DEVELOPMENT AND PERFORMANCE EVALUATION OF A BATCH-TYPE COCOA BEAN DRYER

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KERALA, INDIA

2018

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PROJECT REPORT

Submitted in partial fulfilment of the requirement for the degree

BACHELOR OF TECHNOLOGY

IN

FOOD ENGINEERING

Faculty of Agricultural Engineering and Technology

Kerala Agricultural University

Department of Food and Agricultural Process Engineering

Kelappaji College of Agricultural Engineering & Technology

Tavanur, Malappuram - 679 573, Kerala, India

2018

DECLARATION

We hereby declare that this thesis entitled "**DEVELOPMENT AND PERFORMANCE EVALUATION OF A BATCH-TYPE COCOA BEAN DRYER"** is a bonafide record of research work done by us during the course of academic programme in the Kerala Agricultural University and the thesis 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.

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CERTIFICATE

Certified that this project report entitled "**DEVELOPMENT AND PERFORMANCE EVALUATION OF A BATCH-TYPE COCOA BEAN DRYER"** is a record of project work done jointly by Ms. Drishya C., Mr. Mufassil Usman, Ms. Vinduja P. V. under my guidance and supervision and that it has not previously formed the basis for any degree, diploma, fellowship or associateship or other similar title of another University or Society.

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ACKNOWLEDGEMENT

Any accomplishment requires the efforts of many people and this work is no different. We find great pleasure in expressing our deep sense of gratitude towards all those who have made it possible for us to complete this project with success.

First of all we would like to express our true and sincere gratitude to our mentor **Dr. Rajesh G. K**., Assistant Professor, Dept. of Food and Agricultural Process Engineering, Kelappaji College of Agricultural Engineering and Technology, Tavanur for his dynamic and valuable guidance, care, patience and keen interest in our project work. This project has been a result of combined efforts of our guide and us. He has been a strong and reassuring support to us throughout this project. We consider it as our greatest fortune to have him as the guide for our project work and our obligation to him lasts forever.

With deep sense of gratitude and due respect, we express our heartfelt thanks to **Dr. Santhi Mary Mathew**, Dean i/c, KCAET, Tavanur, for the support that she offered while carrying out the project work.

We engrave our deep sense of gratitude to **Mrs. Sreeja R.,** Assistant Professor, **Er. Sariga S.**, Teaching Assistant and **Dr. Anjineyulu Kothakota,** Teaching Assistant, Department of Food and Agricultural Process Engineering, K.C.A.E.T, Tavanur.

We thankfully remember the services offered by **Mr. Vipin**, Technician, **Mr. Lenin**, Technician and **Mr. Surjith**, Technician, Workshop, KCAET, Tavanur for the completion of project in time.

With great pleasure we express our heartfelt special thanks to our beloved seniors **Dr. Sankalpa, Er. Sreenivas** and **Er. Pooja M.R.** for their care, help, encouragement and moral support which helped us get over all odds and tedious circumstances.

We express our profound sense of gratitude to **Mrs. Jojitha**, **Mrs Geetha** and **Er. Rooshi**, staff members of Department of Food and Agricultural Process Engineering, K.C.A.E.T, Tavanur and **Mr. Radhakrishnan M.V.**, Lab Assistant for their immense help.

We express our thanks to all the **staff members of library**, K.C.A.E.T, Tavanur for their ever willing help and cooperation. We express our sincere thanks and gratitude to **Kerala Agricultural University** for providing this opportunity to do the project work.

We are greatly indebted to our **parents** for their love, blessings, and support which gave strength to complete the study. We also acknowledge our **friends** for their support and care throughout the project duration.

Last but not the least, we bow our heads before **God Almighty** for the blessings bestowed upon us which made us to materialize this endeavour.

DRISHYA C

MUFASSIL USMAN

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SYMBOLS AND ABBREVIATIONS

et al.	:	And others
%	:	Per cent
&	:	And
/	:	Per
<	:	Less than
±	:	Plus or minus sign
Ø	:	Angle of repose
°	:	Degree
°C	:	Degree centigrade
Φ	:	Sphericity
ρ	:	True density
ρ_b	:	Bulk density
µ	:	Coefficient of friction
a*	:	Greenness or redness
B	:	Breadth
b*	:	Blueness or yellowness
cm	:	Centimetre
db	:	Dry basis

etc.	:	Etcetera
F	:	Frictional force
Fig.	:	Figure
g	:	Gram
g/100g	:	Gram per 100 gram
H	:	Height
h	:	Hour
ha	:	Hectares
hp	:	Horse power
kg	:	Kilogram
kg/m^3	:	Kilogram per meter cube
kJ	:	Kilo Joule
Kwh	:	Kilo watt hour
L	:	Length
L*	:	Lightness or darkness
Ltd.	:	Limited
M_b	:	Mass of cocoa bean
m/s	:	Meter per second
Mha	:	Million hectares

min	:	Minute
ml	:	Milliliter
mm	:	Millimeter
mm/s	:	Millimeter per second
N	:	Newton
No.	:	Number
P	:	Combination
pH	:	Percentage of H+ ions
rpm	:	Revolution per minute
s	:	Second
T	:	Thickness
t	:	Temperature
t/ha	:	Tonnes by hectares
V	:	Volts
V_b	:	Volume of cocoa bean
viz	:	Namely
W	:	Watts
wb	:	Wet basis
W_i	:	Intial weight of bean

W_d	:	Dry weight of bean
w/w	:	Weight by weight
AOAC	:	Association of official analytical chemists
APEDA	:	Agricultural Products Export Development Authority
BD	:	Bulk density
FFA	:	Free Fatty Acid
GI	:	Galvanised Iron
HACCP	:	Hazard Analysis Critical Control Point
IOCCC	:	International Office of Cocoa, Chocolate Sugar Confectionery
KCAET	:	Kelappaji College of Agricultural Engineering and Technology
LTD	:	Limited
MT	:	Metric Tonnes
MMT	:	Million Metric Tonnes
PAH	:	Polycyclic Aromatic Hydrocarbons
PVT	:	Private
SD	:	Standard Deviation
SS	:	Stainless Steel
TV	:	Total volume

DEDICATED TO ALL

FOOD ENGINEERS

INTRODUCTION

CHAPTER I

INTRODUCTION

Cocoa, (*Theobroma cacao L.*) a native of Amazon region of South America is an important plantation crop in the world which belongs to Malvaceae family. It is a neotropical perennial crop growing within 20º north and 20º south approximately of the equator. It is grown at an altitude of less than 1312 feet above sea level and optimal temperatures range between 18ºC and 32ºC and rainfall should be at least 100 cm but not more than 1000 cm per year (Anon., 2008).

The global production of cocoa during 2014-2015 was 4.2 million metric tons (MMT) from an area of 6.9 million hectares (Mha) (Anon., 2016a). Africa, Asia, and Latin America are the primary growing regions of Cocoa. Ivory Coast of Africa is the largest cocoa producing country by volume comprising 33 per cent of global supply and Ghana is the second largest cocoa producing country after Ivory Coast.

In India, cocoa is mainly grown in Kerala, Karnataka, Andhra Pradesh and Tamil Nadu as a tropical crop offering considerable scope for the development. Kerala is the leading state among all the above mentioned states; however, current area under cocoa cultivation is very low. The annual production of cocoa in India during 2014-2015 was 16,050 metric tons (MT) from an area of 78,000 ha. Among this, the annual production of Kerala state is 6,000 MT from an area of 14,650 ha during 2014-2015. India has exported 15,962.92 MT of cocoa products to the world during the year 2013-2014 (Anon., 2016b).

Cocoa beans, the seeds of cocoa tree are processed to obtain chocolate liquor, cocoa powder and cocoa butter which are the main ingredients of chocolate and a vast range of products like cocoa beverages, ice cream and bakery products and impart a characteristic and distinctive flavour to its derived products. In addition to its confectionary use, cocoa also has cosmetic and pharmaceutical applications. Cocoa husks can be hydrolyzed to produce fermentable sugar. Cocoa cake is used as part of feed ingredients for poultry, pig, sheep, goat, cattle and fish after removing the theobromine (Adeyanju *et al*., 1975). The cocoa pod is a good source of potassium and can be used in the production of potash fertilizer, local soap, for biogas and particle boards (Adeyanju *et al.*, 1975; Opeke, 1987).

The primary post-harvest processing of cocoa on farm level comprises the steps of pod opening and beans removal from the pod, beans fermentation and drying. In this sequence, the fermentation constitutes an essential critical step for the development of flavor quality attributes of the commercial cocoa beans. The dried seeds are roasted, 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 flavor and makes cocoa beans more brittle.

Drying refers to the removal of moisture from food products to a pre-determined level. It is a thermo-physical and physico-chemical operation by which the excess moisture from the product is removed. Drying makes the food products suitable for safe storage and protects them against attack of insects, molds and other microorganisms during storage. During drying, the moisture from solids get vapourised and diffused in dilute environment (Sahay &Singh, 1994).

Drying is an important step in the postharvest processing of cocoa beans. Cocoa beans are dried after fermentation in order to reduce the moisture content from about 60 per cent to about 6-7 per cent. Drying must be carried out carefully to ensure that off-flavours are not developed. Drying should take place slowly. If the beans are dried too quickly some of the chemical reactions started in the fermentation process are not allowed to complete their work and the beans are acidic with a bitter flavour. However, if the drying is too slow, moulds and off-flavours can develop. Various research studies indicate that bean temperatures during drying should not exceed 65ºC.

The drying process must be carried out carefully to ensure the beans are adequately prepared for storage and transport without becoming contaminated by molds, *Salmonella* bacteria, Polycyclic Aromatic Hydrocarbons (PAH) and other contaminants.

Traditional method of drying cocoa bean is sun drying. In sun drying method, the beans are spread out on mats, trays or on concrete floors under sun. Some countries in the West Indies and South America, drying takes place on wooden drying floors with moveable roofs. The beans are normally turned or raked to ensure uniformity of drying and the beans need to be covered when it rains. Sun drying is used in countries where harvesting occurs in a dry period such as West Africa or the West Indies. With adequate sunshine and little rainfall, sun drying may take about one week, but if the weather is dull or rainy it will take longer.

The main disadvantages of sun drying are: (a) drying can only be done effectively from 9 am to 4 pm; the rest of time is idle (b) since it is done in open field, trees, buildings and other structures may block sunlight and hinder the drying process (c) exposure to dirt, microbes and animals (d) sudden rains and strong winds might completely ruin the whole batch (e) longer duration of drying.

Artificial drying is followed in countries where there is a lack of pronounced dry periods after harvesting and fermentation, such as Brazil, Ecuador and in South East Asia and sometimes in West Africa. The simplest forms of artificial dryers are convection dryers or Samoan dryers which consist of a simple flue in a plenum chamber and a permeable drying platform above. Air inlets must be provided in order to allow the convection current to flow without allowing smoke to taint the beans. These dryers are simple to construct and have been used in Western Samoa, Cameroon, Brazil (the Secador dryer) and the Solomon Islands.

Other artificial dryers are platform dryers using heat exchangers, where the hot air is kept separate from the products of combustion which pass to the beans, or direct fired heaters, where the products of combustion mix with the hot air and are blown through the beans. These dryers can use oil or solid fuels as a source of power. The addition of a fan forces the hot air through the beans and creates a forced draught dryer. Other techniques have been used in association with the above to overcome the problem of turning or raking the beans in the dryer - stirring the beans in a circular bed or turning the beans in a rotary drum.

Smoke contamination and related PAH contamination are very obvious when beans are dried by wood fuelled kiln dryers. When direct fuel burners are used it may be less obvious that contamination has occurred, since there may not be the distinctive smoky aroma, but the beans may well be contaminated with PAH. Hence wood fired artificial dryers are not preferred in most countries due to low quality of cocoa beans produced by this method.

Considering the above facts, a study had been undertaken on **"Development and Evaluation of a Batch-type Cocoa Bean Dryer"** with the following objectives:

1. To study the engineering properties of cocoa beans.
2. To develop a batch-type cocoa bean dryer.
3. To optimize the process parameters of the developed cocoa bean dryer.
4. To conduct the performance evaluation of cocoa bean dryer in terms of efficiency of dryer and quality of cocoa bean.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

This chapter deals with comprehensive review of the research work done by various research workers related to the engineering properties of cocoa bean, cocoa bean dryers and quality parameters of dried cocoa.

2.1. Cocoa

The cocoa tree, *Theobroma cacao L.*, is originated in the tropical regions of South America. It proliferates in tropical climates 20° North and South of the equator. It grows in humid areas with an average annual rainfall and relative humidity of 1250-3000 mm and 70-100 per cent, respectively. Compared to other tropical crops, cocoa is more sensitive to water logging and soil moisture stress. Cocoa 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 in coconut or arecanut fields. The cocoa 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 then 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 180-200 mm long and weighs about 400-500 g.

2.1.1. History

The cocoa 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 variety 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 at least 1500 BC in Central America. Chocolate was introduced to Europe by the Spaniards, and became a popular beverage by the mid-17th century. They also introduced the cocoa 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 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 ("Food of the Gods") cacao (Anon., 2015).

2.1.2. Cocoa production

Globally, eight countries are regarded as major cocoa bean producers. Fig 2.1 shows the production status of cocoa during 2014-15. The total world production of cocoa during 2014-2015 was 4.2 MMT. Africa, Asia, and Latin America are the primary growing regions of Cocoa. Ivory Coast of Africa is the largest cocoa producing country by volume comprising 33 per cent of global supply and Ghana is the second largest cocoa producing country after Ivory Coast. Ivory Coast, Ghana and Indonesia are having most suitable climate for cocoa cultivation.

In India, cocoa is mainly grown in Kerala, Karnataka, Andhra Pradesh and Tamil Nadu. The annual production of cocoa in India during 2014-2015 was 16,040 MT from an area of 78,000 ha. Andhra Pradesh is the largest producer of cocoa in India with an annual production of around 6,300 MT from an area of 23,485 ha followed by Kerala with a production of 6,000 MT from an area of 14,650 ha during 2014-2015. Kerala accounts for 18.7 per cent of area under cultivation and 37.4 per cent of total cocoa production (Anon., 2016b) Fig 2.2 shows the state wise production of cocoa in India for the last three years.India exported 20,877.75 MT of cocoa products worth Rs. 848.62 crores during 2014-15 (Anon., 2016c).

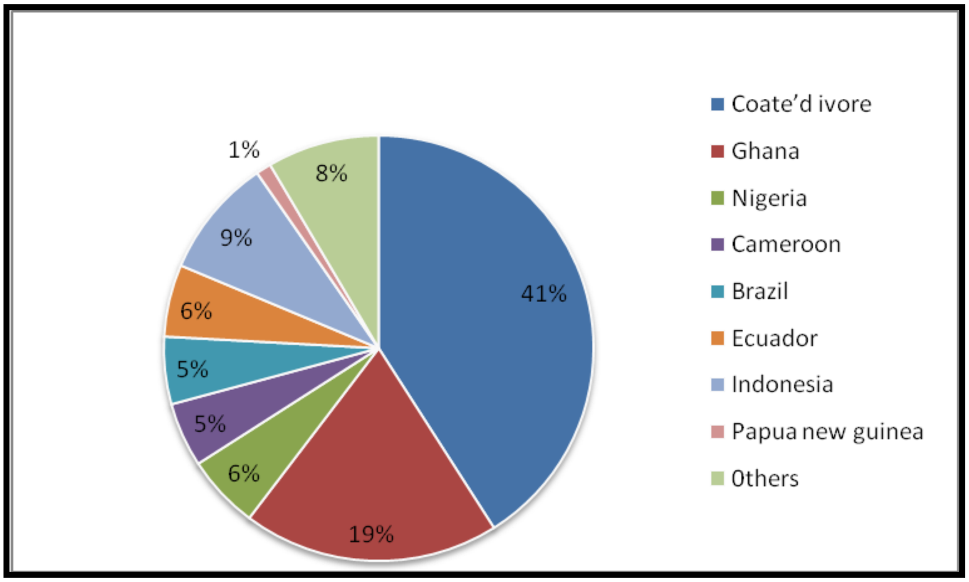

Fig 2.1. World cocoa production (%) in 2014-15

Source*:* Anon., 2016a

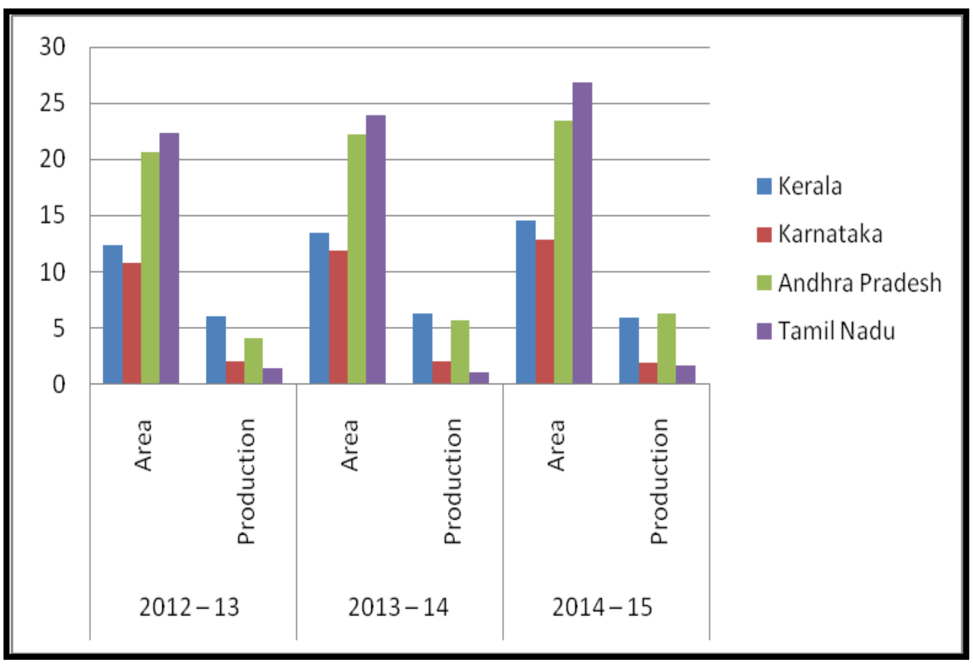

Fig 2.2. State wise production of cocoa in India (in '000ha; '000T)

Source: Indian Horticultural Database 2015

2.1.3. Varieties of cocoa

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

2.1.3.1. Criollo

It is native to Central America and considered the best flavoured cocoa. This variety has white to pale yellow cotyledon. Some types produce a jorquette, while others do not. 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) and plumb. 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 chocolate. With proper attention and care, the yield can be enhanced high as 1.0-1.5 t/ha.

2.1.3.2. 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 precocity, superior growth vigour, and high bean yields as well as appreciable and tolerance to West African virus strains.

2.1.3.3. Trinitario

Trinitario is a product of hybridization between *Criollo* and *Forastero* has its origin in 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 green or pigmented. Beans colour varies from light to very dark purple. The most useful and valuable part of the crop is the bean. The highest percentages of cocoa beans produced in the developing countries are exported. The exported beans are processed abroad and the end products are imported back to the developing countries at a relatively high cost.

2.1.4. Structure of cocoa

The cocoa pod consists of pod, beans, placenta and mucilaginous pulp. Cocoa pods are usually ovoid in shape 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 (Adzimah and Asian, 2010).The schematic diagram of cocoa pod is shown in Fig.2.3.

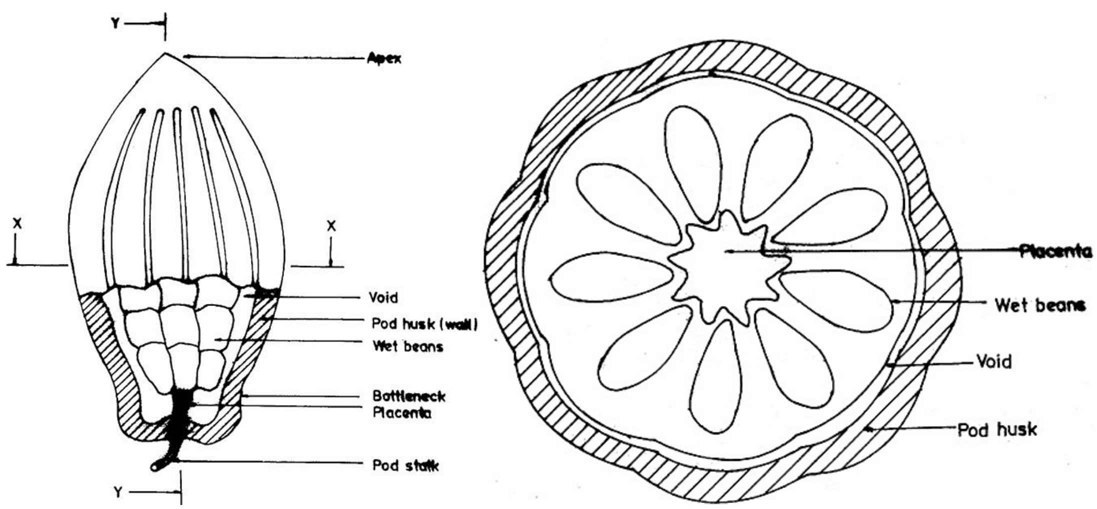

Fig. 2.3. Geometry of cocoa pod

Source: Fabunmi,(2004)

2.2. Cocoa Beans

Cocoa beans, the base for making chocolate, are the seeds of the cacao tree. They are found inside the cacao pods, encompassed by a white 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.

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, and shell removal. After roasting and deshelling an alkalising process can take place, to alter flavour and colour.

2.2.1. Processing

Processing of cocoa beans include cleaning, deshelling, roasting, alkalization and finally grinding to liquor. That can be pressed into cake and butter. The cake is pulverized into powder. But now a days cocoa processing industries becoming highly automated with high technology and capital intensive.

2.2.1.1. Harvesting and pod breaking

Harvesting is done manually through cutlass or long knife to get a pod from the trees with a long handle steel tool. These pods can be opened through a hard stick to get beans from the pod by removing it.

The beans are extracted from cocoa pod by breaking the pods manually or mechanically. Traditionally the process of breaking cocoa pods is done manually using woods and cutlass. 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 move to the shelling section by the gravity. The cocoa pods were broken by means of 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 consists of a frame, collecting containers for cocoa pods and beans and chopping off knives. The knives are actuated by positive displacement hydraulic pumps of 65 hp.

2.2.1.2. 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 cocoa powder.

Seeds of 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 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 formation of precursors of the characteristic aroma, flavor and colour, which are further developed during drying and finally obtained during roasting and further processing (Ardhana and Fleet, 2003).

2.2.1.3. Drying, packing and storage

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

2.2.2. Biochemical composition

The physical and chemical characteristics of hybrid varieties of cocoa were determined by Padilla *et al.,* (2000).The proximal composition, physical and chemical characteristics as well as the fatty acid profile the cocoa beans were estimated using AOAC methods. The result after moisture of the fresh beans was in the range of 29.12 to 34.21 g/100g. The ash content values ranged from 3.37±0.10 to 3.86±0.05 g/100g. The fat content values ranged from 47.27±0.14 to 54.21±0.58 g/100g with an average of 51.51±0.18 g/100g and there were significant differences among all cultivars. The crude fiber content variation was between 5.69 and 8.79 g/100 g. The carbohydrate content for these hybrids presented an average of 21.65 g/100g.

Cocoa pulp is a rich medium for microbial growth. It consists of 82-87 percent water, 10-15 percent sugar, 2-3 percent pentosans, 1-3 percent citric acid and 1-1.58 percent pectin. Proteins, amino acids, vitamins (mainly vitamin C) and minerals are also present (Schwan and Wheals, 2004). The proximate analysis of pulp and seed of fresh cocoa beans as determined by various researchers are consolidated and given in Table 2.1.

2.3. Engineering Properties

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

Table 2.1. Proximate analysis of fresh cocoa beans (pulp and seed)

Component	Average concentration (percent w/w)	
	Pulp	Seed
Water	80-85	35-45
Lipid	<0.5	45-55
Sugars(sucrose, glucose and fructose)	10-16	0.5-2
Polysaccharides	1.5-3	14-20
Pectin	4-7	2.0
Protein	0.6	1.5-1.7
Organic acids (citric acid)	1-3	0.3-0.9
Inorganic salt	0.5-1.0	0.5-1.0
Polyphenols	<0.1	7-10
Alkaloids (theobromine and caffeine)	<0.1	3-3.5

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

2.3.1 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.

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, transportation, processing and storage of 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. The 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).

2.3.1.1. 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).

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

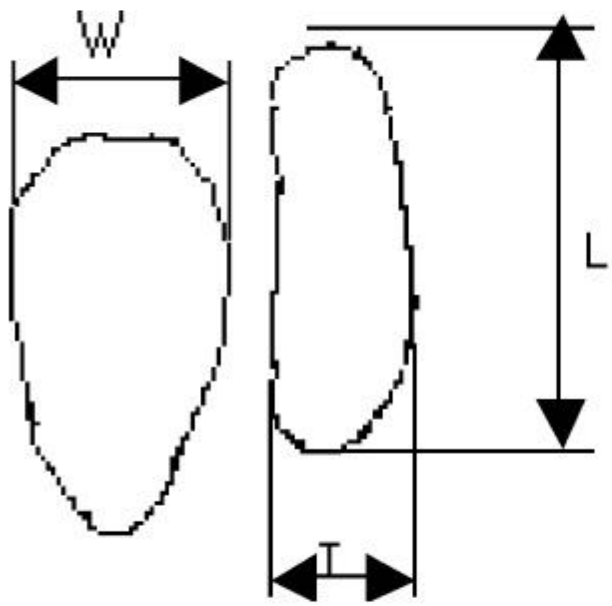

Fig. 2.4. Shape and dimensions of cocoa beans.

Source: Bart Plange *et al.* (2003)

Olukunle *et al*. (2012) investigated some engineering properties of coffee seeds and beans under a recommended range of moisture content not more than 11 per cent db. The geometrical statistical data collected for these coffee seeds and beans in terms of their average length, width and thickness are 9.78 mm, 7.24 mm and 5.23 mm with standard deviation of 0.67, 0.59 and 0.49 respectively for coffee seeds while that of its beans geometry is 8.19 mm, 6.11 mm and 4.60 mm.

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.

Akaaimo and Raji (2006) investigated the physical and engineering properties of *Prosopis africana* seed. The results showed that the length, width and thickness for the *Prosopis africana* seed ranged between 7.86-12.23, 5.35-7.55 and 3.40-6.81mm, 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 7.57mm respectively.

2.3.1.2. 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 category B cocoa beans varied from 0.57 at 8.6 per cent (wb) moisture content to 0.58 at 24.0 per cent (wb) moisture content.

Davies and Mohammed (2014) found that the arithmetic mean diameter, geometric mean diameter, sphericity and surface area of *Forastero* cocoa bean seeds increased linearly from, 13.62 mm to 16.40 mm and 12.69 to 15.46 mm, 0.61 to 0.67 and 505.91 mm^2 to 750.88 mm^2 accordingly at increasing 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 per cent db.

Akaaimo and Raji (2006) reported that the geometric mean diameter and sphericity ranged of *P. africana* seed ranged between 5.72-7.20mm 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.

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).

2.3.1.3. True density, bulk density and porosity

Bart Plange *et al.* (2003) reported that the true density and porosity of category B cocoa beans increased from 946 to 991 kg/m^3 and 20.58 to 31.59 per cent respectively while the bulk density decreased from 560 to505 kg/m^3 in the moisture range between 5 per cent and 24 per cent (wb). Davies and Mohammed (2014) also had similar observations.

Yuwana *et al*. (2015) reported that the average values of porosity, bulk density and true density of coffee beans produced from wet process in respect to different colors of coffee cherries were 0.49 to 0.54, 740 to 788.9 kg/m^3 and 1551.3 to 1614.8 kg/m^3.

Porosity and true density of paddy as reported by Pandiselvam R., *et al*. (2016) decreased from 46.82 to 38.27% and 1069 to 994 kg/m^3 respectively, with an increase in moisture content from 11.86 to 23.61%. Bulk density increased from 568 to 613 kg/m^3.

Akaaimo and Raji (2006) studied some physical properties of *Prosopis africana* seed and the mean bulk and true densities for the seeds were found to be 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 and 0.99 per cent, respectively. The porosity of *P. africana* seeds was calculated as 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 per cent.

2.3.2. 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 color, followed by gloss and translucency or turbidity among other properties.

2.3.2.1. Colour

Colour is an important quality attribute in the food and bioprocess industries, and it influences consumer's 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 were 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 gives specific colour values of the products. The lightness value increased initially and then decreased over time and the r-value was statistically significant ($p<0.01$) at 150ºC whereas not significant at 200ºC and 250ºC. The roasting at 150ºC showed a better positive relationship of lightness (L*) value with time ($r=-0.94$) as compared with the other roasting temperature. Redness (a*) and yellowness (b*) values showed significant ($p<0.01$) relation over roasting time at each temperature during roasting. Study observed that superheated steam roasting at 250ºC showed better relationship in the a* and b* values as compared to roasting at 150ºC and 200ºC temperatures.

2.3.3. Frictional properties

Frictional properties such as 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 also an important role in transports (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.

2.3.3.1. 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 category B cocoa beans.

Yuwana *et al*. (2015) reported that the average values angle of repose for coffee beans produced from wet process in respect to different colors of coffee cherry origins increased from 23.03º to 29.9º

Akaaimo and Raji (2006) measured the angle of repose values of *Prosopis africana* 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°.

2.3.3.1. 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.

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 structural surface had 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 category B cocoa beans. For category D, a linear increment in static coefficient of friction from 0.53 - 0.62 and 0.56 - 0.63 was observed for mild steel and plywood while that for rubber increased non-linearly from 0.12 - 0.32.

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 (*Ficus Carica cv. sabz*). The maximum static coefficient of friction (0.85) was measured on rubber and the minimum (0.34) on galvanized steel.

2.3.4. Textural properties

Texture of food materials plays a key role in consumer acceptance and market value. Texture characteristics are important factors for raw products and for processing, preparation, and consumption. Texture features are also important considerations in quality assurance, including hazard analysis critical control program (HACCP) and food safety issues. Additionally, flavor, juiciness, color, and other appearance characteristics are important factors in food selection and contribute to texture. Some of the descriptive terms utilized to characterize food properties include toughness *vs*. tenderness, hard *vs*. soft, dry *vs*. moist, brittle *vs*. elastic, roughness *vs*. smoothness, crispness *vs*. sogginess, firmness, stickiness, ripeness, springiness, blandness, flakiness, grittiness, aroma, etc.

Wahidu and Tajul (2013) measured texture profile of the roasted beans using Universal Texture Analyser (CNS, Farnell, UK) equipped with the Texture ProTM texture analysis software. A 36mm cylindrical probe P/36 R was used for the measurement of texture in terms of compression force (g) and the instrument was calibrated with a 30 kg load cell. The samples were placed onto the platform. The probe was allowed to compress 5 mm into the sample and the target value was set at 15 mm at 1mm/s. The texture profile analyzer enabled to calculate the hardness and fracturability of the sample beans.

2.4. Drying of Cocoa Beans

Once fermentation process is over, the storage life of the beans is increased by the process of drying. The fermented beans have moisture content about 55 per cent. Such high moisture content products have low shelf life and are prone to putrefaction. For safe storage and transportation, the moisture content is reduced to 6-8 per cent (db) by drying of beans. Generally beans are dried within 24 hours after fermentation to avoid mould growth. During drying process the beans undergo some biochemical reactions. Apart from 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 to optimum quality of end products. Too slow process will lead to mould growth and on the other hand, too fast will prevent the essential oxidative changes and may lead to excess acid formation.

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

2.4.1 Drying methods

2.4.1.1. Sun drying

It is the most common and popular method of drying. Depending upon the climatic conditions, drying period varies from 2 to 3 weeks. This type of method is economical but weather dependent. It is mostly prevalent in the regions where weather is sufficiently sunny like West Africa and Latin America. In West Africa sun dying is practiced by spreading the beans in open air in a raised platform or on a concrete floor. The beans are spread in thin layers (4 inches) and are stirred after a gap of two days.

Basic principle of sun drying is same but the method adopted varies from region to region. West Indies and South America use wooden floors whereas Trinidad and Brazil use movable roofs. Small farmers of Ivory Coast designed a dryer which consists of a bamboo platform with wooden edges and covered with PVC sheeting. The platform is pivoted about its centre so as to facilitate it facing towards the sun.

Comparative study of the performance of partially enclosed solar dryer and traditional sun drying method was done by Adesuyi (1997). It was reported that in solar drying method high temperature, lower humidity and faster drying was achieved in 78 hours as compared to 172 hours in traditional sun drying method. He also reported that less moldiness, no germination and no insect infestation was observed in solar drying.

2.4.1.2. Artificial drying

In Asian cocoa processing countries designs for artificial drying have been reported. These types of dryers are forced air dryers. Basic parameters governing the efficiency of dryer are temperature, air velocity, bean depth and agitation during drying process. Maximum temperature for drying should not exceed 60ºC. Apart from drying effect, air flow helps in oxidative degradation of residual acids. Bean depth and agitation affect the uniformity of the drying process. Thus, optimum process parameter to achieve quicker and economical drying should be high temperature, high air velocity, low bean depth and frequent stirring. But this leads to poor bean quality especially the induction of acid formation. So, proper design should be made taking both economy and quality of product into consideration.

2.4.1.3. Impingement drying

This type of drying method has recently gained importance in food industry. It is used for pizza, potato, crust and cookies. This type of method has also been successfully used for dying granular materials like coffee beans, rice and cocoa beans. The high velocity of air coming out of nozzles fluidizes the material and thus, increases the rate of drying. This type of drying consists of nozzle (Fig. 2.5) or an array of such nozzles directly impinging on the surface. This method is rapid and many varieties of nozzles are available. The temperature achieved is 100 to 350ºC and the air impingement velocity up to 10 to 100 m/s is achieved.

Use of superheated steam in impingement drying increases the textural quality of the products. It causes drying at faster rate. In superheated steam drying, the water vapour evaporated becomes part of heating medium. On the other hand, in dry air heating method, air is regularly replaced by fresh and hot air. Much work on the drying of cocoa by impingement method was not reported.

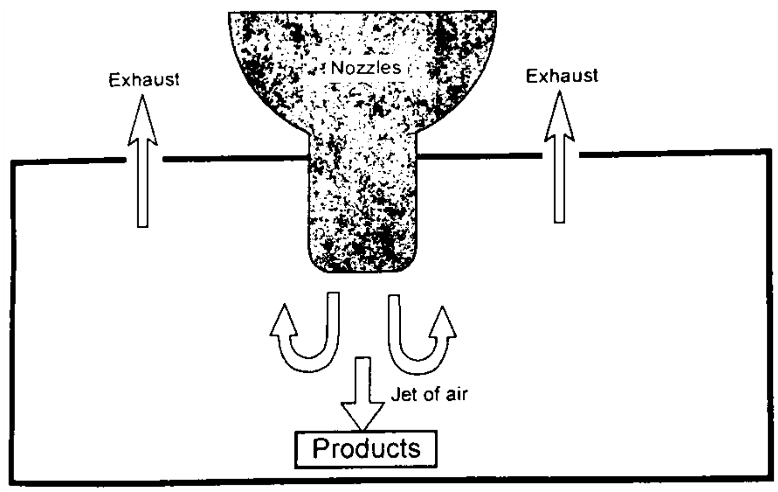

Fig. 2.5. A diagrammatic representation of impingement drying

Source: Moreira *et al.* (2001)

2.4.2. Cocoa bean dryers

Several kinds of mechanical dryers are available differing in their design. Movable tray dryers have trays which move in a tunnel where hot air is circulated. Another kind of dryer is rotary dryers which consist of movable cylinder. These cylinders contain beans and hot air is passed through them, thus, drying is achieved. Precaution should be taken to avoid the exposure of the beans to the smoke and fumes. A platform dryer was designed by Cunha *et al.* (1998). It is more economical, efficient and adaptable to cocoa.

Central Food Technological Research Institute, Kasargod developed a small drier for cocoa beans. The drier consists mainly of a heat source, plenum chamber, exhaust air chamber the materials used for construction are hard wood, GI sheet, aluminium sheet, and a 500 W industrial air heater/kerosene wick stove/biogas burner. As small quantities of beans are handled and slow of the drying operation is preferable for becoming acidic, no blower is fixed in the drier. Fig 2.6 shows a detailed diagram of the drier. At the time of operation 40 kg of fermented beans can be handled in the drier. After loading the beans the tray should be placed in the drying chamber a shown in the figure for uniform drying. When electric heater is used as the heating source there is no need for temperature control as the 500 W heater is found to be incapable of raising the temperature of drying air more than 75^{o}C in the drier. A thermometer is provided in the drier to record the drying air temperature. At every 8 hours interval after the start of the drying operation, the heat source can be put off for about 15 minutes and the position of the trays can be changed. The stage of completion of drying can be judged by the characteristics sound produced when a sample of beans is taken in hand. Also when a dried bean is squeezed between the fingers it should not bend or shatter but should break.

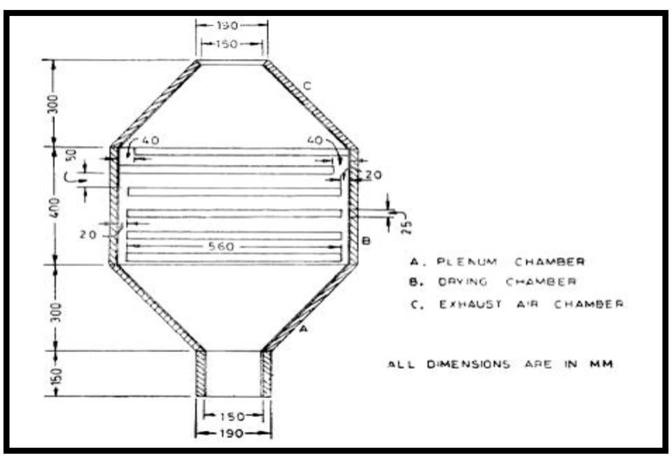

Fig. 2.6. Schematic diagram of cocoa bean dryer

Source: CFTRI, Kasargod

Sari Farah Dina *et al.* (2015) developed a continuous solar dryer integrated with desiccant thermal storage for drying cocoa beans. It consists of three main components: drying chamber, solar collector and thermal energy storage. The drying chamber is a room with dimension of 50 cm × 50 cm × 50 cm. The dried cocoa beans were spread in a drying tray made of perforated aluminum sheet with an area of 49 cm × 49 cm. Thermal storage was placed in an open container made of steel with dimension of 30 cm × 30 cm × 5 cm. Picture of the drying tray, cocoa beans and the thermal storage are shown in Fig. 2.7. (b). The solar collector is a flat plate type with dimension of 2 m × 0.5 m × 0.1 m. The absorber was black-painted made of 1mm galvanized steel sheet. Two plain window glasses separated by a 2 cm air gap were used as transparent covers to prevent the heat loss from the top. The solar collector was oriented northward with a tilt angle of 60^0. Fig. 2.7. (c) shows detailed cross section and thermal resistant analogy of the solar collector envelope. The solar dryer was operated in two drying modes, daytime and nighttime. In the daytime, the cocoa beans is dried inside the drying chamber by using hot air resulted by the solar collector. In the same time, the thermal storage is heated using direct solar energy in order to store the heat and to release the moist. In the nighttime, the thermal storage is placed inside the drying chamber along with cocoa beans and the drying chamber was isolated from the ambient air. Thus, the drying process will be continued, even though temperature is relatively low. The meaning of continuous term here is that during sunshine hours and off-sunshine hours the drying process is uninterrupted. This solar dryer integrated with desiccant thermal energy storage makes drying using solar energy more effective in terms of drying time and specific energy consumption.

Musa (2012) developed an artificial cocoa bean dryer and drying characteristics were studied. The artificial dryer is capable of providing any desired drying air temperature in the range of 0.1-4.5 ms^{-1}. The Fig. 2.8. shows the pictorial view of the artificial dryer. It consisted of two constant speed motors of 0.5 hp each, one for driving a centrifugal blower and the other for driving an extractor, the heating chamber consists of two heating elements for heating air and drying trays made of galvanized wire mesh or holding cocoa beans to be dried. About 2.2 kg of cocoa beans having initial moisture content of 81.2 per cent (db) was put in the drying tray and spread to form three layers. The dryer was switched on air was forced by the blower through the heating elements and after attaining the desired temperature of 60, 75 and 85 and velocity of 1.8, 2.7 and 3.8 m/s, passed through drying chamber. The minimum drying rate of 0.186 kg/h was obtained when the cocoa beans were dried at a temperature of 60ºC with a velocity of 1.8 ms^{-1} while the maximum drying rate of 0.376 kg/h was obtained when the cocoa beans were dried at a temperature of 85ºC with air velocity of 3.8 m/s.

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 hours of continuous drying

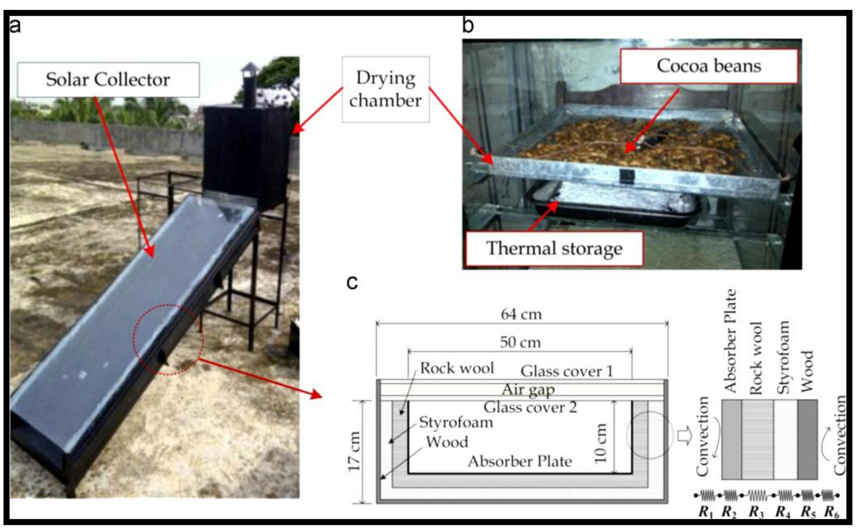

Fig. 2.7. Picture of the (a) experimental solar dryer, (b) drying tray, and (c) thermal resistance analogy of solar collector envelope

Source: Sari Farah Dina *et al.* (2015)

Fig. 2.8. Pictorial view of artificial cocoa bean dryer

Source: Musa (2012)

Duncan *et al.* (1989) studied the effect of drying parameters like temperature and air velocity with respect to some industry specifications. They recommended a two-stage process in which beans are first brought at ambient conditions to about 20 per cent moisture content (wb), followed by drying at 60ºC till 7.5 per cent (wb) obtained. It has also been reported that drying with some intermittent rest period gives the product the quality close to that obtained by traditional sun drying process.

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. Fig. 2.9 shows the drying rate curve during the drying operation.

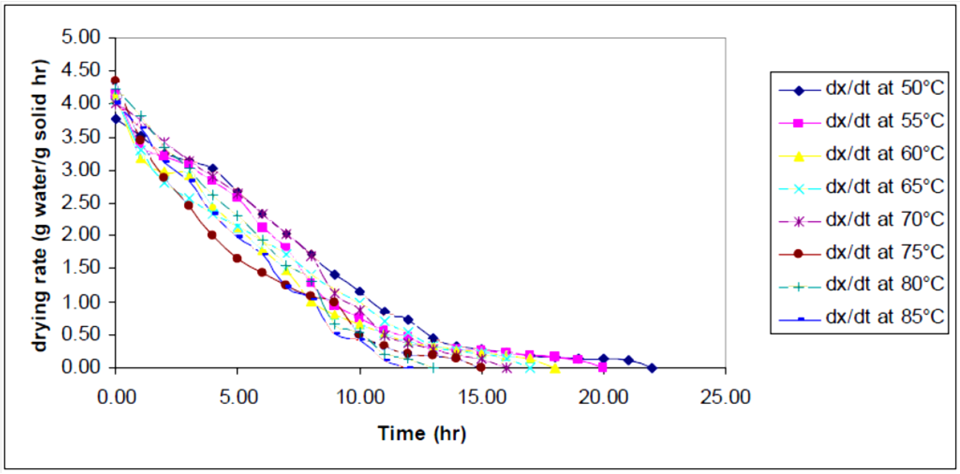

Fig. 2.9. Drying rate against time during the drying operation of cocoa beans

Source: Ajala and Ojewande (2014)

2.4.3. Changes during drying

Though not a quality parameter, it is expected that the free fatty acids (FFA) content must be less than 1.0% to meet the acceptable level of 1.75% in cocoa butter extracted from the dry cocoa beans. Jonfia-Essien (2010) investigated the FFA content of stored dry cocoa beans from Ghana that was generally low compared to that of Côte d'Ivoire. The FFA content of dry cocoa beans increases with storage time and this was evident for both countries. The mean FFA of Ghana's cocoa beans was 2.03% in 1999 and 0.90% in 2008 while that of Cote d'Ivoire's cocoa beans was 2.57% in 2002 and 1.43% in 2008. The low mean moisture content of 6.5% of Ghana cocoa beans and the mean moisture content 8.0% of Côte d'Ivoire cocoa beans influenced the differences in mean FFA levels. Dry cocoa beans were infested with ten young adults of *Lasioderma serricorne* (Fabricus), *Tribolium castaneum* (Herbst), *Cryptolestes ferrugineus* (Stephens) and stored for 9 months under dry condition at 30±2ºC. The mean FFA of the insect infested dry cocoa beans increased from 0.76% at the time of storage to 1.81% after 9 months of storage. However, the mean FFA of the control dry cocoa beans increased from 0.79% at the time of storage to 0.93%

after 9 months of storage. It was therefore concluded that FFA content in dry cocoa beans increases with insect infestation.

Most cocoa beans in Indonesia are traditionally produced by farmers using non-fermented and sun drying method. The quality of cocoa beans produced by farmer may be improved by the fermentation method. However, it needs optimization for best fermentation process. Mulono Apriyanto *et al*. (2016) conducted a study to improve quality of cocoa beans by fermentation of sun dried cocoa beans. The characteristics of fermented cocoa beans were determined by measuring changes pH, acidity and fermentation indices of cocoa beans during fermentation. Preconditioned cocoa beans were obtained from the farmer. Preconditioning was done in order to get 15% moisture content of pulp at same level as moisture content of pulp from traditional process. Before fermentation, sun dried cocoa beans was rehydrated to obtain a moisture content of pulp similar to fresh beans pulp, and then fermentation was conducted for 120 hours. Changes in acidity and fermentation indices of cocoa beans during fermentation were measured. The fermentation process used 3 level treatment i.e. control (without inoculum), mixed culture of microbes added at the beginning of fermentation. All cocoa beans acidity increase during fermentation from 4.48 per cent to 6.45 per cent for control, 4.64 per cent to 6.39 per cent for addition of inoculum at beginning of fermentation and from 4.45 per cent to 6.59 per cent for addition of inoculum at the beginning and middle of fermentation and fermentation indices of cocoa beans increase for all level of inoculum addition i.e. 0.31 to 0.88 for control, 0.32 to 0.99 for addition of inoculum at the beginning fermentation and 0.33 to 1.03 for addition of inoculum at the beginning and middle of fermentation. The study indicated that addition of mix culture microbes in fermentation improved the quality of cocoa beans characterized by pH, acidity and fermentation indices of cocoa beans.

Eboua *et al.* (2011) evaluated Benzo[a]pyrene as well as moisture and physical characteristics of cocoa bean subjected to different mode of drying during the second period of cocoa harvesting in Côte d'Ivoire. The moisture content of smoked beans (8.22±0.06) was significantly lower compared to those sun dried (8.97±0.18). Among the physical characteristics, purple beans were over 4 per cent, and slaty beans 1.57±0.20 per cent. The percentage of moldy beans was significantly higher for sun-dried beans (8.72±0.17%) than for smoked beans (2.13±0.14%). Supplementing sun drying with smoking during the rainy season helped reduce the level of moldy beans. The level of free fatty acid found in beans was in average 1.74% with those subjected to sun drying having significantly (p=0.04) higher levels. These levels were higher than the expected levels (< 1.0%) to meet the acceptable level of 1.75% in cocoa butter extracted from the dry cocoa beans. This high level of free fatty acid found might be favored by the high level of moulds found in beans mostly in sun dried beans. Benzo[a]pyrene was found at the levels ranging from 7.698 to 3701/25 µg/kg in beans sun dried/smoked or smoked only. When beans were dried by smoking only, the level of Benzo[a]pyrene found was significantly (p<0.05) elevated (3709.25±526.03). Based on an estimated daily chocolate consumption of 5.53 g/day, the daily intake of carcinogenic BaP was found to be 1.05 µg/day. This level was two times the recommended background concentration of 0.5 µg/kg recommended by the WHO in food samples.

Bonaparte *et al*. (1998) conducted a study on comparison of solar drying and open-air sun drying of cocoa beans in St Lucia. Four methods of drying (indirect solar drier, direct solar drier, open air/perforated steel surface and open air/non-perforated wooden surface) were examined at three loading rates: 13.7, 26.9 and 40.4 kg/m^2. Beans from the open air had a higher incidence of external mould and poorer external appearance, though differences were minor. Beans dried at the lower rate of 13 kg/m^2 showed the best colour, but the highest titratable acidity. Conversely, beans dried at the higher loading rate of 40.4 kg/m^2 showed significantly lower titratable acidity, but poorer colour. Differences in cut-test score, colour, pH and titratable acidity between the open air and closed driers were small or not significant. While not significant, the indirect drier did show the highest cut-test score and the direct drier the poorest. Beans from the indirect drier were darker and more purple, while those from the direct drier were lighter coloured and less purple. The beans from the direct drier, dried to 6 per cent moisture (wb) were, though not significantly so, more brittle and higher in titratable acidity than those from either the open air or indirect drier. Overall the beans from the indirect drier showed the highest quality and those from the direct drier the poorest.

In Ndukwu *et a*l. (2012) investigated the structural changes of cocoa bean (with and without seed coat) during convective drying. It was found that the removal rate of moisture and air diffusion between the cocoa kernel and seed coat is not the same especially at the temperature of 55ºC and initial drying time for all temperatures used. When the drying temperature increased to 70ºC and 81ºC, the cocoa kernel and the seed coat shrinks simultaneously, indicating that the rate of moisture and air removal from the kernel through the seed coat are the same. Change in sphericity of the bean was more pronounced at the temperature of 55ºC for the seeds with seed coat while for all other drying conditions it remains fairly constant after one-hour drying.

Zahouli *et al*., (2010) studied the effect of drying methods on the chemical quality traits of cocoa. Sun drying method was considered as standard process. Drying trials were conducted in thin layer using natural sun light drying method, heating methods by exposition of the beans to hot air ventilated oven at 60ºC and in sun light consecutive artificial drying methods. Changes in volatile acidity on the drying method were not very clear. Only sun and mixed dried raw cocoa showed a high volatile acidity. Oven and mixed drying methods have caused higher free acidity and higher Ammonium Nitrogen content in raw cocoa than natural drying methods.

Also all studied drying processes did not influence the production of free fatty acids in raw cocoa. Better quality of raw cocoa material could be resulted from natural drying process than heating methods.

Afoakwa *et al*. (2012) studied changes in some biochemical qualities during drying of pulp pre-conditioned and fermented cocoa beans. This study investigated changes in nib acidity, flavour precursors (sugars concentration and proteins) and free fatty acids during drying of pulp pre-conditioned and fermented cocoa beans using a 4 x 3 full factorial experimental design with pod storage (0, 3, 7 and 10 days) and drying time (0, 3 and 6 days) as the principal factors. Non-volatile (titratable) acidity, pH, sugars (reducing, non-reducing and total sugars), changes in protein content and free fatty acids of the beans were studied using standard analytical methods. Increasing pod storage consistently increased pH of the fermented nibs at the end of drying with consequential decrease in titratable acidity. The pH increased from 4.92 for the freshly harvested pods to 6.00 for pods stored for 10 days at the end of the drying process. Similarly, pH of the fermented beans increased with increasing drying time for all pod storage treatment except for pods stored for 10 days. The pH of fermented beans whose pods were stored for 3 and 7 days were 5.26 and 5.56 respectively after drying for 7 days. Protein, reducing sugars, non-reducing sugars and total sugars decreased significantly ($p<0.05$) with increasing duration of drying at all pod storage periods. Pod storage and drying significantly ($p<0.05$) increased the free fatty acids content of the fermented nibs. The FFAs of the dried beans increased from 0.47 per cent for the unstored (freshly harvested) pods to 0.55 per cent for pods stored for 3 and 7 days and 0.58 per cent for pods stored for 10 days. However, FFAs content of all the dried fermented beans were below the acceptable limits of 1.75 per cent oleic acid equivalent in cocoa butter at all pod storage periods. Storage of cocoa pod between 3–7 days with 7 days of drying (after 6 days fermentation) led to considerable reductions in nib acidity, reducing sugars, non-reducing, total sugars and proteins and acceptable FFA levels.

MATERIALS AND METHODS

CHAPTER III

MATERIAL AND METHODS

The various engineering properties required to develop a cocoa bean dryer are discussed in this chapter. Also the methodology of fabrication and evaluation procedures for cocoa bean dryer and the optimization of process parameters are also mentioned in this chapter.

3.1. Raw Materials

Fermented cocoa beans (*Theobroma cacao L.*) were procured from a progressive farmer at Alakode, Kannur district. Materials for the construction of machine were purchased from Coimbatore and Thrissur. Good quality cocoa beans after sorted out from cracked ones were used in this study. Beans having cracks and disease were rejected. Fermented beans were collected in gunny bags and transported to the laboratory with care. In the laboratory, beans were stored at refrigerated condition *viz*., 3-4°C till the conduct the experiment.

3.2. Determination of Engineering Properties of Fermented Cocoa Beans

Prior to the development of cocoa bean dryer, the physical, optical and frictional properties of fermented cocoa beans were studied. Engineering properties of cocoa beans such as mass, size, shape, sphericity, 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

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

3.2.1.1. Determination of moisture content

Moisture content of cocoa beans was determined as per AOAC (2005) method by placing samples of 2 g of 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.

$$\text{Moisture content}\ (\%\ wb) = \frac{W_i - W_d}{W_i} \times 100 \quad \dots (3.1)$$

Where,

W_i- initial weight of the bean, g

W_d- dry weight of the bean, g

3.2.1.2. 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 fermented cocoa beans were selected at random for the determination of the size. A digital vernier caliper 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).

$$D_{gm} = (LBT)^{-3} \quad \dots (3.2)$$

Where,

L- Length of the bean, mm

B- Width of the bean, mm

T- Thickness of the bean, mm.

3.2.1.3. Determination of mass

The mass of individual bean was determined by selecting 15 numbers of sample in random using an electronic balance (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

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.

$$\phi = \frac{\sqrt[3]{LBT}}{L} \quad \dots (3.3)$$

Where,

L- Length of the bean, mm

B- Width of the pod, mm

T- Thickness of the bean, mm.

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

$$\rho_b = M_b / V_b \quad \dots (3.4)$$

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

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

$$\rho_t = W/ TV \ldots (3.5)$$

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

3.2.1.6. Determination of porosity

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.

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

3.2.2. Optical properties

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

3.2.2.1. Determination of colour

The colour of cocoa beans were determined using 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 analyzed to produce numeric results indicative of colour of the sample.

3.2.3. Frictional properties

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

3.2.3.1. Angle of repose

The apparatus for determining angle of repose consists 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 disc of varying diameters like 100, 150, 200 mm are placed. This is 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 was measured and angle of repose calculated using the following equation.

$$ø = \tan^{-1} (2h/d) \quad \dots (3.7)$$

Where,

ø - Angle of repose, deg

h- Height of the cone, mm

d- diameter of the cone, mm.

3.2.3.2. 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 weight of cocoa beans was filled in a PVC cylinder which is 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 is 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 is repeated for other surfaces such as aluminium, GI and plywood. Coefficient of friction was calculated using the following equation.

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

Where,

μ- Coefficient of friction

F- Frictional force, kg

N- Normal force, kg.

3.3. Development of Cocoa Bean Dryer

A batch-type cocoa bean dryer was developed and fabricated in the Kelappaji College of Agricultural Engineering and Technology, Tavanur workshop. It consists of the following parts.

1. Drying chamber
2. Blower
3. Flow control valve
4. Heating coil
5. Rotating paddle type agitator
6. Motor
7. Frame

3.3.1. Drying chamber

It is one of the main components of the machine. The dimension of the chamber was optimized based on bulk density of the cocoa beans. The drying chamber is cylindrical in shape (50 cm diameter and 50 cm height) and made of 2 mm thick stainless steel sheet (Plate 3.1). Cocoa beans are placed over a mesh 15cm from the bottom of the chamber. Hot air is blown from the bottom of the chamber through a cylindrical pipe of 75mm.

3.3.2. Blower

Blower is used to blow fresh air into the drying chamber. A three phase 1 hp centrifugal blower (leaf type) is attached to the drying chamber through a cylindrical pipe of 75 mm diameter (Plate. 3.2). The blower pumps air into the cylindrical pipe at high velocity where air gets heated as it passes through the heating coil.

3.3.3. Flow control valve

A ball valve is used to control the velocity of air coming from the blower (Plate 3.2). The velocity of air flow was determined by anemometer. The air velocity inside the drying chamber is an important parameter concerning drying of cocoa beans.

3.3.4. Heating coil

Heating coil with 500 W capacity was employed for heating air. It was kept inside a stainless steel cylindrical pipe of 75 mm diameter. It heats the high velocity air coming from the blower. A temperature controller with thermostat was used to maintain the required drying temperature inside the drying chamber.

3.3.5. Rotating paddle type agitator

Agitator is mounted inside the drying chamber with the help of a 20 mm diameter shaft. The agitator is made of 3 mm thick stainless steel and is used for turning of cocoa beans during drying for uniform drying of beans. It is 46 cm in length and 32 cm in depth with 2 bars on each side (Plate 3.3). The bars are fitted with a triangular type projection at the end for easy turning of beans.

3.3.6. Motor

A 0.5 hp single phase variable speed DC motor was employed to rotate the agitator. It is mounted to the shaft below the drying chamber to facilitate rotation of agitator at a slow rpm *viz*., 50 rpm at specific intervals. The motor is connected to an AC to DC converter and an alternator to control the agitator speed.

3.3.7. Frame

The frame supports the entire machine component to perform. It was fabricated using GI square section. The units *viz*., drying chamber, blower, heating coil, motor etc. were mounted on the frame.

Plate 3.1. Top view of drying chamber

Plate 3.2. Blower with flow control valve

Plate 3.3. Agitator inside drying chamber

3.4. Experimental Design

The independent and dependent variables considered in the study are given below.

3.4.1. Independent variables

- Temperature of drying chamber (40ºC, 45ºC, 50ºC)

3.4.2. Dependent variables

- pH
- Titrable acidity
- Free fatty acids
- Colour
- Texture

3.4.3. Operation of cocoa bean dryer

Plate 3.4. shows the front view of developed cocoa bean dryer. Fermented cocoa beans were fed into the drying chamber manually. Fresh air was pumped into the machine by the blower. The blower push the air through the ball valve into a cylindrical horizontal pipe, inside which heating coil is placed. Heating coils heats up the air to the required temperature with the help of a thermostat. The heated air was passed into the drying chamber where the beans were kept above a mesh. Drying of

the beans was done due to heat and mass transfer process. The agitator provides occasional turning of beans which helps in proper and uniform drying. Cocoa beans were dried up to a moisture content of 6-7% (wb). The dried beans are then removed from the dryer and stored in gunny bags for further processing.

3.4.5. Sun drying of cocoa beans

A known quantity of cocoa beans were placed in a tray and dried under sun from 9:00 am to 5:00 pm for 4 days. The average temperature ranged from 30-36ºC.

Plate 3.4. Front view of cocoa bean dryer

3.5. Optimization of Drying Temperature

Fermented cocoa beans procured from a progressive farmer from Alakode, Kannur district were used for conducting the experiment. Testing was done at dryer temperature of 40ºC, 45ºC and 50ºC at constant air velocity of 2 m/s. Quality parameters of the mechanically dried cocoa beans such as size, shape, pH, titrable acidity, free fatty acids, colour and texture were determined and compared with that of sun dried cocoa beans. The process parameters were optimized based on the quality of the dried cocoa beans.

3.5.1 Determination of physico-chemical properties of dried cocoa beans

3.5.1.1. Physical properties

The physical properties of dried cocoa beans such as shape and size of dried cocoa beans were determined using the procedure explained in section 3.2.1.

3.5.1.2. pH and titrable acidity

Non-volatile acidity (titrable acidity) of the four samples of cocoa beans were determined separately according to the AOAC (2005) method 970.21 and expressed as the percentage of acetic acid by titrating juice with 0.1N NaOH. Five gram samples of beans were homogenized for 30 s in 100 ml of hot distilled water and vacuum filtered through Whatman filter paper No. 4. A 25 ml aliquot was pipetted into a beaker and the pH measured using a pH meter (Systronics Digital pH meter MK VI, Plate 3.5). A further 25 ml aliquot was titrated to an end point pH of 8.1 with 0.1N NaOH and the values reported as moles of sodium hydroxide per 100 g dry nibs. The analysis was conducted in triplicates and the mean values are reported. The per cent acid was calculated using the following equation.

$$\% \text{ acid} = \frac{\text{Volume of NaOH (ml) x Normality of NaOH (0.1 N) x Equivalent factor (60)}}{\text{Weight of sample (g) x 10}} \quad \ldots(3.9)$$

3.5.1.3. Free fatty acids

Fat from the cocoa bean samples dried at different temperatures were extracted with hexane using the Soxhlet extraction method (AOAC, 2005 method 963.15, Plate 3.6). FFA of the oils extracted was determined using the IOCCC method (1996). Five grams of the oil was weighed into a dry 250 ml stoppered conical flask and 25 ml of 95% ethanol/ether and phenolphthalein indicator were added. The solution was titrated with 0.1N NaOH by shaking constantly until pink colour persisted for 30 s and the per cent FFA (as % oleic acid) was determined. The analysis was conducted in triplicates and the mean values are reported. The % FFA (% oleic acid) was calculated using the following equation.

$$\%FFA = \frac{\text{Volume of NaOH (ml)} \times \text{Normality of NaOH (0.1N)} \times \text{Equivalent factor (28.2)}}{\text{Weight of sample (g)}} \quad \ldots(3.10)$$

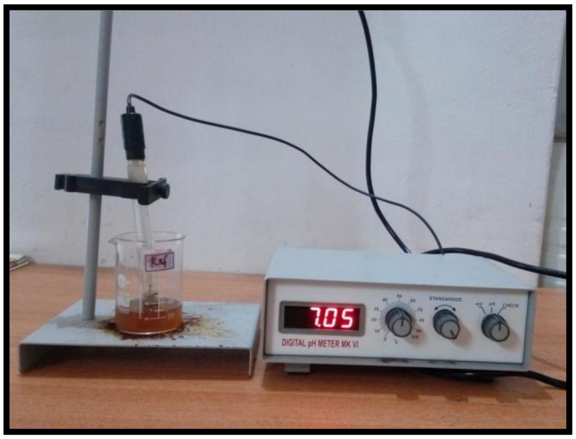

Plate 3.5. pH meter

Plate 3.6. Soxhlet Apparatus

3.5.1.4. Determination of colour

The colour of cocoa beans was determined using colorimeter (HunterLab Colour Flex EZ, Plate 3.7) as explained in section 3.2.2.1. L*, a* and b* values were determined. L* indicates lightness, a* is the red/green coordinate, and b* is the yellow/blue coordinate.

3.5.1.5. Determination of texture

Texture of four samples was determined using texture analyzer (Stable Micro Systems TA.HD plus, Plate 3.8). A 5mm diameter cylindrical stainless steel probe P/5 was used for the measurement of texture in terms of compression force (g). The instrument was calibrated with a 5 kg load cell. The samples were placed onto the platform. The compression probe was moved perpendicular to the cocoa bean surface at a constant speed of 2 mm/s until it ruptures. The force-deformation curves were recorded. The texture profile analyzer enabled to calculate the hardness and fracturability of the sample beans.

Plate 3.7. Colorimeter

Plate 3.8. Texture Analyzer

3.6. Performance Evaluation of Cocoa Bean Dryer

Performance of the cocoa bean batch-type dryer was evaluated in terms of time required for drying, capacity, efficiency and energy requirement.

3.6.1. Determination of time required for drying

The cocoa beans were dried at different temperatures till 6-7 per cent moisture content (wb) and the time taken was recorded. Drying curve was plotted for beans dried at three dryer temperatures (40ºC, 45ºC and 50ºC) with moisture content in per cent db along the y axis and time in hours along x axis.

3.6.2. Determination of capacity of dryer

Size or capacity of a dryer is decided by the amount and variety of grain to be dried per day or for a whole season. Sizes of dryers are expressed in terms of holding capacity or amount of grain to be dried per unit time or the amount of grain passing through the dryer per unit time (Chakraverty, 1995).

3.6.3. Efficiency of dryer

If the drying system is efficiently designed, the drying of products will be faster and uniform. Drying of products will take place within the desirable time and quality products will be obtained.

The heat utilization factor of a drying system is the ratio of drop in ambient temperature of drying air by drying process and the increase in the temperature of ambient air by heating.

$$\text{Heat utilization factor} = \frac{t_2 - t_3}{t_2 - t_1}$$

Where,

t_1- dry bulb temperature of ambient air, ºC

t_2- dry bulb temperature of heated air, ºC

t_3- dry bulb temperature of exit air, ºC

3.5.5. Energy requirement

Energy requirement is the power consumed per unit time. It was calculated as the product of power consumed and working time.

$$\text{Energy requirement (kWh)} = \text{Power} \times \text{Time} \quad \ldots (3.12)$$

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

This chapter deals with results obtained from various experiments conducted to determine the engineering properties of fermented cocoa beans and performance evaluation of the developed batch-type cocoa bean dryer.

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 dryer, selected physical properties of fermented cocoa beans *viz.*, moisture content, length, width, thickness, mass, sphericity, bulk density, true density and porosity were investigated.

The average values of various physical properties of fermented cocoa beans are given in Table 4.1. The average moisture content was 43.12 percent (wb) with a standard deviation (SD) of 1.80. The average length, width and thickness of cocoa beans were found to be 25.63±0.98, 14.63±0.65 and 8.47±0.83 mm, respectively. The average geometric mean diameter was 14.66±0.57 mm. The average mass of an individual cocoa bean was 2.24±0.22 g. The average sphericity was estimated as 0.56±0.01. The average true density and bulk density were 1009.54±10.31 and 621.27±16.38 kg/m^3, respectively. The average value of porosity was 38.31±0.7 per cent.

Table 4.1. Physical properties of fermented cocoa beans

Sl. no.	Physical property	Value
1	Moisture content, % wb	43.12
2	Length, mm	25.63
3	Width, mm	14.63
4	Thickness, mm	8.47
5	Geometric mean diameter, mm	14.66
6	Mass, g	2.24
7	Sphericity	0.56
8	Bulk density, kg/m^3	621.27
9	True density, kg/m^3	1009.54
10	Porosity, %	38.31

4.1.2. Optical properties and frictional properties

The optical property of fermented cocoa beans *viz.*, colour and frictional properties *viz.*, angle of repose and coefficient of friction on four different sufaces were determined. The various optical and frictional properties of fermented cocoa beans are illustrated in Table 4.2. The colour of fermented 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). Coefficient of friction of cocoa beans on four surfaces *viz*., stainless steel, aluminium, GI and plywood was determined. A known weight (100 g) of cocoa was placed in the PVC cylinder to determine coefficient of friction.

Table 4.2. Optical and frictional properties of fermented cocoa beans

Sl. no.	Properties	Value
1	Colour	
	L*	26.55
	a*	8.54
	b*	10.46
2	Angle of repose (deg)	28.31
3	Coefficient of friction	
	Stainless steel	0.40
	Aluminium	0.35
	GI	0.47
	Plywood	0.50

The average L*, a* and b* values was 26.55±0.01, 8.54±0.04 and 10.46±0.0, respectively. The coefficient of friction of cocoa beans on stainless steel, aluminium, GI and plywood was 0.40±0.002, 0.35±0.001, 0.47±0.001 and 0.50±0.002, respectively. This information is useful in estimating the power losses due to friction so that provision can be made for such in computing the power requirement of the machine, and in choosing the appropriate materials for fabrication (Maduako and Hamman, 2004). The average angle of repose of cocoa beans at an average moisture content of 43.12 percent (wb) was 28.31±0.13º.

4.2. Optimization of Drying Temperature

Trials were conducted to dry cocoa beans at various temperatures *viz.*, 40ºC, 45ºC and 50ºC. The drying temperature was optimized in terms of physico-chemical qualities of dried cocoa beans.

4.2.1. Effect of drying temperature on physical properties

The effect of temperature on size *viz.*, length, width and thickness was determined and presented in Fig. 4.1. The length, width and thickness of dried and fermented beans were 24.38±1.02, 13.41±0.31, 8.45±0.75 mm and 25.63±0.98, 14.63±0.65 and 8.47±0.83 mm, respectively. The cocoa beans undergo considerable shrinkage due to removal of moisture.

The sphericity of dried and fermented beans was found to be 0.57±0.01 and 0.56±0.01, respectively. From the graph, it is understood that there is no significant effect of sphericity on dryer temperature.

4.2.2. Effect of dryer temperature on pH

The effect of different drying temperatures *viz.*, 40ºC, 45ºC and 50ºC on pH of cocoa beans is illustrated in Fig. 4.2. The pH of cocoa beans increases with decreasing dryer temperature i.e. the lowest pH is found in cocoa beans dried at 50ºC (pH = 5.9). Compared to pH of sun dried cocoa beans, beans dried at 40ºC was best among the three dryer temperatures. During the drying of fermented cocoa beans, there is loss of volatile acids and water from the beans when this process occurs slowly, results in an increase in pH of the cotyledons. Jinap (1995) *et al*. observed that rapid drying of the beans result in case hardening which prevents outward migration of acetic acid from the beans. Bonaparte (1998) reported that factors which inhibit enzyme activity, such as high temperature and reduced moisture, contribute to acid retention.

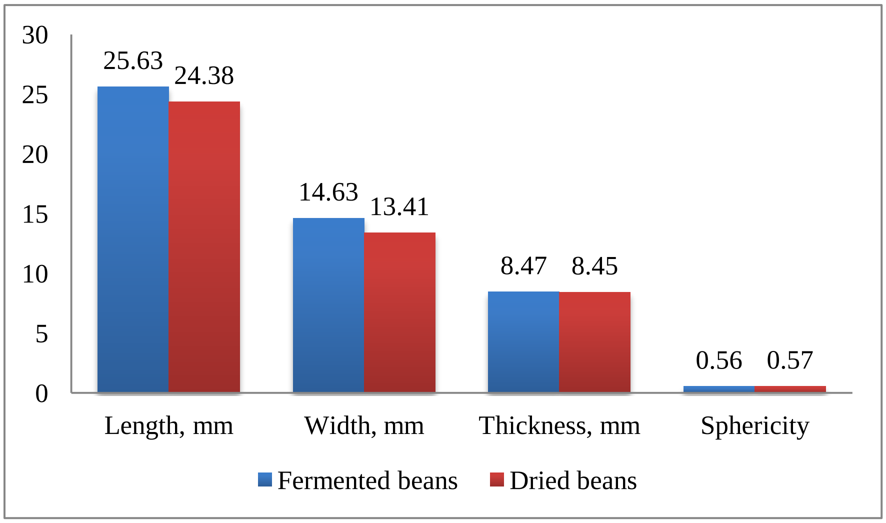

Fig. 4.1. Changes in physical properties of cocoa beans

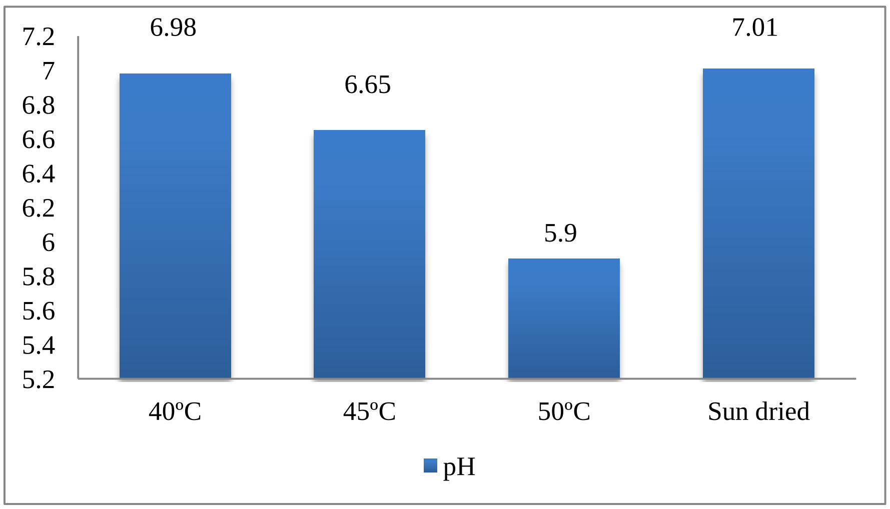

Fig. 4.2. pH of dried cocoa beans

4.2.3. Effect of drying temperature on titrable acidity

The acidity of dried cocoa beans was found to increase with increasing dryer temperature. Fig. 4.3 illustrates the acidity in number of moles of sodium hydroxide per 100 g of cocoa nibs. The lowest titrable acidity was in sun dried beans (0.10 meq of NaOH/ 100g nib) followed by beans dried at 40ºC (0.12 meq of NaOH/ 100g nib). The highest acidity was in beans dried at 50ºC (0.25 meq of NaOH/ 100g nib).

Volatile acidity formed during fermentation of cocoa beans reaches approximately 2% of the dry basis. Acetic acid is reported to form about 90% of these components, which has an important role in the catalysis of enzymatic reactions for producing components of desirable sensorial characteristics. Cocoa drying is a continuation of the oxidative stage of fermentation and therefore plays an important role in reducing acidity of the cocoa beans. The drying process must not be too rapid otherwise the beans tend to retain an excessive amount of acetic acid, and this is deleterious to flavour (Afoakwa *et al*., 2015).

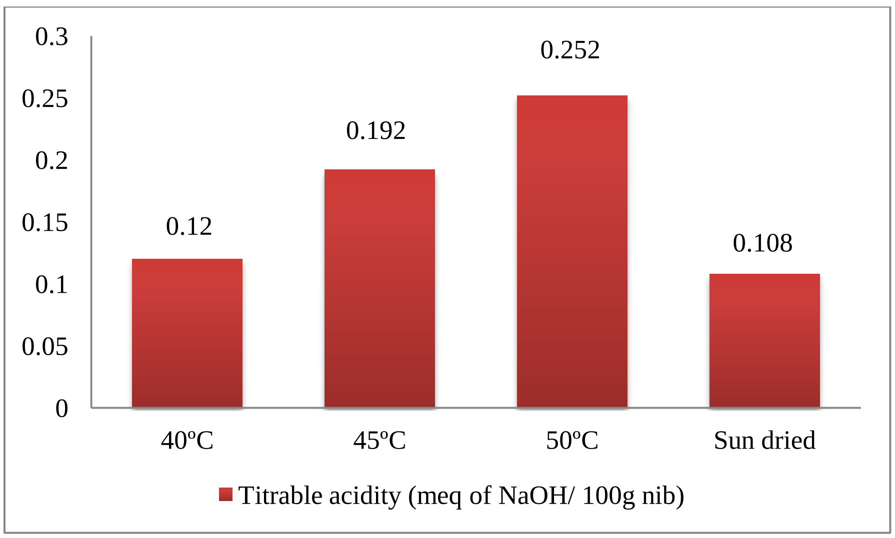

Fig. 4.3. Titrable acidity of cocoa beans in meq of NaOH/ 100g nib

4.2.4. Effect of drying temperature on free fatty acids

The free fatty acid content of cocoa beans increases with increasing dryer temperature. It is depicted in Fig. 4.4. Highest free fatty acid content was found in beans dried at 50ºC (1.38 meq of NaOH/ 100 g nibs) and lowest in sun dried (0.46 meq of NaOH/ 100 g nibs).

The European parliament and European council directive 73/241/EEC limits the maximum FFAs content to 1.75% oleic acid equivalent in cocoa butter. To be able to meet the acceptable level, Dand (1997) reported that the FFAs levels should be less than 1% in fresh cocoa beans and less than 1.75% in dried cocoa beans. The high level of free fatty acid may be attributed to high drying rate which did not allow for the completion of the needed oxidative reaction and acid diffusion process.

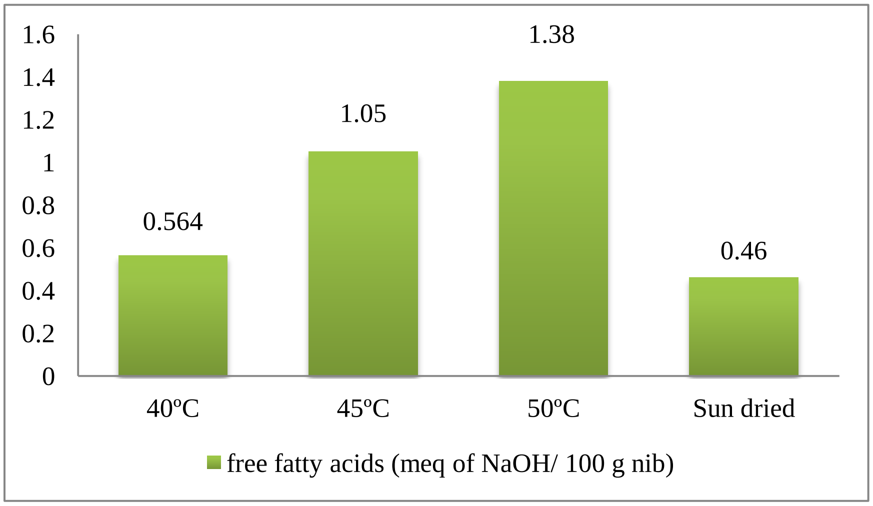

Fig. 4.4. Free fatty acid content in dried cocoa beans in meq of NaOH/ 100g nib

4.2.5. Effect of drying temperature on colour and texture

The colour of dried cocoa beans was expressed in L*, a* and b* values. The L*, a* and b* values of cocoa beans are given in Table 4.3.

The texture of dried cocoa beans was expressed in hardness and fracturability. The values are given in Table 4.4. Texture is another important quality control parameter for drying of cocoa beans. The temperature and moisture content were significant factors that affect the texture of foods. During drying method the texture became more fracture (crispy) and crumbly because of the loss of moisture content. The texture of food can be affected due to changes in the distribution of fracture intensities even at low level of moisture (Wahidu & Tajul, 2013).

Table 4.3. Colour analysis of dried cocoa beans

Sl. no.	Sample	Lightness (L*)	Redness (a*)	Yellowness (b*)
1	40ºC	22.12±0.01	7.77±0.01	9.25±0.01
2	45ºC	26.54±0.01	8.54±0.04	10.48±0.01
3	50ºC	22.72±0.05	8.65±0.01	10.16±0.06
4	Sun dried	23.18±0.01	9.50±0.04	11.33±0.08

Table 4.4. Texture analysis of dried cocoa beans

Sl. no.	Sample	Hardness (N)	Fracturability (N)
1	40ºC	7.06±2.05	8.05±1.82
2	45ºC	8.82±0.98	12.58±0.95
3	50ºC	6.86±2.08	7.88±1.10
4	Sun dried	7.60±3.15	9.29±4.25

4.3. Performance Evaluation of Dryer

Performance of equipment is the basic criteria to evaluate its ability. The performance of the developed batch-type cocoa bean dryer was evaluated in terms of time required for drying, capacity, efficiency and energy requirement.

4.3.1. Time required for drying

Time required for drying of cocoa beans at different temperatures of dryer is given in Table 4.5.

Table 4.5. Time required for drying

Sl. no.	Temperature of drying	Drying time
1	40ºC	10 hrs
2	45ºC	7 hrs
3	50ºC	5.5 hrs
4	Sun drying	4 days

Ndukwu *et al.* (2010) reported that the moisture ratio, moisture content and drying rate decreased continuously with drying time showing a falling rate drying characteristics. There was no constant rate drying period because most crops exhibit the constant rate drying characteristics at their critical moisture content therefore cocoa is not an exception.

Fig. 4.5 shows the drying curve of mechanically dried cocoa beans. The moisture content decreased continuously with drying time showing a falling rate drying characteristics. There was no constant rate drying period. At the falling rate period the movement of moisture within the cocoa to the surface is governed by diffusion since the material is no longer saturated with water. The results gotten are in agreement with the observations of many researchers (Ndukwu *et al.*, 2010).

4.3.2. Capacity of batch-type cocoa bean dryer

The capacity of dryer depends on the dimensions of dryer, bulk density of fermented cocoa beans and depth of cocoa beans. The capacity of dryer was 13.125 kg at 15 cm depth of cocoa beans and 17.50 kg at 20 cm depth.

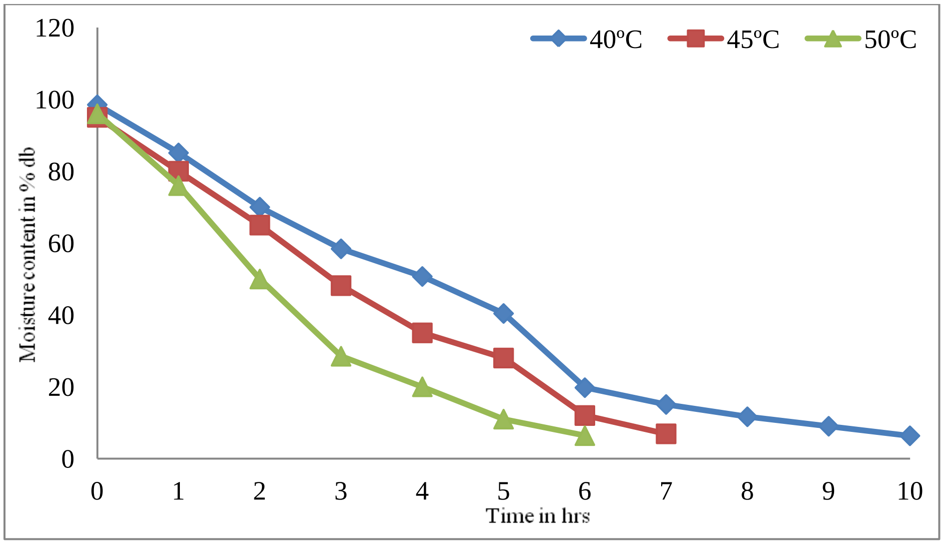

Fig. 4.5. Drying curve for mechanical dryer

4.3.3. Efficiency of dryer

Efficiency of dryer at different drying temperatures 40ºC, 45ºC and 50ºC was 53.02, 48.47 and 36.80 per cent, respectively. The efficiency of dryer primarily depends on the inlet air temperature (drying temperature) and exhaust air temperature.

4.3.4. Energy requirement

The energy requirement of the dryer was determined using energy meter. The average energy requirement for operating the dryer at different temperatures *viz.*, 40ºC, 45ºC and 50ºC was 16, 11.2 and 8.8 kWh, respectively.

SUMMARY AND CONCLUSION

CHAPTER V

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 2014-15 was 4.2 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 2014-2015 was 16,050 MT from an area of 78,000 ha. Cocoa beans from cocoa is the main raw material in the production of chocolates, cosmetics, health drinks 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.

At present drying of cocoa is done mostly by sun drying. Sun drying of cocoa beans has many disadvantages *viz.*, it is weather dependent, exposure to dust, molds and pests, longer drying time etc. Artificial dryers, which are used at present produce low quality cocoa beans with high acidity. Hence an attempt was made to develop a batch-type cocoa bean dryer and optimize the process parameters.

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

The dryer consist of a cylindrical drying chamber, blower, heating coil, DC motor and agitator. Fermented cocoa beans were fed into the drying chamber manually. Fresh air is pumped into the machine by the blower. The blower pushes the air through the ball valve into a cylindrical horizontal pipe inside which heating coil is placed. Heating coils heats up the 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.

Known weight cocoa beans was dried at three different temperatures *viz*., 40ºC, 45ºC and 50ºC at an air velocity of 2 m/s. Known weight of cocoa beans was sun dried at an average temperature of 33ºC. Optimization process parameter of dryer was done on the basis of physico-chemical properties of dried cocoa beans (which was compared with sun dried cocoa beans) *viz*., size, shape, pH, titrable acidity, free fatty acids, colour and texture and energy requirement and efficiency of dryer. The capacity of dryer was also determined.

The results of the above experiments are summarized as following:

The average moisture content of fermented cocoa beans was 43.12±1.8 percent wb. The length, width and thickness were 25.63±0.98, 14.63±0.65 and 8.47±0.83 mm, respectively. The geometric mean diameter and sphericity was 14.66±0.57 mm and 0.56±0.01, respectively. The true density and bulk density was 1009.54±10.31 and 621.27±16.38 kg/m^3, respectively. The porosity was 38.31±0.70 per cent.

The colour of fermented cocoa bean was expressed in terms of L*, a* and b* values. The average L*, a* and b* values was 26.55±0.01, 8.54±0.04 and 10.46±0.01, respectively. The coefficient of friction on stainless steel (SS), aluminium, galvanized iron (GI) and plywood was 0.40±0.002, 0.35±0.001, 0.47±0.001 and 0.50±0.002, respectively. The average angle of repose at an average moisture content of 43.12 percent (wb) was 28.31±0.13º.

The change in size of dried beans was determined in terms of length, width and thickness. The length, width and thickness of dried beans were 24.38±1.02, 13.41±0.31 and 8.45±0.75 mm, respectively. The sphericity of dried beans was 0.57±0.01. The pH of cocoa beans dried at 40ºC, 45ºC and 50ºC and sun dried beans was 6.98, 6.65, 5.9 and 7.01, respectively. The titrable acidity was 0.12, 0.19, 0.25 and 0.11 meq of NaOH/ 100 g nib, respectively. The free fatty acid content was 0.56, 1.05, 1.38 and 0.46 meq of NaOH/ 100 g nib, respectively.

The L*, a* and b* values of cocoa beans dried at 40ºC, 45ºC, 50ºC and sun dried beans was (22.12±0.01, 7.77±0.01, 9.25±0.01), (26.4±0.01, 8.54±0.04, 10.48±0.01), (22.72±0.05, 8.65±0.01, 10.16±0.06) and (23.18±0.01, 9.50±0.04, 11.33±0.08), respectively. The texture of dried cocoa beans was expressed in hardness and fracturability. The hardness and fracturability of cocoa beans dried at 40ºC, 45ºC, 50ºC and sun dried beans was (7.06±2.05, 8.05±1.82)N, (8.82±0.98, 12.58±0.95)N, (6.86±2.08, 7.88±1.10)N and (7.60±3.15, 9.29±4.25)N, respectively.

Time required for drying at 40ºC, 45ºC, 50ºC and sun drying was 10, 7, 5.5 hours and 4 days respectively. The drying curve of dryer temperature at 40ºC, 45ºC and 50ºC was plotted. The capacity of dryer was 13.125 kg at 15 cm depth of cocoa beans and 17.50 kg at 20 cm depth. Efficiency of dryer at different drying temperatures 40ºC, 45ºC and 50ºC was 53.02, 48.47 and 36.80 per cent, respectively. The energy requirement for dryer drying at 40ºC, 45ºC and 50ºC was 16, 11.2 and 8.8 kWh, respectively.

Based on the results, sun dried beans produced highest quality cocoa beans but it took a huge time to dry the beans (4 days). Among artificially dried cocoa beans, beans dried at 40ºC produced high quality beans in terms of physico-chemical qualities. By considering the dryer efficiency and energy requirement of dryer, cocoa beans dried in cocoa dryer at 45ºC with air flow rate 2 m/s and an agitator speed of 50 rpm was selected as optimized parameter.

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CHAPTER VI

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ABSTRACT

DEVELOPMENT AND PERFORMANCE EVALUATION OF A BATCH-TYPE COCOA BEAN DRYER

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ABSTRACT

Submitted in partial fulfilment of the requirement for the degree

BACHELOR OF TECHNOLOGY

IN

FOOD ENGINEERING

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2018

ABSTRACT

Cocoa (*Theobroma cacao L.*) is a tropical crop, native to Amazon region of South America. The primary cocoa growing regions are Africa, Asia and Latin America. In India, cocoa is mainly cultivated in Kerala, Karnataka, Andhra Pradesh and Tamil Nadu. Cocoa beans from cocoa is the main raw material in the production of chocolates, cosmetics, health drinks etc. Drying is an important step in the postharvest processing of cocoa beans. Cocoa beans are dried from about 60 per cent to about 6-7 per cent moisture content (wb). Currently cocoa beans are dried under sun in majority of cocoa producing countries while the rest uses artificial means. Sun drying produces high quality cocoa beans but the time required for drying is more. Whereas in case of existing artificial drying methods although the drying time is less, low quality cocoa is produced. This report outlines determination of engineering properties of fermented cocoa beans, development of a batch-type cocoa bean dryer, optimization of process parameters and performance evaluation of dryer. The dryer was developed based on the engineering properties of fermented cocoa. The dryer was operated at three different temperatures *viz.*, 40ºC, 45ºC and 50ºC with an air velocity of 2 m/s and a slow agitation of 50 rpm at specific intervals. A known quantity of cocoa beans was sun dried and compared with the mechanically dried cocoa beans. The process parameters was optimized based on physico-chemical qualities of dried cocoa beans such as pH, titrable acidity, free fatty acids, colour, texture etc. and performance evaluation was done based on time required for drying, capacity, efficiency and energy requirement of the dryer. The capacity of dryer was 13.125 kg at 15 cm depth of cocoa beans and 17.50 kg at 20 cm depth. Time required for drying at 40ºC, 45ºC, 50ºC and sun drying was 10, 7, 5.5 hours and 4 days respectively. Efficiency of dryer at different drying temperatures 40ºC, 45ºC and 50ºC was 53.02, 48.47 and 36.80 per cent, respectively. The energy requirement for dryer drying at 40ºC, 45ºC and 50ºC was 16, 11.2 and 8.8 kWh, respectively. Based

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