STUDIES ON FEASIBILITY OF COCOA (*Theobroma cacao* L.) FERMENTATION INSIDE A POLYHOUSE

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PROJECT REPORT

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DECLARATION

We hereby declare that this project report entitled **"Studies on Feasibility of Cocoa Fermentation Inside a Polyhouse "** is a *bonafide* record of project work done by us during the course of project and that the report has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this project report entitled **"Studies on Feasibility of Cocoa Fermentation Inside a Polyhouse "** is a record of project work done jointly by Abha,G. Anu, S. Raj and Reshma, M. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to them.

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DEDICATED TO OUR LOVING PARENTS AND TO THE PROFESSION OF AGRICULTURAL ENGINEERING

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SYMBOLS AND ABBREVATIONS

%	per cent
/	per
º	degree
ºC	degree Celsius
ºF	degree Fahrenheit
AOAC	Association of Official Analytical Chemists
BC	Before Christ
cm	centimeter
CRIG	Cocoa Research Institute of Ghana
DCCD	Directorate of Cashewnut and Cocoa Development
eg.	Example
et al.,	and others
etc.	et cetra
FFA	Free Fatty Acid
Fig.	Figure
FRP	Fibre glass Reinforced Plastic
g	gram

g kg^{-1}	gram per kilogram
h	hour
i.e.	that is
ICCO	International Cocoa Organisation
KCAET	Kelappaji College of Agricultural Engineering and Technology
LDPE	Low Density Poly Ethylene
m	metre
mg	milligram
PHT & AP	Post Harvest Technology and Agricultural Processing
TNAU	Tamil Nadu Agricultural University
USDA	United States Department of Agriculture
UV	Ultra Violet
viz.,	namely
wb	wet basis

INTRODUCTION

Chapter 1

INTRODUCTION

Cocoa (*Theobroma cacao* L.) originated from Amazonian region of Brazil and grown in tropical countries like Nigeria, Ghana, Ivory Coast, Brazil, Malaysia, Venezuela and Indonesia (Beckett, 1994).Cocoa belongs to the Sterauliaceae family. Cocoa tress grows in a limited geographical zone, of approximately 20 degrees to the north and south of equator (Buijsse *et al*., 2006). It will grow from sea level up to a maximum of 1,000 meters (3,300 feet). The trees must be protected from strong winds (the root system is not robust), soils must be well aerated, and pests and diseases must be carefully controlled.

Cocoa beans are the primary raw material for confectioneries, beverages, chocolates, other edible products, pharmaceuticals, cosmetics and toiletry products. It is also associated with health benefits such as anti-carcinogenic, anti-athergenic, anti-ulcer, anti-thrombotic, anti-inflammatory, immune modulating, anti-microbial, vasodilatory, and analgesic (Porter, 2006;Taubert *et al*., 2007).

The world demand for cocoa beans has steadily increased over recent decades as a direct result of increased world demand for chocolate and chocolate-flavored products. Today, cocoa trees are cultivated in more than 40 countries around the world, across an estimated area of 5 million hectares (12.5 million acres), producing an annual crop of more than 3.6 million tons of dried beans ready for processing (ICCO,2012)

Cocoa was first introduced into India in 1796. Administratively it is conferred plantation status like coffee, tea and rubber but is seldom recognized as a plantation

crop under the Indian Agrarian Administrative Sector (TNAU, 2012). It is also one of the supporters of Agro-based industry in India. The total production of cocoa in India during 2009-10 was 12954tonnes. Cocoa production in India increased from 6540tonnes to 12954tonnes between 2000 and 2010 (DCCD, 2012). The commercial sector of cocoa in India hardly takes place in a major way in the international export trade. Majority of the processed cocoa products are consumed within India. The tropical diversified congenial climate available in India provides immense scope for its cultivation particularly in the states of Kerala, Karnataka, Tamil Nadu and Andhra Pradesh.

There are three broad types of cocoa - Forastero and Criollo, as well as Trinitario, a hybrid of the two. Producing the greater part of all cocoa grown, Forastero is hardy and vigorous, producing beans with the strongest flavour. The Forastero variety is most widely grown in India, West Africa and Brazil. With its mild or weak chocolate flavour, Criollo is grown in Indonesia, Central and South America. Trinitario cocoa trees are grown mainly in the Caribbean, and also in Cameroon and Papua New Guinea.

Raw cocoa beans have an astringent, unpleasant flavor and have to be fermented, dried, and roasted to obtain the desired characteristic cocoa flavour . Fermentation is hence the first step in cocoa processing. It is carried out spontaneously in heaps, boxes, baskets, or trays in cocoa-producing countries. The final chocolate flavour is influenced by the origin and cultivar of the cocoa beans, the on-the farm fermentation and drying process, and the roasting and further processing performed by the cocoa and chocolate manufacturer. One of the objectives of fermentation is to free the beans from adhering pulp. But the fermentation process accomplishes several other desirable changes such as prevention of germination, release of enzymes in the beans, reduction of astringency, richness of colour, altered texture of the seed coat etc.

During fermentation, the temperature of the beans will rise from ambient to about 50 to 55°C due to the exothermic oxidation reaction. Fermentation is the initial step needed in the development of various flavour precursors in the beans. There is a microbial succession of a wide range of yeasts, lactic-acid, and acetic-acid bacteria during which high temperatures of up to 50°C and microbial products, such as ethanol, lactic acid, and acetic acid, kill the beans and cause production of flavor precursors. Over-fermentation leads to a rise in bacilli and filamentous fungi that can cause off-flavors.

During rainy season it is found to be difficult to obtain the required temperature for fermentation. In such a situation a better option is to conduct the process inside a polyhouse which ensures a warmer environment than the surrounding. In order to study the effectiveness of the fermentation process inside a polyhouse, a project was undertaken at Kelappaji College of Agricultural Engineering and Technology, Tavanur. The following are the main objectives of the project:

1. To study the feasibility of the use of polyhouse in the fermentation process during rainy season.
2. Comparative study of different methods of fermentation (tray and heap methods) inside and outside polyhouse.
3. Effect of using polyhouse in reduction of number of days required for fermentation.
4. Quality evaluation of dried product.

REVIEW OF LITERATURE

Chapter 2

REVIEW OF LITERATURE

This chapter gives general information on cocoa, post harvest processes including fermentation and drying, quality assessments and polyhouse. Research done on these aspects are also reviewed and discussed in detail.

2.1 Cocoa

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

2.2 History

The cacao tree is native to the Americas. It may have originated in the foothills of the Andes in the Amazon and Orinoco basins of South America, current day Venezuela, where today, examples of wild cacao still can be found. However, it

may have had a larger range in the past, evidence for which may be obscured because of its cultivation in these areas long before, as well as after, the Spanish arrived. It was first cultivated by the Olmecs at least 1500 BC in Central America.

The cocoa bean was a common currency throughout Mesoamerica before the Spanish conquest.

Chocolate was introduced to Europe by the Spaniards, and became a popular beverage by the mid 17th century. They also introduced the cacao tree into the West Indies and the Philippines. It was also introduced into the rest of Asia and into West Africa by Europeans. In the Gold Coast, modern Ghana, cacao was introduced by an African, Tetteh Quarshie.

The cacao plant was first given its botanical name by Swedish natural scientist Carl Linnaeus in his original classification of the plant kingdom, who called it Theobroma ("food of the gods") cacao (Anon., 2012).

2.3 Genotypes/varieties

Three major varieties of cocoa exist: Criollo, Forastero and Trinitario (Cheesman, 1944). The varieties are recognized based on genetic origin, pod morphology and size as well as the colour and Flavour of the beans (Cook, 1982; Laurent, 1994).

Forestero, also known as ‘Bulk cocoa’ is the main type of cocoa grown all over the world, accounting for about 80-90% of the world’s production (Cook, 1982). It is high yielding, more resistant to pest and diseases and more tolerant to drought. Forastero cocoa bean has a strong inherent flavour, inclined to be somewhat bitter and usually dark brown in colour. The variety originates from the Upper Amazon region and grows in several South American countries including Peru, Ecuador, Colombia, Brazil, Guyana, French Guyana and Southern Venezuela. It also found in West Africa mainly, Ivory Coast, Ghana, Nigeria and Cameroun, as well as in South-East Asia (Beckett, 2009).

Criollo cocoa was originally cultivated by the Mayas of Central America and represents the first domesticated cocoa. In the sixteenth and seventeenth centuries cocoa was introduced into Asia and this was of the Criollo variety. Criollo cocoa beans have white cotyledons and a mild nutty flavour. They are susceptible to diseases and produce low yields. Criollo is now rare and only found in old plantations in Venezuela, Central America, Sri Lanka and Samoa. It also grows on the islands of the Indian Ocean such as Java, Madagascar and Comoros. The variety now accounts for only 1-5% of the world's production and is characterized by slight bitterness (but not unpleasantly so), mild astringency, flavour finesse, a pale colour that gives chocolate a reddish tinge (Hurst *et al*., 2002; Beckett, 2009).

Trinitario accounts for 10-15% of the world's production (Beckett, 2009). It originates from the island of Trinidad and is a result of hybridization between Criollo and Forastero. The crossing between the two varieties became necessary in the eighteenth century when the island's Criollo plantations were almost wiped out by an environmental disaster. Trinitario variety is now grown wherever Criollo is found and also in Cameroon (Beckett, 2009). It has characteristics which are between the parent varieties.

2.4 Propagation

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

levels. Cocoa may also be propagated by marcottage (air-layering) and budding and grafting (Jonathan *et al*., 2012).

2.5 Cocoa Beans

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

Table 2.1 Chemical composition of cocoa bean (Rohan, 1963)

Constituent	% of beans on dry wt.basis	Constituent	% of beans on dry wt.basis
Cotyledon	89.63	Glucose	0.30
Shell	9.69	Starch	6.10
Germ	0.77	Pectins	2.25
Total fat	55.05	Fibre	2.09
Water	3.65	Cellulose	1.92
Ash	2.63	Pentosans	1.27
Total nitrogen	2.28	Mucilage gum	0.38
Protein nitrogen	1.50	Tannins	7.54
Theobromine	1.71	Oxaloc acid	0.29
Caffeine	0.085		

2.6 Cocoa Pulp: The Fermentation Substrate

The pulp which surrounds the beans is made up largely of water. The composition of the pulp is important since this has a profound influence on the

fermentation. On fresh weight basis, 75% of the cocoa fruit is accounted for by the fruit wall. However, on dry weight basis, the beans and the pulp constitute 45% of the fruit weight (Rohan, 1963).

Cocoa pulp is a rich medium for microbial growth. It consists of 82–87% water, 10–15% sugar, 2–3% pentosans, 1–3% citric acid, and 1–1.5% pectin. Proteins, amino acids, vitamins (mainly vitamin C), and minerals are also present. The concentration of glucose, sucrose, and fructose is a function of fruit age (Roelofsen, 1958). More glucose and fructose and a slight increase in total sugar concentration were observed in samples 6 days after harvest than in freshly harvested (ripe) pods (Saposhnikova,1952) . In a comparative analysis of pulp from beans collected in the Ivory Coast, Nigeria, and Malaysia, differences were found in the amounts of water, citrate, hemicellulose, lignin, and pectin. Pectin content, approximately 1% on a fresh weight basis, was found to 37.5 and 66.1 g kg^{-1} dry weight pulp (Pettipher, 1986).

Table 2.2 Composition of cocoa pulp (Rohan, 1963)

	% of pulp	
Constituent	Minimum	Maximum
Water	80.0	90.0
Albuminoids	0.5	0.7
Glucose	8.0	13.0
Sucrose	0.4	1.0
Salts	0.4	0.5

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

2.7 Harvesting

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

2.8. Post Harvest Processing of Cocoa

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

2.8.1 Sweating

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

2.8.2 Fermentation

Fermentation of cocoa is the most critical process that results in the formation of Flavour precursors and the development of the chocolate brown colour. Fermentation is carried out in different ways depending on the producer and the cocoa variety as different types of cocoa require different amounts of fermentation (Beckett, 2008).

Prior to fermentation, cocoa beans are astringent and bitter with no hint of chocolate Flavour. They have a slaty, grey colour rather than the brown or purple-

brown colour of fermented dried cocoa beans. During fermentation, the mucilaginous pulp surrounding the beans which is rich in sugars undergoes ethanoic, acetic and lactic acid fermentation by yeasts, acetic and lactic acid bacteria respectively. The acid and heat generated kills the bean, making the cell membrane permeable. This allows a diffusion of acids into the bean and an increased temperature (up to 50ºC), culminating in the formation of Flavour precursors, namely amino acids, peptides and reducing sugars as well as some Flavour compounds (Gill *et al*., 1984; Hansen *et al*., 1998; Thompson *et al*., 2001; Schwan and Wheals, 2004; Nielsen *et al*., 2007).

The method of fermentation varies from country to country and even from region to region within the same country. The most common methods, however, include box, basket, heap and recently, tray fermentations (Lehrain and Patterson, 1983). In all instances, the bottom of the fermenting container has holes to allow drainage of the drippings from the pulp. The duration of fermentation also depends on the type of cocoa being fermented. Two to three days is sufficient for Criollo cocoa whereas Forastero cocoa is fermented for 5-8 days with periodic mixing to homogenize the treatment and aerate the fermenting mass (Lopez and Dimick, 1991; Biehl and Ziegleder, 2003).

2.8.2.1 Heap

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

2.8.2.2 Box

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

2.8.2.3 Basket

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

2.8.2.4 Tray

A different method of cocoa fermentation developed by the Cocoa Research Institute of Ghana (CRIG) is the Tray system. This was developed to resolve the issue of uneven fermentation that sometimes arises with big heaps that are not turned. This is a method in which the cocoa beans are fermented in 10 cm deep wooden tray; 8-10 trays can be stacked on top of each other and the topmost tray covered with banana or plantain leaves. Air is allowed to circulate between beans in the trays without having to turn. This is reported to give higher quality fermented beans in shorter time (Allison and Rohan, 1958; Allison and Kenten, 1963).

Coffee on the other hand which is also a beverage crop undergoes fermentation. Coffee is fermented, to ease the removal of a layer of mucilage from the seed/inner integument to which it adheres. The temperature of the processes is scarcely raised above ambient temperature reflecting the lack of oxygen diffusion to the heart of the mass. Coffee fermentation is not significantly self-heating so prevailing climatic conditions control temperature. Depending on conditions, the beans can be fermented for 18-36 hours, or until the mucilage easily tears away from the bean (www.coffeechemistry.com).

The time required for coffee fermentation can be reduced to about 12 h by the addition of relatively small amounts of an inoculum derived from over-fermented beans (Butty, 1973).

Studies on cocoa fermentation in baskets or wooden boxes were carried out on cocoa pods which had been stored for 4 or 7 days after harvesting by Bhumibhamon *et al*., (1993).The results showed that the beans fermented in boxes had slightly better cut test values than those in baskets.

Guehi *et al.,* (2010) reported that among three cocoa fermentation methods (wooden box, plastic box and in heaps) performed during their study, fermentation in heaps appeared to be better for the production of a good quality raw cocoa.

The study by Rodriguez-Campos *et al.,* (2012) concluded that the optimal conditions for fermentation and drying of cocoa beans were 6 days and 70^0C.

2.9. Changes during fermentation

2.9.1 Changes in pulp:

Two major changes occur in the pulp: namely, conversion of sugars into alcohol and further to ascetic acid. The pulp cells are broken down by pectic enzymes, reducing it to a turbid yellow liquid, which drains out slowly from the system. The temperature during fermentation process rises to as high as $45\text{-}50^0$ C in some places, due to the fermentation action of yeast and ascetic acid bacteria. The temperature is influenced by the size of the batch and the extend of aeration permitted (Potty, 1979).

The pH of the pulp shows a gradual rise during fermentation, probably to dissimilation of citric acid by yeast and lactic acid bacteria and its replacement with less dissociated lactic and ascetic acids (Potty, 1979).

Various fermentation techniques using rattan basket, plastic bucket, plastic sack and gunnysack were evaluated by HiiChing *et al.,*(2002). Studies showed that mass temperature profiles for the plastic sack treatments were below 40°C during fermentation. Temperature profiles in other treatments were in the region of 40 to

50°C after the first and second turning. The pH measured at the end of fermentation in all the treatments was less than 5.0 indicating acidic beans were being produced.

2.9.2. Changes in bean:

Due to drainage of sweating, the beans lose about 25% of their weight during fermentation. A further loss of 40% is incurred during drying. Normally, the unfermented beans consists of 0.77% germ, 9.63% shell and 89.60% cotyledons while fermented beans have 0.70% germs, 10.74% shell and 88.56% cotyledons (Potty, 1979)

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

Unfermented beans are oval and somewhat flat. Before fermenting, pigmented cells comprise about 10% of the entire tissue of purple beans. These cells contain neither starch nor fat. After fermenting, the entire cotyledon is uniformly tinted by the pigment released from the pigment cells.

Rise in temperature and formation of alcohol and acetic acid in the pulp during fermentation are responsible for killing the germ in the cotyledons. The germinating power of cocoa is destroyed at 43-44^{0}C; especially, the Criollo germ is killed at still lower temperatures in a shorter duration. Usually the germs are killed on the third day and the cotyledon start absorbing moisture on the fourth day of fermentation. The beans become rounded on the fifth day when the space between the cotyledons is filled with a brown gummy juice containing compounds of tannin with theobromine and caffeine(Potty,1979).

Some of the enzymes identified in cocoa beans include, oxidases, peroxidases, catalase, reductase, invertase, maltase, amylase, dextrinase, phytase and proteases.These enzymes become activated after the seed is killed at warmer temperatures, and are primarily responsible for lowering the astringency and development of flavour. Oxidizing enzymes are instrumental in the colour change resulting in the brown final product.

One of the most significant changes occurring in the cotyledon during fermentation is the rapid destruction of anthocyanin pigments, accompanied by development of a pale purple colour. Reduction in anthocyanin levels is accompanied by rapid development of chocolate flavour. In fact, within 12 hours of the death of the germ, it could be dried to give an acceptable product. It is presumed that certain chemical compounds are formed during fermentation, which subsequently transformed themselves into the characteristic flavour and aroma of cocoa during roasting operations .Sufficient indications are available to infer that the complex leucoanthocyanidin fraction of the polyphenols react with theobromine to produce cocoa aroma. The fact is that fresh beans (unfermented) after sundrying and roasting, give a product which is extremely astringent, bitter and unpleasant to taste, thus proving the significant role played by the fermentation process(Potty,1979)

2.10 Drying

Following fermentation, the beans are either dried in the sun or by artificial means. The method of drying is critical to preserve the delicate flavour precursors which have been formed during fermentation. Chemical changes taking place in the beans during fermentation continues during drying until the moisture content drops from about 60% to about 7.5%. Both the high drying temperature and drop in moisture level causes enzymes to be inactivated. This is necessary to stabilize the beans for storage and shipment. Drying is also important for further development of the chocolate brown colour due to the quinone protein reaction and for loosening of the shell from the bean (Cook, 1982; Hashim *et al*., 1998; Ramli *et al.*, 2006).

Drying should not take place too quickly as exposure to intense heat causes the skin of the beans to wrinkle and promotes oxidative changes and destruction of flavour precursors. This may result in development of off-flavours and the retention of acetic acid, giving beans acidic and bitter flavour.(Jinap *et al*., 1994). On the other hand, if drying takes place too slowly, molds and off-flavours can develop. The quality of dried beans depends on temperature, rate of airflow, and the depth of the beans during the drying process. There are reports of development of flavour compounds during drying (Hashim *et al*., 1998).

2.10.1 Sun drying

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

2.10.2 Artificial drying

In instances or countries where sun-drying is not possible, artificial means are used to dry the beans after fermentation. Artificial drying is also mostly used where large lots of cocoa beans are being processed. Many types and sizes of mechanical dryers have been developed over the years. The method is common in some South American and Asian countries where cocoa is cultivated on large plantations and where the weather may be too wet for sun-drying. In some instances, cocoa beans are

dried by fire. Wooden fires are lit in a chamber below the drying area, and the hot gas is led through a duct or pipe beneath the drying platform and then out through a vertical chimney. The problem with this method is the risk of smoke leakage from the fire which can contaminate the beans. The use of forced-air dryers and efficient heat exchangers can prevent smoke reaching the beans (Cook, 1982; Beckett, 2008). Artificial dryers can help to avoid moldy beans in wet seasons (Mossu, 1992).

Bonaparte *et al*., (1998) stated that low cost solar drying has the potential of enhancing drying rate in cocoa beans, after surveying quality characteristics of solar-dried cocoa beans. They also found that the solar dryer did not cause problems associated with drying at high temperatures.

Experiments have shown that during artificial drying of cocoa beans, volatile fatty acids are not reduced to the same level as that during sun drying and therefore the former tends to give beans of a higher acidity (Jinap *et al*., 1994; García-Alamilla *et al*., 2007).

The results of studies by Fagunwa *et al.,* (2009) showed that the solar dryer is able to dry cocoa beans with a moisture level from 53.4 % to 3.6 % within 72 hours. The quality of the beans was good, and comparable to that of traditionally sun dried cocoa beans .

In another experiment with solar dryers, a solar tunnel dryer was built in Malaysia for drying longan fruits from moisture content of 84 % before drying to 12 % after drying. Longan fruit are, like cocoa beans, sun dried on mats or more often, mechanically dried with hot air. The experiment resulted in good quality and considerable reduction in drying time, compared to natural sun drying (Janjai *et al.*, 2009).

Ndukwu (2009) studied the effect of some drying parameters and drying conditions of cocoa bean and reported that the drying rate increased with increase in temperature and air velocity but decreased with time.

Although sun-drying is mostly preferred over mechanical drying, the latter has the following advantages:

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

Disadvantages of mechanical drying include the following:

- Often by too fast drying or too high temperatures the drying period is shortened so much that enzymatic action is not fully completed resulting in incomplete development of the chocolate flavour precursors.
- Excessive heat and rapid drying may not allow for adequate loss of volatile acids, especially acetic acid and this will affect the flavour quality.
- If smoke comes into contact with the beans during drying, a smoky off-flavour can result because cocoa easily absorbs volatile phenols from smoke.
- Costly investment especially for the small grower. (Cook, 2008).

Sunilkumar *et al* (2008) reported that artificial drying could be feasible during adverse climatic conditions to save the beans from spoilage.

Hii *et al*., (2009) stated that raw cocoa beans can be artificially dried using an air ventilated oven at temperature of 60 ^{0}C until moisture content of 7%.

Oke *et al*.,(2011) carried out drying experiments to investigate the effect of forced-air, artificial intermittent drying system on quality of fermented cocoa beans harvested in south-western Nigeria. From the test results, the free fatty acid and acetic acid levels increases with increase in drying temperature, also, the pH level decreases with increase in drying temperature. Optimum bean-quality was obtained for cocoa beans dried at 45°C oven temperature.

2.11 Greenhouse

Greenhouses are framed or inflated structures covered with transparent or translucent material large enough to grow crops under partial or fully controlled environmental conditions to get optimum growth and productivity, permitting sufficient quality and quantity of solar radiation to enter the structure.

2.11.1 Classification of greenhouses

Greenhouse structures of various types are used for crop production. Although there are advantages in each type for a particular application, in general there is no single type greenhouse, which can be constituted as the best. Different types of greenhouses are designed to meet the specific needs. The different types of greenhouses based on shape, utility, material and construction are briefly given below:

2.11.1.1 Greenhouse type based on shape

For the purpose of classification, the uniqueness of cross section of the greenhouses can be considered as a factor. The common types of greenhouses used in India are ridge and furrow type, saw tooth type, tunnel type and maxi-vent greenhouses

2.11.1.2. Greenhouse type based on Utility

Classification can be made depending on the functions or utilities. Of the different utilities, artificial cooling and heating are more expensive and elaborate. Hence based on this, they are classified in to two types, greenhouses for active heating greenhouses for active cooling.

2.11.1.3. Greenhouse type based on construction

The type of construction predominantly is influenced by structural material, though the covering material also influences the type. Higher the span, stronger should be the material and more structural members are used to make sturdy tissues. For smaller spans, simple designs like hoops can be followed. So based on construction, greenhouses can be classified as wooden framed structure, pipe framed structure and truss framed structure.

2.11.1.4. Greenhouse type based on covering material

Covering material is one of the important components of the greenhouse. They have direct influence on greenhouse effect, and they alter the air temperature inside. The types of frames and method of fixing also varies with covering material. The common cladding materials used are Fibre glass reinforced plastic (FRP) materials and plastic films. The FRP sheets are either plain sheets or corrugated sheets. Ultra violet stabilized Low Density Polythene(LDPE) sheets are widely used in India as greenhouse cladding material. Plastic shade nets are also used for growing crops which are to be grown under shade.

2.11.2 Advantages

- The yield may be 10-12 times higher than that of outdoor cultivation depending upon the type of greenhouse, type of crop, environmental control facilities.
- Year round production.
- Off-season production.
- Water requirement of crops very limited and easy to control.

- Most useful in monitoring and controlling the instability of various ecological system.

2.11.3 Disadvantages

- In windy areas dirt seems to collect on the surface and become ingrained. It may be most difficult to clean off and attempts may lead to making the scratches and abrasion worse.
- Some plastics also change chemically with time and on exposure to sunlight over long periods. They usually tend to become brittle and they may crack and disintegrate.
- A further disadvantage is that water does not wet a plastic surface and form a film as it does on glass. This often causes condensation to collect in droplets. These may constantly drip, especially if the roof is insufficiently sloped (Andreas, 2010).

2.12 Polyhouse

A polyhouse is basically a large framework of semi-hoops covered in polythene plastic. A greenhouse cladded with polythene sheet is called as polyhouse. The polythene traps the sun's energy creating an increase in temperature. The polythene is treated to resist UV damage. Polythene can have a thermal, anti-fog cover that prevents moisture forming into larger drops that will block sunlight to drip on the plants. Structures must be clad in fabric to prevent damage to the plastic when it rubs against the frame. A polyhouse can also be called a plastic or polythene tunnel or greenhouse, growhouse, or poly tunnel (www.growingraw.com).

The studies by Long *et al.*,(2010) showed that the inside temperature of southern-type solar greenhouse could be maintained above 5°C during night in winter and the temperature difference between inside and outside could achieve 4.7-12.7°C.

The results of studies by Nan et al (2010) showed that the maximum temperature difference was 20.8°C between outside and inside the greenhouse at noon in clear days. The minimum temperature difference was between 0.65°C-1.75°C at night, and the temperature inside was lower than outside in the evening in clear days and cloudy days.

2.13 Quality aspects of fermented cocoa

Chocolate and cocoa contain a high level of flavonoids, specifically epicatechin, which may have beneficial cardiovascular effects on health. Foods rich in cocoa appear to reduce blood pressure. Cocoa and chocolate naturally contain several minerals – including copper, magnesium, potassium and calcium – that may help support a healthy cardiovascular system (Taubert *et al*., 2007;Schoreter *et al*.,2006) A typical analysis of the nutrient content is given below.

Table 2.3 Nutritional value of 100g dry powder, unsweetened cocoa (USDA National Nutrient Database for Standard Reference,2006**)**

Constituent	Value	Constituent	Value
Water	3.0g	Iron	12.9mg
Protein	19.6g	Magnesium	499mg
Fat	13.7g	Phosphorus	734mg
Carbohydrate	54.3g	Potassium	1524mg
Fiber	33.2g	Theobromine	2057mg
Calcium	128mg	Caffine	230mg

Aroma formation begins with fermentation of the pulp surrounding the beans which contains mainly sugars. The first of the Flavour compounds undoubtedly is ethanol, acetic and lactic acids from the activities of yeast, acetic acid bacteria and lactic acid bacteria, respectively (Hansen *et al*., 1998; Schwan, 1998; Schwan and

Wheals, 2004; Camu *et al*., 2008). Acetic and lactic acids have been implicated as the cause of acidic Flavour or sourness in cocoa and products produced from it (Jinap *et al*., 1995).

Both under-fermentation and over-fermentation are detrimental to the flavour quality of the beans. The former results in what has come to be known as 'purple beans' with bitter, astringent, acidic flavour, incomplete development of the chocolate brown colour and flavour. On the other hand, over-fermentation can result in a detrimental hammy off-flavour defect caused by a direct aerophilic microbial attack on beans, destroying the cocoa flavour potential, increasing pH and blackening the beans (Beckett, 2009). The hammy off-flavour can be explained by the formation of a surplus of propanoic acid, methyl propanoic acid and methyl butanoic acid (Lopez and Quesnel, 1973), although there are suggestions that these acids in usual levels of concentration are important in cocoa flavour (Ziegleder, 1991; Schnermann and Schieberle, 1997).

Flavour development continues with the drying process. During drying, some amount of the acidic content of the beans diffuses out and is lost through evaporation. Incomplete drying may result in mould contamination which gives the final product an off-flavour (Hansen and Keeney, 1970).

Various aspects of quality can be divided into two categories. First there are those that affect the acceptability of a parcel of beans to a manufacturer. These include flavour, purity and grade, which embrace the items covered by grading standards and food regulations. The other category includes those physical characteristics which affect the yield of edible materials which a manufacturer can obtain from a particular parcel.

2.13.1 Cut test

Cut test is a guide to determine the degree of fermentation. It also detects defects and presence of mouldy and unfermented beans (Haendler, 1980).

The cut test involves cutting lengthwise beans taken from a random sample of cocoa whose quality is to be assessed. Both halves are usually laid on a board and are examined. When the cut is complete the number of defective beans is counted. In order to assess the degree of fermentation, cut test can be divided into four categories (Anon., 1968).

- Fully brown
- Partly brown ,Partly purple
- Fully purple
- Slaty

The first category (fully brown) should include all fully fermented beans, even though the colour cannot properly be described as brown. Second category (partly brown, partly purple) should include all beans showing any blue, purple or violet colour on the exposed surface, whether suffused or as a patch. The third category (fully purple) should include all beans showing completely blue, purple or violet colour over the whole exposed surface. Slaty beans are generally unfermented beans (Anon., 1968).

The colours of a normal sample of cut beans cover a range from the chocolate brown of the fully fermented beans to the fully purple of beans that have been inadequately fermented. Beans described as ‘ partly brown’, ‘partly purple’ are not defective and should be present at least to the extent of 20%.A proportion of 30-40% is acceptable but samples with more than 50% in this category have probably been inadequately fermented for some reaction and may give rise to bitter and astringent flavours.(Anon.,1968).

Over fermentation can be revealed by a dull dark appearance of the beans, when cut but such beans cannot be clearly defined. Over fermentation give rise to unpleasant smell in the fermenting mass. This inevitably leads to loss of chocolate flavour and production of unpleasant off-flavours. (Wood, 1985).

Table 2.4 Causes of defective beans **(**Are and Gwynne-Jones, 1974)

Defective beans	Causes
Slaty	A dark colour indicates that the bean has not been fermented. Slaty beans have not developed the characteristic chocolate aromas and brown colour.
Purple	The beans are under fermented. Glycosides have not yet broken down
Dark	Too slow drying of the beans, or drying on metal. Beans from black pod diseased pods.
Flat	The beans are collected from immature pods.
Moldy	Develops when moisture content has not been reduced to less than 7.5 %.
Germinated	Fermenting in holes in the ground. Not turning the beans during fermentation. Leaving unharvested, ripe pods on the trees for several weeks.

Table 2.5 Grading of cocoa beans **(**Lockhart, 2010)

Defect	Grade 1	Grade 2
Mouldy beans	3%	4%
Slaty beans	3%	8%
All other defective beans	3%	6%
Purple beans	20%	45%

2.13.2 pH

The pH value is indicative for proper fermentation. The initial pH is relatively low (pH = 3.3–4.0), primarily due to a high concentration of citric acid (1–3%) (Roelofsen , 1958). Beans of higher pH (5.5-5.8) are considered unfermented - with low fermentation index and cut test score - and those of lower pH (4.75- 5.19), well fermented. (Holm *et al*., 1993; Beckett, 2008; Afoakwa and Paterson, 2010).

Guehi *et al.,* (2010) reported that the sun-dried beans pH ranged from 4.5 to 5.5, while the pH of both oven- and mixed-dried beans was between 3.8 and 5.2.

2.12 Storage

Store raw cocoa beans in bags made of jute, sisal or similar material. Line the insides of the bags with plastic (low density polyethylene vinyl alcohol/linear low density polyethylene, oriented nylon/polyethylene or oriented polypropylene/polypropylene). Lining the insides of the bags with plastic helps prevent the most common problems associated with raw cocoa bean storage such as insect damage, mold infection and absorption of extra moisture that can lead to early spoilage.

The test results of Oke and Omotayo(2012) on effects of hermetic storage on artificially- dried cocoa beans stored in hot-sealed plastic bags showed that the moisture content, free fatty acid, pH and acetic acid values increases after storage but marginally.

MATERIALS AND METHODS

Chapter 3

MATERIALS AND METHODS

This chapter mainly deals with the various methods followed for the fermentation of *Theobroma cocoa* and also methodology for determining the quality of dried beans.

3.1 Raw Materials

Cocoa (*Theobroma cocoa*) of Forestero variety, which is widely grown in our state was procured from a progressive farmer at Thrissur. This cocoa was harvested in the month of October 2012. Matured, uniformly coloured beans without any insect damage were sorted and used for this study. Two sets of 6kg sample were equally distributed among the three trays of both plastic and bamboo. Another 6kg sample was taken on a heap. Thus altogether 18 kg of cocoa beans was placed in the open condition. A similar set of 18kg sample was placed in the polyhouse.

3.2 Determination of Moisture Content:

The amount of moisture present in the cocoa beans was determined gravimetrically as recommended by International Standard Organization (ISO) table of standard 2291 – 1972 (E) and AOAC (1984). A known weight of the sample was kept inside a hot air oven at a temperature of 103 °C. After 16 hours of drying the sample was weighed again. The moisture content was expressed as the percentage change in weight (AOAC, 1984).

$$\text{Moisture content (\%)} = \frac{Winitial - Wfinal}{Winitial} \text{ X } 100 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Where, $W_{initial}$ = Initial weight of sample

W_{final} =Final weight of sample

3.3 Fermentation Studies

Conventionally fermentation of cocoa beans is carried out either by heap method or basket method. In addition to these methods, trays of plastic and bamboo were also considered for the fermentation study. Bamboo trays were used to replicate the traditional basket method.

Plastic and bamboo trays of dimensions 27 X 22 X 6cm and 40 X 40 X 5.5 cm respectively were used. Frames were made for holding the fermentation trays. The specifications of the frame material are as follows:

- Supporting leg made of GI square tube of 3/4".
- Supporting platform made of 30mmX3mm mild steel flat and mild steel round rod of 1/4″.

Separate frames were made for holding plastic and bamboo trays. Holes of 6mm were drilled on the material holding trays to drain out the sweatings during the fermentation.

Plate 3.1Plastic tray with drilled holes

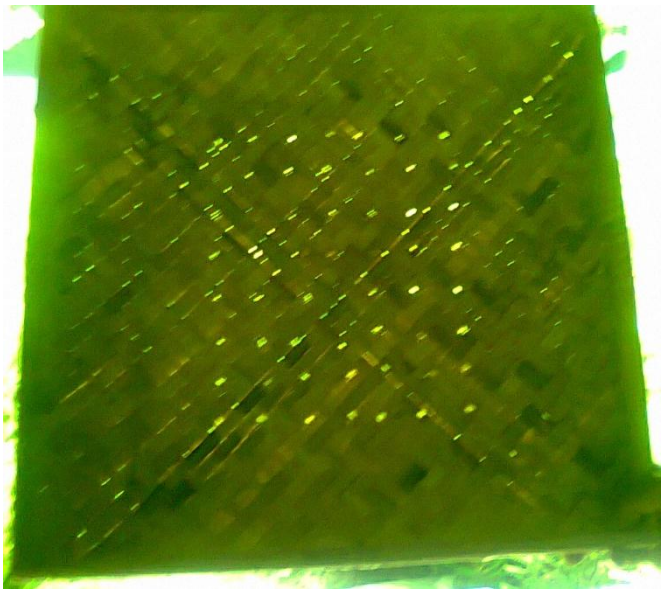

Plate 3.2 Bamboo tray with drilled holes

Traditionally heap method of fermentation is followed in which cocoa is usually heaped on a platform having arrangements for drainage of sweating. A wooden platform of 60cmX60cm with holes of 6mm diameter drilled on the platform was made. It was covered with shade net to drain out the sweating.

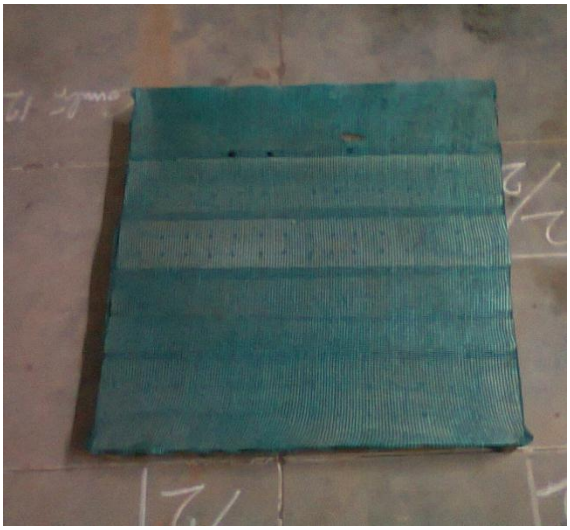

Plate 3.3 Fermentation platform for heap method

3.4 Experimental set up

For studying the tray method of fermentation six trays were stacked together. The material holding trays and collecting trays were alternately placed. Thus a set consisted of 3 sample holding trays and 3 collecting trays. Four similar set were made.

Plate 3.4 Arrangement of plastic and bamboo trays

In order to study the effect of temperature and also to continue the fermentation on rainy season, a fermentation trial on polyhouse was also conducted. A low tunnel type polyhouse of length 4m, breadth 1.5m and height 1.25m was set up. It was completely covered using 200 micron polythene sheet. For comparing the variation of quality of beans on fermentation the same set of experiment was conducted in the polyhouse.

Plate 3.5 Low tunnel polyhouse

Temperature and humidity of ambient air in both conditions were recorded with a thermo-hygro clock and temperature of each of the samples was taken using thermometer. Readings were recorded thrice a day; morning, noon and evening.

Plate 3.6 Thermo hygro clock

3.5 Treatments

As heap method is generally followed for the fermentation hence it was considered as control.

H1- Heap in the open condition

H2- Heap inside polyhouse

T1-Tray 1 in open condition

T2- Tray 2 in open condition

T3- Tray 3 in open condition

T4- Tray 1 inside a polyhouse

T5- Tray 2 inside a polyhouse

T6- Tray 3 inside a polyhouse

B1- Bamboo tray 1 in open condition

B2- Bamboo tray 2 in open condition

B3- Bamboo tray 3 in open condition

B4- Bamboo tray 1 in polyhouse

B5- Bamboo tray 2 in polyhouse

B6- Bamboo tray 3 in polyhouse

The samples were covered with polythene of 50 microns and jute bags were placed over it to build up the required temperature. Turning was done once in two days. When the beans are turned, clumps of beans were broken up by hand, otherwise these beans will not ferment properly.

Plate 3.7 Experimental set up inside the polyhouse

3.6 Drying

The fermented samples were sun dried 8 hours daily for about one week.

3.7 Quality Assessment

The quality of fermented cocoa was assessed in terms of colour variations during cut test, number of good sized beans in terms of grade and pH level as per standard procedure.

3.7.1 Cut Test:

Fermented samples from the treatments T1, T2, T3 were collected together as a single set S1 and B1, B2, B3 collectively formed set S2. Similarly the corresponding treatments in polyhouse were taken together.

S1- Sample from plastic tray in open condition

S2- Sample from bamboo tray in open condition

S3- Sample from heap in open condition

S4- Sample from plastic tray inside the polyhouse

S5- Sample from bamboo tray inside the polyhouse

S6- Sample from heap inside the polyhouse

Twenty five beans were randomly selected from each set of the fermented cocoa. The International Standards Organisation cut test procedure states that for a complete determination of bean quality, beans shall be opened or cut lengthwise through the middle, so as to expose the maximum cut surface of cotyledons. Both halves of each bean are visually examined. Each defective type of bean shall be counted separately, and the result for each kind of defect shall be expressed as a percentage of the beans examined. In order to assess the degree of fermentation, cut test can be divided into four categories.

- Fully brown
- Partly brown, partly purple
- Fully purple
- Slaty

3.7.2 Bean count:

In order to determine the bean count, 100 gram of the sample was weighed from each lot. The total number of good sized, small sized, flat and mouldy beans was counted and the sample was graded.

3.7.3 Determination of pH:

Ten gram of the nibs was homogenized in 200 ml distilled water; the homogenate was filtered and the pH of the supernatant was measured using litmus paper.

3.8 Storage

Dried cocoa beans were stored in jute bags lined with LDPE for one week. No storage studies were conducted.

RESULTS AND DISCUSSION

Chapter 4

RESULTS AND DISCUSSION

Results and discussion of the experiments carried out on the various methods of fermentation are presented in this chapter. In this study, cocoa of Forestero variety was used for the fermentation. The effect of temperature variations on quality of fermented cocoa beans inside a polyhouse were studied and compared it with the existing method. Quality of dried cocoa beans in terms of colour, bean count and pH were studied and discussed.

4.1. Test Sample

Cocoa beans, procured from a progressive farmer were used for the experiments. The initial moisture content was estimated by the standard method explained in chapter 3 and was found to be 72.3%.

4.2. Temperature variation in open condition and in polyhouse.

The temperature variation in open condition and inside the polyhouse was recorded for 6 days by using a thermo-hygro clock. Fig. 4.1 shows the variation in temperature in both the cases.

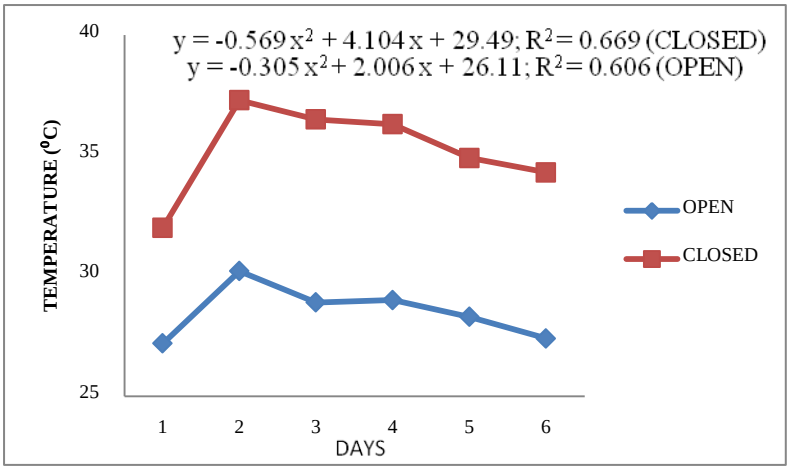

Fig.4.1 Temperature variation in open condition and inside polyhouse

On the first day of fermentation the temperature inside the polyhouse recorded was 32°C whereas it increased up to 37.3°C in the second day. The corresponding temperature recorded in the open condition was 27.2°C and 30.2°C respectively. On the later days also significant variation in the temperature was observed. Even in the early morning the temperature varied from 0.3-1.8°C inside and outside the polyhouse. During the evening the temperature variation was in the range of 0.2-1.4°C. The maximum temperature was recorded in the afternoon in both the cases. A temperature difference of 7.1°C was recorded in the polyhouse than in the open condition. This temperature increment can be attributed to the green house effect.

The observation was in accordance with the results obtained by Nan *et al.,* (2010) which reported the maximum temperature difference between inside and outside of a polyhouse to be 20.8°C.

4.3. Fermentation Process

Fermentation was conducted in tray method and it was compared with the traditional heap method. In the tray method the bamboo trays and plastic trays were used. Their effects on building up of temperature for the fermentation process were separately studied in both open and closed conditions.

The top layer of fermenting cocoa was covered with jute bags. This inhibits too much air penetration into the fermenting cocoa and also stops too much moisture from being lost which affect the proper fermentation An additional reason for covering the fermenting cocoa with jute bags is not to lose heat by dissipation during the fermentation.

4.3.1 Effect of temperature on various treatments in open condition

The fermentation studies were conducted on heap, plastic and bamboo trays. Each treatment was conducted with 6 kg of fresh cocoa beans and the temperature

was noted thrice a day. Effect of temperature on fermentation of cocoa in open condition is shown in the fig.4.2.

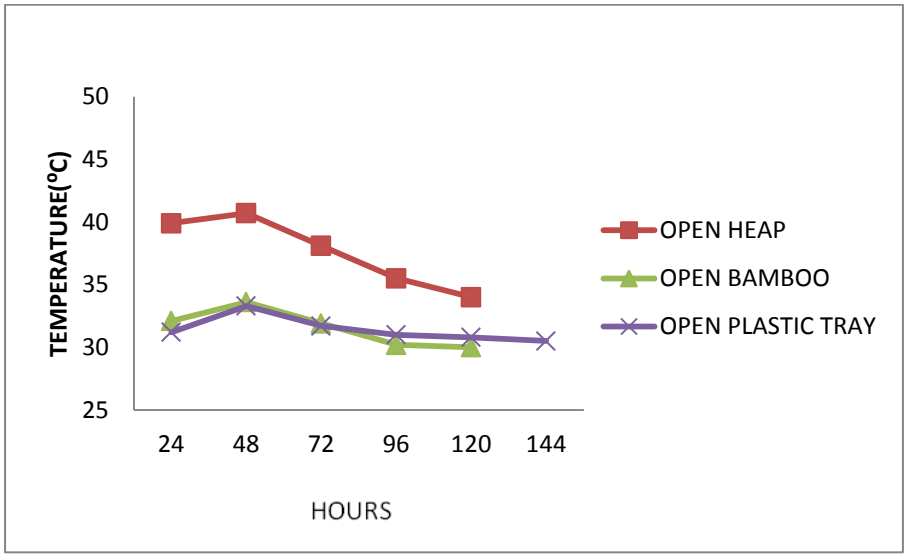

Fig.4.2 Effect of temperature on various treatments in open condition

Studies were conducted by taking 6kg samples in each treatments and the effect of temperature on the completion of the fermentation process were recorded. From the graph it is observed that the time taken for the complete fermentation of cocoa beans is minimum for bamboo trays and maximum for the samples in the plastic trays. It is also noted that the time taken for the complete fermentation in the heap method was almost comparable with that of the bamboo tray with a difference of about 1 hour. From the results it is also noted that the time taken for the complete fermentation of samples in the plastic tray was about 144 hours and this may be due to the minimum natural aeration and lesser temperature build up. Hence it is concluded that the plastic trays cannot be recommended for the fermentation of cocoa beans.

4.3.2 Effect of temperature on various treatments inside a polyhouse

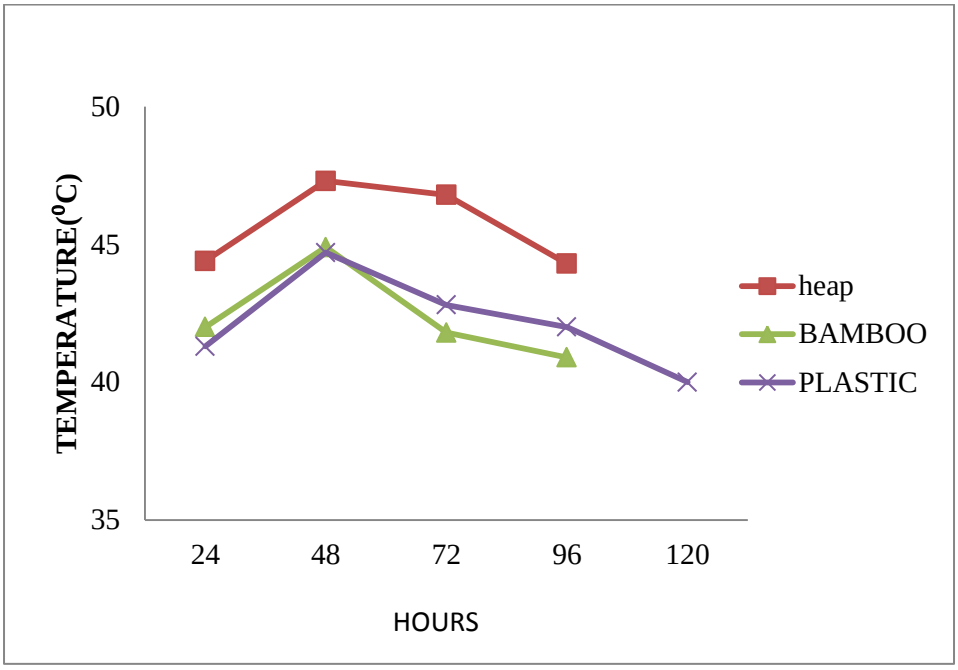

Fig.4.3 Effects of temperature on various treatments in polyhouse condition

Fig 4.3 shows the effect of temperature on various treatments inside a polyhouse. From the graph, it is evident that the time required for the complete fermentation of cocoa beans in the bamboo and heap treatments is almost same (96 hours). The time taken for the fermentation in the plastic tray was 120 hours. From the graph, the minimum time taken for the fermentation of cocoa beans in bamboo trays was only 96 hours whereas the time taken for the same treatment in the open method was 120 hours. The minimum time taken for the fermentation of cocoa beans inside the polyhouse was due to the greenhouse effect.

The temperature range recorded during the fermentation process in a polyhouse was from 40°C to 47.3°C where as in the open condition this temperature range is from 30°C to 40.7°C. Higher the temperature, lower the time of fermentation. This may also help in the reduction in time of fermentation inside the

polyhouse. Wood and Lass (1985) also reported that the suitable temperature for efficient cocoa fermentation is between 45°C and 50°C.

4.5. Drying of fermented cocoa

After the fermentation process, all the samples were sun dried to get safe storage moisture content of 7% (wb). The maximum drying time of 56 hours was taken for the sample in the plastic tray (both in open and polyhouse). This may be due to the incomplete removal of sweatings, which reduces the rate of diffusion of moisture and the sticky nature of the samples fermented in the plastic tray.

The minimum time of 40 hours was taken for the sample in the heap.

4.6. Quality of fermented cocoa beans

The quality of the fermented beans was assessed on the basis of colour, pH and number of good sized beans as per the standard procedures explained in Chapter 3.

4.6.1 Cut Test

Twenty five beans were randomly selected for this test from each set in both conditions. The results were tabulated as follows:

Table 4.1 Colour variation observed in the cut test (in %)

	S1	S2	S3	S4	S5	S6
Fully brown	68	72	78	70	80	88
Partly brown, partly purple	24	20	16	16	16	8
Fully purple	4	Nil	8	8	4	4
Slaty	4	8	Nil	8	Nil	Nil

The highest numbers of fully fermented beans were obtained from the sample S6, which represented the beans from heap inside the polyhouse. The increased percentage of brown beans is due to the more uniform build up of optimum temperature.

During fermentation the anthocyanins and polyphenols present inside the cocoa beans undergo series of chemical reaction to form condensed tannins which impart the brown colour to the beans (Kim and Keeney,1984).

Beans described as ‘partly brown’ and ‘partly purple’ are not defective. For good cocoa flavour development the degree of fermentation (% fully brown beans) should be above 60%(Wood and Lass, 1985) .In the study the percent of fully brown beans was more than 65% in all the samples.

Plate 4.1 Cut test result of sample placed in heap (polyhouse)

4.5.2 Bean count

The bean count analysis of the dried sample was done as per the procedure explained in 3.7.2. The results obtained are tabulated below:

Table 4.2 Bean count analysis of dried beans

	S1	S2	S3	S4	S5	S6
Bean count	120	136	134	132	134	130
Good sized(%)	60	66.17	74.6	64.3	76.12	86.15
Small sized(%)	34.16	27.9	23.8	28	20.8	12.3
Flat(%)	5.83	5.88	1.49	7.5	2.98	1.49
Mouldy	Negligible					

From the results the highest proportion of good sized beans were obtained for S6 (86.15%) followed by S5 (76.12%) and S3 (74.6%).

4.5.3 pH

The pH of the sample varied between 4 to 5 which shows that the fermented beans are acidic in nature. The presence of acetic acid contributes acidity to the fermented beans. The studies of Holm *et al*., (1993), Beckett,(2008)and Afoakwa and Paterson (2010) supports our findings.

Based on the quality parameters the beans fermented in heap in a polyhouse is superior to all the samples fermented in other treatments.

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APPENDICES

APPENDIX A

Table A.1 Temperature readings of plastic tray in open condition and in polyhouse

		MORNING			AFTERNOON			EVENING		
HOURS	TRAY	P1	P2	P3	P1	P2	P3	P1	P2	P3
24	T1	31.5	31	31.5	31	30	31	33.5	32	32.5
	T2	31.2	31	32	32	32	32	33	31	33.5
	T3	31	31	32	31.2	31	31	33	32	33
	T4	27.5	27	27.5	41	41.8	41.6	38	38	38.2
	T5	29.2	29.2	31	40.2	42	41	37.5	39	38.5
	T6	29	29	29	40	40.8	41.8	37.2	37	37.2
48	T1	32	31.5	32	33.2	33	33	32	32	32
	T2	33	34	33	33.5	34	34	32.2	32.3	32
	T3	32.2	32	32	32.8	33	33	31.5	31.8	31.5
	T4	34.5	34.5	34	46.5	46	46.2	39	38	38.4
	T5	33	34.5	34	44.8	44.5	45	38	37.2	38
	T6	31.5	32.5	31	43	42.8	43.5	36	36	35.5
72	T1	31	31	31	32	32	32	32	32.3	32
	T2	32	32	31.8	32	32.1	31.8	31.8	32	32.3
	T3	31.4	31.8	31	31.2	31.2	31.1	31	31	31
	T4	33.2	32	32.2	45.5	44	45	42.2	42	41
	T5	34	34	33.8	43	43	43	40	39.2	39.8
	T6	32	32	32	40.5	40.5	40.8	38	39	37
96	T1	29.2	29.8	29.8	31	31.5	30.5	31.2	31.5	31
	T2	30	29	30	30.6	30.5	31	31	31	31.5
	T3	29	29.4	29	30.5	30	30	30.5	30.5	31
	T4	30	29.8	29.5	43.2	42.8	42.5	39	38	38
	T5	29	29	29	42	43	42	38.6	39	38.6
	T6	29	29	29	42.2	42	41.9	36.5	36	36
120	T1	30	30	29.4	31	32	31	32	32	31.5
	T2	29.8	30	30	31	31	30.8	31.5	31	31.2
	T3	29.3	29	29.4	30.5	30.8	30.5	31	31	31
	T4	29.5	29.8	29	40.2	40.4	40	41	42	41.2
	T5	29	29.5	29	40	40	40	39.5	40	38
	T6	29	29	29	39.8	39.6	40	37	37.5	36.8
144	T1	29	29	29	31	31	31	31.5	32	32

	T2	29	29.8	29	30.5	30.5	30.5	31.8	31	31.8
	T3	29	30	29	30.2	30	30	31.2	31	31.2
	T4	Nil								
	T5									
	T6									

Temperature in °C

P1-Position 1

P2-Position 2

P3-Position 3

T1,T2,T3- Trays in open condition

T4,T5,T6-Trays inside polyhouse

Table A.2 Temperature readings of bamboo tray in open condition and inside polyhouse

HOUR	BAMBOO TRAY	MORNING			AFTERNOON			EVENING		
		P1	P2	P3	P1	P2	P3	P1	P2	P3
24	B1	31.5	33	31	32	32.5	31	34.5	34	34
	B2	31	32	32	32	32	33	35	35	35
	B3	32.8	32	31	33	32.4	31	33.5	33	34
	B4	30	31	30.5	41.8	42	42.5	40	40.5	40.2
	B5	29	30	29	41.8	42.2	42	39	39	39
	B6	30.5	30	29.7	41.5	42	41.6	39	38.5	39.5
48	B1	33.8	33.5	32.5	32.2	33	32.2	32	32	32
	B2	34	35	34	34.8	34	34	32	33	32.5
	B3	33	34	33	33.8	34	34.2	32.5	32.4	32
	B4	35.2	36.5	35	46.8	47	47	39.5	40	39.8
	B5	34	34	34	44.8	45	45	38	38	38
	B6	32	33	33	43	43	43	37	37	37
72	B1	30.3	31	30.4	32	32	32	32	31.5	32
	B2	31.8	32	31.3	31.8	32	31.8	31.4	32.5	32
	B3	30.5	31	30	32	32	31.8	32	32	31.5
	B4	33.2	33.5	33	45.5	45	45	42	42	41.8
	B5	33	34	32.8	40.2	41.4	40.3	39.5	39	38
	B6	31.2	32.2	32	39.5	40	39.5	37	37.5	37
96	B1	29	29	29	30	31	31	31.8	31.2	32
	B2	29.8	30	29	30	30	30	31	31	31
	B3	29.5	29	28	29.8	29.9	29.8	29.8	30.2	30
	B4	29	30.5	29	41	41.2	40.5	39	39	38.5
	B5	28.8	29.6	28.5	41.5	42	41.7	38	37.5	37.5
	B6	29	29	28.8	40	40	40	36.8	37.5	36.5
120	B1	29.8	29.8	29.5	30.2	30	30	31.5	31.2	32
	B2	29.8	30	29.5	30	30	29.9	31	31	31
	B3	29	29	29	30.4	30	29.5	31	30.5	31
	B4	Nil								
	B5									
	B6									

Temperature in ^{o}C

P1-Position 1

P2-Position 2

P3-Position 3

B1,B2,B3-Bamboo trays in open condition

B4,B5,B6- Bamboo trays inside polyhouse

Table A.3 Temperature readings in heap in open condition and inside polyhouse

HOUR	HEAP	MORNING			AFTERNOON			EVENING		
		P1	P2	P3	P1	P2	P3	P1	P2	P3
24	H1	36	36	37	39.8	41	39	41	41.2	42
	H2	33	32	34.5	45	44	44.2	45.2	44	45
48	H1	40.8	41.5	39	40.5	41	40.2	37	37	37
	H2	40	40	40.8	48	46	47.8	43	42	43
72	H1	40	40	39	38.2	38	38	38.4	39	36
	H2	38.5	39	41	47.5	46	47	45	44	45
96	H1	33	35	29.5	35.5	35.5	35	36	35.5	36
	H2	35.8	35.5	35.9	45	43	44.8	43	43	43
120	H1	37	37	36	34	33.8	34.2	35	36	35
	H2	NIL								

Temperature in ^{o}C

P1-Position 1

P2-Position 2

P3-Position 3

H1-Heap in open condition

H2-Heap inside polyhouse

Table A.4 Temperature variation inside and outside the polyhouse

DAY	TEMPERATURE (°C)					
	OPEN			POLYHOUSE		
	M	A	E	M	A	E
1	26.3	27.2	26.7	26.6	32	28.1
2	25.2	30.2	28.2	25.8	37.3	29.3
3	26.9	28.9	28.8	28.6	36.5	29
4	25.7	29	28.6	27.2	36.3	28.9
5	26.2	28.3	29.6	27.1	34.9	29.8
6	26.3	27.4	29.3	27	34.3	29.2

M-Temperature in the morning

A-Temperature in the afternoon

E-Temperature in the evening

STUDIES ON FEASIBILITY OF COCOA (*Theobroma cacao* L.) FERMENTATION INSIDE A POLYHOUSE

BY

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ANU S RAJ

RESHMA M

ABSTRACT OF PROJECT REPORT

Submitted in partial fulfillment
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In

Agricultural Engineering

Faculty of Agricultural Engineering and Technology
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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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2013

ABSTRACT

Fermentation process is indispensible part of cocoa processing as it is responsible for the development of required flavour precursors. The temperature range of 45-50°C is inevitable for effectiveness of fermentation, which is a major constraint during rainy season. In order to overcome this problem fermentation studies were conducted inside a polyhouse and compared with that of the open conditions. Results of the experiments conducted in this regard revealed that the polyhouse is effective in building up the required temperature for the fermentation. Out of the two methods studied, heap method of fermentation conducted inside the polyhouse was found to be more appealing than the tray methods (bamboo and plastic) in both open and polyhouse condition. Also, quality analysis of the fermented beans showed a more positive result for the polyhouse condition than the open one.