DEVELOPMENT AND PERFORMANCE EVALUATION OF COCOA FERMENTER

By,

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR-679573, MALAPPURAM

KERALA, INDIA

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PROJECT REPORT

Submitted in partial fulfillment of the requirement for the degree of

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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 project report entitled "Development and Performance Evaluation of Cocoa Fermenter" is a bonafide record of project work done by us during the course of project and that the report has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Place

Date

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CERTIFICATE

Certified that this project report entitled “Development and Performance Evaluation of Cocoa Fermenter” is a record of project work done jointly by Aryasree N V, Diya N Sabu, Meera Madhavan P S, Minu Paul V and Rinu Remold under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to them.

Place

Date

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DEDICATED TO

OUR LOVING PARENTS

AND TO THE PROFESSION OF

AGRICULTURAL ENGINEERING

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SYMBOLS AND ABBREVATIONS

%	percent
/	per
^{0}	degree
^{0}C	degree Celsius
^{0}F	degree Fahrenheit
AOAC	Association of Official Analytical Chemists
cm	centimetre
CRIG	Cocoa Research Institute of Ghana
DCCD	Directorate of Cashewnut and Cocoa Development
eg.	Example
etal.,	and others
etc.	etcetra
FFA	Free FattyAcid

Fig.	Figure
FRP	Fibre glass ReinforcedPlastic
g	gram
gkg^{-1}	gram perkilogram
h	hour
i.e.	thatis
ICCO	International Cocoa Organisation
KCAET	Kelappaji College of Agricultural Engineering and Technology
LDPE	Low Density PolyEthylene
m	metre
mg	milligram
UV	Ultra Violet
viz.,	namely
wb	wet basis

INTRODUCTION

CHAPTER 1

INTRODUCTION

Cocoa (*Theobroma cacao L.*) is an important commercial plantation crop in the world which belongs to Malvaceae family. It is a tropical crop, grows within 15-20° latitude from equator and is originated in the amazon region of South America. The global production of cocoa during 2018-2019 was 4.87 Million Metric Tons (MMT) with major share (76.6%) is from Africa. Globally, cocoa is widely cultivated in Africa, Asia and Latin America. Ivory Coast is the largest producer of cocoa in the world.

Cocoa has widespread application in sectors such as cosmetics, confectioneries, health drinks, pharmaceuticals etc. The cocoa bean is fermented and then dried, from which cocoa fat can be extracted. The major constituent is fat (about 50%), which is useful in the production of candle, ointments, pharmaceutical products, cosmetics etc. The next most important ingredient is the protein or nitrogenous elements, including the theobromin and caffein, which exist in small quantities in the bean. Starches and sugars together form from 20 to 25 percent of the weight of the bean. In round numbers the ash amounts to 4 percent and the theobromin to about 1 percent. Cocoa bean powder is the raw material for the preparation of chocolates, ice cream, beverages and other confectioneries.

Cocoa is a commercial plantation crop in India. In India, Cocoa is being cultivated in the states of Kerala, Karnataka, Andhra Pradesh and Tamil Nadu. The annual production of cocoa in India during 2018-2019 was 20,000 metric tons (MT) from an area of 78,000 ha. The second largest producer of cocoa in India is Kerala state, produced cocoa of 6300 metric tons from an area of 16000 hectares during 2018-19. Andhra Pradesh produces 8000 metric tons during 2018-19.

Cocoa cultivation in India was started during 18th century. M/s. Cadbury India private limited, initiated cocoa as a feasible cash crop in India had started a demonstration farm at Chundale, Wayanad district of Kerala in 1965. During 1970, M/s Mondelez India Foods Private Limited started planting of cocoa on a commercial scale by supplying free planting material and technical knowledge to the farming community. Research activities on cocoa had been started in Central Plantation Crops Research Institute (CPCRI) and Kerala

Agricultural University (KAU) during this period.

The cocoa production procedure encompasses harvesting of cocoa pods from the tree, stripping the beans from the pods and thereby fermentation emerges out to be the first step in cocoa processing. The quality of value-added product from cocoa depends on cocoa fermentation. In traditional method, the beans are tumbled in heaps, boxes, baskets and trays covered with plantain leaves and left to ferment for 5-7 days (Fowler, 1999). The fermentation process accomplishes several other desirable changes such as prevention of germination, release of enzymes in the beans, reduction of astringency, richness of color, altered texture of the seed coat and most important factor is the growth of micro-organisms (Schwan and Wheals,2004).

During fermentation, due to exothermic oxidation reaction, the temperature of fermenting bean mass increases to 45-50°C. This is considered inevitable for the successful fermentation and the development of chocolate flavor. During fermentation the microbial succession of a wide range of yeasts, lactic-acid, and acetic-acid bacteria and microbial products, such as ethanol, lactic acid, and acetic acid, kill the beans embryo and cause production off-flavor precursors. Increase in acetic acid leads to a rise in bacilli and filamentous fungi that can cause off-flavors.

Fermented beans are then subjected to drying. The most cocoa growers follow the traditional drying methods like sun drying and wood-fired dryers and the drying temperature recommended is 50-60°C. Dried bean quality gets deteriorated, due to substandard fermentations. The development of mould attack during storage process depends on the rate of drying process, storage condition such as relative humidity, temperature and packaging material of dried cocoa (Renaud,1954).

At present, the conventional methods of cocoa fermentation are still in practice. Among the various conventional methods adopted for cocoa fermentation includes Heap, Box, Tray and Basket methods. This is an arduous task, apart from the large labor requirement and time consumed during the operation. During monsoon season, the fermentation process is often affected as the standard duration of fermentation varies which in turn reduces the quality and the market value of cocoa. Continuous stirring is an indispensable part of fermentation which is also quite labor intensive. At times, the manual mixing of the beans may lead to fungal attack.

In the recent years, several research have been carried out to develop a mechanical cocoa fermenter. The mechanical method of cocoa fermentation reduces the fatigue of the farmers and labors and thereby encourages the people to be more engaged in cocoa cultivation. Also, the losses occur during monsoon can be reduced which enhances the income of farmers. The large requirement of labor during manual method results in high production cost due to wage and problem of supervision and the mechanical method can reduce these expenditures. Considering these benefits, cocoa production and processing must be mechanized and properly improved to increase income and reduce losses.

Considering the above facts, a study had been undertaken on "Development and Performance Evaluation of Cocoa Fermenter" with the following objectives:

1. To study the engineering properties of cocoa bean.
2. To develop a batch type cocoa fermenter.
3. Performance evaluation of cocoa fermenter in terms of quality of fermented dried cocoa bean.

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

This chapter describes general information on cocoa, post-harvest processes including fermentation and drying, quality assessments and research works on determining various engineering properties. Research done on these aspects are also reviewed and discussed in detail.

2.1 COCOA

The cocoa tree, *Theobroma cocoa L.,* is indigenous to South America. It thrives in tropical climates 20º north and south of the equator. Being a tropical crop, it grows very well in areas with an average rainfall of 1250-3000 mm per annum and preferably between 1500-2000mm and a dry season of not more than 3 months. It requires high humidity, often 70-100% and varying soil conditions. Cocoa is more sensitive to soil moisture stress than other tropical crops, but is also sensitive to waterlogging. It is either cultivated by seeds or vegetative by budding or grafting. The trees are relatively small, 12-15 m in height and are often sheltered by intercropping plants such as banana. The cocoa tree start bearing pods after two to three years, but it is not until six or seven years before they give a full yield (Cook, 1982; Beckett, 2008; Beckett, 2009). First bearing may start after the third year. The fruit is fully grown after 143 days and the process of ripening starts. Maturity is attained after 170 days as indicated by the colour of the pod walls. Harvesting is done twice a year. On an average a fruit is 180-200mm long and weighs about 400-500g.

2.2 HISTORY

The cacao tree is native to the Americas. It may have originated in the foothills of the Andes in the Amazon and Orinoco basins of South America, current day Venezuela, where today, examples of wild cacao still can be found. However, it may have had a larger range in the past, evidence for which may be obscured because of its cultivation in these areas long before, as well as after, the Spanish arrived. It was first cultivated by the Olmecs in Central America. The cocoa bean was a common currency throughout Mesoamerica before the Spanish conquest. Chocolate was introduced to Europe by the Spaniards, and became a popular beverage 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 into West Africa by Europeans. In the Gold Coast, modern Ghana, cacao was introduced by an African, Tetteh Quarshie. The cacao 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 ("food of the gods") cacao (Anon., 2012).

2.3 GENOTYPES/VARIETIES

Three major varieties of cocoa exist: Criollo, Forastero and Trinitario (Cheesman, 1944). The varieties are recognized based on genetic origin, pod morphology and size as well as the color and flavor of the beans (Cook, 1982; Laurent, 1994). Forestero, also known as ‘Bulk cocoa’ is the main type of cocoa grown all over the world, accounting for about 80-90% of the world’s production (Cook, 1982). It is high yielding, more resistant to pest and diseases and more tolerant to drought. Forastero cocoa bean has a strong inherent flavor, inclined to be somewhat bitter and usually dark brown in color. The variety originates from the Upper Amazon region and grows in several South American countries including Peru, Ecuador, Colombia, Brazil, Guyana, French Guyana and Southern Venezuela. It also found in West Africa mainly, Ivory Coast, Ghana, Nigeria and Cameroun, as well as in SouthEast Asia (Beckett, 2009). Criollo cocoa was originally cultivated by the Mayas of Central America and represents the first domesticated cocoa. In the sixteenth and seventeenth centuries cocoa was introduced into Asia and this was of the Criollo variety. Criollo cocoa beans have white cotyledons and a mild nutty flavor. They are susceptible to diseases and produce low yields. Criollo is now rare and only found in old plantations in Venezuela, Central America, Sri Lanka and Samoa. It also grows on the islands of the Indian Ocean such as Java, Madagascar and Comoros. The variety now accounts for only 1-5% of the world’s production and is characterized by slight bitterness (but not unpleasantly so), mild astringency, flavor finesse, a pale color that gives chocolate a reddish tinge (Hurst et al., 2002; Beckett, 2009). Trinitario accounts for 10-15% of the world’s production (Beckett, 2009). It originates from the island of Trinidad and is a result of hybridization between Criollo and Forastero. The crossing between the two varieties became necessary in the eighteenth century when the island’s Criollo plantations were almost wiped out by an environmental disaster. Trinitario variety is now grown wherever Criollo is found and also in Cameroon (Beckett, 2009). It has characteristics which are between the parent varieties.

2.4 PROPAGATION

Cocoa may be grown from seed, although depending upon the seed source, it may not result in the exact same plant as the parent, and it may have pollination problems. Cocoa may also be propagated from upright stem cuttings possessing 2 to 5 leaves and including 1 to 2 buds. The cutting should be taken early in the morning and the leaves cut to about ½ their length and then dipped in a rooting hormone and placed in a small container filled with moist, clean, well-draining, soil media. The cutting should then be covered with a polyethylene bag and placed in a warm but shaded area. The soil should be kept moist but not overly wet. Rooting should take place in about 4 weeks, during which time the bag may be slowly opened. Once the plant is fully rooted and growing, it may be moved repeatedly to increasing light levels. Cocoa may also be propagated by marcottage (air-layering) and budding and grafting (Jonathan et al., 2012).

2.5 COCOA BEANS

The cocoa beans, which are embedded in a mucilaginous pulp inside the pods have two important parts namely seed coat or testa and the kernel or cotyledon. Seed cotyledon is the material in which characteristic flavor and aroma are produced during processing of the fruits. While testa constitutes 10-14% of seed weight and has little utility value, cotyledon accounting for 86-90% of the seed is processed into a variety of products. Table 2.1 shows the chemical composition of cocoa bean.

Table 2.1 Chemical composition of cocoa bean

Constituents	Percentage (%)
Moisture Content	50-55
Fat	30-32
Protein	8-10
Carbohydrate	4-6
Polyphenols	5-6
Caffeine	1
Acids	1
Minerals	<1

2.6 COCOA PULP

The fermentation substrate, pulp which surrounds the beans is made up largely of water. The composition of the pulp is important since this has a profound influence on the fermentation. On fresh weight basis, 75% of the cocoa fruit is accounted for by the fruit wall. However, on dry weight basis, the beans and the pulp constitute 45% of the fruit weight (Rohan, 1963). Cocoa pulp is a rich medium for microbial growth. It consists of 82–87% water, 10–15% sugar, 2–3% pentosans, 1–3% citric acid, and 1–1.5% pectin (Table 2.2). Proteins, amino acids, vitamins (mainly vitamin C), and minerals are also present. The concentration of glucose, sucrose, and fructose is a function of fruit age (Roelofsen, 1958). More glucose and fructose and a slight increase in total sugar concentration were observed in samples 6 days after harvest than in freshly harvested (ripe) pods (Saposhnikova,1952) . In a comparative analysis of pulp from beans collected in the Ivory Coast, Nigeria, and Malaysia, differences were found in the amounts of water, citrate, hemicellulose, lignin, and pectin. Pectin content, approximately 1% on a fresh weight basis, was found to 37.5 and 66.1 g kg^{-1} dry weight pulp (Pettipher, 1986). Seeds within 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, unwashed baskets used for transport of seeds, and dried mucilage left on the walls of boxes from previous fermentations.

Table 2.2 Chemical Composition of cocoa pulp

Constituent	Percentage (%)
Water	82-87
Sugar	10-15
Pentosans	2-3
Citric Acid	1-3
Pectin	1-1.5
Minerals	1.5-2
Vitamins	2-2.5

2.7 HARVESTING

First step in the processing of cocoa beans is harvesting of the pods. Ripe pods are easy to identify by having another color than the immature pods. For instance, Forestero turns from green to yellow when ripe. The ripening process is slow, and a mature pod will remain suitable for harvesting for two or three weeks. It is important that only well ripe pods are taken. Unripe pods will not undergo fermentation, and over ripe pods often become dry (Barclays Bank,1970).

2.8 POST-HARVESTING PROCESSING OF COCOA

The post harvesting process involves mainly six unit operations namely: collection of pods, breaking of pods, fermentation of beans, drying of beans, bagging and storage and transportation to the port for shipment (Lowor et al., 2012).

2.8.1 Sweating

The sweating (pulp juice) is an acidic juice with ~12 % sugar (Adomako, 1997). It is used for by-products such as gin, brandy, vinegar, vine, jam and pectin. Collecting the sweating is feasible when large amounts of cocoa beans are going to be fermented. Collection of sweating normally takes 6 – 12 hours depending on amount of beans. The by-products from sweating are an extra income from something that normally goes waste (Adomako and Takrama, 1996; Cudjoe et al., 2009).

2.8.2 Fermentation

Fermentation of cocoa is the most critical process that results in the formation of flavor precursors and the development of the chocolate brown color. Fermentation is carried out in different ways depending on the producer and the cocoa variety as different types of cocoa require different amounts of fermentation (Beckett, 2008). Prior to fermentation, cocoa beans are astringent and bitter with no hint of chocolate flavor. They have a slaty, grey color rather than the brown or purple- brown color of fermented dried cocoa beans. During fermentation, the mucilaginous pulp surrounding the beans which is rich in sugars undergoes ethanoic, acetic and lactic acid fermentation by yeasts, acetic and lactic acid bacteria respectively. The acid and heat generated kills the bean, making the cell membrane permeable. This allows a diffusion of acids into the bean and an increased temperature (up to 50ºC), culminating in the formation of flavor precursors, namely amino acids, peptides and reducing sugars as well as some flavor compounds (Gill et al., 1984; Hansen et al., 1998; Thompson et al., 2001; Schwan and Wheals, 2004; Nielsen et al., 2007). The method of fermentation varies from country to country and even from region to region within the same country. The most common methods, however, include box, basket, heap and recently, tray fermentations (Lehrain and Patterson, 1983). In all instances, the bottom of the fermenting container has holes to allow drainage of the drippings from the pulp. The duration of fermentation also depends on the type of cocoa being fermented. Two to three days is sufficient for Criollo cocoa whereas Forastero cocoa is fermented for 5-8 days with periodic mixing to homogenize the treatment and aerate the fermenting mass (Lopez and Dimick, 1991; Biehl and Ziegleder, 2003).

2.8.2.1 Heap

The predominant method practiced by farmers in Ghana as well as in other West African countries is the heap system in which the beans are piled and covered with banana leaves or plastic sheet to protect the beans from insect-infestation and also to conserve heat (Wood and Lass, 1985; Aneani and Takrama, 2006). The heaps differ in size and may range from 20 to 1000 kg. Big heaps have to be turned every 24-72 hours to achieve even fermentation (Baker et al., 1994). Cocoa fermentation by this method is carried out for 4-6 days depending on the size of the heap.

2.8.2.2 Box

Cocoa beans fermentation can also be carried out in wooden boxes which may be lined on the inside with banana leaves or polystyrene in some cases to hold in the heat. In both instances, the bottom of the box is provided with drainage holes to remove the liquid from the pulp (Lehrian and Patterson,1983).

2.8.2.3 Basket

In basket fermentations the beans are fermented in baskets lined on the sides, bottom and top with banana leaves. This prevents the cocoa from drying and also acts as insulation to hold in heat (Cook, 1982).

2.8.2.4 Tray

A different method of cocoa fermentation developed by the Cocoa Research Institute of Ghana (CRIG) is the Tray system. This was developed to resolve the issue of uneven fermentation that sometimes arises with big heaps that are not turned. This is a method in which the cocoa beans are fermented in 10 cm deep wooden tray; 8-10 trays can be stacked on top of each other and the topmost tray covered with banana or plantain leaves. Air is allowed to circulate between beans in the trays without having to turn. This is reported to give higher quality fermented beans in shorter time (Allison and Rohan, 1958; Allison and Kenten, 1963).Coffee on the other hand which is also a beverage crop undergoes fermentation. Coffee is fermented, to ease the removal of a layer of mucilage from the seed/inner integument to which it adheres. The temperature of the processes is scarcely raised above ambient temperature reflecting the lack of oxygen diffusion to the heart of the mass. Coffee fermentation is not significantly self-heating so prevailing climatic conditions control temperature. Depending on conditions, the beans can be fermented for 18-36 hours, or until the mucilage easily tears away from the bean (www.coffeechemistry.com). The time required for coffee fermentation can be reduced to about 12 h by the addition of relatively small amounts of an inoculum derived from over-fermented beans (Butty, 1973). Studies on cocoa fermentation in baskets or wooden boxes were carried out on cocoa pods which had been stored for 4 or 7 days after harvesting by Bhumibhamon et al., (1993).The results showed that the beans fermented in boxes had slightly better cut test values than those in baskets. Guehi et al., (2010) reported that among three cocoa fermentation methods (wooden box, plastic box and in heaps) performed during their study, fermentation in heaps appeared to be better for the production of a good quality raw cocoa. The study by Rodriguez-Campos et al., (2012) concluded that the optimal conditions for fermentation and drying of cocoa beans were 6 days and 70^0C.

2.9. CHANGES DURING FERMENTATION

2.9.1 Changes in Pulp

Two major changes occur in the pulp *viz.*, conversion of sugars into alcohol and further to ascetic acid. The pulp cells are broken down by pectic enzymes, reducing it to a turbid yellow liquid, which drains out slowly from the system. The temperature during fermentation process rises to as high as 45-50^0 C in some places, due to the fermentation action of yeast and ascetic acid bacteria. The temperature is influenced by the size of the batch and the extend of aeration permitted (Potty, 1979). The pH of the pulp shows a gradual rise during fermentation, probably to dissimilation of citric acid by yeast and lactic acid bacteria and its replacement with less dissociated lactic and ascetic acids (Potty, 1979). Various fermentation techniques using rattan basket, plastic bucket, plastic sack and gunnysack were evaluated by HiiChing et al.,(2002). Studies showed that mass temperature profiles for the plastic sack treatments were below 40°C during fermentation. Temperature profiles in other treatments were in the region of 40 to 50°C after the first and second turning. The pH measured at the end of fermentation in all the treatments was less than 5.0 indicating acidic beans were being produced.

2.9.2. Changes in Bean

Due to drainage of sweating, the beans lose about 25% of their weight during fermentation. A further loss of 40% is incurred during drying. Normally, the unfermented beans consists of 0.77% germ, 9.63% shell and 89.60% cotyledons while fermented beans have 0.70% germs, 10.74% shell and 88.56% cotyledons (Potty, 1979) 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. Great care is exercised in handling fermented beans lust any fracture caused may expose the kernel to insect and mold attack. 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). Unfermented beans are oval and somewhat flat. Before fermenting, pigmented cells comprise about 10% of the entire tissue of purple beans. These cells contain neither starch nor fat. After fermenting, the entire cotyledon is uniformly tinted by the pigment released from the pigment cells. Rise in temperature and formation of alcohol and acetic acid in the pulp during fermentation are responsible for killing the germ in the cotyledons. The germinating power of cocoa is destroyed at 43-44^{0}C; especially, the Criollo germ is killed at still lower temperatures in a shorter duration. Usually the germs are killed on the third day and the cotyledon start 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). Some of the enzymes identified in cocoa beans include, oxidases, peroxidases, catalase, reductase, invertase, maltase, amylase, dextrinase, phytase and proteases.These enzymes become activated after the seed is killed at warmer temperatures, and are primarily responsible for lowering the astringency and development of flavor. Oxidizing enzymes are instrumental in the color change resulting in the brown final product. One of the most significant changes occurring in the cotyledon during fermentation is the rapid destruction of anthocyanin pigments, accompanied by development of a pale purple color. Reduction in anthocyanin levels is accompanied by rapid development of chocolate flavor. In fact, within 12 hours of the death of the germ, it could be dried to give an acceptable product. It is presumed that certain chemical compounds are formed during fermentation, which subsequently transformed themselves into the characteristic flavor and aroma of cocoa during roasting operations .Sufficient indications are available to infer that the complex leucoanthocyanidin fraction of the polyphenols react with theobromine to produce cocoa aroma. The fact is that fresh beans (unfermented) after sundrying and roasting, give a product which is extremely astringent, bitter and unpleasant to taste, thus proving the significant role played by the fermentation process(Potty,1979)

2.10 DRYING

Following fermentation, the beans are either dried in the sun or by artificial means. The method of drying is critical to preserve the delicate flavor precursors which have been formed during fermentation. Chemical changes taking place in the beans during fermentation continues during drying until the moisture content drops from about 60% to about 7.5%. Both the high drying temperature and drop in moisture level causes enzymes to be inactivated. This is necessary to stabilize the beans for storage and shipment. Drying is also important for further development of the chocolate brown color due to the quinone protein reaction and for loosening of the shell from the bean (Cook, 1982; Hashim et al., 1998; Ramli et al., 2006). Drying should not take place too quickly as exposure to intense heat causes the skin of the beans to wrinkle and promotes oxidative changes and destruction of flavor precursors. This may result in development of off-flavors and the retention of acetic acid, giving beans acidic and bitter flavor (Jinap et al., 1994). On the other hand, if drying takes place too slowly, molds and off-flavors can develop. The quality of dried beans depends on temperature, rate of airflow, and the depth of the beans during the drying process. There are reports of development of flavor compounds during drying (Hashim et al., 1998).

2.10.1 Sun Drying

In areas where the weather permits, the fermented beans are sun-dried. In this method, the beans are spread out an inch or two deep on raised platforms, mats, trays or a terrace on the ground and exposed to the sun until dry. The beans are occasionally turned over to ensure uniform drying and also to remove those with obvious defects. In the event of rain and during the night, they are covered with banana leaves or if they are on platforms, these are sometimes roofed. If the beans happen to get wet, they must be stirred well and re-dried quickly. Raised wooden racks which support drying mats made of bamboo are common in many African cocoa producing areas. Sun-drying is environmentally friendly, cheap and gives beans of a good quality and is therefore the preferred method of drying (Cook, 1982; Beckett, 2008).

2.10.2 Artificial Drying

In instances or countries where sun-drying is not possible, artificial means are used to dry the beans after fermentation. Artificial drying is also mostly used where large lots of cocoa beans are being processed. Many types and sizes of mechanical dryers have been developed over the years. The method is common in some South American and Asian countries where cocoa is cultivated on large plantations and where the weather may be too wet for sun-drying. In some instances, cocoa beans are dried by fire. Wooden fires are lit in a chamber below the drying area, and the hot gas is led through a duct or pipe beneath the drying platform and then out through a vertical chimney. The problem with this method is the risk of smoke leakage from the fire which can contaminate the beans. The use of forced-air dryers and efficient heat exchangers can prevent smoke reaching the beans (Cook, 1982; Beckett, 2008). Artificial dryers can help to avoid moldy beans in wet seasons (Mossu, 1992). Bonaparte et al., (1998) stated that low cost solar drying has the potential of enhancing drying rate in cocoa beans, after surveying quality characteristics of solardried cocoa beans. They also found that the solar dryer did not cause problems associated with drying at high temperatures. Experiments have shown that during artificial drying of cocoa beans, volatile fatty acids are not reduced to the same level as that during sun drying and therefore the former tends to give beans of a higher acidity (Jinap et al., 1994; García-Alamilla et al., 2007). The results of studies by Fagunwa et al., (2009) showed that the solar dryer is able to dry cocoa beans with a moisture level from 53.4 % to 3.6 % within 72 hours. The quality of the beans was good, and comparable to that of traditionally sun-dried cocoa beans. In another experiment with solar dryers, a solar tunnel dryer was built in Malaysia for drying longan fruits from moisture content of 84 % before drying to 12 % after drying. Longan fruit are, like cocoa beans, sun dried on mats or more often, mechanically dried with hot air. The experiment resulted in good quality and considerable reduction in drying time, compared to natural sun drying (Janjai et al., 2009). Ndukwu (2009) studied the effect of some drying parameters and drying conditions of cocoa bean and reported that the drying rate increased with increase in temperature and air velocity but decreased with time. Although sun-drying is mostly preferred over mechanical drying, the latter has the following advantages:

- Freedom from dependence on the weather with consequent dependability on production time schedule.
- Completion of drying in shorter time.
- Reduction in vulnerability to contamination by foreign matter (sticks, stones, visits by domestic animal, etc.).
- Less possibility of mould growth.
- Better potential control over final moisture content of beans.

<u>Disadvantages of mechanical drying include the following:</u>

- Often by too fast drying or too high temperatures the drying period is shortened so much that enzymatic action is not fully completed resulting in incomplete development of the chocolate flavor precursors.
- Excessive heat and rapid drying may not allow for adequate loss of volatile acids, especially acetic acid and this will affect the flavor quality. If smoke comes into contact with the beans during drying, a smoky off flavor can result because cocoa easily absorbs volatile phenols from smoke.
- Costly investment especially for the small grower.

Sunilkumar et al (2008) reported that artificial drying could be feasible during adverse climatic conditions to save the beans from spoilage. Hii et al., (2009) stated that raw cocoa beans can be artificially dried using an air ventilated oven at temperature of 60°C until moisture content of 7%. Oke et al.,(2011) carried out drying experiments to investigate the effect of forced-air, artificial intermittent drying system on quality of fermented cocoa beans harvested in south-western Nigeria. From the test results, the free fatty acid and acetic acid levels increases with increase in drying temperature, also, the pH level decreases with increase in drying temperature. Optimum bean-quality was obtained for cocoa beans dried at 45°C oven temperature.

2.11 ENGINEERING PROPERTIES

Engineering properties are important in many problems associated with the design of machines and the analysis of behaviour of the product during post-harvest operations such as handling, threshing, cleaning, sorting and drying. The solutions to problems of these process involve knowledge of the engineering properties (Irtwange, 2000).

2.6.1 Physical Properties

Prior to the design and development of machine the physical properties *viz*., sphericity, roundness, mass, geometric mean diameter, surface area, volume, porosity, true density, bulk density etc are to be conducted.

2.6.1.1 Size

Size is the measure of physical dimensions of the object. Fruits and vegetables are irregular in shape and a complete specification of their form theoretically requires an infinite number of measurements. From 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).

Alamilla*et al.* (2012) conducted the physical properties of criollo variety of cocoa. The average bean length and width was 25.5 mm and 13.9 mm, respectively. The average number of seeds per pod was 37.

Bamgboye and Ojoh (2004) determined engineering properties of amazon fresh cocoa beans at average moisture content of 67.8 per cent (wb). The length and diameter of cocoa bean were 24.5 mm and 15.4 mm, respectively.

Akaaimo and Raji (2006) investigated the physical and engineering properties of *Prosopisafricana*seed. The results showed that the length, width and thickness for the *Prosopisafricana*seed ranged between 7.86-12.23, 5.35-7.55 and 3.40-6.81 mm, respectively.

Davies (2009) conducted studies on groundnut. The results show that the average magnitudes of the major, intermediate, and minor diameters for groundnut were 14.42, 9.94 and 7.57 mm respectively.

The physical properties of musk lime were estimated by Abdullah *et al*. (2012). The average moisture content, length, breadth and thickness of musk lime was 85.10 per cent, 26.40 mm, 26.30 and 25.30 mm,respectively.

Cangi*et al*. (2011) investigated the physical properties of kiwi fruit at various maturity index and ripening period. The mean length, width, thickness and geometric mean diameter of kiwi fruits was 62.1, 52.0, 46.5 and 53.2 mm, respectively.

The physical and mechanical properties of Russian olive fruit were investigated by Zare*et al.* (2012). The average length, breadth, thickness of Russian olive fruits was 18.80, 16.80, and 15.70 mm, respectively.

2.6.1.2 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).

Akaaimo and Raji (2006) reported that the geometric mean diameter and sphericity ranged of *P. africana*seed ranged between 5.72-7.20 mm and 0.56-0.75, respectively. The sphericity values for *the P. africana*seed fall within the range of 0.32-1.00 as reported by Mohsenin (1986) for agricultural products.

Goyal *et al.* (2007) investigated the physical and mechanical properties of three varieties of aonla fruits *viz*., Krishna, NA-7 and Chakaiya. The sphericity and surface area for Krishna, NA-7 and Chakaiya were 1.08±0.036, 1.04±0.09,1.10±0.11 and 37.25±1.81 cm^2, 35.78±4.44 cm^2, 37.10±6.10 cm^2, respectively. Surface area of fruits from Krishna cultivar was more than the varieties fruits.

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).

Abdullah *et al*. (2012) estimated the physical properties of *Citrus microcarpa*. The average values of sphericity and aspect ratio were found as 98.69 per cent and 100.23 per cent, respectively.

The engineering properties of Russian olive fruit were investigated by Zare*et al.* (2012). The mean values of geometric mean diameter, sphericity, aspect ratio and surface area were 17.06 mm, 0.81, 0.72 and 8.96 cm^2, respectively.

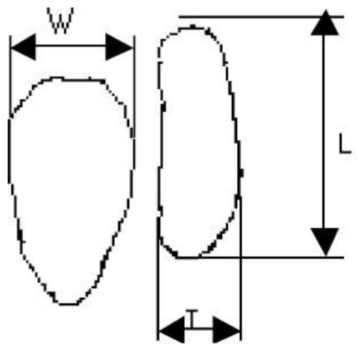

Fig 2.1 Shape and dimensions of cocoa beans

2.6.1.3 Mass and volume

Volume of a material can be measured by buoyancy force; liquid, gas or solid displacement; or gas adsorption; it can also be estimated from the geometrical dimensions (Rao *et al.*, 2005).

Bamgboye and Ojoh (2004) reported that the average weight and volume of Amazon cocoa bean as 1.5 g and 1760 mm^3, respectively.

Akaaimo and Raji (2006) reported the individual seed weight and volume of *Prosopisafricana*seeds were 0.198 g and 0.14 cm^3, respectively. The moisture content of pod used was 9.5 per cent while that of the seeds was 11 per cent all in wet basis.

The physical properties of *Citrus microcarpa*fruit were estimated by Abdullah *et al.* (2012). The average mass and volume of the fruits were 10 g and 8800 mm^3,respectively.

Adzimah and Asiam (2010) has conducted an experiment to find the average weight and percentage weight of wet and dry cocoa pods of three varieties.

2.6.1.4 True density, bulk density and porosity

The average bulk density and mass density of the Amazon cocoa bean was 548.1 kg/ m^3 and 1091 kg/m^3, respectively. (Bamgboye and Ojoh. 2004).

Akaaimo and Raji (2006) studied some physical properties of *Prosopisafricana*seedandthemeanbulkandtruedensitiesfortheseedswerefoundtobe 899.67 and 1397.17 kg/ m^3 with a SD of 1.73 and 13.91 and a CV of 0.19 per cent and0.99percent,respectively. TheporosityofP.*africana*seedswascalculatedas 35.6 per cent.

Davies (2009) investigated the physical properties of groundnut. The bulk density was 479.28±16.23 kg/m^3 for groundnut while the true density was 753.34±17.76 kg/m^3. The mean porosity of groundnut grain was 36.4±2.1 per cent.

The true and bulk densities for African nutmeg were 830.54 and 488.76 kg/m^3, respectively. The porosity of nutmeg was 41±4 per cent (Burubai*et al.*,2007).

Davies (2010) estimated the average true and bulk densities of arigo seed were 1066.7 kg/m^3 and 989.78 kg/m^3, respectively. The average porosity of arigo seeds was 31.1 percent.

The physical properties of *Citrus microcarpa*fruit were measured by Abdullah *et al.* (2012). The average true density, bulk density and porosity of the fruits were 1002 kg/m^3, 501 kg/m^3 and 49.89 per cent,respectively.

The average bulk density, true density and porosity of kiwi fruits ranged from 374.5

to 397.7 kg/ m^3, 1014.6 to 1047.8 kg/ m^3 and 63.2 to 61.1 per cent at different physiological maturity levels and ripening period, respectively (Cangi*et al.*, 2011).

2.6.2 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 case of foods, the main optical property considered by consumers in evaluating quality is color, followed by gloss and translucency or turbidity among other properties.

2.6.2.1 Color

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

Wahidu and Tajul (2013) studied the color of cocoa beans during superheated steam roasting. The surface color of the roasted cocoa bean samples 19 were measured using a Minolta CM-3500D colorimeter after calibration against white and black glass standards. The colors were expressed in CIELAB color 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 color values (L*, a*, and b*) are the three dimensions which gives specific color values of the products.

2.6.3 Frictional Properties

2.6.3.1 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.

The static coefficient of friction of *Citrus microcarpa* fruit was evaluated by Abdullah *et al*. (2012). The coefficient of static friction for glass and stainless steel was 0.238 and 0.247, respectively.

Jayashree (2009) reported the coefficient of friction of ginger rhizomes. The coefficient of friction of fresh ginger rhizomes at a moisture content of 81.70 per cent (wb) against plywood, stainless steel, aluminium, galvanized iron and mild steel surfaces was 0.53, 0.57, 0.68, 0.72 and 0.74, respectively.

Mishra and Kulkarni (2009) found out the coefficient of friction of turmeric rhizomes (variety-Sangli). The static co-efficient of friction against four metal surfaces namely, mild steel (0.51 to 0.66), galvanized iron (0.47 to 0.64), aluminum (0.40 to 0.56) and stainless steel (0.37 to 0.54).

Davies (2009) studied the coefficient of friction of ground nut and results showed that coefficient of friction was highest against concrete surface 0.16±0.003 followed by mild steel 0.14±0.009 and plywood 0.13±0.03. The least coefficient of friction was observed with glass 0.10±0.002.

Loghavi et al. (2010) investigated some moisture and ripeness dependent physical and mechanical properties of Estahban edible fig (*FicusCarica cv. sabz*). The maximum static coefficient of friction (0.85) was measured on rubber and the minimum (0.34) on galvanized steel.

2.6.3.2 Angle ofrepose

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).

Mishra and Kulkarni (2009) identified the angle of repose of fresh turmeric rhizome, by using a bottomless cylinder placed on a flat surface and filled it with turmeric rhizomes. The cylinder was raised slowly allowing the rhizomes to flow and assume a natural slope in the form of cone. The angle of repose was calculated based on the measured values of diameter and height of cone. The angle of repose for fresh turmeric rhizome was 33°.

Akaaimo and Raji (2006) measured the angle of repose values of *Prosopisafricana*seed and the values of angle of repose of the seed as measured by the cone method using two cylinders were 22.31° and 22.41°, with a mean value of 22.35°.

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

This chapter deals with various engineering properties required to develop a cocoa fermenter. The development and evaluation procedures for cocoa bean fermenter and the different quality analysis of fermented cocoa beans are also mentioned in this chapter.

3.1 RAW MATERIALS

Matured cocoa fruit (*Theobroma cacao L.*) were procured from a progressive farmer at Karuvarakundu, Malappuram district. Materials for the construction of machine were purchased from Coimbatore. Pods having cracks or skin injuries and disease were rejected. Harvested pods were collected in gunny bags and transported to the laboratory with care. From the sorted pods the beans were separated and taken for the experiment.

3.2 DETERMINATION OF ENGINEERING PROPERTIES OF COCOA BEANS

Prior to the development of cocoa fermenter, the physical, frictional and optical properties of cocoa bean were studied. Engineering properties of cocoa bean such as mass, size, shape, sphericity, volume, density and moisture content were determined by standard methods as explained in the following section. Frictional parameters, such as coefficient of friction and angle of repose were also determined.

3.2.1 Physical Properties of Cocoa Bean

The important physical properties of cocoa pod viz., shape mass moisture content, size, bulk density, and true density were determined as per methods explained in the following section.

3.2.1.1 Moisture content of cocoa beans

Moisture content of cocoa beans was determined as per AOAC (2005) method by placing samples of 2 g of fresh cocoa bean in a ventilated hot air oven at 105±2°C and dried to constant weight, which took about 10 h. The moisture content expressed as percentage wet basis (wb). The experiments were repeated 5 times and the average value was reported.

$$Moisture\ content(\%wb) = \frac{W_i - W_d}{W_i} \times 10$$

$$Moisture\ content(\%wb) = \frac{W_i - W_d}{W_i} \times 10$$

...(3.1)

Where,

` Wi - initial weight of the bean, g

Wd - dry weight of the bean, g

3.2.1.2 Determination of size of cocoa bean

Size refers to the characteristic of an object which determines the space requirement and it is expressed in terms of length, width and thickness. 5 numbers of whole matured cocoa bean were selected at random for the determination of the size. A digital vernier caliper was used to measure the diameter as well as bean thickness with a least count of 0.01 cm.

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

$$Dgm = \sqrt[3]{LBT}\,Dgm = \sqrt[3]{LBT}$$

..(3.2)

Where,

L - Length of the bean, mm

D - Diameter of the bean, mm.

T – Thickness of the bean, mm.

3.2.1.3 Determination of mass of cocoa bean

The mass of individual cocoa bean was determined by selecting 5 numbers of samples in random using an electronic balance (M/s Ashlyn Chemunnoor Instruments PVT. LTD) to an accuracy of 0.01 g and the mean value was reported.

3.2.1.4 Determination of shape of cocoa bean

Shape is an important property in grading fruits and vegetables and 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.

$$\emptyset = \frac{\sqrt[3]{LD^2}}{L}\emptyset = \frac{\sqrt[3]{LD^2}}{L}$$

..(3.3)

Where,

L - Length of the bean, mm

D - Diameter of the bean, mm

3.2.1.5. Determination of volume of cocoa bean

Volume of the cocoa bean was determined by volume analyser method (Micromeritics, 2006). The volume of cocoa bean was determined by comparing the weight of the sample in air to the weight of the sample immersed in a liquid of known density. The volume of the sample is equal to the difference in the two weights divided by the density of the liquid.

$$Volume\ of\ cocoa\ bean(m^3) = \frac{Weight\ of\ displaced\ water(kg)}{Density\ of\ water(\ kg/m^{-1})}$$

$$Volume\ of\ cocoa\ bean(m^3) = \frac{Weight\ of\ displaced\ water(kg)}{Density\ of\ water(\ kg/m^{-1})}$$

..(3.4)

3.2.1.6 Determination of true and bulk density of cocoa bean

For determining true density, known weight of cocoa beans was transferred into a measuring cylinder. Slowly add toluene to the cylinder to fill the voids. Measure the amount of toluene added. True density of cocoa beans was determined using the following equation.

$$True\ density\left(\frac{kg}{m^3}\right) = \frac{Mass\ of\ cocoa\ bean(kg)}{Volume\ of\ cocoa\ bean(m^3)}$$
$$True\ density\left(\frac{kg}{m^3}\right) = \frac{Mass\ of\ cocoa\ bean(kg)}{Volume\ of\ cocoa\ bean(m^3)}$$

..(3.5)

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 mass of bulk cocoa bean to the volume of container (Davies *et al*., 2014).

$$Bulk\ density\left(\frac{kg}{m^3}\right) = \frac{Weight\ of\ the\ cocoa\ bean(kg)}{Volume\ of\ the\ container(m^3)}$$

$$Bulk\ density\left(\frac{kg}{m^3}\right) = \frac{Weight\ of\ the\ cocoa\ bean(kg)}{Volume\ of\ the\ container(m^3)}$$

..(3.6)

3.2.1.7 Determination of porosity of cocoa bean

Porosity (P) 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 5 replications.

$$Porosity = \frac{True\ density - Bulk\ density}{True\ density} \times 100$$
$$Porosity = \frac{True\ density - Bulk\ density}{True\ density} \times 100$$

..(3.7)

3.2.2 Friction Properties

Frictional properties of cocoa beans such as angle of repose and coefficient of friction on mild steel, rubber and plywood was determined using methods explained in the following section.

3.2.2.1 Coefficient of friction

Coefficient of friction of cocoa beans on different surfaces such as stainless steel (SS), rubber and plywood was determined by the following method. A known quantity of cocoa beans was filled in a PVC cylinder of open bottom 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 was 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 a rubber and plywood. Coefficient of friction was calculated using the following equation.

$$\mu = F/N \quad ..(3.8)$$

Where,

μ- Coefficient of friction

F- Frictional force, kg

N- Normal force, kg.

3.2.2.2 Angle of repose

The angle made by a biological material with horizontal surface when piled from a known height is known as angle of repose. It was measured by using bottomless cylinder placed on a flat surface and filled it with cocoa beans. The cylinder was raised slowly allowing the beans to flow and to form a heap on the surface (Mishra and Kulkarni, 2009). The angle of repose was calculated using the measured value of diameter and height of cone.

$$\theta = tan^{-1}\frac{H}{R}\theta = tan^{-1}\frac{H}{R} \quad ..(3.9)$$

Where,

H - height of cone (cm)

R - radius of cone (cm)

3.2.3 Optical Property

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

3.2.3.1Determination of color

The color of cocoa beans was determined using colorimeter (HunterLabColour Flex EZ). The ColorFlex EZ spectrophotometer is a versatile color 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 38 of the light at different wavelengths along the visible spectrum (400-700 nm) are then analyzed to produce numeric results indicative of color of the sample.

3.3 COMPONENTS AND GENERAL LAYOUT OF THE MACHINE

The cocoa fermenter consists of the following components:

1. Fermentation chamber
2. Handle
3. UCP bearing
4. Frame assembly

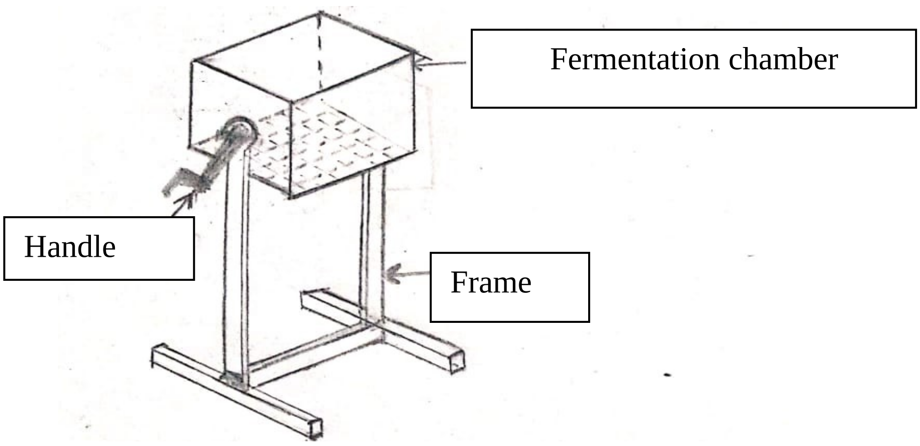

Fig 3.1 Concept diagram of cocoa bean fermenter

3.3.1 Fermentation Chamber

This is the main component of the cocoa fermenter. Fermentation of cocoa was done inside the chamber. The fermentation chamber was fabricated using mild steel.

The chamber was fabricated using 3 rectangular and 2 square mild steel sheets having 2 mm thickness, the remaining one side of chamber is of mild steel mesh. The length, breadth and height of the fermentation chamber were 405 mm, 255 mm and 255mm, respectively. The bottom side of the chamber was fitted with mild steel square mesh of size 16mm. These sheets are welded to a cuboidal skeletal frame.The top of the chamber was covered using MS sheet of length 405 mm and breadth 255 mm, respectively. The top cover was connected to the chamber with a mechanical hinge. Top opening was provided for the easy loading and unloading of the cocoa beans.

3.3.3 Handle

Handle was used to rotate the chamber for stirring cocoa beans. The main purpose of rotation of fermentation chamber is to ensure even fermentation. The handle was made up of cast iron and was connected to the shaft.

3.3.4 UCP Bearing

The rotation of fermentation chamber was made possible by using a pair of UCP bearing, which was inserted on each shaft and placed over the frame, joined by a pair of nut and bolt on both side. The UCP pillow block consists of a bearing insert with a spherical outer diameter in a two bolt cast iron housing. The bearing is usually fixed to the shaft by means of two set screws in the extended portion of the inner ring. Dimension of bearing is 20 mm, which is the inner diameter of bearing.

3.3.4 Frame assembly

The frame assembly was made to house and support the fermentation chamber and the fittings of the fermentation unit. It is used to provide support to bear the load and help in stirring of cocoa during fermentation. The frame assembly is fabricated using mild steel. This section holds the fermentation chamber.

Plate 3.1 Components of cocoa fermenter

Plate 3.2 Cocoa fermenter

Plate 3.3 Cocoa Fermenter (Modified)

3.4 OPERATION OF COCOA FERMENTER

12 kg of fresh cocoa beans were loaded in the cocoa fermenter through the top opening. This amounts to 75% of the total volume of the fermentation chamber. The chamber was closed and kept idle for 24 hours to collect the cocoa sweating (cocoa honey). Sweatings are released due to the breakdown of mucilaginous pulp surrounds the cocoa beans. After 24 hours, the cocoa beans were properly mixed by rotating the cocoa chamber. Again, the chamber was kept idle for another 6 days after providing proper insulation to the chamber using jute gunny bags. The mixing of cocoa beans was done at every two days interval. The

fermentation study was conducted for 7 days. The fermented cocoa beans were taken out, dried and conducted quality analysis.

3.5 ANALYSIS OF FERMENTED COCOABEANS

The cocoa beans which were fermented and dried had remarkably pleasant smell and negligible damage. Samples of the fermented cocoa were sent to Cocoa Research Centre at Kerala Agricultural University for analysis and results were obtained.

3.5.1 CutTest

Cut tests are one of multiple analyses done to evaluate fermentation and give some indication of flavor. Cut tests are used to evaluate cocoa bean health. They are also a way to assess whether or not a batch of cocoa has been correctly fermented. Hundred seeds from fermented lot was taken and cut longitudinally with a sharp knife and observed the cotlydon color by placing on a white background. Based on the color, beans were characterized into fully fermented, partially fermented, not fermented, slaty and mouldy. They are usually performed on at least ten beans to have a representative sample of each batch. At least 70% of the beans must be fermented to the correct level to be considered successful. A major cut test of about 50 beans at the end of fermentation. This is done to check the overall fermentation level.

3.5.2 Moisture Content

Moisture content of cocoa beans was determined as per AOAC (2005) method by placing samples of 2 g of dried fermented cocoa bean in a ventilated hot air oven at 105±2°C and dried to constant weight, which took about 10 h. The moisture content expressed as percentage wet basis (wb). The experiments were replicated three times and the average value was reported.

$$\textit{Moisture content (\%) wb}=W1-W2/W1 \; \frac{Wi-Wd}{Wi} \qquad ...(3.10)$$

Where, Wi - Weight of sample before drying

Wd – Weight of sample after drying

3.5.3 Fat

Ten grams of cocoa powder was wrapped in a blotting paper and tied with a twine. The sample was taken in the extraction tube of soxhlet apparatus, The fat present in the cocoa powder was extracted through siphoning of petroleum ether through the apparatus and fat will settle at the bottom of the flask along with little amount of petroleum ether. This was transferred to a pre-weighed beaker and kept open for petroleum ether to evaporate. The cream colored substances left behind after evaporation of solvent was the fat which is weighed and expressed as percentage.

3.5.4 Free FattyAcid

One to ten grams of cocoa butter extracted from fermented cocoa beans was weighed into 250ml conical flask to which added 50 ml of a mixture of equal volumes of alcohol and diethyl ether previously neutralized, after the addition of 1ml of phenolphthalein indicator. The solution is titrated with N/10 KOH with constant shaking until pink color persists for 15 seconds. The titre value in ml (V) was noted.

$$Acid\ value = \frac{(Titre\ value\ x\ Normality\ of\ KOH\ x\ 56.1)}{(Weight\ of\ sample)}$$

$$= \frac{(Titre\ value\ x\ Normality\ of\ KOH\ x\ 56.1)}{(Weight\ of\ sample)}$$

...(3.11)

3.5.5 Polyphenols

Exactly 500mg of powdered defatted sample were taken and ground it with 80 percent ethanol using mortar and pestle and centrifuged at 10,000rpm for 20 minutes. The supernatant was collected in a beaker and the remaining settled residue was extracted with five times the volume of 80 percent ethanol. Again centrifuged and the supernatant was collected and pooled in the beaker. Then supernatant was allowed to evaporate. Five milliliter water was poured to the residue to dissolve the phenols in it. Pipetted out 0.2ml of the solution into a test tube and then make up the volume to 3ml using distilled water followed by the addition of 0.5ml of Folin-Ciocalteau reagent. Kept it for three minutes and add 2 ml of 20 per cent sodium carbonate solution and mixed well. The total test tubes were kept in a boiling water bath exactly for one minute and after that it was cooled to room temperature and incubated for 60 minutes for color development. A blue colored complex, molybdenum blue was formed as the phenol undergoes a complex redox reaction with phosphomolibdic acid present in Folin-Ciocalteau reagent in alkaline medium. Absorbance was read at 650nm.

The detector was calibrated for quantification of total phenols using following procedure. The total phenols in the extracts were assayed in terms of catechin taken as the reference.100mg of catechol dissolved in 100ml of distilled water was taken as stock solution. Working standards were prepared from this. Pipette out 1ml aliquot from the stock solution into a 1oml of standard flask and made up the volume. For the measurement of absorbance value. Pipette out 0.2ml from this to a test tube and made up the volume to 3ml distilled water followed by the addition of 0.5ml of Folin-Ciocalteau reagent. Kept it for three minutes and 2ml of 20 percent of sodium carbonate solution was added and mixed thoroughly. The absorbance was read at 650nm.

Concentration of phenols present in the extract was worked out by substituting the absorbance value, thus obtained in the calibration equation. The total phenol content was calculated as mg catechol equivalent of phenol per gram sample and expressed it as percent.

$$\textit{Total phenol} = \frac{(OD\ sample\ /OD\ standard\ ) \qquad (OD\ sample\ /OD\ standard\ )}{(Conc\ of\ standard\ /Vol\ of\ sample\ )(Conc\ of\ standard\ /Vol\ of\ sample\ )} x100 \quad ...(3.12)$$

RESULT AND DISCUSSION

CHAPTER 4

RESULTS AND DISCUSSION

This chapter deals with the results obtained from various experiments conducted to determine the engineering properties of raw cocoa beans and the performance evaluation of developed cocoa bean fermenter.

4.1 ENGINEERING PROPERTIES

The results of physical properties *viz.*, size, shape, mass, porosity, density; optical properties like colour and frictional properties like coefficient of friction, angle of repose etc. are presented and discussed in this section.

4.1.1 Physical Properties

Prior to the development of cocoa bean fermenter, selected physical properties of raw cocoa beans *viz.*, moisture content, length, width, thickness, geometrical mean diameter, mass, sphericity, bulk density, true density and porosity were investigated.

The average values of various physical properties of raw cocoa beans are presented in Table 4.1. The average moisture content of raw cocoa beans was 58.33 percent (wb). The average length, width and thickness of cocoa beans were found to be 24.54 mm, 13.64 mm and 10.86 mm, respectively. The average geometric mean diameter was 15.04 mm. The average mass of an individual cocoa bean was 1.2 g. The average sphericity was estimated as 0.64. The average surface area of raw cocoa beans was found to be 616.54 mm^2. The average true density and bulk density were 978.2 and 554 kg/m3, respectively. The average value of porosity was 25.79 per cent. The average volume of a cocoa bean was 1735.46 mm^3.

Table 4.1 Physical properties of raw cocoa beans

Sl No	Parameters	Mean value
1	Length (mm)	24.54
2	Width (mm)	13.64
3	Thickness (mm)	10.86
4	Geometric mean diameter (mm)	15.04
5	Sphericity(Ø)	0.64
6	Surface area(mm2)	616.54
7	Porosity(%)	25.79
8	Mass(g)	1.20
9	Bulk density(kg/m^3)	0.554
10	True density(kg/m^3)	0.978
11	Volume(mm^3)	1735.46
12	Moisture content (%)	58.38

4.1.2 Frictional and Optical Properties

Frictional properties *viz.,* angle of repose and coefficient of friction are important in designing equipment related to solid flow and storage structures. The coefficient of static friction plays also an important role in the transportation of goods and its storage. The frictional properties of raw cocoa beans *viz*., angle of repose and coefficient of friction on three different surfaces were determined. The various frictional properties of raw cocoa beans are illustrated in Table 4.2.

Table 4.2 Frictional and optical properties of raw cocoa beans

Sl No	Parameters	Mean value
1	Angle of repose	27.86°
2	Coefficient of friction Stainless steel Rubber Plywood	 0.52 0.25 0.61
3	Colour- L* a* b*	 22.21±0.01 7.77±0.01 9.25±0.01

4.2 PERFORMANCE EVALUTION OF COCOA BEAN FERMENTER

The performance evaluation of cocoa bean fermenter was conducted in terms of quality of fermented dried cocoa beans *viz.*, moisture content, free fatty acid, fat content and polyphenol content.

4.2.1 Cut Test

100 cocoa beans were randomly selected for cut test and the results are tabulated in Table 4.3. From the Table, it is observed that the percentage of fully fermented beans and partially fermented beans were 72 per cent and 28 per cent, respectively. During fermentation, the anthocyanins and polyphenols present inside the cocoa beans undergo series of chemical reaction to form condensed tannins which impart the brown color to the beans (Kim and Keeney,1984). Beans described as ‘partly brown’ and ‘partly purple’ are not defective. For good cocoa flavor development the degree of fermentation (% fully brown beans) should be above 60%(Wood and Lass, 1985) .In the study the percent of fully brown beans was more than 70% in all the samples.

Fig4.1 Fermented cocoa beans for quality analysis

Table 4.3 Cut test of the cocoa beans

Number of Sample	100
Fully fermented(Fully brown)	72
Partially fermented(Partly brown)	28
Fully purple	0
Salty	0

4.2.2 Quality Analysis of Fermented Cocoa Beans

Fermented dried cocoa beans were selected randomly and the quality parameters such as moisture content, free fatty acid, fat content and polyphenol content were determined using the standard procedures mentioned in chapter 3. According to the results of the quality analysis of the fermented cocoa beans, the percentage of components such as moisture content(7.6%),free fatty acid(2.1%),fat content(47.16%),polyphenol(7.6%) are almost equivalent to standard values of the components obtained during fermentation of traditional methods. The higher value of free fatty acid of fermented cocoa beans might be due to the growth of *Aspergillus sp* during fermentation process. According to Pitt and Hocking (1997), species of Aspergillus are the predominant spoilage fungi in tropical areas and Penicillium spp. occur in more temperate zones. Properties of fungal lipases and mycotoxin-producing abilities of fungi isolated from raw cocoa beans showed good evidence to support their potential toxicogenic abilities and the free fatty acids (FFA) content (Guehi et al., 2007).

Table 4.4 Quality parameters of fermented cocoa beans

Parameters	Mean value(%)
Moisture content	7.6
Free fatty acid	2.1
Fat content	47.16
Polyphenols	7.6

4.3 COMPARSON OF COCOA BEAN FERMENTER WITH TRADITIONAL FERMENTATION METHODS

The comparison of developed cocoa fermenter with traditional fermentation methods are presented in Table 4.5. From the Table, it is observed that the polyphenol content(%)of cocoa beans fermented using heap, box, basket, tray methods and the developed cocoa fermenter was found to be 4.5, 5.2, 6.1, 4.2 and 5.52 respectively. Similarly, total fat(%), moisture content(%) and free fatty acid(%) using the above-mentioned methods were 43.18, 45.3, 46.7, 43.6,47.16; 7.4, 7.2, 7.6, 7.9, 7.6 and 1.75, 1.54, 1.69, 1.52, 2.1, respectively.

Table 4.5 Comparison of developed cocoa fermenter with traditional fermentation methods

Components(%)	Heap	Box	Basket	Tray	Fermenter
Polyphenols	4.5	5.2	6.1	4.2	5.52
Total fat	43.18	45.3	46.7	43.6	47.16
Moisture content	7.4	7.2	7.6	7.9	7.6
Free fatty acid	1.75	1.54	1.69	1.52	2.1

The results of the quality parameters of cocoa beans fermented using cocoa fermenter when compared with the standard values of traditional methods were relatively same and the free fatty acid content variation will be corrected if the number of days of fermentation and the material of construction is changed (stainless steel). For the cocoa beans fermented in the developed fermenter, the percentage of components was relatively similar to the ones fermented by traditional methods. Hence it is concluded that the quality of fermented cocoa bean using the developed cocoa fermenter is on par with the traditional cocoa fermentation methods.

SUMMARY AND CONCLUSION

CHAPTER 5

SUMMARY AND CONCLUSION

Cocoa (*Theobroma cacao L.*) is a tropical crop and native to Amazon region of South America. It grows in tropical environment within 15-20° latitude from equator. The primary cocoa growing regions are Africa, Asia and Latin America. The global production of cocoa during 2018-19 was 4.8 MMT. Cocoa is a commercial plantation crop in India. It is mainly cultivated in Kerala, Karnataka, Andhra Pradesh and Tamil Nadu. The annual production of cocoa in India during 2018-2019 was 20,000 MT from an area of 78,000 ha. Cocoa is the main raw material in the production of chocolates, cosmetics, health drinks, pharmaceuticals etc. It contains about 50 per cent fat, which is useful in the production of candle, soap, ointments etc. Cocoa butter is also used in the production of pharmaceutical products. The cocoa bean powder is the raw material for the preparation of chocolates, ice cream, soft drinks and confectionaries.

Presently, the fermentation of cocoa beans is conducted as a simple, traditional process. Cocoa pods are harvested from the trees, the pods are broken open, and the beans are manually extracted. The beans (50–500 kg) are assembled into heaps on the ground, or placed into boxes, trays, or baskets; and the fermentation is allowed to develop spontaneously. The micro-organisms responsible for the fermentation are originated from the natural contaminants formed during the process. After fermentation, the beans are placed onthe ground or drying platforms and dried in the sun until a moisture content of less than 11% is achieved. Often during rainy season it is difficult to obtain good quality cocoa.

Before the fabrication of the fermenter, the engineering properties of cocoa beans *viz*., physical and frictional properties of raw cocoa beans were studied. Physical properties studied were moisture content, size, sphericity, mass, volume, porosity and density. The frictional properties angle of repose and coefficient of friction were determined as per the standard procedures. Optical property was also determined.

The developed cocoa fermenter consists of fermentation chamber, handle,UCP bearing and frame assembly. They were fabricated using mid steel material. Fermentation chamber which is the main component of the cocoa fermenter. Fermentation of cocoa was done inside the chamber, Handle is used to rotate the chamber for stirring cocoa beans.

Rotation is done to ensure even fermentation. The rotation of fermentation chamber was made possible by using a pair of UCP bearing and frame assembly which is made to house and support the fermentation chamber and the fittings. The cocoa beans about 12 Kg were fed into the fermentation chamber. Then chamber of the fermenter is filled with cocoa beans till 3/4th its capacity. Then it was closed and left idle at room temperature, to allow the sweatings drain out through the bottom potion of fermentation chamber which was made of mild steel wire mesh. Using the rotating handle, the chamber is rotated during the alternative days (3rd and 5th day) so that cocoa beans were mixed properly, for equal distribution of heat to all cocoa beans and for proper fermentation period of 7 days.

The results of present study summarized as following; the average moisture content of fermented cocoa beans was found to be 7.6%, free fatty acid content of the fermented cocoa beam was found to be 2.1%, fat content of the fermented cocoa bean was found to be 47.16% and polyphenol content in fermented cocoa bean was found to be 7.6%.

The performance evaluation was done on the basis of all above factors which showed slight variations than the values set by the traditional method. The higher values of free fatty acid of fermented cocoa beans might be due to the formations of fungus (*Aspergillusniger*), increases in number of days of fermentation, rection with the material used for construction etc. It was then inferred that a change in the material and also reduced fermentation days can provide a better-quality cocoa which will be beneficial for farmers.

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APPENDIX

Table A-1 Physical properties of Forastero variety cocoa

Sl No	Parameters	T1	T2	T3	T4	T5	Mean value
1	Length (mm)	22.4	24.5	22.8	25.7	25.7	**24.54**
2	Width (mm)	13.9	11.2	15.1	14.5	13.5	**13.64**
3	Thickness (mm)	11.3	11.5	9.6	10.7	11.2	**10.86**
4	Geometric mean diameter (mm)	14.8	16.1	14.1	15.9	14.3	**15.04**
5	Sphericity (ϕ)	0.61	0.63	0.64	0.65	0.67	**0.64**
6	Surface area(mm^2)	505.91	560.22	610	655.7	750.88	**616.54**
7	Porosity (%)	20.58	22.6	25.3	28.88	31.59	**25.79**
8	Mass(g)	1.11	1.15	1.21	1.26	1.31	**1.20**
9	Bulk density (kg/m^3)	0.554	0.561	0.552	0.548	0.555	**0.554**
10	True density (kg/m^3)	0.971	0.968	0.97	0.997	0.985	**0.978**
11	Volume (mm^3)	1710.3	1841.33	1789.1	1647	1689.6	**1735.46**
12	Moisture content (w.b %)	58.2	57.8	59.7	58.9	57.3	**58.38**

Table A-2. Frictional properties of Forastero variety cocoa

Sl No	Coefficient of friction for steel	Coefficient of friction for plywood	Coefficient of friction for rubber
T1	0.49	0.61	0.22
T2	0.52	0.59	0.28
T3	0.45	0.65	0.19
T4	0.58	0.58	0.24
T5	0.6	0.63	0.22
Mean	**0.528**	**0.612**	**0.23**

ABSTRACT

Cocoa, *Theobroma cacao L*, also called the cacao tree and the cocoa tree, is a evergreen tree in the family Malvaceae native to the deep tropical regions of Mesoamerica. Its seeds, cocoa beans, are used to make chocolate liquor, cocoa solids, cocoa butter and chocolateIt 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 consist of two parts- seed coat and seed cotyledon. Seed cotyledon is the material in which characteristic flavor and aroma produced during fermentation. Fermentation of cocoa beans is the first step in the chocolate-making chain. Cocoa bean fermentation is most crucial step which decides further quality of cocoa products. Microbial fermentation of cocoa removes mucilage and induces a set of internal biochemical reactions in the cotyledon that lead to modification of the chemical composition of cocoa beans and the formation of aromatic precursors. The temperature range of 45-50^{0}C is inevitable for effectiveness of fermentation, which is a major constraint during rainy season. In order to overcome this problem a ‘cocoa fermenter’ was developed which helped in building up a temperature suitable for fermentation.

The cocoa fermenter consists of fermentation chamber, handle, UCP bearing and frame assembly. The cocoa beans (12.3 Kg) were fed into the fermenter through the top portion of fermentation chamber by removing top cover, beans were filled up to ¾thof thecapacityof fermenter. After closing the chamber the fermenter was then kept idle for one day to drain the sweating through bottom side. Using the rotating handle the chamber is rotated at 3rd and and 5th day so that cocoa beans were mixed properly, for equal distribution of heat to all cocoa beans and for proper fermentation cocoa. The fermentation period took about 7 days. At the final day fermented cocoa beans were taken out and dried.

Performance of the machine was evaluated by quality of fermentation. Quality analyses of the fermented dried cocoa beans were done based on moisture content (7.6%), free fatty acid (2.1%), fat (47.16%) and polyphenols (7.6%). The results of the quality parameters of cocoa beans fermented using cocoa fermenter when compared with the standard values of traditional methods were relatively same and the free fatty acid content variation can be corrected by altering the number of days of fermentation and change the material of construction.