the nibs, which is later kibbled, ground and pressed to obtain cocoa butter and cocoa powder.

During the shelling operation, shells should be perfectly separated and leaving nib particles practically unbroken (Beckett, 2009). Shelling of cocoa is a very difficult and time-consuming operation. In the past, shelling was done manually by humans or with the help of animals. But nowadays, different shelling machines are available at industrial level.

Codex Alimentarius establishes a maximum amount of 5% of cocoa shells in the cocoa cake (based on the fat-free dry matter) (Codex Alimentarius, 2016). Analysis of cocoa shell in cocoa products might be done following the AOAC 968.10 or the 970.23 methods (Codex Alimentarius, 2016). The first method, called spiral vessel count consists of counting the spiral vessels in a defatted, ground and digested sample with the help of a microscope adjusted to mold counting (AOAC, 1984). The second method, called stone cell count, consists of microscope assisted counting the stone cells present in the samples after a laborious preparation (AOAC, 1984).

Husking by rubber roll (paddy) is caused by shear and compression of the two rotating rubber surfaces, is sufficient to split and separate the husk from the grains. The paddy is passed through the clearance between two rubber rolls, rotating in opposite directions at a different speed. The clearance between them is smaller than the mean thickness of paddy. One part of the husk is subjected to shearing force whereas the other part in contact with the slower roll is under compression and is thus subjected to a breaking force (Ezaki, 1973).

Sharma and Mandhyan (1988) developed a hand-operated pea shelling machine. They tried three different surfaces (i) punched tin sheet (ii) cycle tyre treads and (iii) gunny bag cutting.

Ademosun (1990) designed a medium-scale cocoa dehulling and winnowing machine. The performance evaluated that the machine was easy to operate with only the adjustment of roller clearance. The machine was found to have high dehulling and winnowing efficiencies at the optimum roller clearance.

Singh (1983) modified two peanut shellers, one manual and other hand power operated to improve their performance. The modified manual peanut sheller has a mechanism to adjust the clearance, and round tooth shelling bars, with a capacity of 32 kg (seed)/h with about 4.8% breakage and 96% shelling efficiency. The modified power operated peanut sheller has, a feeding mechanism and a blower with a capacity of 175 kg (seed)/h at 145 strokes/min shelling bar speed and 2 cm clearance has shelling efficiency of 97% with 4.7% breakage, 0.2% blower loss, 98.3% cleaning efficiency with 2.2 kW power consumption.

The present method of obtaining the kernel from the shea nut in Nigeria involves manual cracking of the nut using stones, mortar and pestle. This method is not only laborious and time-consuming but also risky and wasteful. The developed cracking unit consists of a cylindrical shell, a spinning disc that is concentrically positioned within the shell and horizontally mounted on a vertical shaft, and the cracking surface, which is formed by the inner wall of the shell. The spinning disc is mounted to give a clearance that is equal to the nut size with cracking surface. The disc is driven by its vertical shaft, which is powered by a horizontal shaft, via an arrangement of the bevel gear drive. (F.A. Oluwole *et al*., 2004).

2.6.6 Winnowing

Winnowing is the process of removing the cocoa shells and other foreign matters from the mixture of cracked cocoa beans (cocoa nibs) and shells. It is an important unit operation because if there is a high percentage of the husk present along with cocoa nibs, it will affect the quality of the chocolate. Hence proper winnowing has to be done before proceeding to the next unit operation, i.e. grinding.

Hand winnowing is the practice performed in rural villages to separate cocoa nib from roasted cocoa beans. This is an arduous task, apart from the large labour requirement and time consumed during the operation. Cocoa shell has a lower density than cocoa nibs. An optimum velocity of airflow can separate the shell from the nib. Hence, we used a cocoa winnower for this purpose.

Winnower machine separates roasted cocoa beans from shells, consequently roasted cocoa nibs can be processed into cocoa mass (Hartanto, 2012). It is expected that the winnower produces cocoa nibs with uniform size and doesn't have any tiny cocoa shell parchment mixed with the cocoa nibs (Afoakwa, 2010).

By using the winnower machine, it is expected that the shell texture is fragile as a result it is easier to break and separate. Roasted cocoa beans should also have a low water content to get uniform fractions of roasted cocoa nibs. Another method to get uniform fractions of roasted cocoa nibs is by sieving the nibs (Beckett, 2010).

Previously, the winnower machine consisted of double rolls with some space producers in between for breaking down cocoa beans without grinding them and then sieving the broken beans. Another machine was in the form of a serrated cone cylinder installed to hollowed cone stator widely known as kibbling cones type (Knapp, 1920). The machine was later developed by providing air suction and cyclone-shaped funnel. Roasted cocoa beans are peeled using rotor-stator and then they go to the exhausting channel that is connected to a suction fan that results in smaller fractions of cocoa shell parchment to be sucked out of the exhausting channel and the nibs to be collected in the storage funnel (Beckett, 2009).

Hendy Firmanto *et al*. (2016) conducted an experiment in Postharvest Laboratory at the Indonesian Coffee and Cocoa Research Institute using roasted cocoa bean grade A. The shell content of 15% originated from Forastero cocoa. Working performance of the home-scale winnower was evaluated based on shell parchment content in the output, its capacity, energy consumption and power transfer efficiency value by several air suction rates as a variable. The optimum machine performance was obtained on 0.72 m/s of air suction rate with total winnowing capacity of 2.615 kg/h, energy consumption of 132 Watt, power transfer efficiency value of 61.01% and shell parchment content of 1.06%.

2.7 ENGINEERING PROPERTIES

The physical and engineering properties are important in solving many problems associated with the design of machines and analysis of the behaviour of the product during post-harvest operations such as handling, threshing, cleaning, sorting and drying. Finding solutions to the problems associated with the processes require knowledge about the physical and engineering properties (Irtwange, 2000).

2.7.1 Physical Properties

Prior to the design and development of the machine, the physical properties *viz.*, sphericity, roundness, mass, geometric mean diameter, surface area, volume, porosity, true density, bulk density etc. are to be found. The physical properties of cocoa beans like those of other grains and seeds are required in the design and construction of equipment and structures for handling, transporting, processing and storing the beans and in the assessment of the product quality. Various types of cleaning, grading, separation and conveying equipment are designed and constructed on the basis of the physical properties of grains and seeds. Among these properties, angle of repose and coefficient of static friction are the physical properties that affect the conveying characteristics of grains and seeds (Bart Plange *et al*., 2003).

2.7.1.1 Size

Size is the measure of physical dimensions of an object. Fruits and vegetables are irregular in shape and a complete specification of their form on a theoretical basis requires an infinite number of measurements. From a practical point of view, measurements of several mutually perpendicular axes are to be taken. However, the measurements along major and minor axes were taken for describing the size of the bean (Mohsenin, 1986).

Bart Plange *et al.* (2003) determined the moisture dependent physical properties of category B cocoa beans. The length, width and thickness of the bean which are shown in Fig. 2.4, were determined using a micrometre screw gauge with 0.01 mm accuracy. 87% of the beans had their length between 20.0 and 26.0 mm, 87% had their width between 10.0 and 14.0 mm and 95% had their thickness between 6.0 and 10.0 mm.

Davies and Mohammed (2014) determined moisture dependent engineering properties of *Forastero* cocoa bean seeds. The effects of moisture content on the physical, mechanical and frictional properties of cocoa seeds were investigated at four different moisture content levels (9%, 14%, 19% and 26% db). The seed principal axes (length, width and thickness) were found to increase linearly from 20.84 mm to 24.05 mm, 11.42 mm to 14.80 mm and 8.60 mm to 10.39 mm.

Yuwana *et al*. (2015) characterized some engineering properties of coffee beans produced from wet process in respect to different colors of coffee cherries. The average values of length, width and thickness were 11.61 to 12.1 mm, 8.35 to 8.84 mm and 5.04 to 5.45 mm respectively.

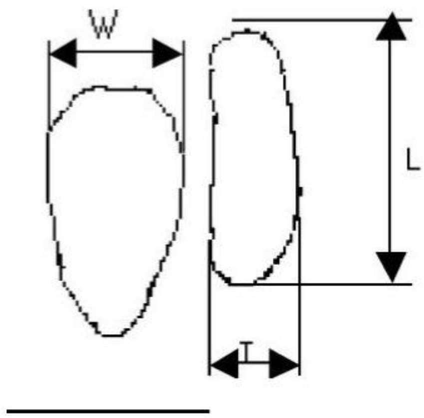

Fig. 2.5 Shape and dimensions of cocoa beans.

Source: Bart Plange *et al*., 2003

Pandiselvam R., *et al*. (2016) determined the physical properties of paddy (ADT-43) namely, size, shape, thousand paddies mass, aspect ratio, surface area, volume, bulk density, true density and porosity at moisture contents ranging from 11.86 to 23.61 per cent db using standard techniques. At the moisture content of 11.86 per cent (db), the average length, width and thickness of paddy (ADT-43) were 7.79, 2.38 and 1.77 mm, respectively.

2.7.1.2 Shape

Shape characteristics are necessary for removing debris and other undesirable materials mixed with the dried fruits and also in sorting and grading machinery (Loghavi *et al*., 2010).

Bart Plange *et al*. (2003) reported that the sphericity of cocoa beans varied from 0.57 at 8.6% (wb) moisture content to 0.58 at 24.0% (wb) moisture content.

Pandiselvam R., *et al*. (2016) reported that equivalent diameter, sphericity and aspect ratio of paddy increased from 3.22 to 3.39, 0.41 to 0.42 and 30.55 to 31.91 per cent, respectively, with an increase in moisture content from 11.86% to 23.61% db.

The mean sphericity of arigo seed was 0.80±0.09. The corresponding values for nutmeg, simarouba fruit, simarouba kernel and jatropha seed and its kernel were 0.74, 0.69, 065, 0.64 and 0.68, respectively. The sphericity of arigo seed was higher than nutmeg, simarouba and jatropha, while the sphericity values obtained in simarouba and jatroph were almost similar (Davies, 2010).

2.7.1.3 True density, bulk density and porosity

Bart Plange *et al*. (2003) reported that the true density and porosity of cocoa beans increased from 946 to 991 kg/m^3 and 20.58 to 31.59%, respectively, while the bulk density decreased from 560 to 505 kg/m^3 in the moisture range between 5% and 24% (wb).

2.7.2. Optical Properties

Optical properties are those material properties resulting from physical phenomena occurring when any form of light interacts with the material under consideration. In the case of foods, the main optical property considered by consumers in evaluating quality is colour, followed by gloss and translucency or turbidity among other properties.

2.7.2.1 Colour

Colour is an important quality attribute in the food and bioprocess industries, and it influences consumers' choice and preferences. Food colour is governed by the chemical, biochemical, microbial and physical changes which occur during growth, maturation, postharvest handling and processing. Colour measurement of food products has been used as an indirect measure of other quality attributes such as flavour and contents of pigments because it is simple, faster and correlates well with other physiological properties (Pankaj, 2013).

Wahidu and Tajul (2013) studied the colour of cocoa beans during superheated steam roasting. The surface colour of the roasted cocoa bean samples was measured using a Minolta CM-3500D colorimeter after calibration against white and black glass standards. The colours were expressed in CIELAB colour values (L*, a*, b*) where the L* value represents the lightness to darkness gradation, a* value represents the greenness to redness spectrum and the b* value represents the blueness to yellowness spectrum. The colour values (L*, a*, and b*) are the three dimensions which give specific colour values of the products.

2.7.3 Frictional Properties

Frictional properties such as the angle of repose and coefficient of friction are important in designing equipment for solid flow and storage structures and the angle of internal friction between seed and wall in the prediction of seed pressure on walls. The coefficient of static friction plays an important role in the transport (load and unload) of goods and storage facilities. Coefficient of friction is important in designing storage bins, hoppers, chutes, screw conveyors, forage harvesters and threshers.

2.7.3.1 Angle of Repose

The angle of repose is the angle between the base and the slope of the cone formed on a free vertical fall of granular materials over a horizontal plane. The size, shape, moisture content and orientation of the grains affect the angle of repose (Sahay and Singh, 1994).

Bart Plange *et al*. (2003) reported that the filling and emptying angles of repose increased with increase in moisture content from 23.7º to 33.8º and 27.3º to 37.5º, respectively, for cocoa beans.

2.7.3.2 Coefficient of Friction

The coefficient of friction between granular materials is equal to the tangent of the angle of internal friction for the material. The frictional coefficient depends on grain shape, surface characteristics and moisture content (Sahay and Singh, 1994).

Bart Plange *et al.* (2003) reported that the coefficient of friction of cocoa beans increased from 0.20 to 0.25, 0.45 to 0.60 and 0.53 to 0.7 for rubber, galvanised steel and plywood, respectively, with increasing moisture content.

Davies and Mohammed (2014) determined the coefficient of friction for four structural surfaces namely, fibreglass, galvanised iron sheet, rubber and plywood sheet. The plywood as the structural surface had the highest coefficient of static-dynamic friction for all the structural surfaces investigated.

Bart Plange *et al*. (2012) found that the coefficient of friction increased linearly from 0.48 - 0.60, 0.56 - 0.69, and 0.21 - 0.28 for mild steel, plywood, and rubber, respectively, for cocoa beans.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

This chapter describes the methodology for the fabrication of the cocoa bean sheller cum winnower. Selected engineering properties related to the fabrication of the machine and its evaluation were also studied and presented in this chapter.

3.1. 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 were used in this study. Beans having cracks and diseases were rejected. 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 the dry condition in the laboratory util the conduction of the experiment.

3.2 DETERMINATION OF ENGINEERING PROPERTIES OF DRIED COCOA BEANS

Before the development of the cocoa bean sheller, the physical, optical and frictional properties of dried cocoa beans were studied. Engineering properties of cocoa beans such as mass, size, shape, sphericity, density, specific gravity, porosity and moisture content were determined by standard methods as explained in the following section. Frictional parameters, such as the coefficient of friction and angle of repose were also determined.

3.2.1 Determination of Moisture Content by Infrared Method

In this method, moisture content was directly measured by evaporation of the water from a sample with an infrared heating lamp. The instrument consists of a balance, a pan counterbalanced by a fixed weight and variable length of weighing chain. An infra-red lamp was mounted on an arm above the pan with provision to change its height. A scale calibrated in percentage moisture content is incorporated in the stem of the instrument. At the end of the test, when the balance is zeroed, direct reading of moisture content was obtained (Sahay and

Singh, 1994). For measurement, 5 g of ground sample was used. The moisture content of the sample was expressed in percentage (wb).

Plate 3.1: Determination of moisture content by infrared method

3.2.2 Determination of Size

Size refers to the characteristic of an object which determines the space requirement and is expressed in terms of length, width and thickness. 10 numbers of whole roasted cocoa beans were selected at random for the determination of the size. A digital Vernier Calliper was used to measure the length, width and thickness with a least count of 0.01cm.

The geometric mean diameter D_{gm} of the bean was computed using the equation mentioned by Sahay and Singh (1994).

$$D_{gm} = (LBT)^{-3} \quad \ldots(3.1)$$

Where,

L- Length of the bean, mm

B- Width of the bean, mm

T- Thickness of the bean, mm

3.2.3 Determination of Mass

The mass of individual bean was determined by selecting 15 numbers of the sample in random using an electronic balance to an accuracy of 0.01 g. The mean value of these samples was reported.

3.2.4 Determination of Shape

The shape is an important property in grading fruits and vegetables and in its quality evaluation. The shape of a food material is usually expressed in terms of sphericity (ϕ). The sphericity (ϕ) is determined by the formula given below.

$$\Phi = \frac{\sqrt[3]{LBT}}{L} \qquad \ldots(3.2)$$

Where,

L- Length of the bean, mm

B- Width of the pod, mm

T- Thickness of the bean, mm.

3.2.5 Determination of True and Bulk Density

Cocoa beans were put into a container with known mass and volume (250 ml) at a constant rate. Bulk density was calculated from the ratio of the mass of bulk cocoa beans to the volume of the cocoa beans. (Davies *et al.*, 2014).

$$\rho_b = \frac{M_b}{v_b} \qquad \ldots(3.3)$$

Where,

ρ_b- Bulk density, kg/m^3

M_b- Mass of the cocoa beans, kg

V_b- Volume of the cocoa beans, m^3

A known quantity of cocoa beans was transferred into a measuring cylinder. Toluene was slowly added into the measuring cylinder to fill the voids. The amount of toluene added was measured.

The True density of cocoa beans was determined using the following equation.

$$\rho_t = \frac{W}{TV} \quad \dots (3.4)$$

Where,

ρ_t - True density, kg/m^3

W - Weight of beans, kg

TV - True volume of beans, m^3 = Bulk volume – Volume of toluene

3.2.6 Determination of Specific Gravity

The specific gravity bottle or pycnometer and toluene are used for determination of the specific gravity of granular agricultural materials (Sahay and Singh, 1994). The same method was followed for cocoa beans. The following formula was used for determining its specific gravity

$$\text{Specific gravity of cocoa beans} = \frac{\text{Specific gravity of toluene} \times \text{Weight of cocoa bean}}{\text{Weight of the toluene displaced by the cocoa bean}} \quad \dots(3.5)$$

3.2.7 Determination of Porosity

The porosity of the cocoa bean was computed from the bulk and true density using a formula as explained by Mohsenin (1986). The reported values are means of 10 replications.

$$\text{Porosity} = \frac{\text{True density} - \text{Bulk density}}{\text{True density}} \times 100 \quad \dots(3.6)$$

3.3 OPTICAL PROPERTIES

In the case of foods, the main optical property considered by consumers in evaluating quality is colour. Colour was determined as per the method explained in the following section.

3.3.1 Determination of Colour

The colour of cocoa beans was determined using a colorimeter (HunterLab Colour Flex EZ). The ColorFlex EZ spectrophotometer is a versatile colour measurement instrument that can be used on products of virtually any size, and in industries as diverse as paint, food, and textiles. The instrument uses a xenon flash lamp to illuminate the sample. The light reflected from the sample is then separated into its component wavelengths through a dispersion grating. The relative intensities of the light at different wavelengths along the visible spectrum (400-700 nm) are then analysed to produce numeric results indicative of the colour of the sample.

Plate 3.2: ColorFlex EZ Spectrophotometer

3.4 FRICTIONAL PROPERTIES

Frictional properties of cocoa beans such as the angle of repose and coefficient of friction on stainless steel, aluminium, galvanized iron and plywood were determined using methods explained in the following section.

3.4.1 Determination of Angle of Repose

The apparatus for determining the angle of repose consisted of a funnel-like feed hopper, the bottom of which can be opened or closed using a sliding shutter. At the bottom of the funnel-shaped hopper, iron discs of varying diameters like 100, 150, 200 mm were placed. This was mounted on a stand. Cocoa beans were filled in the hopper and the funnel was opened. The beans heaped to form a cone shape on the circular disc. The diameter and height of the cone were measured and the angle of repose was calculated using the following equation.

$$ø = \tan^{-1} \left(\frac{2h}{d}\right) \qquad \ldots(3.7)$$

Where,

ø - Angle of repose, degree

h- Height of the cone, mm

d- diameter of the cone, mm.

3.4.2 Determination of Coefficient of Friction

Coefficient of friction of cocoa beans on different surfaces such as stainless steel (SS), aluminium, galvanized iron (GI) and plywood was determined by the following method. A known quantity of cocoa beans was filled in a PVC cylinder which was placed on a plane surface made of stainless steel. This is the total normal force (N) acting on the surface. A loop and pulley arrangement were provided to add weight at the other end of the sliding surface. After keeping the cylinder with cocoa beans at one end of the sliding surface, add weight until the cylinder containing material tends to start sliding from its initial position. This is the weight required to overcome the frictional force (F). The procedure was repeated for other surfaces such as aluminium, GI and plywood. Coefficient of friction was calculated using the following equation.

$$\mu = \frac{F}{N} \qquad \ldots(3.8)$$

Where,

μ- Coefficient of friction

F- Frictional force, kg

N- Normal force, kg

3.5 DEVELOPMENT OF THE COCOA BEAN SHELLER

3.5.1 First Model of the Cocoa Bean Sheller

The initial model of the cocoa bean sheller consisted of a feed hopper, roller and concave mechanism, motor and frame assembly. Roller was a GI cylindrical pipe, where square cross-sectional rubber rods were bolted on its outer circumference along its length. The roller rotates in an anti-clockwise direction with the help of a motor. The breaking unit consisted of a roller and concave mechanism, both lined with a cushioning of rubber rods to avoid bean damage. The machine works on the combined action of compression and shear force. Proper clearance was provided between the roller and concave to remove the shell of cocoa beans and to reduce the damage to the nibs. The performance evaluation of the developed machine was conducted in terms of capacity, shelling efficiency, energy requirement etc. During the evaluation, the shelling efficiency of the cocoa bean sheller was found to be just 82% which is not economical. To improve its efficiency, a second model was designed.

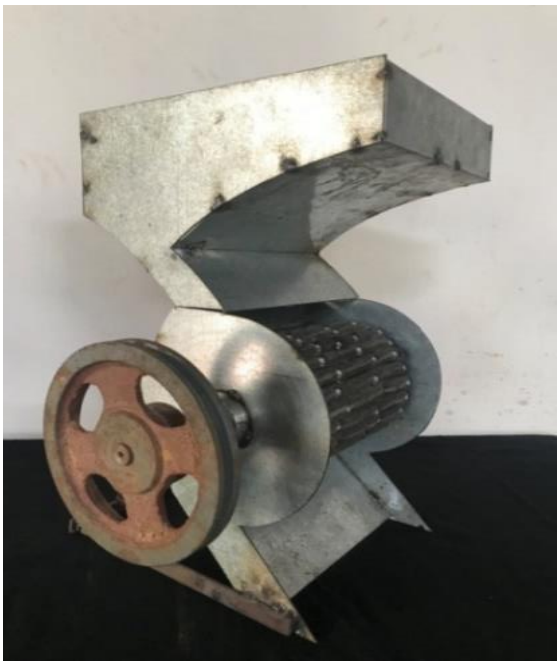

Plate. 3.3: Cocoa bean sheller – The first model

3.5.2 Final Model of the Cocoa Bean Sheller

It consisted of the following parts:

a) Feed Hopper

b) Metallic rollers

c) Chute

d) Motor

e) Frame assembly

a) Feed Hopper

Roasted cocoa beans were fed to the roller assembly through the feed hopper. It was rectangular and was 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 were 35.5 cm, 27.7cm and 17.5cm, respectively. It was made of 2 mm thick mild steel sheet with 45° inclination with a horizontal surface to facilitate easy feeding.

b) Metallic Rollers

The working element of the machine consisted of a pair of ribbed rollers. The rollers rotated horizontally on its axis in opposite directions with the same speed. It was enclosed inside a concentric cylinder. Each roller was 25cm in length with 12 straight ribbed strips mounted on the shaft. The diameter of the shaft, as well as the roller, were 2.5cm and 5.6 cm, respectively. The ribbed rollers were intermeshed with each other and rotated in opposite directions at a speed of 38 rpm. The clearance between the rollers was 0.6cm.

c) Chute

A chute was placed at the bottom end of the roller assembly to collect the shelled cocoa beans. It was made up of 2mm thick MS sheet, with dimension 26×26 cm inclining 40° with the horizontal to facilitate easy discharge of products.

d) 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 of 38 rpm was attained using a drive gear assembly. The roller got power from the motor with the help of a jaw coupling.

e) Frame Assembly

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

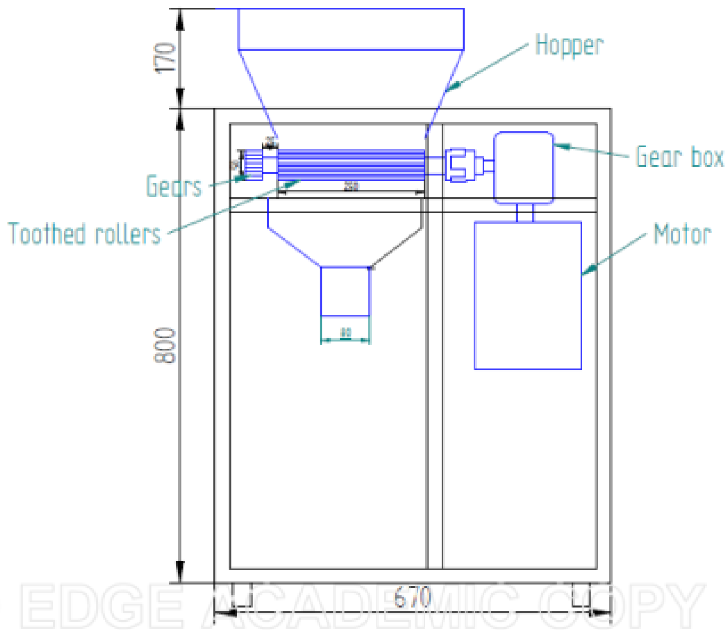

Fig.3.1: Line diagram of the cocoa bean sheller (final model)

(all dimensions in mm)

3.6 OPERATIONAL PROCEDURE OF THE COCOA BEAN SHELLER

Well matured, dried, roasted cocoa beans were selected for testing. Roasting of cocoa beans was done at 130°C for 15 min using a cocoa roaster. The proper and slow roasting of the beans was required for effective shelling. Roasted cocoa beans were fed into the machine through feed hopper. With an adjustable sleeve, uniform flow of cocoa beans was maintained and spread evenly to the shelling chamber. The cocoa beans were fed in thin layers between the intermeshed rotating rollers that rotated in opposite directions. A suitable clearance of 0.6

cm was provided between the rollers for efficient shelling. The combined action of compression and shearing force acted on the roasted cocoa beans, which resulted in shelling action. A mixture of cocoa nibs and broken shells passed through the chute and got collected at the product outlet.

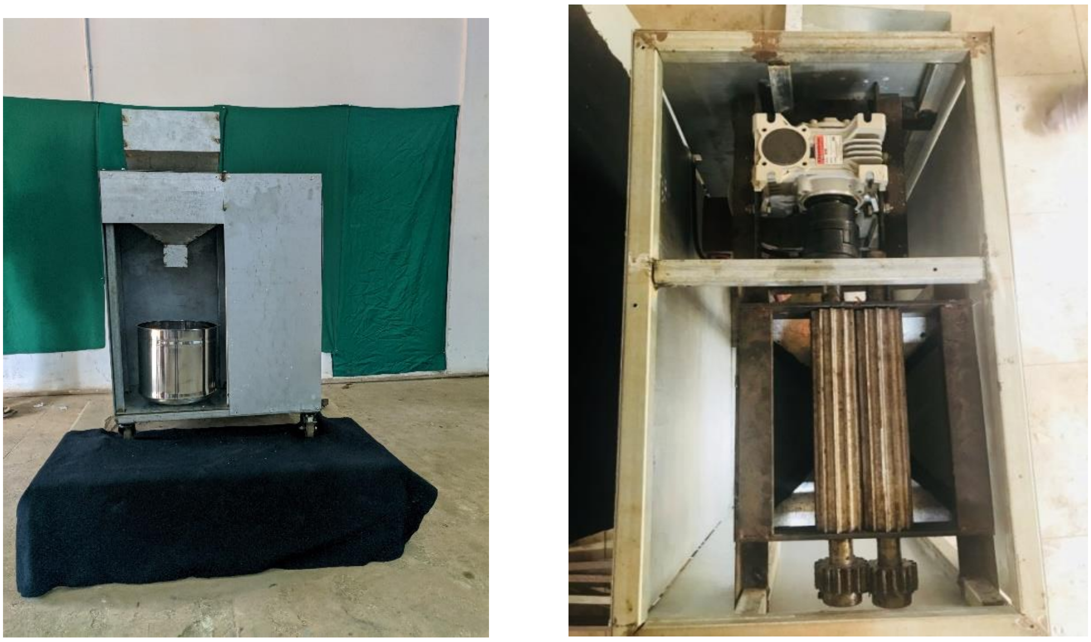

Plate 3.4: Cocoa bean sheller – The final model

3.7 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.

3.7.1 Determination of Percentage of Cracked and Uncracked Beans and Shelling Efficiency

The feed hopper was filled with dried and roasted beans at an optimum moisture content. The total number of beans (N_T) 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 were maintained, which also spreads the beans evenly to the gap between the rotating rollers along its length. The shelling was done due to the combined effect of compression and shear forces acted against the cocoa bean surface. The numbers of beans that were completely cracked (N_1), the number of uncracked nuts (N_2) 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

$$\mu = \frac{N1}{NT} \times 100 \quad \text{…(3.9)}$$

b) Percentage of uncracked beans

$$\mu_1 = \frac{N2}{NT} \times 100 \quad \text{…(3.10)}$$

c) Shelling Efficiency (%)

$$\eta = \frac{w}{wt} \times 100 \quad \text{…(3.11)}$$

Where,
w = total weight of shelled nibs
w_t = total input weight

3.7.2 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 the working part of this machine. The energy consumption was measured using an energy meter which is expressed in terms of kWh.

3.7.3 Determination of Time Required for Shelling

A stopwatch was used to determine the time taken for 1kg of beans to be shelled after it has been fed into the sheller. It is expressed in s.

3.7.4 Determination of Capacity of the Sheller

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

3.8 THE COCOA BEAN WINNOWER

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 which have a lower density than cocoa nibs are collected at the low-density fraction while the nibs are collected at the high-density fraction. 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.

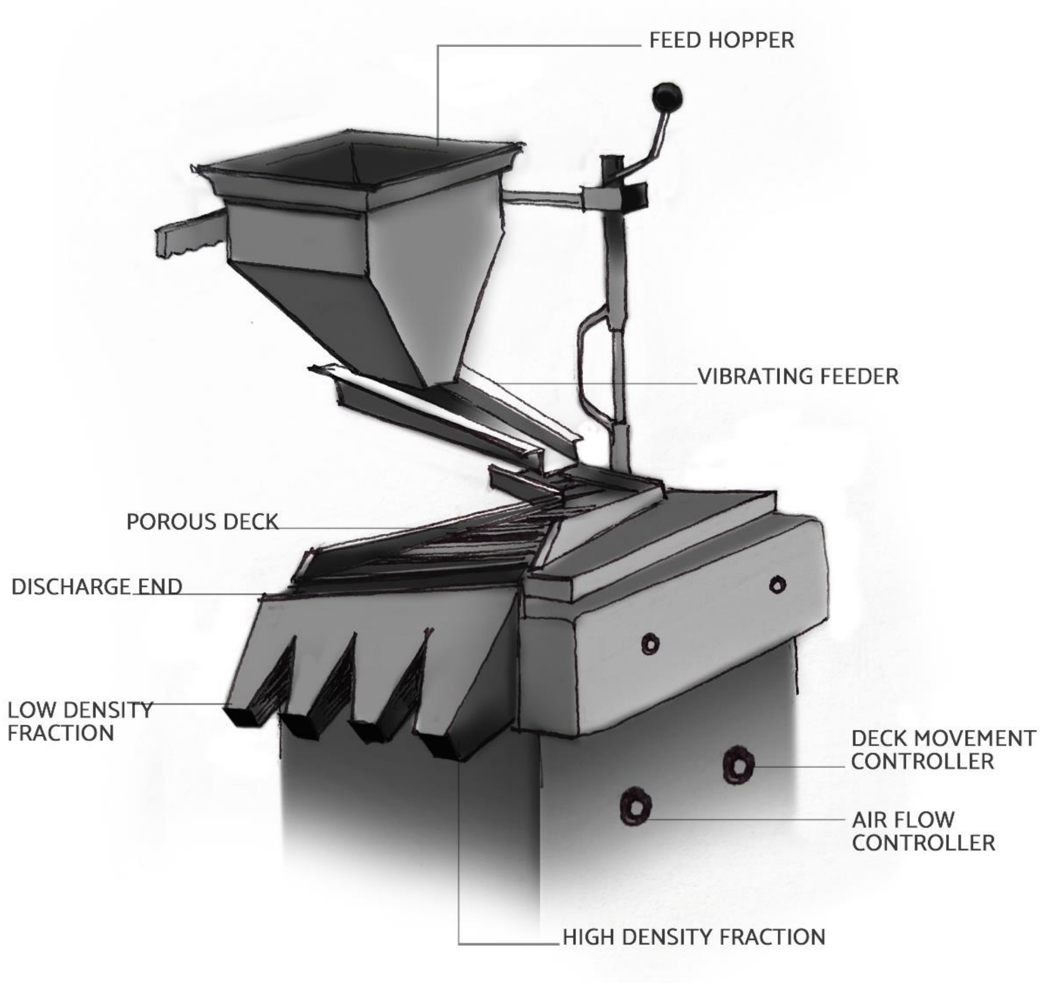

Fig. 3.2: Schematic diagram of the cocoa bean winnower

3.9 OPERATIONAL PROCEDURE OF THE COCOA BEAN WINNOWER

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 turns into a mixture of nibs and shells. This mixture is fed into the cocoa bean winnower for separation of the nibs. It depends on two factors – the vibrational motion of the deck and the air movement. The terminal velocity of the air is adjusted 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 these actions take place at the same time all across the deck of the 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. (Guy C Satterlee 1960, Sahay and Singh, 1994).

3.10 PERFORMANCE EVALUATION OF THE COCOA BEAN WINNOWER

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

3.10.1 Determination of Cleaning Efficiency of the Winnower

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

$$\text{Cleaning efficiency (\%)} = \frac{E(F-G)(E-F)(1-G)}{F(E-G)^2(1-F)} \quad \ldots(3.12)$$

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

3.10.2 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.

3.10.3 Determination of Time Required for Winnowing

A stopwatch was used to determine the time taken for 1kg of the mixture of nibs and shells to be separated after it has been fed into the winnower. It is expressed in min.

3.11 COST ECONOMICS

The operational cost of the cocoa bean sheller and the cocoa bean winnower was calculated by considering the fixed and variable cost and is presented in Appendix B.

RESULTS AND DISCUSSIONS

CHAPTER IV

RESULTS AND DISCUSSIONS

This chapter includes the results of physical properties *viz.*, size, shape, mass, porosity, density, optical properties like colour, frictional properties like the coefficient of friction, angle of repose etc, and performance evaluation of the cocoa bean sheller and the cocoa bean winnower.

4.1 ENGINEERING PROPERTIES

Before the development of the cocoa bean sheller, engineering properties *viz.*, physical properties (shape, mass, moisture content, size, bulk density, true density, porosity etc), optical properties like colour and frictional properties (coefficient of friction, angle of repose) of roasted cocoa beans were determined by standard methods.

4.1.1 Physical Properties

The physical properties (shape, mass, moisture content, size, bulk density, true density, porosity, optical etc) of roasted cocoa beans were determined by standard methods and is given in Table 4.1.

Roasted cocoa beans had an initial moisture content of about 5.30±0.13 (wb). The size of cocoa beans which includes 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. Mass of roasted cocoa beans in g, geometric mean diameter in mm, and sphericity of cocoa beans were found to be 1.60±0.12, 14.55±0.37 and 0.558±0.71, respectively. Bulk density and true density values of roasted cocoa beans were obtained as 614±10.32, 858.54±11.32 in kg/m^3 and the porosity was found to be 28.31±0.45%. Terminal velocity of cocoa beans was obtained as 14±02 m/s and specific gravity as 0.848.

Table 4.1. Physical properties of roasted cocoa beans

SL.No	Physical 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±02
12	Specific gravity	0.848

4.1.2 Optical Properties

The optical property of roasted cocoa beans *viz*., the colour was determined. The colour of the roasted cocoa bean was expressed in terms of L*, a* and b* values. The three coordinates represent the lightness of the colour (L* = 0 yields black and L* = 100 indicates diffuse white; specular white may be higher), its position between red/magenta and green (a*, negative values indicate green while positive values indicate magenta) and its position between yellow and blue (b*, negative values indicate blue and positive values indicate yellow).

The optical property of roasted cocoa beans is illustrated in Table 4.2. The L*, a*, b* values were 25.75±0.01, 9.54±0.04 and 9.66±0.0, respectively.

Table 4.2. 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

4.1.3 Frictional Properties

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

Table 4.3 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 4.3. Frictional properties of roasted cocoa beans

SL.No	Properties	Mean Value ± SD
1	Angle of repose	22.37±0.13º
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

4.2 PERFORMANCE EVALUATION OF THE COCOA BEAN SHELLER

Performance of equipment is the basic criteria to evaluate its ability. The performance of the developed cocoa bean sheller was evaluated in terms of percentage of cracked and uncracked beans, shelling efficiency, energy requirement, time required for shelling and capacity. The Performance evaluation of the developed cocoa bean sheller is presented in Table 4.4.

4.2.1 Percentage of Cracked and Uncracked Beans and Shelling Efficiency

1kg of cocoa beans were selected in this study. Shelling efficiency and other parameters were calculated from the quantity of cracked and uncracked beans received at the sheller outlet after the experiment. At the end of the manual inspection, 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 were found to be 96.04% and 3.95%, respectively. The shelling efficiency of the developed cocoa bean sheller was 96%. The cost of operation of the cocoa bean sheller with a capacity of 155 kg/hr was estimated as ₹ 76.35/h.

4.2.2 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 was 0.373 kWh for the sheller.

4.2.3 Time Required for Shelling

A stopwatch was used to determine the time taken for 1kg of beans to be shelled after it has been fed into the sheller. The total time required to shell 1 kg of roasted cocoa beans was approximately 28 s.

4.2.4 Capacity of the Sheller

Capacity is defined as the ratio of total weight of the cocoa bean taken for shelling to the total time taken for shelling. The capacity of the developed sheller was measured to be 155 kg/hr.

Plate 4.1: Mixture of cocoa nibs and shells after the shelling process

Table 4.4. Performance of the cocoa bean sheller

SL.No	Parameters	Value
1	Capacity	155 kg/hr
2	Shelling efficiency	96%
3	Energy requirement	0.373 kWh
4	Time required for shelling	28s (1kg)
5	Cost of operation	₹ 76.35/h

4.3 PERFORMANCE EVALUATION OF THE COCOA BEAN WINNOWER

The performance evaluation of the cocoa bean winnower was done in terms of its cleaning efficiency, capacity and time required for winnowing. The performance of the cocoa bean winnower is presented in Table 4.5.

4.3.1 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 cleaning efficiency was calculated based on the formulae mentioned in section 3.9.1. The fraction of cocoa nibs at clean seed outlet (E), in the 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 89.38%. The cost of operation of the cocoa bean winnower was found to be ₹ 82.85/h.

4.3.2 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. The capacity of the cocoa bean winnower was found to be 30 kg/h.

4.3.3 Time Required for Winnowing

A stopwatch was used to determine the time taken for 1kg of the mixture of nibs and shells to be separated after it has been fed into the winnower. The approximate time required for winnowing the 1kg mixture of shells and nibs was found to be 2 min.

Plate 4.2: Cocoa nibs after winnowing process

Table 4.5. Performance of the cocoa bean winnower

SL.No	Parameters	Value
1	Cleaning efficiency	89.38%
2	Capacity	30 kg/h
3	Time required for winnowing	2 min(1kg)
4	Cost of operation	₹ 82.85/h

4.4 COST ECONOMICS

The cost of operation of the cocoa bean sheller and the cocoa bean winnower was estimated as ₹ 76.35/h and ₹ 82.85/h, respectively. The detailed cost economics is given in Appendix B.

SUMMARY & CONCLUSION

CHAPTER V

SUMMARY AND CONCLUSION

Theobroma cacao also called the cacao tree is a small evergreen tree in the family Malvaceae, native to the deep tropical regions of Mesoamerica. Cocoa is an important commercial plantation crop in India. Its seeds, cocoa beans, are used to make chocolate liquor, cocoa solids, cocoa butter and chocolate, cosmetics, health drinks etc. The process of shelling enables the removal of shell from the roasted cocoa bean. The shelling process is one of the primary processes and critical steps in the processing of chocolate or any product that is derived from cocoa beans. It affects the quality of the cocoa nibs in terms of flavour and purity.

The shelling of cocoa is a very difficult and time-consuming operation. It affects very much on the processing of products. An effort was taken to develop a cocoa bean sheller cum winnower to improve the efficiency of shelling and to reduce time and wastage during the shelling process. The objective of the study was to develop a cocoa bean sheller cum winnower and to carry out its performance evaluation in terms of percentage of cracked and uncracked beans, shelling efficiency, capacity, and energy requirement.

Before the fabrication of the sheller, the engineering properties of cocoa beans *viz.*, physical, optical and frictional properties of dried cocoa beans were studied. Physical properties such as moisture content, size, shape, mass and density were also studied. The optical and frictional properties *viz.*, colour, angle of repose and coefficient of friction were determined as per the standard procedures.

The sheller consisted of a feed hopper, metallic rollers, chute, motor and frame assembly. Roasted cocoa beans were fed into the machine through feed hopper. The cocoa bean reached in thin layers between the intermeshed rotating rollers that rotate in opposite directions. The combined action of compression and shearing force acted on the roasted cocoa beans and resulted in shelling action. A mixture of cocoa nibs and broken shells were passed through the chute and got collected at the product outlet.

The collected mixture was fed to the cocoa bean winnower for the separation of the nibs from shells. The separation depends on two factors – the vibrational motion of the deck and the air movement. 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.

The results of the present study are summarized as the following:

•The average moisture content of roasted cocoa beans was found to be 5.3±0.13% wb.

• The length, width and thickness were 25.12±0.88, 13.92±0.55 and 7.87±0.93 mm, respectively.

•The geometric mean diameter and sphericity was found to be14.55±0.37 mm and 0.558±0.71, respectively.

•The true density and bulk density were found to be 858.54±11.2 and 614±10.32 kg/m^3, respectively. The porosity was found to be 28.31±0.45%.

•The colour of the roasted cocoa bean was expressed in terms of L*, a* and b* values. The average L*, a* and b* values were 25.75±0.01, 9.54±0.04 and 9.66±0.0, respectively.

•The coefficient of friction on stainless steel (SS), aluminium, galvanized iron (GI) and plywood was found to be 0.20±0.002, 0.20±0.001, 0.30±0.001 and 0.40±0.002, respectively.

•The average angle of repose at an average moisture content of 5.3% (wb) was obtained as 22.37^o.

•The performance evaluation of the cocoa bean sheller was calculated in terms of percentage of cracked and uncracked beans, shelling efficiency, capacity, time required for shelling and energy requirement. Capacity, shelling efficiency, energy requirement and cost of operation of the developed cocoa bean sheller was found to be 155 kg/h, 96%, 0.373 kWh and ₹ 76.35/h, respectively.

•The percentage of cracked and uncracked beans were found to be 96.04% and 3.95%, respectively. Time required for shelling 1 kg of cocoa beans was found to be 28 s.

•The cleaning efficiency and capacity of the cocoa bean winnower was found to be 89.38% and 30 kg/hr, respectively. Its cost of operation was estimated as ₹ 82.85/h. Time required for winnowing 1 kg of mixture cocoa nibs and shells was found to be 2 min.

The major purpose of construction of the cocoa bean sheller cum winnower was to facilitate it to the small-scale farmers who can thereby conduct low-cost processing of cocoa and produce several value-added products from it. The constructed 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.

5.1 SCOPE FOR FUTURE WORKS

The major scope for bettering the working of the developed machine is to convert it into a continuous process where the winnowing action is performed immediately after the shelling is completed. This will improve both the shelling and winnowing efficiency of the machine. Apart from this, the feed given into the sheller section can also be subjected to a controlled action which can avoid chances of overloading of the cocoa beans and thereby jamming of the rollers.

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CHAPTER VI

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APPENDICES

APPENDIX – A

Table A-1. Physical properties of cocoa beans

SL.No	l (mm)	b (mm)	t (mm)	D_g (mm)	Sphericity
1	25.45	13.20	7.95	13.87	0.576
2	23.37	13.26	7.23	13.08	0.592
3	25	13.57	8.63	14.30	0.599
4	25.68	14.84	7.04	13.89	0.579
5	24.06	13.7	7.00	13.21	0.561

Table A-2. Angle of repose of cocoa beans

SL.No	**d (cm)**	**h (cm)**	**$\theta = \tan^{-1}(\frac{2H}{D})$ (cm)**
1	22.40	4.20	20.55
2	20.30	4.00	21.50
3	20.60	4.00	21.22
4	19.60	4.50	24.60
5	19.60	4.40	24.17

APPENDIX-B

B1. Cost economics of the cocoa bean sheller

Capacity of the cocoa bean sheller = 155 kg/hr

Life span of cocoa bean sheller (n)= 7 years

Annual usage = 120 days

Daily usage = 6 h

Interest rate (i) = 10.5% per annum

Total cost of equipment (c)= ₹ 35,000/-

A) Fixed cost

i) Fixed cost of equipment = $\frac{i(i+1)^n}{(i+1)^n+1} \times C$

$$= \frac{0.105(0.105+1)^7}{(0.105+1)^7+1} \times 35{,}000$$

= ₹ 2454.70/-

ii) Housing charge = ₹ 100/month

Housing charges/year = ₹ 1200/year

Total fixed cost/year = ₹ 2454.70 + 1200

= ₹ 3654.70

B) Variable cost

i) Repair and maintenance = 5% of initial cost

= ₹ 1750/year

ii) Labour cost,

Labour cost / day = ₹ 400

Total labour cost =₹ 400×120= ₹ 48,000 /year

C) Cost of Energy

Energy requirement = 2.237 kWh/day

Electricity charges = ₹ 5.85/kWh

Electricity consumptions charges = No. of days ×energy/day × rate

= 120 × 5.85 × 2.237

= ₹ 1570.37

Total Variable Cost = 1750 + 48000 +1570.37

= ₹ 51320.374

Total cost for shelling/year = Total fixed cost + Total variable cost

= 3654.70 + 51,320.37

= ₹ 54,975.074/year

= ₹ 458.18/day

= ₹ 76.35/h

B2. Cost economics of the cocoa bean winnower

Capacity of the cocoa bean winnower = 30 kg/hr

Life span of cocoa bean winnnower (n)= 7 years

Annual usage = 120 days

Daily usage = 6 h

Interest rate (i) = 10.5% per annum

Total cost of the equipment (c)= ₹ 80,000/-

A) Fixed cost

i) Fixed cost of equipment = $\frac{i(i+1)^n}{(i+1)^n+1} \times C$

$$= \frac{0.105(0.105+1)^7}{(0.105+1)^7+1} \times 80{,}000$$

= ₹ 5610.76/-

ii) Housing charge = ₹ 100/month

Housing charges/year = ₹ 1200/year

Total fixed cost/year = ₹ 5610.76 + 1200

= ₹ 6810.76

B) Variable cost

i) Repair and maintenance = 5% of initial cost

= ₹ 4000/year

ii) Labour cost,

Labour cost / day = ₹ 250

Total labour cost =₹ 250×120 = ₹ 30,000 /year

C) Cost of Energy

Energy requirement = 26.84 kWh/day

Electricity charges = ₹ 5.85/kWh

Electricity consumptions charges = No. of days ×energy/day × rate

= 120 × 5.85 × 26.84

= ₹ 18841.68

Total Variable Cost = 18841.68+30000+4000

= ₹ 52841.68

Total cost for winnowing/year = Total fixed cost + Total variable cost

= ₹ 52841.68 + ₹ 6810.76

= ₹ 59,652.44/year

= ₹ 297.10/day

= ₹ 82.85/h

ABSTRACT

DEVELOPMENT AND PERFORMANCE EVALUATION OF COCOA BEAN SHELLER CUM WINNOWER

By

ANJALI PALAKKEEL (2016-06-003)

ANJANA NARAYANAN (2016-06-028)

APARNA SURESH (2016-06-006)

JASEERA NASRIN (2016-06-014)

SANJAY P (2016-06-019)

ABSTRACT

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TAVANUR-679573, MALAPPURAM KERALA, INDIA

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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. The cocoa beans which are embedded in a mucilaginous pulp inside the pod consists of two parts- seed coat (shell) and seed cotyledon (nib). Shell is removed from the cocoa bean before or after the seeds are roasted. Shelling is one of the primary processes and critical step in the processing of chocolate or any product that is derived from cocoa beans. It affects the quality of the cocoa nibs in terms of flavour and purity. Shelling of cocoa bean is a very difficult and time-consuming operation. Traditionally, cocoa shelling was done manually or with the help of animals. But nowadays, different shelling machines are available in the industry.

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.

Physical properties *viz.*, shape, size, true density, bulk density, specific gravity etc and optical properties like colour, frictional properties like angle of repose etc. of roasted cocoa beans were examined to design and develop the model. Roasted cocoa beans were shelled using the developed cocoa bean sheller. The shelled cocoa beans underwent winnowing operation by cocoa bean winnower to remove the shells from the nibs, which were later kibbled, ground and pressed to obtain cocoa butter and cocoa powder. The difference in size, shape and the specific gravity of particles were utilised to separate the lighter shell from the nib with the help of a cocoa bean winnower. The actual separation took place in the vertical direction at first by stratification of seeds and second in the horizontal direction by the table motion and gravity. The performance evaluation of the developed machine was carried out using standard methods.

Capacity, shelling efficiency, energy requirement, cost of operation of the developed cocoa bean sheller was found to be 155 kg/h, 96%, 0.373kWh and ₹ 76.35/h, respectively. The cleaning efficiency of the cocoa bean winnower was found to be around 89.38% and its cost of operation was estimated as ₹ 82.85/h.