DEVELOPMENT AND EVALUATION OF A CONTINUOUS COCOA POD BREAKER

by

SRIKANTH VANKAYALAPATI

Department of Food and Agricultural Process Engineering

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679573, MALAPPURAM

KERALA, INDIA

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(2014 – 18 – 119)

THESIS

Submitted in partial fulfillment of the requirement for the degree of

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IN

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Department of Food and Agricultural Process Engineering

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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DECLARATION

I, hereby declare that this thesis entitled **"DEVELOPMENT AND EVALUATION OF A CONTINUOUS COCOA POD BREAKER"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Place: Tavanur **Srikanth Vankayalapati**

Date: **(2014-18-119)**

CERTIFICATE

Certified that this thesis entitled **"DEVELOPMENT AND EVALUATION OF A CONTINUOUS COCOA POD BREAKER"** is a record of research work done independently by **Mr. Srikanth Vankayalapati (2014-18-119)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

Place: Tavanur,

Date:

Dr. Rajesh G.K.
(Major Advisor, Advisory Committee)
Assistant Professor,
Department of Food and Agricultural
Process Engineering,
KCAET, Tavanur

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Srikanth Vankayalapati

Dedicated to
My Beloved
Parents and family

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LIST OF SYMBOLS AND ABBREVIATIONS

^{0}C	-	degree Celsius
%	-	percentage
/	-	per
&	-	and
ANOVA	-	Analysis of variance
AOAC	-	Association of official analytical chemists
CPCRI	-	Central Plantation Crop Research Institute
CV	-	Coefficient of variation
Cfu	-	Colony forming unit
Cfu/ml	-	Colony forming unit per millimeter
cm	-	centimeter
cm^3	-	centimeter cube
D	-	diameter
et al	-	and other
etc	-	etcetera
db	-	dry basis
deg	-	degree
df	-	degrees of freedom
g	-	gram
g/l	-	gram per liter
h	-	hour
H	-	Height
ha	-	hectare
i.e.	-	that is
J	-	joule
K.C.A.E.T	-	Kelappaji College of Agricultural Engineering and Technology
kg	-	kilogram

kg/h	-	kilogram per hour
kgf	-	kilogram force
kg/m^3	-	kilogram per meter cube
kJ	-	kilojoule
kN/m^2	-	kilogram per meter square
kWh	-	kilo Watt hour
L	-	length
m	-	meter
mg	-	milligram
min	-	minute (s)
ml	-	milliliter
mm	-	millimeter
MMT	-	million metric tonnes
MS	-	mean square
MT	-	metric tonnes
N	-	Newton
PROB	-	probability
R	-	radius
RBD	-	randomized block design
rpm	-	revolutions per minute
SD	-	standard deviation
SED	-	standard error deviation
SS	-	sum of square
T	-	temperature
viz.,	-	videlicet (namely)
wb	-	wet basis

CHAPTER I

INTRODUCTION

Cocoa (*Theobroma cacao L.*) is an important plantation crop in the world, belongs to Malvaceae family. It is a tropical crop, grows within 15-20° latitude from equator and is originated in the amazon region of South America. The global production of cocoa during 2014-2015 was 4.2 million metric tons (MMT) from an area of 6.9 million hectares (Mha) (Anon., 2016a). Globally, cocoa are widely cultivated in Africa, Asia and Latin America. Ivory Coast is the largest producer of cocoa in the world, accounting for about 40 per cent of the global production (Anon., 2015a).

Cocoa is the main raw material in the production of chocolates, cosmetics, health drinks, pharmaceuticals etc. It contains about 50 per cent fat, which is useful in the production of candle, ointments, pharmaceutical products, cosmetics etc. (Opeke, 1987). The cocoa bean powder is the raw material for the preparation of chocolates, ice cream, beverages and other confectioneries. 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 world demand for cocoa bean has been steadily increased over recent decades due to the increased world demand for chocolate and chocolate flavoured products. At present, cocoa trees are cultivated globally in more than 40 countries, across an estimated area of 6.9 Mha, producing an annual crop more than 4.2 MMT of dried beans annually (Anon., 2016a).

Cocoa is a commercial plantation crop in India. It is widely grown in south Indian states *viz*., Kerala, Karnataka, Andhra Pradesh and Tamil Nadu. The annual production of cocoa in India during 2014-2015 was 16,050 metric tons (MT) from an area of 78,000 ha. The second largest producer of cocoa in India is Kerala state with an annual production of 6,000 MT from an area of 14,650 ha during 2014-2015 (Anon., 2016b).

India joined in cocoa cultivating countries group during 18th century. M/s. Cadbury India private limited, initiated cocoa as a feasible cash crop in India had started a demonstration farm at Chundale in Wyanad district of Kerala in 1965. During 1970, Mondelez India Foods Private Limited started planting of cocoa on a commercial scale by supplying free planting material and technical knowledge to the farming community. Also, the research activities on cocoa had been started in Central Plantation Crops Research Institute (CPCRI) and Kerala Agricultural University (KAU) during this period (Anon., 2015b). The climatic conditions for cocoa cultivation are conducive in southern and eastern places of India.

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

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

Fermented beans are then subjected to drying. The most cocoa growers follow the traditional drying methods like sun drying and wood-fired dryers and the drying temperature is 40-60°C. Dried bean quality gets deteriorated, due to substandard fermentations. The development of mould attack during storage process depends on the rate of drying process, storage condition such as relative humidity, temperature and packaging material of dried cocoa (Renaud, 1954).

At present the process of breaking cocoa pods is done manually and crudely by the use of wood and cutlass. This is an arduous task, apart from the large labour requirement and time consumed during the operation. The cutlass damages the beans, resulting to increase losses and reduce profit. The strenuous task causes the frequent weakness and sickness of the labour and farmer resulting in low standard of their health (Vejesit and Salohkhe, 2004). Cocoa pod breaking and bean separation are done manually and need more labour. Manual chopping could increase the number of damage beans resulting in fungal attack (Wood and Lass, 1985).

In recent years, few researches have been carried out to develop a mechanical cocoa pod breaker. The mechanical method of breaking cocoa pods will reduce fatigue of the farmers and the labours and thereby encouraging people to be engaged in cocoa cultivation. Also the losses usually occur during the manual breaking of the pods with wood and cutlass will be reduced which enhances income for the farmers. The time required in breaking pods using the manual method will be reduced by mechanical method. The saved time can be used to perform another form of operation thereby increasing production. The large requirement of labour during manual method results in high cost of production due to wage and problem of supervision and the mechanical method could reduce these expenditures. Considering these benefits, cocoa production and processing must be mechanized and properly improved to increase income and reduce losses.

Considering the above facts, a study had been undertaken on **"Development and Evaluation of a Continuous Cocoa Pod Breaker"** with the following objectives:

1. To develop a continuous cocoa pod breaker
2. To optimize the process parameters of the developed cocoa pod breaker.
3. To conduct performance evaluation of cocoa pod breaker in terms of capacity and efficiency.
4. To conduct fermentation studies of extracted cocoa beans.

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, cocoa pod breaker and fermentation techniques.

2.1. Coca Production and Biochemical Composition

2.1.1 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 after the 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.

2.1.2 History

The cocoa tree is native to the 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., 2015a).

2.1.3. 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 in 2014-2015 was 4.2 MMT.

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, Out of which Kerala account for 18.7 per cent of area and 37.4 per cent of total 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).

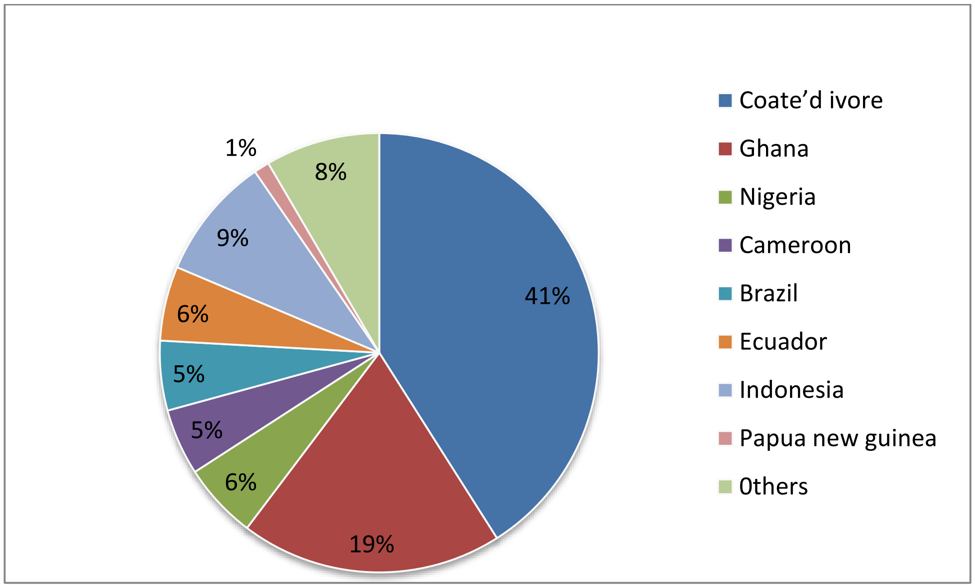


Fig 2.1. World cocoa production (%) in 2014-15

Source*:* Anon., 2016a

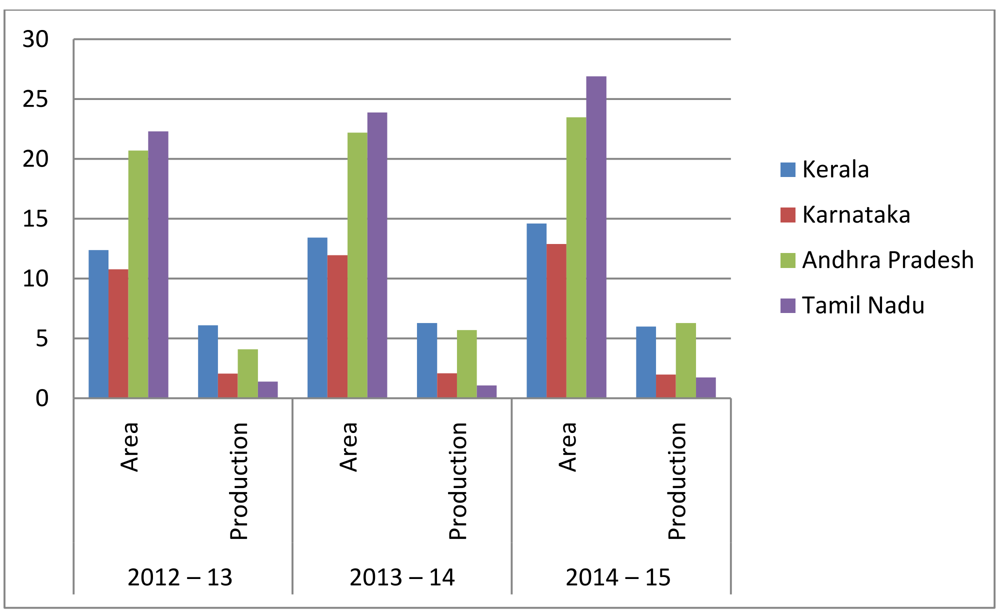


Fig 2.2. State wise production of cocoa in India (in '000ha; '000T)

Source: Indian Horticultural Database 2015

2.1.4. Varieties of cocoa

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

2.1.4.1. 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.

2.1.4.2. Forastero

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

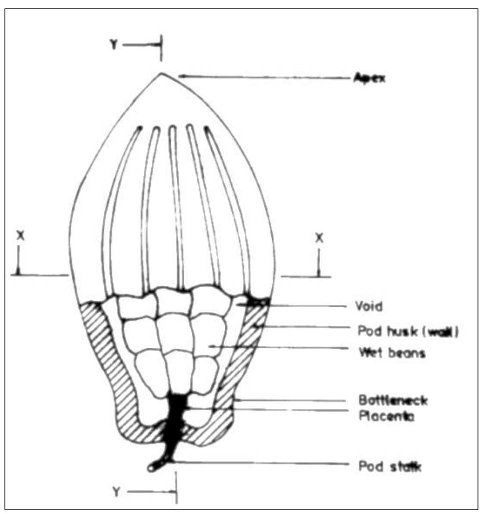
2.1.4.3. Trinitario

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.

2.1.5. 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. Cocoa bean is encompassed by mucilaginous pulp. The number of beans per pod ranges between 30 and 40. Bean consists of two convoluted cotyledons and a germ, all enclosed in the testa. The colour of the cotyledon varies from white to purple (Adzimah and Asian, 2010). The schematic diagram of cocoa pod is shown in Fig. 2.3.



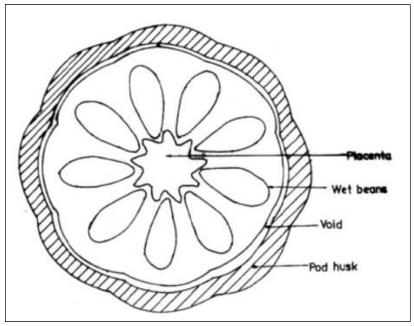


Fig. 2.3. Geometry of cocoa pod

Source: Fabunmi, (2004)

2.1.6. Biochemical composition of cocoa pod husk, shell and beans.

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/100 g. The ash content values ranged from 3.37±0.10 to 3.86±0.05 g/100 g. The fat content values ranged from 47.27±0.14 to 54.21±0.58 g/100 g with an average of 51.51±0.18 g/100 g 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/100 g.

Cocoa pulp is a rich medium for microbial growth. It consists of 82-87 per cent water, 10-15 per cent sugar, 2-3 per cent pentosans, 1-3 per cent citric acid and 1-1.58 per cent pectin. Proteins, amino acids, vitamins (mainly vitamin C) and minerals are also present (Schwan and Wheals, 2004).

Oddoye *et al*. (2010) used fresh cocoa pod husk as an ingredient in the diets of growing pigs and concluded that feeding fresh (wet) cocoa pod husk to growing pigs, up to 300 g/kg (dry weight basis) of the diet had no deleterious effects on the pigs. The proximate analysis for the fresh cocoa pod husk is presented in Table 2.1.

Table 2.1. Proximate analysis of fresh cocoa pod husk

Components	Content
Dry matter (g/kg)	130
Organic matter, g/kg DM (dry mater)	938
Crude protein, g/kg DM	78
Ether extract, g/kg DM	19
Crude fibre, g/kg DM	179
Nitrogen-free extract, g/kg DM	565
Calcium, g/kg DM	8.0
Phosphorous, g/kg DM	4.1

Source: Oddoye *et al*. (2010)

The total phenolic compound content, proximate compositions and biological activity of cocoa bean shell was evaluated by Atindana *et al*. (2012). The dietary fiber, protein, fat, polyphenols and moisture present in cocoa bean shell were 50, 16.93, 6.87, 4.85 and 3.73 per cent, respectively. Due to higher dietary fiber content, it has wide applications in confectionery, bakery or in the preparation of low fat, high fiber dietetic products.

The proximate analysis of pulp and seed of fresh cocoa beans as determined by various researchers are consolidated and given in Table 2.2.

Table 2.2. Proximate analysis of fresh cocoa beans (pulp and seed)

Component	**Average concentration (per cent 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)

2.2 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).

2.2.1 Physical properties

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

2.2.1.1. 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 pod (Mohsenin, 1986).

Alamilla *et al.* (2012) conducted the physical properties of criollo variety of cocoa. The average pod length and width was 18.57 and 8.75 cm, respectively. The average number of seeds per pod was 37.

Adewumi and Fatusin (2006) classified the cocoa pods into small (50-64 mm), medium (65-80 mm) and big (81-96 mm) sizes according to the dimension of their mid diameters.

Bamgboye and Ojoh (2004) determined engineering properties of amazon fresh cocoa pods at average moisture content of 77.9 per cent (wb). The length and diameter of cocoa pod were 153.7 mm and 76 mm, respectively. The average thickness of husk at the furrow was 9.2 mm and 12.2 mm at the ridge.

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 3.40-6.81 mm, respectively.

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

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

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

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

2.2.1.2. Shape

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

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

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

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

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

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

2.2.1.3. Mass and Volume

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

Bamgboye and Ojoh (2004) reported that the average weight and volume of Amazon cocoa pod as 406 g and 517 cm^3, respectively.

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

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

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

Table 2.3. Average and percentage mass of various components of wet and dry cocoa pod

Parameter	**Amezonia**	**Amelonado**	**Hybrid**
Average mass of cocoa pod (kg)	0.40	0.37	0.48
Parts of wet cocoa pods (%)			
Beans with pulp	3	24.93	30.21
Placenta	27	0.56	3.12
Husk	70	74.51	66.67
Parts of dry cocoa pods (%)			
Beans with pulp	7.5	10.08	15.21
Placenta	0.5	0.57	0.56
Husk	19	14.29	10.83

Source: Adzimah and Asiam (2010)

Table 2.3 shows that the mass of cocoa pod is maximum for hybrid variety than the Amezonia and Amelonado. It may be due to the higher quantity of beans per pod in hybrid variety. Still the percentage husk of hybrid variety was lower than the other two varieties. Also, the hybrid variety continues to bear fruits throughout the year while the other varieties bear only in the peak season. Hence most farmers prefer the hybrid variety.

2.2.1.4. True density, bulk density and porosity

The average bulk density and mass density of the Amazon cocoa pod was 456.6 kg/m^3 and 793.4 kg/ m^3, respectively. (Bamgboye and Ojoh, 2004).

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.

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

The average bulk density, true density and porosity of kiwi fruits ranged from 374.5 to 397.7 kg/ m^3, 1014.6 to 1047.8 kg/ m^3 and 63.2 to 61.1 per cent at different physiological maturity levels and ripening period, respectively (Cangi *et al.,* 2011)

2.2.2. Mechanical properties:

2.2.2.1. Compression test

Bamgboye and ojoh (2004) conducted the impact and uni-axial compression tests on cocoa pods along lateral and longitudinal axis. The mean values for the minimum impact load and rupture energy were 2.27 kN and 5.14 kJ for loading along the lateral axis and 2.42 kN and 8.1 kJ along the longitudinal axis. The mean values of maximum compression rupture and toughness are 1.38 kN and 5.44 kJ for compression along the lateral axis and 1.95 kN and 24.23 kJ along the longitudinal axis. The average stiffness modulus was 124.5 kN/m.

The crushing load of Egyptian onion cultivars increased with the increase in onion bulb size for all cultivars. For all sizes of white onion, the average crushing load ranged from 443.3 to 819.7 N. This range was from 341.4 to 980.7 N for the red onion and from 400 to 780 N for the yellow onion. There were no significant differences among the cultivars in the resistance to penetration. The lowest penetration load was recorded for the white onion cultivars (29.7 N) and the highest for the yellow onion (45 N) (Bahnasawy *et al*., 2004).

Adewumi and Fatusin (2006) developed a manually operated impact-type machine for breaking cocoa pods. Impact energy of 30.9 J is required to break one pod while 78.6 J is required five pods at a time. The total load on the pulley shaft was 143.52 N.

The mechanical properties of fresh dura and tenera varieties of oil palm fruits were evaluated by Owolarafe *et al*. (2007). The mean values of cracking force as well as pressure required to break for dura and tenera varieties of oil palm fruits were 2301 N, 1149 N and 5.79 N/mm^2 and 2.00 N/mm^2, respectively.

Zare *et al*. (2012) investigated the mechanical properties of Russian olive fruit. The mean rupture force, deformation, energy absorbed and hardness of Russian olive fruit were 15.45 N, 3.85 mm, 5.01 N-mm and 19.10 N/mm, respectively.

2.2.3. Frictional properties:

2.2.3.1. 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.

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

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

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

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

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

2.2.3.2. 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).

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

Akaaimo and Raji (2006) measured the angle of repose values of *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. Equipment for cocoa pod breaking.

Traditionally the process of breaking cocoa pods is done manually using woods and cutlass. This is an arduous task, apart from the large labour requirement and more time consumed during the operation. The cutlass damages the beans results into damaged beans. This makes some of the beans unsuitable for fermentation causing losses (Bamgboye 2003). Also, the man-hours required for this manual operation vary and depend on the crop factors such as variety and workers attitude and supervision (Opeke, 1987).

The beans are extracted from cocoa pod by breaking the pods manually or mechanically. The engineering properties employed for the design and development of cocoa pod breaker are compressive, impact or shearing forces (Audu *et al*., 2004; Vejesit and Salohkhe, 2004; Adewumi *et al.*, 2006). Jabagun (1965) reported that the first cocoa pod breaker in Nigeria was constructed at the Cocoa Research Institute of Nigeria (CRIN).

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. Schematic diagram of cocoa pod breaking machine is shown in Fig. 2.4.

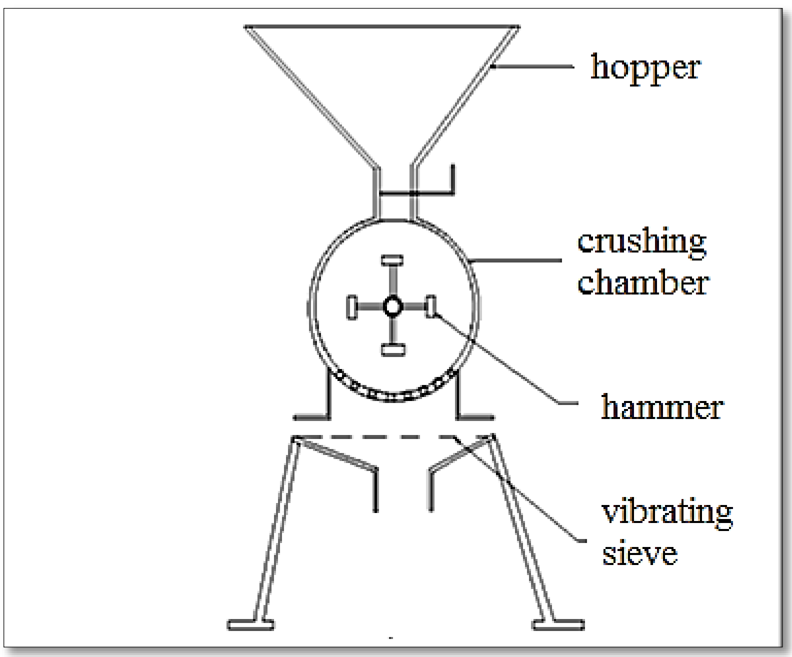


Fig 2.4. Cocoa pod braking machine

Source: M/s Christy and Norris Limited of England 1974

Adewuni and Fatusin (2006) developed a manually operated impact-type machine for breaking the cocoa pods. The major components of the machine include a frame, rail hammer, pulley, bearings and rope. The machine requires a shaft diameter of 14.6 mm, the power requirement of the machine was 201.6 W. The minimum of 0.34 per cent seed damage 738 kg/h capacity and 100 per cent efficiency were recorded for two big pods of cocoa loaded at once.

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.

2.4. Fermentation of Cocoa Beans

2.4.1. Fermentation process

Microbial fermentation followed by drying is required to initiate the fermentation of the precursors of cocoa flavor (Lopez and Dimick, 1995). Harvested seeds are immediately allowed to undergo a natural fermentation during which microbial action on the mucilaginous pulp produces ethanol and acids as well as liberate heat.

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. Earlier studies on the microbiology of cocoa bean fermentation have shown that both yeasts, filamentous fungi, lactic acid bacteria, acetic acid bacteria and bacillus species might contribute to the fermentation (Ardhana and Fleet, 2003).

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

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

The common methods of fermentation followed by cocoa growers are box, basket, heap and tray fermentations (Lehrain and Patterson, 1983). The bottom of the fermenting container has provided holes to allow drainage of the drippings from the pulp. The fermentation period depends on the type of cocoa being fermented. The fermentation period for *Criollo* and *Forastero* variety of cocoa is 3 to 4 days and 5 to 8 days, respectively. (Lopez and Dimick, 1995; Biehl and Ziegleder, 2003).

2.4.2. Microbial fermentation

The microbial succession in the fermentation process has been clearly established. Early on in the fermentation; several species of yeasts proliferate, leading to production of ethanol and secretion of pectinolytic enzymes. This is followed by a phase in which bacteria appear, principally lactic-acid bacteria and acetic-acid bacteria, which is followed by growth of aerobic spore-forming bacteria. Finally, some filamentous fungi may appear on the surface (Schwan and Wheals, 2004).

Majority of flavor compounds in cocoa are formed due to biochemical and enzymatic reactions that occur within the cotyledon. The major role of microorganisms is to produce acids and alcohols that will penetrate the testa and start the chemical reactions that will form the precursors of chocolate flavor. There is no evidence that enzymes inside the beans are activated by microbial metabolites such as acetic acid (Voig *et al.*, 1994).

2.4.2.1. Yeast

Yeasts have been isolated from cocoa fermentations by many groups (Lehrian and Patterson, 1983). Based on shell content, nib color and chocolate sensory criteria, the yeast growth and activity are essential for successful cocoa bean fermentation. Inhibition of yeast growth leads to the increased shell content, the absence of ethanol, higher alcohol and ester production throughout fermentation and lesser presence of pyrazines in the roasted product (Graham *et al.*, 2014). In 2004 Schwan and Wheals reported yeasts dominate the fermentation during the first 24 h and plays following important roles:

i. Ethanol production
ii. Breakdown of citric acid
iii. Production of organic acids
iv. Production of volatiles
v. Production of pectinolytic enzyme
vi. Yeast varieties

2.4.2.2. Bacteria

More than 30 different species of bacteria have been isolated during fermentations (Ostavar and Keeney, 1973, Passos *et al.*, 1984)

2.4.2.3. Filamentous fungi

Filamentous fungi are not considered to be an important part of the microbial succession of cocoa fermentation. They have been found quite often, however, in the well-aerated parts of the fermenting mass and during the drying process. It is likely that they may cause hydrolysis of some of the pulp and even the testa of the seeds; they may also produce acids or impart off-flavors to the beans. Although the numbers were small, a great diversity of species was seen in the first 44 h fermentation. There after *Aspergillus Fumigatus* and *Mucorracemous* dominated the fungal population up to the end of fermentation. Most of these fungi are reported to be unable to grow at temperature higher than 45°C, but they have been isolated when the temperature of the fermenting mass was around 50°C (Schwan and Wheals, 2004).

2.4.3. Methods of fermentation

The manner of cocoa fermentation varies considerably from region to region. Many traditional methods of cocoa fermentation such fermentation conducted in banana leaves lined holes in the ground or fermentation of cocoa in the basket or boxes have been performed. Beans are applied in either heaps, boxes, trays or small basket, covered with plantain leaves and left to ferment for 5-7 days (Fowler, 1999).

In cocoa fermentation could be classified into five categories *viz*., fermentation on drying platforms, fermentation in heaps, fermentation in basket, fermentation in trays and fermentation in boxes (Lopez and Dimik, 1995).

2.4.3.1 Box fermentation

Fresh cocoa beans were put in 1×1.2×1 m high wooden boxes covered with jute gunny and subjected to fermentation for assumed 160 h. During this process, cocoa bean mass was mixed for aeration by transferring the material from one wooden box to another after approximately 24, 48, 96 and 144 h. Samples about 20 beans were taken at 8 h interval from different points, approximately 30 cm from the walls and 4 cm from the upper surface, using a sterile dipper. The cocoa bean samples were immediately transferred to Erlenmeyer with 20 ml of peptone water (0.1 %) and sand previously autoclaved (Passos *et al*., 1984).

Galvez *et al.* (2007) carried out natural fermentation with 100 kg of fresh cocoa per trial, in wooden boxes measuring 60×60×60 cm. Fermentation was conceded over 6 days, stirring after 24, 48 and 96 h. The three fermentation methods were monitored by taking random bean samples from different zones in the mass of cocoa, so as to obtain 100 kg samples for microbiological analysis, or 800 g samples for biochemical analysis.

Ardhana and Fleet (2003) performed fermentation operation at three estates in east in Java. Beans of the *Forastero* cultivar were used at estate A and beans of the *Trinitario* cultivar were used at estates B and C. At each fermentation, the beans (1000 kg approximately) were placed in wooden boxes (150-200 cm long×100 cm wide×25-100 cm deep) where natural fermentation developed. After 12-16 h, the beans were mixed by transferring them to another box. Such transfers were repeated for every 20-24 h until fermentation was complete, which was 6 days for estate A and 4 days for estates B and C. The wooden boxes were not cleaned between operations, and contained holes drilled in the base and sides to allow drainage of liquid (sweating) generated by the fermentation.

Campos *et al.* (2011) carried out natural fermentation process with 1000 kg of raw material (cocoa beans plus surrounding mucilaginous pulp), in batteries of wooden boxes of 1 m^3 capacity, at environmental temperature for 8 days. The cocoa beans were manually forming up moving the total mass from one box to other box once per day, to ensure aeration and uniform fermentation. Afterwards cocoa beans were placed on a concrete floor in layers 5 to 10 cm thick and they were exposed to sun drying. The beans were mixed manually every day to obtain uniform drying for five days.

2.4.3.2. Heap fermentation

Tomlins *et al.* (1993) carried out a total of 12 experiments cocoa fermentation at the Cocoa Research Institute of Ghana (CRIG). The fermentation was varied by cultivar (Amelonado, Upper Amazon, Tafo Series II Hybride) post-harvest pod storage (1-7days) fermentation method (heap, box) and drying method (sun, mechanical). Traditional plantain leaf covered heap fermentation was carried out in the field close to where the pods were harvested. Each fermentation process comprised between 5000 and 8000 pods. The duration of each fermentation was 6 days, the beans being turned to achieve thorough mixing, on the second and forth days. At the completion of each fermentation process, the beans were divided into two portions, one of which was sun dried and the other mechanically dried.

Cocoa pods from mixed hybrid cocoa tree plantations (*Criollo* and *Forastero*) were harvested and used for fermentation within 2 to 3 days. Only matured pods were used for fermentation. Approximately 250 to 1000 kg of wet beans and pulp were placed on banana leaves on the ground for fermentation, resulting in heaps of 95 to 180 cm diameter and 40 to 64 cm. The entire fermentation lasted 6 days. The drainage of liquid produced during fermentation (sweating) was allowed to penetrate in to the ground. Drying of the fermented cocoa beans took around 10 to 14 days depending up on the weather and resulted in amount of 33 to 200 kg of dried beans (Camu *et al*., 2007).

Cocoa pods, mostly from *Criollo* and *Forastero* hybrid cocoa trees, were harvested by traditional method and opened within one to three days. In Ivory Coast, one heap and one box fermentation were performed at the same farm, with cocoa pods harvested from the plantation of that farm and carefully selected while opening. For the heap fermentation, 150 kg of fresh cocoa pulp bean mass was piled into a heap onto plantain leaves laid on the ground and the heap was covered with additional plantain leaves. For the box fermentation, 1200 kg of fresh cocoa pulp bean mass was placed in a wooden box (1 m^3) and covered with plantain leaves and jute sacks. During all fermentations, 500 g samples were taken at the start of the fermentation (0 h) and after every 6 h interval till 144 h of fermentation. Temperature and pH of the fermenting cocoa pulp bean mass were measured at the sampling times. The environmental temperature was measured online with temperature recorders. Natural sun drying of the fermented cocoa beans was carried out on cane platforms for between five and ten days, depending on the weather conditions, and samples were taken at the end of the drying process (Papalexandratoua *et al*., 2011).

2.4.3.3. Tray fermentation

Cocoa Research Institute of Ghana (CRIG) has developed the tray fermentation system. The cocoa beans are fermented in 10 cm deep wooden tray covered with banana or plantain leaves. 8-10 trays are stacked on top of each other. Air is allowed to circulate between beans in the trays without having to turn. (Allison and Rohan, 1958; Allison and Kenten, 1963).

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.* (2010b) 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°C.

2.4.4. Biochemical changes during fermentation

2.4.4.1. Changes in pulp

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

Various fermentation techniques using rattan basket, plastic bucket, plastic sack and gunny sack 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.

2.4.4.2. Changes in bean

Due to drainage of sweating, the beans lose about 25 per cent of their weight during fermentation. A further loss of 40 per cent is incurred during drying. Normally, the unfermented beans consists of 0.77 per cent germ, 9.63 per cent shell and 89.60 per cent cotyledons while fermented beans have 0.70 per cent germs, 10.74 per cent shell and 88.56 per cent 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. The shell gains about 10 per cent 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 per cent 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°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).

Brito *et al*. (2000) studied the structural and chemical changes during cocoa bean fermentation, drying and roasting. They reported that the total phenol, protein, reducing sugar and oligosaccharide content were not having much difference between starting and after 72 h fermentation. Nevertheless, after drying and roasting the levels decreased markedly. Concomitantly, the amino-terminal groups, free amino acids content increased after fermentation and remained during drying but decreased after roasting. The starch content increased after drying and roasting.

Guehi *et al*. (2010a) investigated the influence of time and turning of spontaneous cocoa heap fermentation on quality. They found that the purple bean percentage reduced from 28.17 to 1.17 whereas, the brown bean percentage increased from 63 to 90.5. Also, the defective bean per cent reduced from 8.83 to 7.67. There was no mouldy bean present on 4, 5 and 6th day of fermentation. The acidity value decreased with fermentation time. The total filamentous fungi population became almost constant during fermentation period. The temperature and the pH during fermentation were ranged between 29 to 44.2°C and 3.6 to 8.5, respectively.

Microbial and chemical changes in cocoa need to be studied simultaneously since they are, measure of cause and effect, respectively. Samah *et al.* (1993) reported the changes in microbial population, with respect to some of the products formed during cocoa fermentation of post-harvest stored cocoa beans. The pH of the beans markedly increased on the fifth and sixth day of fermentation, reaching a maximum of 5.35. The major acids produced were also detected. Maximum concentrations of acetic and lactic acids produced during fermentation were 140 mg/10 g and 45 mg/10 g on wet weight basis of beans respectively. Cut-test studies on beans fermented for 6 days indicated 45 per cent brown beans.

2.5. 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 (Schoreter *et al*., 2006).

Aroma formation begins with fermentation of the pulp surrounding the beans which contains mainly sugars. The primary flavour compounds undoubtedly are 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).

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).

2.5.1. 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.*, (2010a) 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.

Chapter III

MATERIALS AND METHODS

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

3.1. Raw Materials

Matured cocoa fruit (*Theobroma cacao L.*) were procured from M/s Cadbury unit of Kerala Agricultural University and from a progressive farmer at Karuvarakundu, Malappuram district. Materials for the construction of machine were purchased from Coimbatore. Good quality cocoa pods after sorted out from cracked ones were used in this study. Pods having cracks or skin injuries and disease were rejected. Harvested pods were collected in gunny bags and transported to the laboratory with care. In the laboratory, pods were stored at ambient condition (Temperature 27-30°C and Relative humidity 65-67%) for conducting the experiment.

3.2. Determination of Engineering Properties of Cocoa Pods

Prior to the development of cocoa pod breaker, the physical, mechanical and frictional properties of cocoa pod were studied. Engineering properties of cocoa pods such as mass, size, shape, sphericity, volume, density and moisture content were determined by standard methods as explained in the following section. Frictional parameters, such as rolling angle and angle of repose were also determined.

3.2.1. Physical properties of cocoa pod

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

3.2.1.1. Moisture content of cocoa pod and beans

Moisture content of cocoa pods and beans was determined as per AOAC (1984) method by placing samples of 5 g of fresh cocoa pod (whole pod in case of pod moisture content) in a ventilated hot air oven at 105±2°C and dried to constant weight, which took about 10 h. The same procedure was followed for the determination of moisture content of whole cocoa beans. The moisture content expressed as percentage wet basis (wb). The experiments were replicated three times and the average value was reported.

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

Where,

W_i - initial weight of the husk, g

W_d - dry weight of the husk, g

3.2.1.2. Determination of size of cocoa pod

Size refers to the characteristic of an object which determines the space requirement and it is expressed in terms of length and width. 10 numbers of whole matured cocoa pods were selected at random for the determination of the size. A digital vernier caliper was used to measure the diameter as well as pod thickness with a least count of 0.01 cm. The length and longitudinal axis of cocoa pod were measured along its longitudinal axis and lateral axis, respectively using a height gauge. (Maduako and Faborode, 1994).

The geometric mean diameter (D_{gm}) of the pod was computed using the equation mentioned by Sharifi *et al.* (2007)

$$D_{gm} = \sqrt[3]{LD^2} \qquad \text{... (3.2)}$$

Where,

L - Length of the pod, mm

D - Diameter of the pod, mm.

3.2.1.3. Determination of mass of cocoa pod

The mass of individual pod, seed and husk were determined by selecting 15 numbers of samples 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 of cocoa pod

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) and aspect ratio (R_a). The sphericity (ϕ) is determined by the formula given below.

$$\Phi = \frac{\sqrt[3]{LD^2}}{L} \qquad \ldots (3.3)$$

The aspect ratio (R_a) is also used to express the shape of a material. It is ratio of width to length of pod. (Maduako and Faborode, 1990).

$$R_a = \frac{D}{L} \qquad \ldots (3.4)$$

Where,

L - Length of the pod, mm

D - Diameter of the pod, mm.

3.2.1.5. Determination of volume of cocoa pod

Volume of the cocoa pod was determined by platform scale method (Mohsenin, 1986). The cocoa pod was completely submerged in water using the sinker rod without touching the sides or bottom of the beaker by the pods. Volume was calculated as the ratio of the weight of water displaced by the solid sample to weight density of water.

$$\text{Volume of cocoa pod, } (m^3) = \frac{\text{Weight of displaced water (kg)}}{\text{Density of water, } (\text{kg m}^{-3})} \qquad \ldots (3.5)$$

3.2.1.6. Determination of true and bulk density of cocoa pod

The true density of the cocoa pod was determined by the water displacement technique (Dutta *et al.*, 1988). Ten numbers of randomly selected cocoa pods were weighed individually and immersed in water in a measuring cylinder and ensured that the cocoa pod was completely submerged during immersion in water. The volume of water displaced by each pod was recorded and the true density was calculated using the following equation:

$$\text{True density, } (\text{kg/m}^3) = \frac{\text{Mass of cocoa pod, (kg)}}{\text{volume of cocoa pod, } (m^3)} \qquad \ldots (3.6)$$

The bulk density of cocoa pod was assessed using an empty carton box of 300×185×120 mm having an internal volume of 6660 cm^3. The box was filled with cocoa pods and the bulk weight was measured. The bulk density was calculated using the formula given below. The experiment was replicated 10 times and the mean value was recorded.

$$\text{Bulk density, } (\text{kg/m}^3) = \frac{\text{weight of cocoa pods, (kg)}}{\text{volume of container, } (m^3)} \qquad \ldots (3.7)$$

3.2.1.7. Determination of porosity of cocoa pod

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

$$\text{Porosity} = \frac{\text{True density - Bulk density}}{\text{True density}} \times 100 \qquad \ldots (3.8)$$

3.2.2. Mechanical properties

3.2.2.1. Compression test

Compression test was conducted to determine the force required to break the cocoa pod. The test carried out using Universal testing machine (UTM). By properly aligning the specimens with respect to the compressing unit, it was ensured that a truly axial load was applied so that bending stresses were not set up. Each pod was compressed between two parallel plates at the rate of 5 mm/min and the readings were recorded. 10 cocoa pods were selected randomly and compressed by two loading orientations *viz*., laterally and longitudinally (Aviara *et al.,* 2007). Experiments were carried out in triplicates and mean values reported were taken.

3.2.3. Friction properties

3.2.3.1. Coefficient of friction

Coefficient of friction is defined as the frictional force acting between the surface of contact and sample at rest. It is the ratio of the force required to slide the pods over a surface to the normal force applied by the pods against the surface. Coefficients of friction experiments were done for cocoa pods using four surfaces *viz*., stainless steel, galvanized iron, aluminum and plywood. The apparatus used for the determination of coefficient of friction of cocoa pod consists of a frictionless pulley fitted on a frame or bottomless hollow cylinder, a loading pan and test surface. The cocoa was tied at one end using a thread and placed on the test surface and weight was added on loading pan until the cocoa pod began to slide. The weight of the pod and the weight added on loading pan represents the normal force (N) and lateral force (F), respectively (Sahay and Singh, 2010). The coefficient of static friction was calculated as given below

$$\text{Coefficient of Friction} = \frac{\text{Frictional force, (Kg)}}{\text{Normal force, (Kg)}} \quad \ldots (3.9)$$

3.2.3.2. Angle of repose

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

$$\theta = \tan^{-1}\frac{H}{R} \qquad \ldots (3.10)$$

Where,

H - height of cone (cm)

R - radius of cone (cm)

3.3. Development of Cocoa Pod Breaker cum Bean Extractor

Cocoa pod breaker cum beans extractor was developed and fabricated in the Kelappaji College of Agricultural Engineering and Technology, Tavanur Workshop. It consists of the following parts.

a. Hopper
b. Metallic rollers
c. Chute
d. Rotating cylindrical strainers
e. Frame
f. Prime mover and pulleys.

3.3.1. Cocoa pod breaker

3.3.1.1. Hopper

It is one of the important components of the machine. It helps to feed the cocoa to the roller assembly. The dimension of the hopper was optimized based on the length and diameter of the cocoa. The hopper is made of 2 mm thick mild steel sheet with 45° inclination towards the horizontal to facilitate easy feeding. It is rectangular in shape and is mounted over the roller assembly. (Plate 3.1)

3.3.1.2. Discharging chute

Chute is made up of 2 mm thick mild steel sheet with 40° inclinations towards horizontal to facilitate easy discharge. The chute is fixed at the bottom end of the roller assembly. It is attached to the frame using spring assembly for easy discharge. The broken pod slides downward through the chute into the strainer.

3.3.1.3. Frame

The frame supports the entire machine component and it was fabricated using GI square section. The components *viz.*, feeding unit, roller, chute, motor etc. were mounted on the frame.

3.3.1.4. Rollers

Four sets of calendar rollers of dimension 30 cm length and 8 cm diameter were used for cocoa pod breaking of which two rollers were fixed while other were adjustable. First and third rollers are adjustable while the second and fourth rollers are fixed. The gap between first and second rollers was varied between 80-100 mm. Similarly, the gap between second and third & third and fourth rollers was 60-80 mm and below 60 mm, respectively. Alternate rollers were fixed to rotate in opposite direction at different speeds of 260 rpm, 360 rpm and 460 rpm. The clearance between the rollers was adjustable based on the size of the cocoa pod. (Plate 3.2)

Plate 3.1. Feed hopper

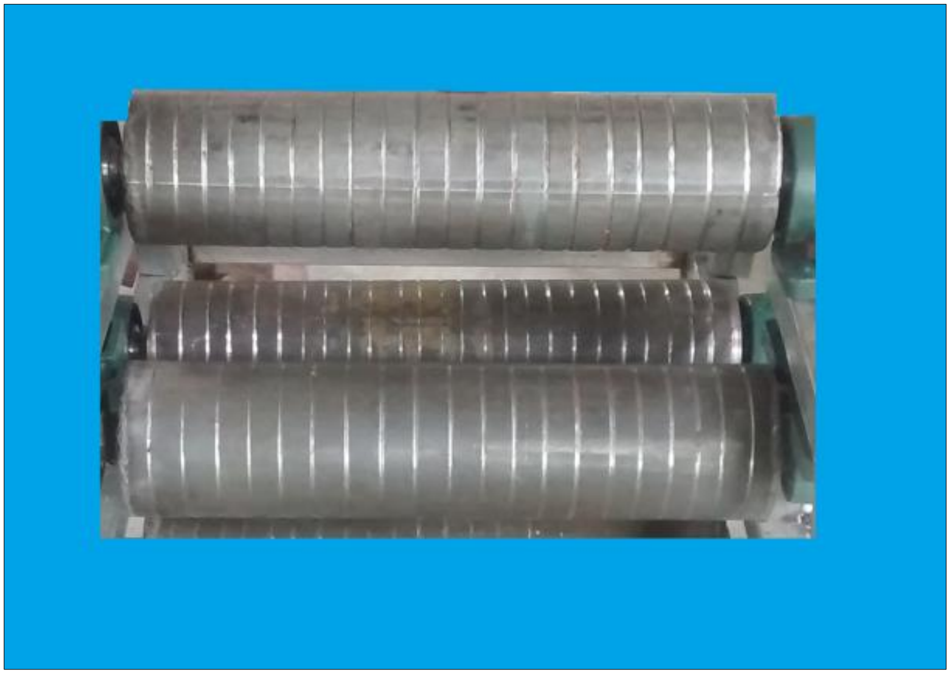


Plate 3.2. Rollers

3.3.1.5. Motor specification and belt assembly

An electric motor of 0.25 hp motor having a speed of 1420 rpm was used as prime mover for operation. The speed of the roller could be changed using belt and pulley arrangement. The diameters of pulley and size of belt used in this study were 25, 20, 15 cm and 127.5, 120, 107.5 cm, respectively.

3.3.2. Bean extraction mechanism

3.3.2.1. Cylindrical drum strainers

Cylindrical drum strainer was fabricated to separate bean from broken pod. It consists of two concentrical or coaxial rotating inclined cylinder mesh made of wire screen mesh. The size of inner and outer square mesh were 2.5 cm and 3.75 cm, respectively. The diameter and length of inner and outer cylinder were 39, 43 cm and 100, 100 cm, respectively. The inclination of strainer used is 40°, 45° and 50°.

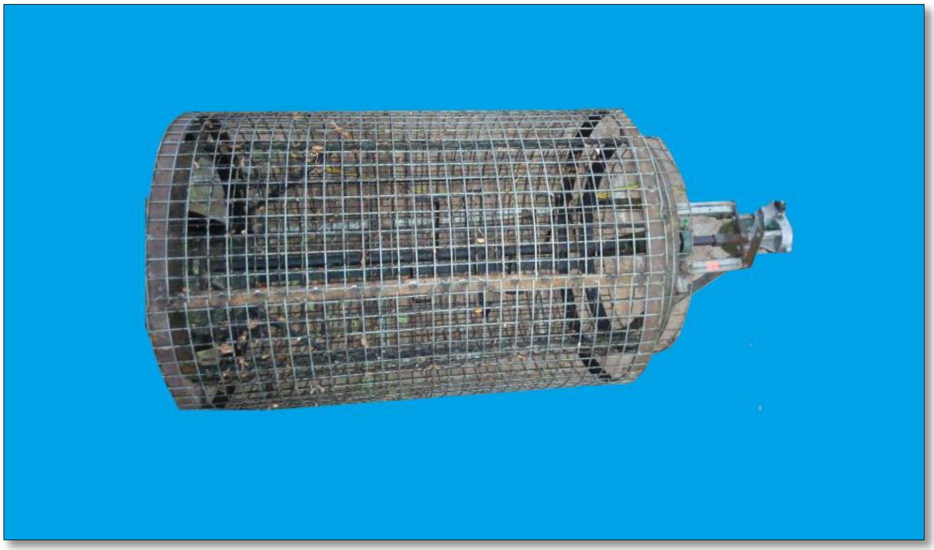


Plate 3.3. Strainer

3.4. Experimental Design

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

3.4.1. Development of cocoa pod breaker

3.4.1.1. Independent variables

- Speed of the rollers (260±10 rpm, 360±10 rpm and 460±10 rpm)
- Size of cocoa pod (<140 mm, 140-170 mm and >170 mm)

3.4.1.2. Dependent variables

- Capacity
- Breaking efficiency of pod breaker
- Energy requirement

3.4.2. Development of cocoa bean extractor

3.4.2.1. Independent variable

- Inclination angle of strainer (40°, 45° and 50°)

3.4.2.2. Dependent variables

- Cocoa beans separation efficiency
- Shelling efficiency
- Percentage of undamaged bean

3.4.3. Fermentation studies of extracted beans

3.4.3.1. Independent variables

- Treatments (T1-T12)
- Fermentation period (D1-D5)

3.4.3.2. Dependent variables

- Temperature
- pH
- Moisture content
- Microbial load

3.4.3. Operation of cocoa pod breaker and beans extractor

3.4.3.1. Pod breaking

Cocoa fruit was fed manually in to breaker unit through hopper. Gap between the rollers was set so as the cocoa kernels were not damaged during the pod breaking process. Tangential force of the roller pushed the cocoa pod towards the gap resulted in breakage. Cocoa pod, kernels and placenta were then discharged to strainer through chute. Rotation of strainer separated the cocoa kernels from cocoa pod and placenta, and passed through the mesh of the strainer. It was then collected and could be directly sent for fermentation process. The broken pods remained above the strainer and got separated.

3.4.3.2. Bean extraction

The broken pods entered into the rotating strainer. Rotation of strainer separated the cocoa beans from cocoa pod and placenta and passed through the pores of the strainer. It was them collected and directly sent to fermentation process. The broken pods spread over the mesh were conveyed due to gravity and got removed at the other end of the strainer.

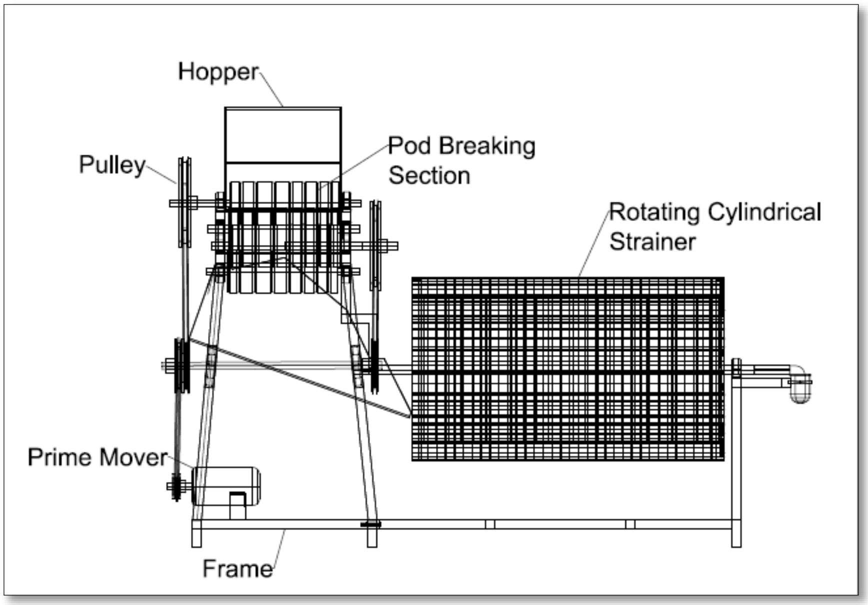


Fig 3.1. Schematic diagram of cocoa pod breaker

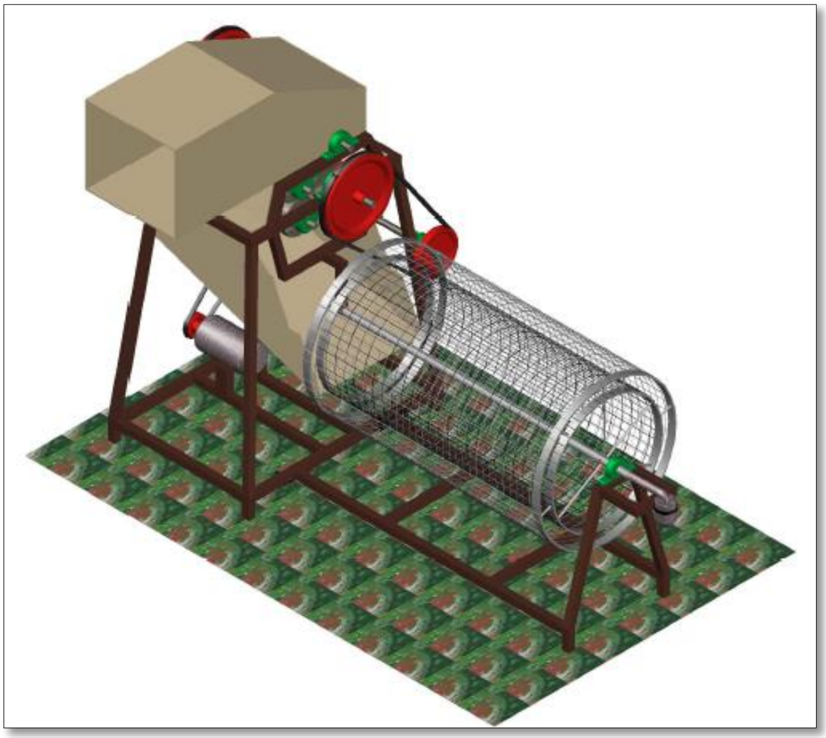


Fig 3.2. Isometric view of cocoa pod breaker

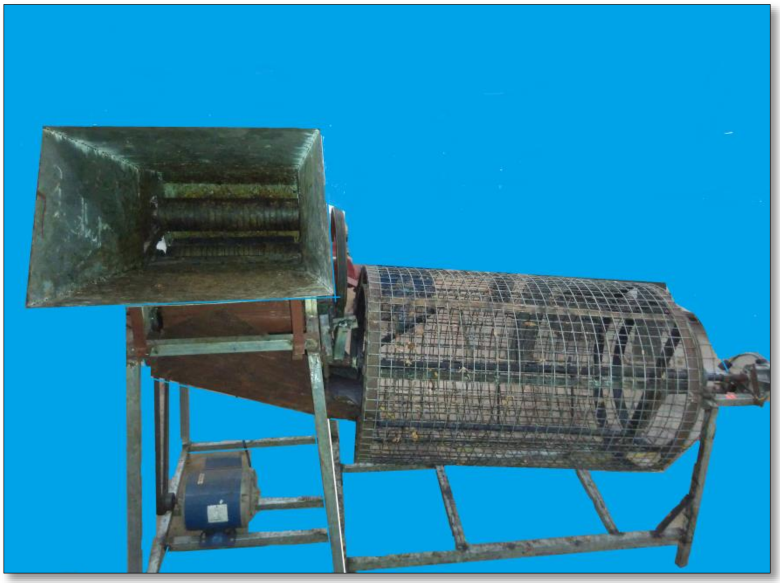


Plate 3.4. Front view of cocoa pod breaker

Plate 3.5. Side view of cocoa pod breaker

3.5. Performance Evaluation of the Machine

Matured cocoa beans procured from Cadbury unit of Kerala Agricultural University were used for conducting the experiment. The gap between the rollers of the machine was adjusted according to medium size cocoa pods. Testing was done at roller speed was 260 rpm, 360 rpm and 460 rpm. Performance of the machine was evaluated in terms of capacity, percent bean damage, and machine efficiency. (Adewumi and Fatusin, 2006).

3.5.1. Capacity

3.5.1.1. Capacity of breaking unit

Capacity is defined as the ratio of total weight of cocoa taken for breaking to the total time taken for breaking. It is expressed in kilogram per hour

$$\text{Capacity (kg/hr)} = \frac{\text{Total weight of cocoa pods fed in to the machine, (kg)}}{\text{Time taken for breaking, (hr)}} \quad \ldots (3.11)$$

The cocoa of different size were weighed separately and the total time taken for extraction was recorded

3.5.2. Breaking efficiency

3.5.2.1. Efficiency of the pod breaker

Efficiency of cocoa pod breaker is the ratio of the number of the broken pod to the total number of cocoa pods taken for breaking

$$\text{Breaking efficiency(\%)} = \frac{\text{Number of broken pods}}{\text{Total number of cocoa pods taken for breaking}} \times 100$$

… (3.12)

3.5.2.2. Bean separation efficiency

Beans separation efficiency is the ratio of total beans recovered to the total bean fed in to the strainer.

$$\text{Beans separation efficiency}(\%) = \frac{X_1}{X_1 + X_2} \times 100 \qquad \ldots (3.13)$$

Where,

X_1= Weight of bean extracted

X_2= Weight of bean remained in the strainer

3.5.2.3. Shelling efficiency

Shelling efficiency is the ratio of weight of pod collected at the foreign matter outlet to the total pod fed in to the strainer.

$$\text{Shelling efficiency}(\%) = \frac{Y_1}{Y_1 + Y_2} \times 100 \qquad \ldots (3.14)$$

Where,

Y_1 = Weight of pod separated in the strainer

Y_2 = Weight of pod mixed with beans

3.5.3. Beans damage percentage

Percent damaged beans are the ratio of number of damaged beans to the total number of bean recovered.

$$\text{Damaged beans }(\%) = \frac{\text{Number of damaged beans}}{\text{Total number of beans extracted}} \times 100 \qquad \ldots (3.15)$$

3.5.4. Energy requirement

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

Energy requirement (kJ) = Power × Time … (3.16)

3.6. Field Trial of the Developed Cocoa Pod Breaker

The field evaluation of the developed machine was done with two cocoa varieties *viz*., *Criollo* and *Foraste*ro of three different sizes-large, medium and small in the farmer's field at Karuvarakundu village in Malappuram district. The performance of the machine was evaluated based on its capacity, per cent bean damage, efficiency of cocoa pod breaker etc. Testing was done at a roller speed and strainer inclination which was already optimized during the lab trial as mentioned in section 3.5. The capacity, per cent bean damage, efficiency of cocoa pod breaker and energy requirement of the machine was calculated as mentioned in the sections 3.5.1.1, 3.5.3, 3.5.2.1 and 3.5.4.

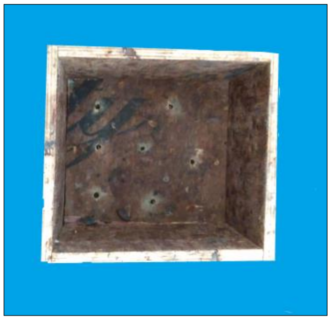
3.7. Bean Fermentation, Sampling and Metabolite Target Analysis

3.7.1. Fermentation studies

The freshly harvested matured cocoa pods procured from the progressive cocoa farmer at Karuvarakundu, Malappuram district. The cocoa pod was opened using the developed cocoa pod breaker. The beans were separated from placenta by using the developed beans extractor. Germinated, black or diseased beans or pieces of shell or placenta fragments were separated from the extracted beans. The sound beans were mixed and divided in to 12 batches for the fermentation experiments, each contain 4 kg beans.

Four methods of fermentation were studied.

1. Fermentation in bamboo baskets
2. Fermentation in heaps, where the beans were placed on plantain leaves placed on the ground.
3. Fermentation in wooden box, where the beans were placed in boxes having dimensions was 21.5 cm × 20 cm × 14 cm
4. Fermentation in plastic tray, where the beans were placed in tray having dimensions was 27.5 cm × 22.5 cm × 6.5 cm



(a)

(b)

(c)

Plate 3.6. Methods of fermentation a) box, b) basket and c) tray

3.7.2. Experimental set up

The wooden box, tray and bamboo baskets were lined with one or two layers of plantain leaves. Fresh beans were loaded in to lined baskets and beans were covered with plantain leaves to prevent any heat and moisture loss during fermentation. The heap was set by spreading one or two layers of plantain leaves on floor then the wet beans are piled on to it. In heap method, the heap of wet cocoa beans was covered with other fresh plantain leaves and gunny bags to insulate the top of heap. The bottom of the wooden box, tray and bamboo baskets facilitated draining acidic liquid resulted from liquefaction of mucilaginous pulp during fermentation.

In order to study the effect of temperature on fermentation, studies were conducted in fermented chamber, poly house and ambient condition. A low tunnel type poly house of length 4 m, breadth 1.5 m and height 1.25 m was set up. It was completely covered using 200 micron polythene sheet. A Fermentation chamber is rectangular chamber made of wood with dimension 1.90 m × 0.85 m × 0.85 m. It consists of a heating unit and drying chamber. Four 100 W electric bulbs placed diagonally 150 mm from the corner of the rectangular chamber act as the heating source. The temperature inside the chamber was regulated by using a thermistor.

Plate 3.7. Fermentation chamber

The experimental treatments were as follows;

T1 = Beans fermented in tray at open condition

T2 = Beans fermented in box at open condition

T3 = Beans fermented in heap at open condition

T4 = Beans fermented in basket at open condition

T5 = Beans fermented in tray at poly house

T6 = Beans fermented in box at poly house

T7 = Beans fermented in heap at poly house

T8 = Beans fermented in basket at poly house

T9 = Beans fermented in tray at fermentation chamber

T10 = Beans fermented in box at fermentation chamber

T11 = Beans fermented in heap at fermentation chamber

T12 = Beans fermented in basket at fermentation chamber

3.7.3. Physico-chemical analysis

Observations were recorded at daily interval on pH, temperature and moisture content of fermenting mass.

3.7.3.1. pH of pulp and bean

Samples were drawn from three different positions (top, center and bottom) of fermenting mass. Cotyledons (10 g) or pulp and testa (5 g) were weighed into a 100 ml blender jar followed by the addition of 90 ml boiling distilled water. After blending for 2 min, the resultant homogenate was filtered through a whatman No. 4 filter paper and 50 ml were collected (Tomlins *et al.,* 1993). Immediately after cooling to 20-25°C, the pH was measured using a digital pH meter (ELICO-612 model), which had been, calibrated with buffers at pH 7 as described by Hii *et al.,* (2009).

3.7.3.2. Temperature profile of the fermenting mass

The ambient temperature and the temperature of the fermented cocoa mass were monitored by inserting an ordinary thermometer (0-60°C range) into the fermenting mass at three different positions. From each position, observations was taken thrice and the average was calculated (Sunilkumar, 2005).

3.7.3.3. Moisture content of fermenting beans

Moisture content was determined in compliance with international standard ISO 2291-1972. The whole cocoa beans drawn at different stages of fermentation were placed in a hot air oven at 105±2°C for 10 h and the moisture content was determined as explained by Lagunes-Galvez *et al.* (2007).

3.7.3.4. Microbial analysis

Samples (5 g) of beans were aseptically scooped from three different zones (top, center and bottom) of the fermenting mass at intervals of 48 h. A sample of 1 g was weighed and transferred aseptically to 10 ml sterile distilled water to get 10^{-1}

dilution and mixed well. From 10^{-1} dilution, 1 ml of aliquote was transferred to another test tube containing 9 ml sterile distilled water to get 10^{-2} dilution. Then this procedure was repeated up to 10^{-6} dilution. For the enumeration of bacteria, yeast and fungi, 1 ml of aliquotes from different dilution were transferred to sterile petriplates and poured with 15-20 ml of appropriate growth media at specified temperature (45-50°C) and gently rotates the plates to get uniform distribution of inoculum and allowed to solidify (Two replicates were kept in each dilution)

Bacteria : Nutrient Agar

Yeasts and Filamentous fungi : Rose Bengal Agar Base

Inoculated agar plates were incubated at room temperature (24-48 h) for bacteria and 3-5 days for yeast and fungi. After incubation, the colonies developed in each petriplate were counted and estimated the colony forming units.

3.8. Cost Economics

The cost of development of the cocoa pod breaker was estimated by considering the fixed and variable cost. The fixed cost was calculated by using the following equation described by Palanisami *et al*., (1997)

Fixed cost of unit/ year = Initial cost of equipment × Capital recovery factor

… (3.17)

$$\text{Capital recovery factor (CRF)} = \frac{R_i \times (1 + R_i)n}{(1 + R_i)n - 1} \quad \text{… (3.18)}$$

Where,

R_i = rate of interest

n = life period of the equipment, years

The variable cost of unit was calculated by considering electricity charges, repairs and maintenance, raw materials and cost of labour.

3.9. Statistical Analysis

The data obtained were statistically analyzed by Randomized Block Design (RBD) using the statistical package AGRES. The analysis of variance (ANOVA) and mean table for different parameters were tabulated and the level of significance was reported.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter deals with results obtained from various experiments conducted to determine the engineering properties of cocoa pod, fermentation techniques of cocoa beans and field evaluation of the continuous cocoa pod breaker.

4.1 Engineering Properties

The results of physical properties *viz.*, size, shape, mass, porosity, volume, aspect ratio, mechanical properties like compressive force and frictional properties like rolling angle, 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 pod breaker, selected physical properties of coca pod *viz.*, moisture content, length, diameter, volume, mass, sphericity, bulk density, true density, porosity and aspect ratio were investigated.

4.1.1.1. Moisture content of cocoa husk and beans

The mean value of moisture content of fresh cocoa husk and beans are presented in Table 4.1. The two varieties cocoa pods, namely *Criollo* and *Forastero* were chosen to test the moisture content. The average moisture content of fresh cocoa husk of *Criollo* and *Forastero* variety was 81.21 per cent (wb) with standard deviation (SD) of 1.88 and 79.45 per cent (wb) with standard deviation of 1.25, respectively. Similarly, the moisture content of fresh cocoa beans of *Criollo* and *Forastero* varieties were 57.66 per cent (wb) with standard deviation of 1.10 and 58.33 per cent (wb) with standard deviation 2.05, respectively.

Table 4.1. Moisture content of two varieties of cocoa husk and beans on wet basis

Sl. No	Particulars	Average moisture content,% (wb)			
		Criollo	SD	*Forastero*	SD
1	Fresh cocoa husk	81.21	1.88	79.45	1.25
2	Fresh cocoa beans	57.66	1.10	58.33	2.05

4.1.1.2. Size of cocoa pod

The two varieties of cocoa pods, *viz.*, *Criollo* and *Forastero* were grouped into small, medium and large size based on their dimensions, with each group containing 10 pods. The classifications of cocoa pods are shown in the Plate 4.1.

The average length of small, medium and large cocoa pod of *Criollo* variety was measured as 124.6±11.12, 159.3±7.19 and 188.55±7.85 mm, respectively. Similarly, for *Forastero* variety cocoa pods, the average lengths were 130.6±9.01, 158.9±8.51 and 187.2±10.17 mm, respectively. The average length of cocoa pod (*Criollo* variety and *Forastero* variety) was calculated as 160.4±24. Adewumi and Fatusin, (2006) reported that the length of cocoa pods ranges between 112.5-202.0 mm.

The average diameter of cocoa pod of *Criollo* variety and *Forastero* variety for small, medium and large pods was measured as 73.19±7.26, 83.44±5.06, 97.01±6.16 mm and 73.70±7.48, 83.32±9.97 and 92.63±7.34 mm, respectively. The average diameter of cocoa pod (*Criollo* variety and *Forastero* variety) was calculated as 78.3±10.70 mm. Adewumi and Fetusin, (2006) reported that the maximum diameter of cocoa pod ranges between 61.6-96.00 mm. The size of cocoa pod is applicable in fixing the gap between the rollers of cocoa pod breaking machine.

Plate 4.1. Classification of cocoa pods

The average geometric mean diameter (D_{gm}) of *Criollo* variety pods for small, medium and large cocoa pods was 87.19±6.11, 103.44±4.50 and 120.95±5.24 mm, respectively. Similarly, the average geometric mean diameter for *Forastero* variety cocoa pods was 89.13±7.75, 103±8.26 and 117.05±7.54 mm, respectively. The size distribution of cocoa pod is given in Table 4.2.

Table 4.2. Size distribution of cocoa pods based on length

Variety	Category	No. of samples	Size range (mm)	Mean	SD
Criollo	Large	10	170-210	188.5	7.85
	Medium	10	140-170	159.3	7.19
	Small	10	110-140	124.6	11.12
Forestreo	Large	10	170-210	187.2	10.17
	Medium	10	140-170	158.9	8.51
	Small	10	110-140	130.6	9.01

4.1.1.3. Shape of cocoa pod

The average sphericity of cocoa pods (*Criollo* variety and *Forastero* variety) is presented in Table 4.3 and Table 4.4. The average sphericity of *Criollo* variety and *Forastero* variety cocoa pods for small, medium and large pods was estimated as 0.70±0.06, 0.65±0.01, 0.64±0.03 and 0.68±0.03, 0.65±0.06, 0.62±0.02, respectively. Similarly, the aspect ratio of *Criollo* variety and *Forastero* variety cocoa pods were 0.59±0.08, 0.52±0.07, 0.51±0.04 and 0.56±0.04, 0.52±0.07, 0.49±0.03, respectively. Abdullah *et al*. (2012) reported that the higher values of sphericity showed that the pod is possible to roll than slide. The shape factor has more practical application in handling operations.

4.1.1.4. Mass of cocoa pod

The average values of mass of pod, seed and husk are presented in Table 4.3 and Table 4.4. From the tables, it is observed that the mass of cocoa pod of *Criollo* variety for small, medium and large cocoa pods were 244.95±40.35, 358.59±63.36 and 630.47.04±104.9 g, respectively. Similarly for *Forastero* variety cocoa pods, the mass of cocoa pods was 254.12±30.19, 304.48±56.16 and 488.34±53.30 g, respectively for small, medium and large pods. The average husk-pod mass ratio and beans-pod mass ratio of *Criollo* and *Forastero* variety was 0.7±0.01 and 0.3±0.03, respectively. Adzimah and Asiam (2010) conducted the physical properties of *Amezonia*, *Amelonado and Hybrid* varieties of cocoa pods. The average mass of *Amezonia*, *Amelonado and Hybrid* varieties of cocoa pods measured was 400, 370 and 480 g, respectively.

4.1.1.5. Volume of cocoa pod

The average volume of cocoa pods (*Criollo* variety and *Forastero* variety) is shown in Table 4.3 and Table 4.4. The average volume of cocoa pod of *Criollo* variety and *Forastero* variety for small, medium and large pods was measured as 307.7±45.33, 410.8±61.48, 785.7±143.01 cm^3 and 293.3±43.57, 394.9±63.15, 634.5±74.69 cm^3, respectively. Bamgboye and Ojoh (2004) observed that the average volume of *Amazon* variety of cocoa pod was 571±4.9 cm^3.

Table 4.3. Physical properties of cocoa pods (*Criollo* variety)

Sl. No.	Parameters	Small		Medium		Large	
		Mean	SD	Mean	SD	Mean	SD
1.	Length (mm)	124.60	11.12	159.30	7.19	188.5	7.85
2.	Diameter (mm)	73.19	7.26	83.44	5.06	97.01	6.16
3.	Geometric mean (mm)	87.19	6.11	103.44	4.55	120.95	5.24
4.	Sphericity	0.70	0.06	0.65	0.18	0.64	0.03
5.	Aspect ratio	0.59	0.08	0.52	0.07	0.51	0.04
6.	Mass (g)	244.95	40.35	358.59	63.36	630.47	104.90
7.	Volume (cm^3)	307.70	45.33	410.80	61.48	785.70	143.01
8.	True density (kg/m^3)	795.57	53.31	871.78	80.90	809.40	87.88
9.	Bulk density (kg/m^3)	417.24	6.64	384.94	19.45	406.53	32.08
10.	Porosity (%)	47.50	10.08	55.95	15.57	49.77	12.49

Table 4.4. Physical properties of cocoa pods (*Forastero* variety)

Sl. No.	Parameters	Small		Medium		Large	
		Mean	SD	Mean	SD	Mean	SD
1.	Length (mm)	130.60	9.01	158.9	8.51	187.20	10.17
2.	Diameter (mm)	73.70	7.48	83.32	9.97	92.63	7.34
3.	Geometric mean (mm)	89.13	7.75	103.00	8.26	117.05	7.54
4.	Sphericity	0.68	0.03	0.65	0.06	0.62	0.02
5.	Aspect ratio	0.56	0.04	0.52	0.07	0.49	0.03
6.	Mass (g)	254.12	30.19	304.48	56.16	488.34	53.30
7.	Volume (cm^3)	293.30	43.57	394.90	63.15	634.50	74.69
8.	True density (kg/m^3)	861.97	48.53	864.23	56.48	774.11	73.31
9.	Bulk density (kg/m^3)	413.90	9.30	395.15	8.56	400.28	16.01
10.	Porosity (%)	51.90	8.08	54.27	8.48	48.29	7.80

4.1.1.6. True density and bulk density of cocoa pod

The average true density values of *Criollo* variety and *Forastero* variety cocoa pod are shown in Table 4.3. and Table 4.4. The true density of *Criollo* variety and *Forastero* variety cocoa pod for small, medium and large pods was

795.57±53.31, 871.78±80.90, 809.40±87.88 kg/m^3 and 861.97±48.53, 864.23±56.48, 774.11±73.31 kg/m^3, respectively. Similarly, the average bulk density of *Criollo* variety and *Forastero* variety cocoa pod was 417.24±6.64, 384.94±19.45, 406.53±32.08 and 413.9±9.30, 395.15±8.56, 400.28±16.01 kg/cm^3, respectively. Bamboye and Ojoh (2004) observed that the true and bulk densities of *Amazon* variety cocoa pod were 793.4±2.00 and 456.6±1.80 kg/m^3, respectively. The capacity of cocoa pod breaking machine could be designed based on bulk density.

4.1.1.7. Porosity of cocoa pod

Table 4.3 and Table 4.4 show the average porosity of cocoa pods. The porosity of *Criollo* variety and *Forastero* variety cocoa pod for small, medium and large pods was 47.5±10.08, 55.95±15.57, 49.77±12.49 and 51.90±8.08, 54.27±8.48, 48.29±7.80 per cent, respectively. Bamgboye and Ojoh, (2004) observed that the porosity of *Amazon* variety cocoa pod was 42.45±9.43 per cent. The average porosity of the citrus *microcarpa* fruits was measured as 49.81 ± 3 per cent by Abdullah *et al.* (2012). True density, bulk density and porosity values are useful for determining the size of the hopper of the cocoa pod breaker.

4.2. Mechanical and Frictional Properties

4.2.1. Compression test of cocoa pod

The maximum compressive rupture force of cocoa pods (*Criollo* variety and *Forastero* variety) for three grades *viz*., small, medium and large. It is observed that the rupture force was increased with increase in pod size. The average compression force of *Criollo* variety and *Forastero* variety cocoa pods for small, medium and large size was 5.2, 5.9, 6.3 kgf and 5.5, 6.1, 6.5 kgf, respectively. Maduako and Faborode (1994) observed by the maximum shear force required to rupture a fresh pod husk ranged from 570 to 860 N and the corresponding shear strength varied from 242 to 357 kN/m^2 at 95 per cent confidence level for all four varieties of cocoa and the pooled data gave a correlation coefficient of 0.274 and 0.208, respectively for maximum shear load and shear strength versus husk thickness.

4.2.2. Coefficient of friction of cocoa pod

Table 4.5 and Table 4.6 show the average coefficient of friction of cocoa pod against four surfaces *viz*., plywood, galvanized iron sheet, aluminum sheet and stainless steel sheet. From the table, it is observed that the small size cocoa pod had the highest coefficient of static friction on galvanized iron sheet and plywood, followed by aluminum sheet and the least for stainless steel sheet. The coefficient of friction values on stainless steel sheet, aluminum sheet, galvanized iron sheet and plywood of *Criollo* variety and *Forastero* variety cocoa pods for small size were 0.31, 0.32, 0.35, 0.33 and 0.31, 0.32, 0.34, 0.33, respectively. Similarly the coefficient of friction of *Criollo* variety and *Forastero* variety cocoa pods for medium size cocoa pods and large size cocoa pods on various surfaces were 0.33, 0.35, 0.36, 0.34; 0.35, 0.32, 0.36, 0.34 and 0.35, 0.39, 0.42, 0.37; 0.29, 0.34, 0.43, 0.38, respectively. The coefficient of friction value is low due to the smooth surface of the cocoa pod 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).

4.2.3. Angle of repose of cocoa pod

Angle of repose of cocoa pods (*Criollo* variety and *Forastero* variety) for small, medium and large pods is shown in Table 4.5 and Table 4.6. Angle of repose value was decreased with increase in pod size for both varieties. The average angle of repose of *Criollo* variety and *Forastero* variety for small, medium and large pods was 23.21±1.18°, 22.76±1.57°, 20.91±0.87° and 25.15±1.17°, 22.32±0.96°, 20.07±1.25°, respectively. The average angle of repose of russian olive fruit was 20.6±3°, according to Zare *et al.* (2012). The gradient of the hopper and chute of cocoa pod breaking machine is designed based on angle of repose.

Table 4.5. Frictional properties of cocoa pods (*Criollo* variety)

Properties	Small		Medium		Large	
	Mean	SD	Mean	SD	Mean	SD
Coefficient of friction						
Strain less steel	0.31	0.002	0.33	0.002	0.35	0.002
Aluminum sheet	0.32	0.001	0.34	0.002	0.37	0.002
Galvanized iron	0.35	0.001	0.36	0.001	0.42	0.002
Plywood	0.33	0.002	0.35	0.002	0.39	0.002
Angle of repose (deg)	23.21	1.18	22.76	1.57	20.91	0.87

Table 4.6. Frictional properties of cocoa pods (*Forastero* variety)

Properties	Small		Medium		Large	
	Mean	SD	Mean	SD	Mean	SD
Coefficient of friction						
Strain less steel	0.31	0.001	0.30	0.002	0.29	0.002
Aluminum sheet	0.32	0.002	0.32	0.003	0.34	0.002
Galvanized iron	0.34	0.002	0.36	0.002	0.43	0.002
Plywood	0.33	0.002	0.34	0.002	0.38	0.002
Angle of repose (deg)	25.15	1.17	22.32	0.96	20.07	1.25

4.3 Performance Evaluation of the Developed Continues Cocoa Pod Breaker

The performance of equipment is the basic criteria to evaluate its ability. The performance of the developed continuous cocoa pod breaker was evaluated in terms of its capacity, efficiency and energy requirement.

4.3.1. Effect of speed on capacity of cocoa pod breaker

The capacity of machine was optimized using three grades of cocoa pods (small, medium and large) and three different speeds (S_1=260 rpm, S_2=360 rpm and S_3=460 rpm). The effect of speed on capacity of cocoa pod breaker for three grades of cocoa pods is shown in Fig 4.1.

The capacity values for each treatment was statistically analyzed and was found to be highly significant ($p<0.01$). Statistically analyzed results are presented in Appendix B-4. The capacity of cocoa pod breaker had a significant effect on roller speed and size of cocoa pod. The maximum capacity was found to be 626.81 kg/h for small size cocoa pods at a speed of 460±10 rpm. The minimum capacity was found to be 512.33 kg/h for large size cocoa pods at speed 260±10 rpm. The capacity of the machine at three different speeds *viz*., S_1, S_2 and S_3 for small size cocoa pods was 586.95, 610.67 and 626.81 kg/h, respectively. Similarly, the capacity of the machine for medium and large size cocoa pods at different speeds was 553.56, 579.71, 610.16 kg/h and 512.33, 535.55, 564.21 kg/h, respectively. Widyoto *et al.* (2009) developed a motorized cocoa pod breaker and reported that the capacity of cocoa pod breaker was 9000 cocoa pods per hour at motor rotation of 2,000-2,200 rpm.

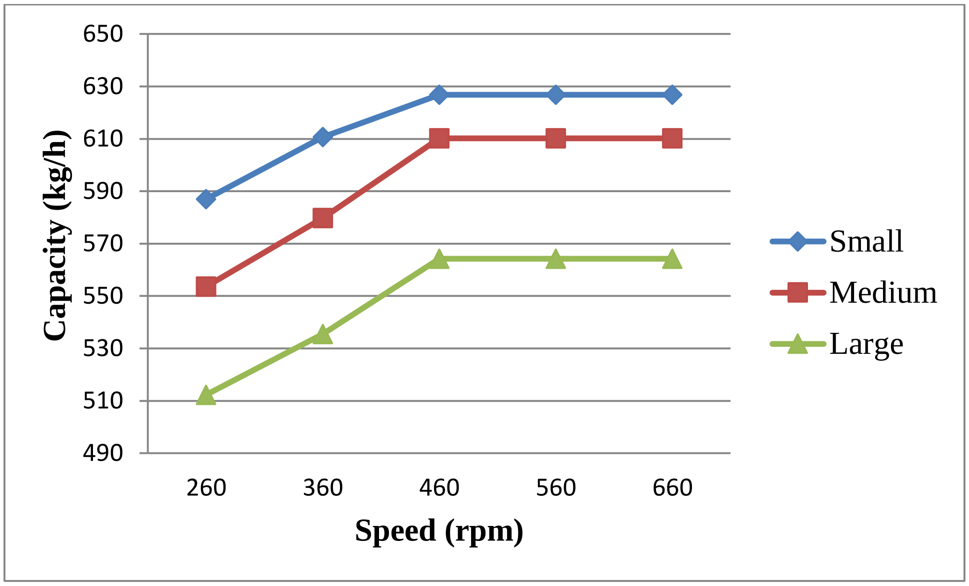


Fig. 4.1. Effect of speed on capacity of cocoa pod breaker

4.3.2. Effect of speed on breaking efficiency of cocoa pod breaker

The breaking efficiency of machine with three different speeds (S_1=260 rpm, S_2=360 rpm and S_3=460 rpm) and three grades of cocoa pods (small, medium and large) are presented in Fig 4.2. Statistically analyzed results are shown in Appendix B-3. The breaking efficiency values for each variable were found to be highly significant ($p<0.01$). But interaction between speed and size was not significant.

The breaking efficiency of the cocoa pod breaker increased significantly with increase in roller speed and cocoa pod size. The maximum breaking efficiency was found to be 96.97 per cent at 460±10 rpm for large size cocoa pods. The minimum breaking efficiency of 94.53 per cent was obtained at 260±10 rpm for small size cocoa pods. The average breaking efficiency of the machine at three different speeds (260±10 rpm, 360±10 rpm and 460±10 rpm) for small, medium and large size cocoa pods was 94.53, 95.30, 95.54; 94.93, 95.63, 95.97 and 96.16, 96.43, 96.67 per cent, respectively. Aliu and Ebunilo, (2011) conducted studies on development and performance evaluation of cocoa pod breaking machine. The result showed that the efficiency of cocoa pod braking machine increased with motor speed and a maximum efficiency of 95 per cent was achieved.

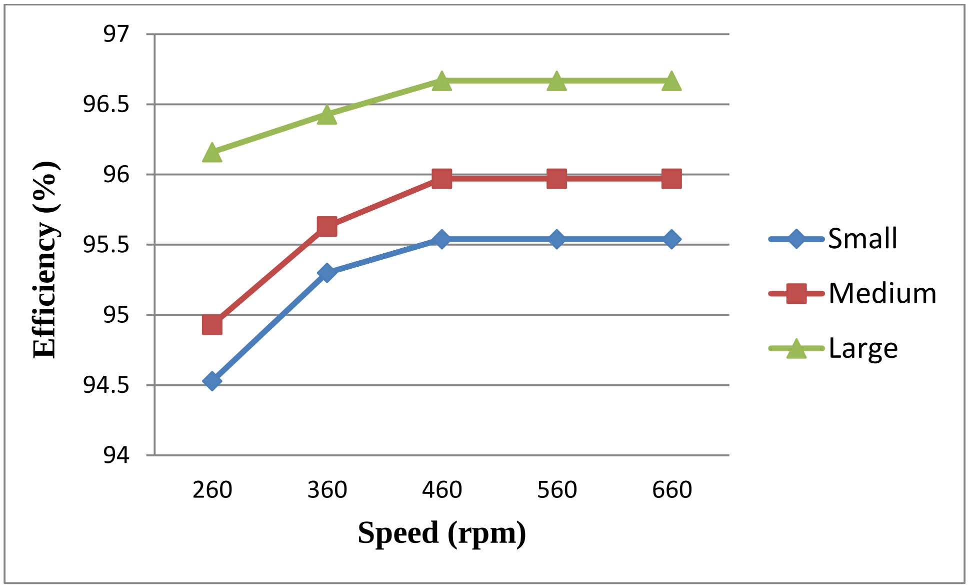


Fig. 4.2. Effect of speed on breaking efficiency of cocoa pod breaker

4.3.3. Effect of speed on energy requirement of cocoa pod breaker

The effect of speed (S1=260 rpm, S2=360 rpm and S3=460 rpm) and size of cocoa pods (small, medium and large) on energy requirement of cocoa pod breaker is shown in Fig 4.3. The energy requirement values for each variable were found to be highly significant ($p<0.01$). Statistically analyzed results are shown in Appendix B-5.

The energy requirement had an inverse relationship with roller speed and a direct relationship with cocoa pod size. The maximum energy requirement of cocoa pod breaker was found to be 13.10 kJ for large size cocoa pod at speed 260±10 rpm. The minimum energy requirement of cocoa pod breaker was measured to be 10.71 kJ for small size cocoa pods at speed 460±10 rpm. The energy requirement of the machine at three different speeds (260±10 rpm, 360±10 rpm and 460±10 rpm) for small, medium and large size cocoa pods was 11.43, 11.15, 10.71; 12.12, 11.58, 11.00 and 13.10, 12.46, 11.38 kJ, respectively. Adewumi and Fatusin (2006) conducted studies on design, fabrication and testing of an impact type hand operated cocoa pod breaker. The result shows that the impact energy of 30.90 J is required to break one pod while 78.60 J is required for five pods at a time.

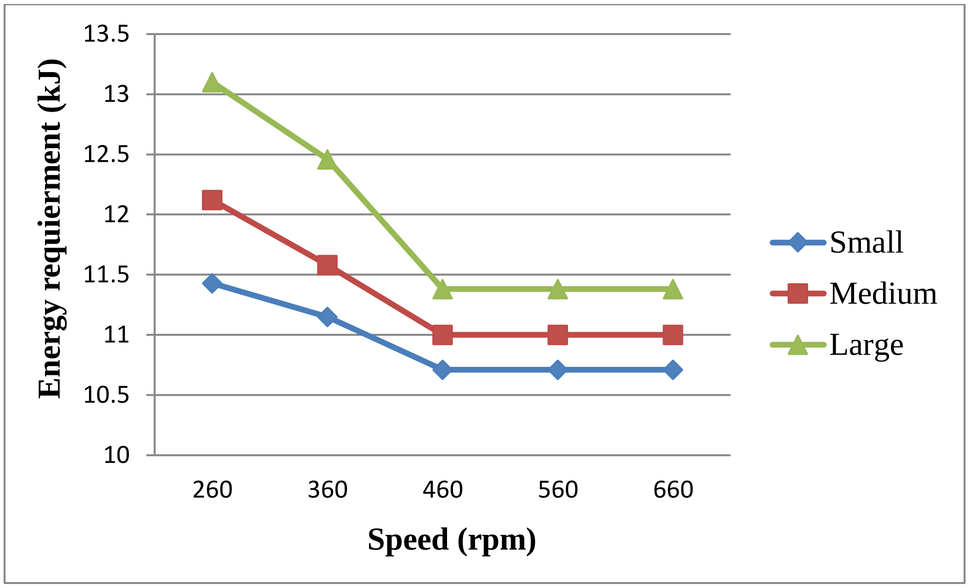


Fig. 4.3. Effect of speed on energy requirement of cocoa pod breaker

4.3.4. Performance evaluation of strainer

The performance of the developed strainer was evaluated in terms of percentage bean damage and shelling efficiency. The evaluation of the strainer was conducted at three angle of inclinations *viz.*, 50°, 45° and 40°.

4.3.4.1. Effect of inclination of strainer on cocoa bean damage percentage

The bean damage percentage was estimated as 0.5 per cent and it had no effect on the inclination of strainer.

4.3.4.2. Effect of inclination of strainer on shelling efficiency

The effect of inclination of strainer on shelling efficiency is shown in Fig 4.4. Shelling efficiency of strainer increased with increase in inclination. The maximum shelling efficiency was obtained at 45° inclination. The shelling efficiency of the strainer at inclinations, 44°, 45° and 46° were 94.3, 96.42 and 94.4 per cent, respectively.

4.3.4.3. Effect of inclination of strainer on beans separation efficiency

The effect of inclination of strainer on beans separation efficiency is shown in Fig 4.4. The beans separation efficiency of strainer increased with increase in inclination. The maximum beans separation efficiency was obtained at 45° inclination. The beans separation efficiency of the strainer at inclinations, 40°, 45° and 50° were 83.5, 86.5 and 84.5 per cent, respectively.

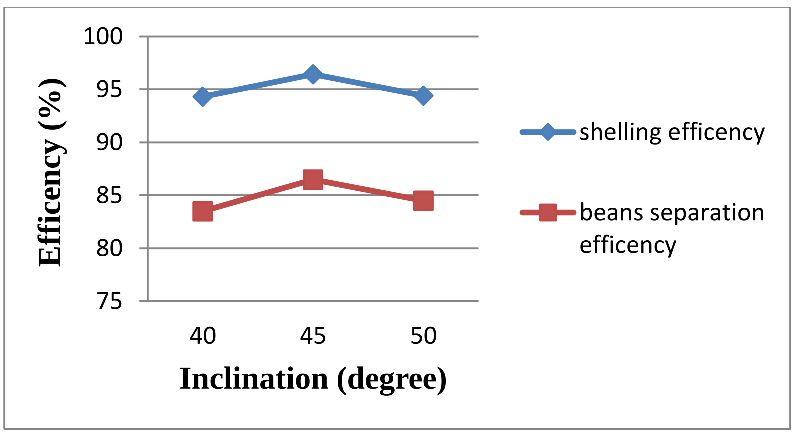


Fig. 4.4. Performance evaluation of strainer

4.3.5. Comparison of cocoa pod breaker with manual pod breaking

The performance of the developed cocoa pod breaker was compared with traditional method of pod breaking. Table 4.7. show the comparison between manual method of pod breaking and mechanical pod breaker. From table 4.7. shown that the total time required to 100 kg cocoa pods and separate the beans in mechanical and manual method were 10.44 and 50.17 minutes, respectively.

Table 4.7. Performance of manual and mechanical pod breaker

Method	Weight of pods	Time taken (min)	Capacity (kg/h)	Efficiency (%)	Bean damage (%)	No. of worker
Mechanical	100 kg	10.44	574.7	98	< 1	1
Manual	100 kg	50.17	107.4	100	1	3

4.4. Field Trial of Developed Cocoa Pod Breaker

The field evaluation of the developed machine was done in the farmer's field at Karuvarakundu village in Malappuram district and the results are presented in Appendix B-2.

For *Criollo* variety, the total time required to break 100 kg of small, medium and large size cocoa pods was 9.58, 9.83 and 10.16 min, respectively. Similarly, the efficiency and energy requirement of the cocoa pod breaker for three size were 96.32, 97.12, 98.00 and 107.20, 110.84, 113.72 kJ, respectively.

For *Forastero* variety, the total time required to break 100 kg of small, medium and large size cocoa pods was 9.71, 10.15 and 10.35 min, respectively. Similarly, the efficiency and energy requirement of the cocoa pod breaker for three size were 95.25, 95.85, 96.90 and 108.60, 113.54, 115.82 kJ, respectively.

From the field trial it is understood that, the efficiency of the machine is higher for *Criollo* variety as compared to *Forastero* variety. It may be due to the high brittleness of *Criollo* variety. The *Criollo* variety pods are brittle, easy to break and do not have the woody layer found in other varieties (Adewumi, 1997).

Plate 4.2. Performance evaluation of cocoa pod breaker

4.5. Fermentation techniques

Fermentation of cocoa beans was conducted by four methods (heap, box, basket and tray) and it was compared with three different ambient conditions (ambient, polyhouse and fermentation chamber). The effects of treatments on dependent variables like temperature, pH, moisture content and microorganisms during fermentation process were studied and presented.

4.5.1. Effect of treatments on temperature of fermenting mass

The temperature profile of the fermenting mass was recorded daily in relation to fermentation methods, environment conditions and fermentation time which are shown in Fig 4.5, Fig 4.6 and Fig 4.7. The temperature profile of fermenting mass for each treatments were found to be highly significant ($p<0.01$). The statistical results are shown in Appendix C-5.

The temperature of fermenting mass increased up to third day of fermentation and then slightly decreased at the end of fermentation. The temperature of fermenting mass under ambient, poly house and artificial fermentation chamber was risen from 35.5°C to 40.54°C, 38.1°C to 42.01°C and 40.5°C to 43.07°C, respectively. Ardhana and Fleet (2003) reported that the temperature of the fermenting mass gradually increased throughout fermentation, from initial values of 20-25 °C to values of 48-50 °C.

From Appendix C-1, the mean temperature of fermenting mass increased from the initial value of 38.39 to 41.16°C on fourth day of fermentation. From Fig 4.5, Fig 4.6 and Fig 4.7. The maximum temperature of fermenting mass of was recorded on box method in three environmental conditions. The maximum temperature recorded on tray, box, heap and basket method in ambient condition at the third day of fermentation was 39.94, 40.54, 39.54 and 39.98°C, respectively. Similarly, the maximum temperature recorded in poly house and artificial fermentation chamber was 41.85, 42.04, 41.74, 41.52°C and 42.93, 43.07, 42.82, 42.80°C, respectively. The beans prepared in box covered by banana leaves exhibited the maximum temperature among the other treatments. The mucilagous pulp surrounding the cocoa bean is rich in sugar which serves as the substrate for microbial fermentation (Ardhana and Fleet, 2003). The conversion of fermentable substrate into desirable metabolite byproducts is performed exothermally result in increase in temperature (Schwan and Wheals, 2004).

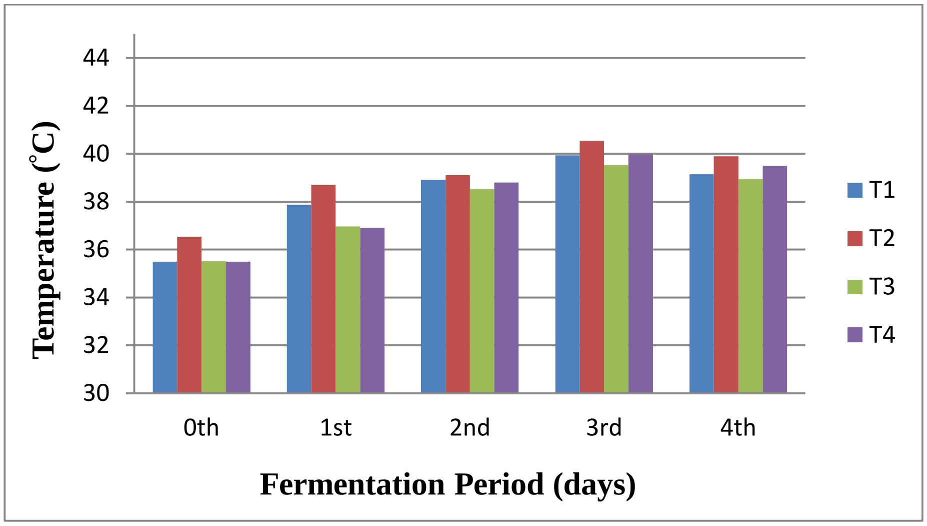


Fig. 4.5. Temperature profile of fermenting mass kept under ambient condition

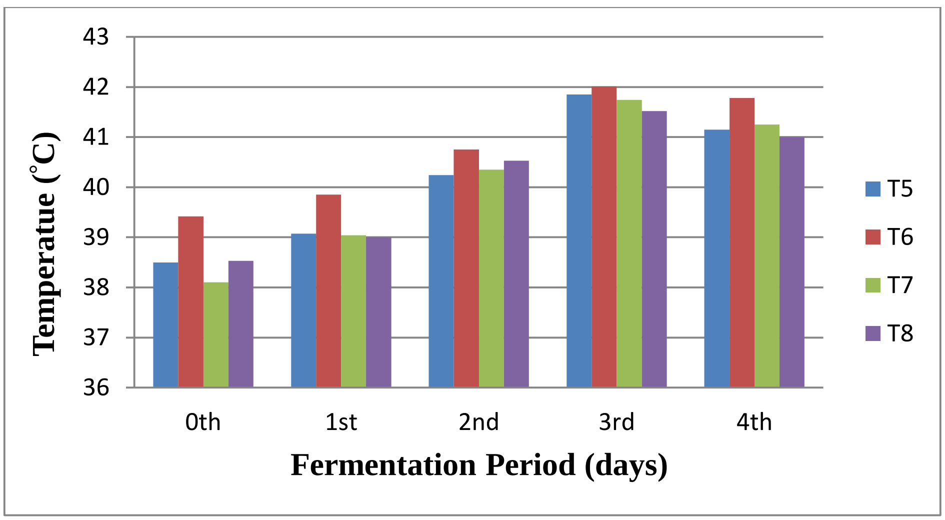


Fig. 4.6. Temperature profile of fermenting mass kept under poly house

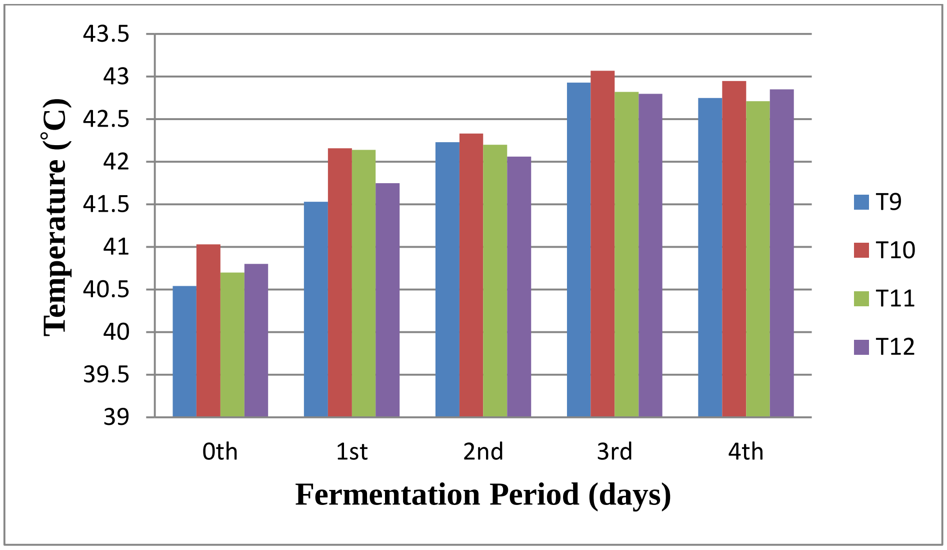


Fig. 4.7. Temperature profile of fermenting mass kept under artificial fermentation chamber

4.5.2. Effect of treatments on pH of fermenting mass

Cocoa fermentation is a complex biochemical reaction occurred due to aerobic or anaerobic hydrolytic process. The effect of treatments on pH of fermenting mass is presented in Fig 4.8, Fig 4.9 and Fig 4.10. Statistical results showed that the difference in pH within the treatments was highly significant. Also the fermentation time had a significant effect on pulp pH and bean pH of fermenting mass (Appendix C-6 and Appendix C-7).

The pH of mucilage pulp increased with increase in fermentation time (Fig 4.8, Fig 4.9 and Fig 4.10). The average pH of the mucilage pulp that undergone fermentation ranging from 3.88 to 4.50. The maximum pH of mucilage pulp of 4.99 was recorded on box method in artificial fermentation chamber. The maximum pH recorded on tray, box, heap and basket method in ambient condition at the end of fermentation was 4.31, 4.39, 4.32 and 4.37, respectively. Similarly, the maximum pH recorded in poly house and artificial fermentation chamber was 4.37, 4.42, 4.33, 4.29 and 4.96, 4.99, 4.82, 4.90, respectively. From Fig 4.6, the maximum pH of mucilage pulp of fermenting mass was recorded on box method in three environmental conditions. The initial low pH of cocoa mucilage pulp was due to the presence of citric acid that favors the yeast to grow. However as fermentation proceed, the dominant yeasts with good pectinolytic activity degraded the mucilage pulp and removed the citric acid to allow subsequent bacteria to grow resulted in higher pH (Ganeswari *et al.*, 2015). An increase in pH towards the end of fermentation was caused by citric acid conversion. During fermentation, the sugar present in cocoa mucilage pulp gets converted to ethyl alcohol, lactic acid and acetic acid. A portion of acid is drained out from fermenting mass as sweating leads to increase in pH (Sunil kumar, 2005).

The effect of various treatments on pH of cocoa beans during fermentation is shown in Fig 4.11, Fig 4.12 and Fig 4.13. During the fermentation period, pH of cocoa beans recorded a decreasing trend for all treatments. The least pH of beans 4.09 was recorded on box method in poly house. The minimum pH of beans recorded on tray, box, heap and basket method in poly house at the end of fermentation was 4.37, 4.09, 4.19, and 4.22, respectively. Similarly, the minimum pH recorded in ambient condition and artificial fermentation chamber was 4.33, 4.21, 4.38, 4.36 and 4.45, 4.32, 4.43, 4.49, respectively. From Appendix C-3, the mean pH of beans decreased from the initial value of 5.34 to 4.32 on fourth day of fermentation. During fermentation, the sugars present in cocoa mucilage pulp get converted to ethanol, lactic acid and acetic acid. A portion of acid intrudes into the beans which reduces the pH of beans (Sunil kumar, 2005).

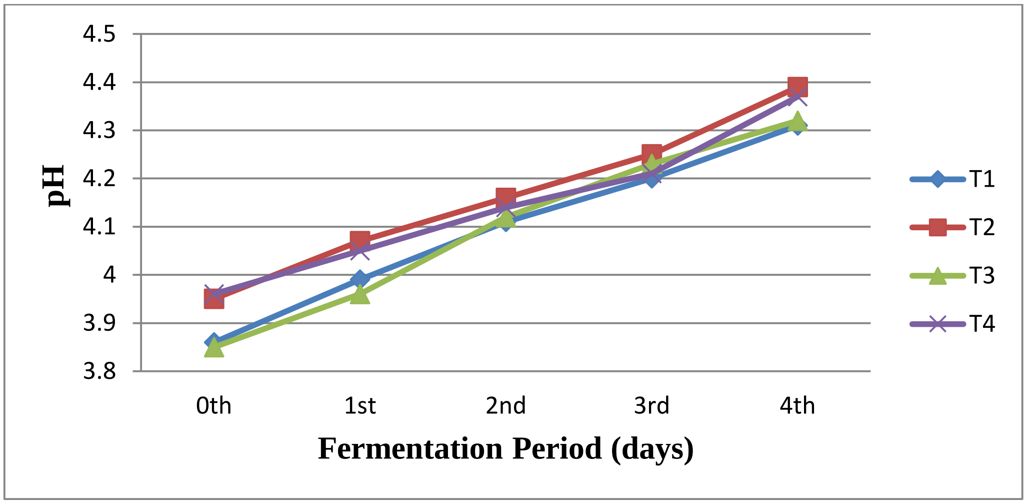


Fig. 4.8. pH of mucilage pulp kept under ambient condition

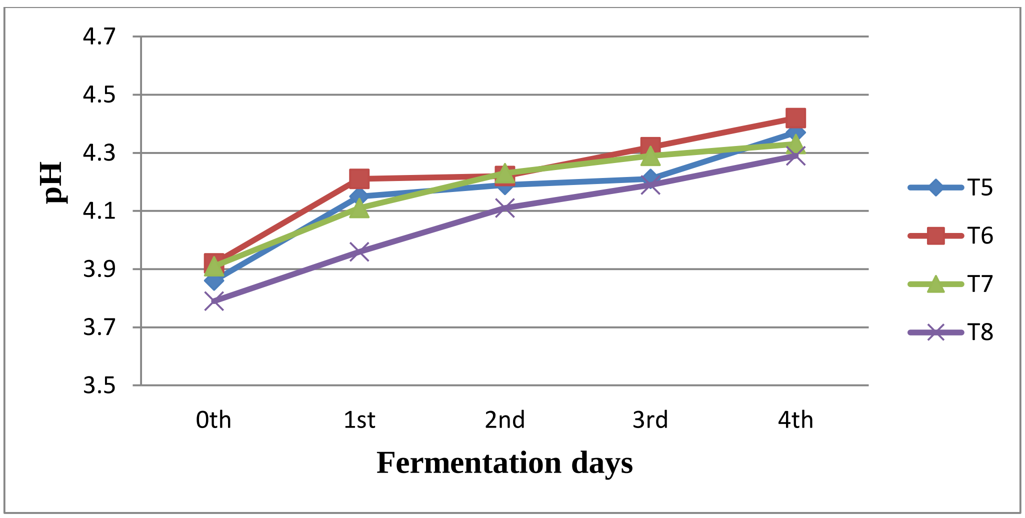


Fig. 4.9. pH of mucilage pulp kept under poly house

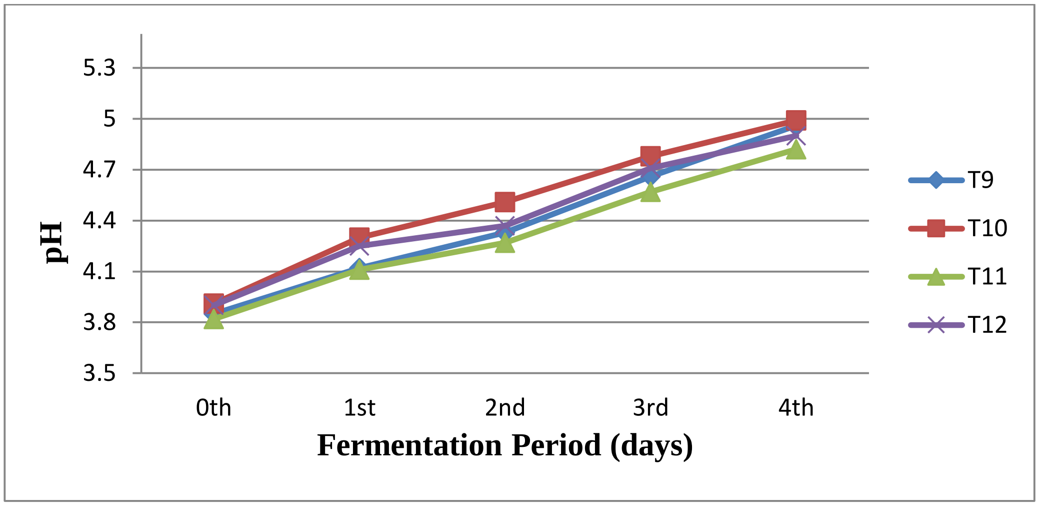


Fig. 4.10. pH of mucilage pulp kept under artificial fermentation chamber

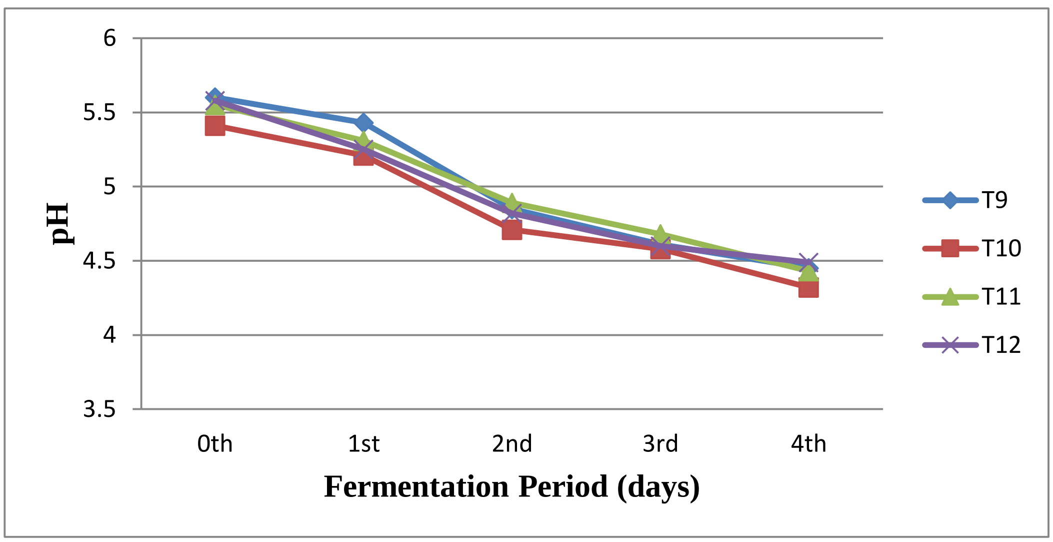


Fig. 4.11. pH of beans kept under ambient condition

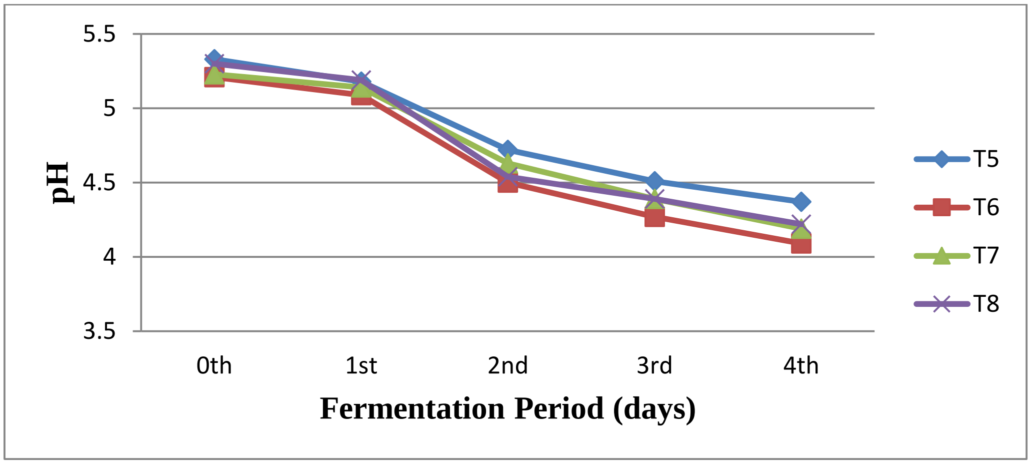


Fig. 4.12. pH of beans kept under poly house

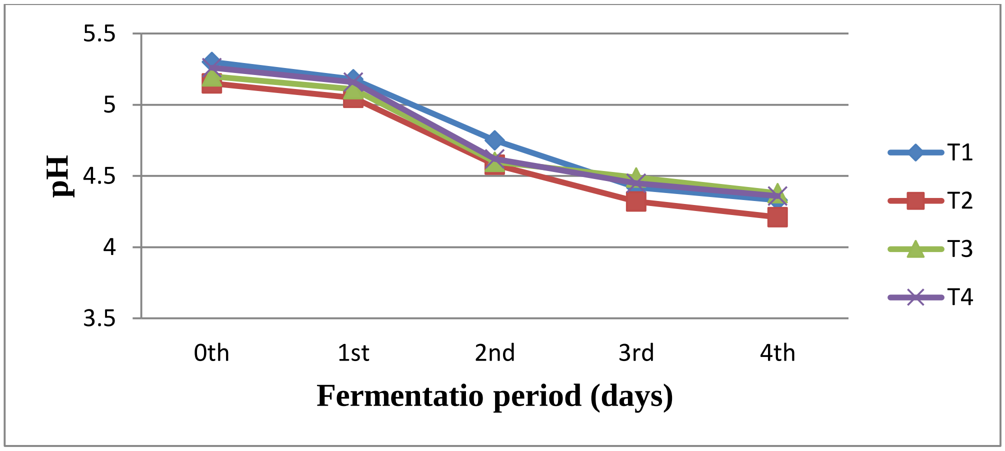


Fig. 4.13. pH of beans kept under artificial fermentation chamber

4.5.3. Effect of treatments on moisture content of fermented beans

The effect of treatments on moisture content of cocoa beans were statistically analyzed and presented in Appendix C-8. The fermentation time had a significant effect on moisture content. From the Fig 4.14, Fig 4.15 and Fig 4.16, it was observed that the moisture content decreased during fermentation for all treatments. The sample prepared in box placed under artificial fermentation chamber (T10) recorded the lowest moisture content of 50.17 per cent (wb). The minimum moisture content of beans recorded on tray, box, heap and basket method in ambient condition at the end of fermentation was 51.27, 51.18, 51.95 and 52.05 per cent (wb), respectively. From Appendix C-4, the mean moisture content decreased from the initial value of 57.81 to 51.43 on fourth day of fermentation. Similarly, the minimum moisture content recorded in poly house and artificial fermentation chamber was 51.85, 51.03, 52.94, 52.94 and 50.94, 50.17, 50.64, 50.25 per cent (wb), respectively. From Fig 4.8, the minimum moisture content of beans was recorded on box method in three environmental conditions. Galvez *et al*. (2007) reported that the moisture content of beans during fermentation was reduced from an initial moisture content of 76.6 per cent to 68.3 per cent at the end of fermentation.

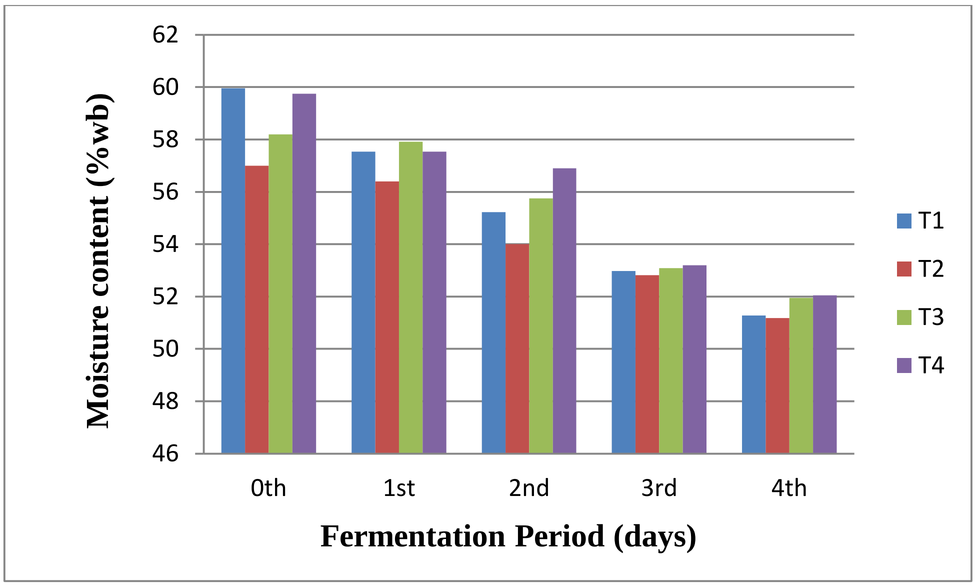


Fig. 4.14. Moisture content of beans kept under ambient condition

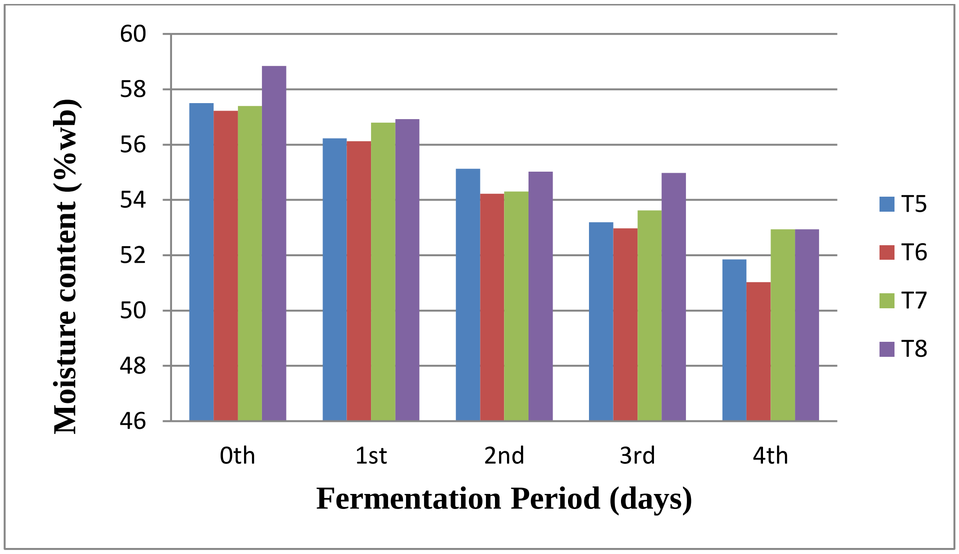


Fig. 4.15. Moisture content of beans kept under poly house

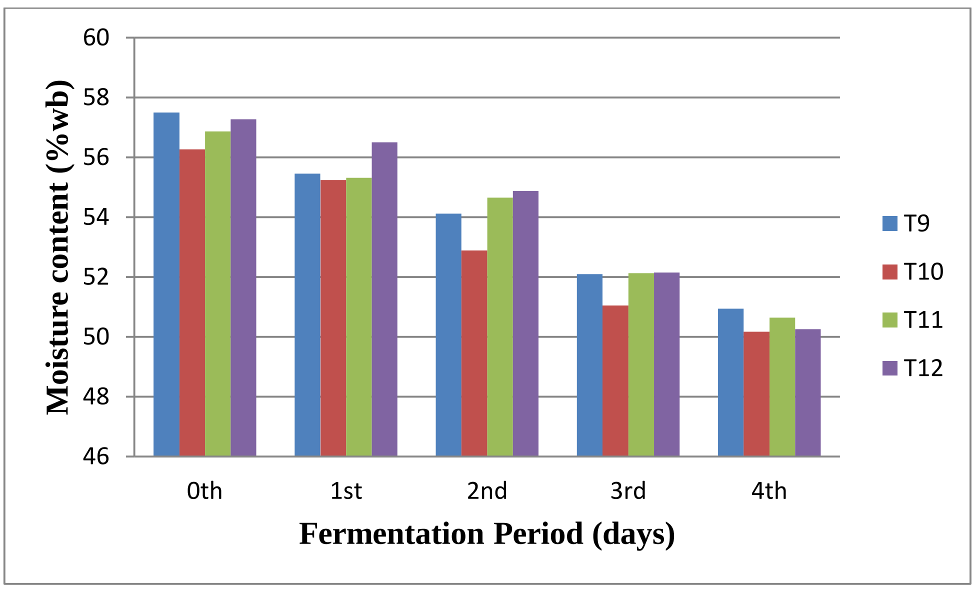


Fig. 4.16. Moisture content of beans kept under artificial fermentation chamber

4.5.4. Effect of treatments on microbial population during fermentation

The population dynamics of yeast and bacteria are shown in Plate 4.2.

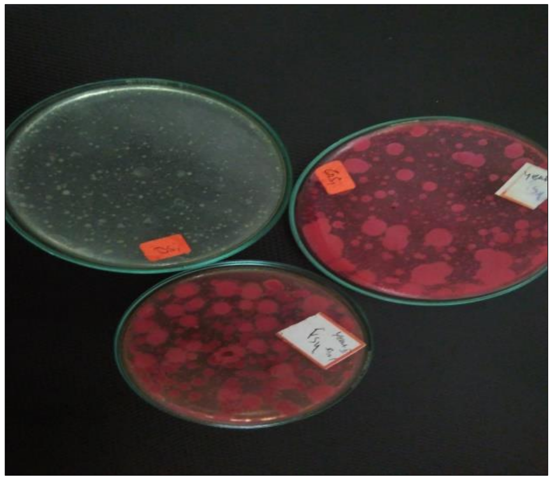


Plate 4.3. Population of bacteria and yeast

The population of yeast and bacteria during fermentation under ambient condition is shown in Fig 4.17 and Fig 4.18. The microbial population (yeast and bacteria) increased significantly during the first 2 days of fermentation process and then decreased at the end of fermentation. The maximum population of yeast was observed on second day of fermentation. The yeast count measured on tray, box, heap and basket method under ambient condition at the second day of fermentation was 3.31×10^5, 5.3×10^5, 3.3×10^5 and 4.3×10^5 cfu/ml, respectively. Similarly, the maximum bacteria population estimated on tray, box, heap and basket method under ambient condition at the second day of fermentation was 47.34×10^5, 27.65×10^5, 23.34×10^5 and 28.36×10^5 cfu/ml, respectively. According to Ardhana and Fleet (2003), a yeast count of 10^4-10^5 cfu/g in cocoa beans is able to initiate cocoa bean fermentation.

Yeasts, lactic acid bacteria and acetic acid bacteria are the main microfloras involved in spontaneous cocoa bean fermentation as each of them are responsible to the synthesize and production of related metabolites such as ethanol, lactate, acetate, heat and also volatile precursors (Lopez and Dimick, 1995). The initial phases of the fermentation growth of yeasts are favoured due to the high sugar content, low pH and limited oxygen availability in the mucilage pulp (Thompson *et al.*, 2001).

Cempaka *et al.* (2014) concluded that the optimal temperature and pH for yeast growth was 30ºC and 4.5, respectively. The yeast fermentation produces various organic acids, such as acetate and citrate. It normally produces ethanol as metabolic product. The increase in ethanol concentration may also have ceased the yeast growth after 30 hours of fermentation (Cempaka *et al.*, 2014).

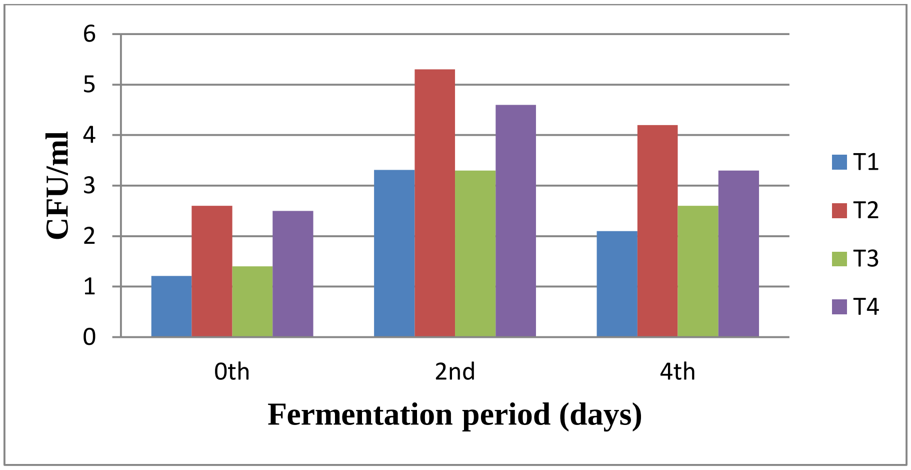


Fig. 4.17. Yeast population kept under ambient condition

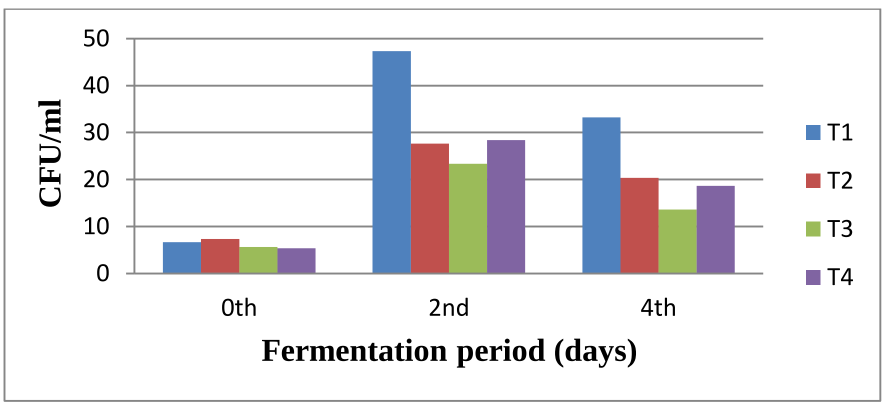


Fig. 4.18. Bacteria population kept under ambient condition

The maximum yeast count measured on tray, box, heap and basket method under poly house at the second day of fermentation was 19.33×10^5, 25.60×10^5, 14.36×10^5 and 21.61×10^5 cfu/ml, respectively. Similarly, the maximum bacteria population estimated on tray, box, heap and basket method poly house at the second day of fermentation was 13.67×10^5, 15.32×10^5, 11.02×10^5 and 18.6×10^5 cfu/ml, respectively. The population of yeast and bacteria during fermentation under poly house is shown in Fig 4.19 and Fig 4.20.

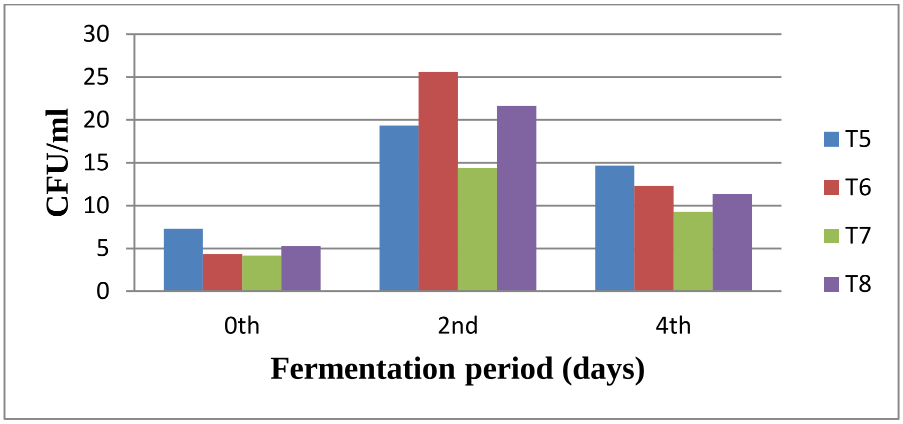


Fig. 4.19. Yeast population kept under poly house

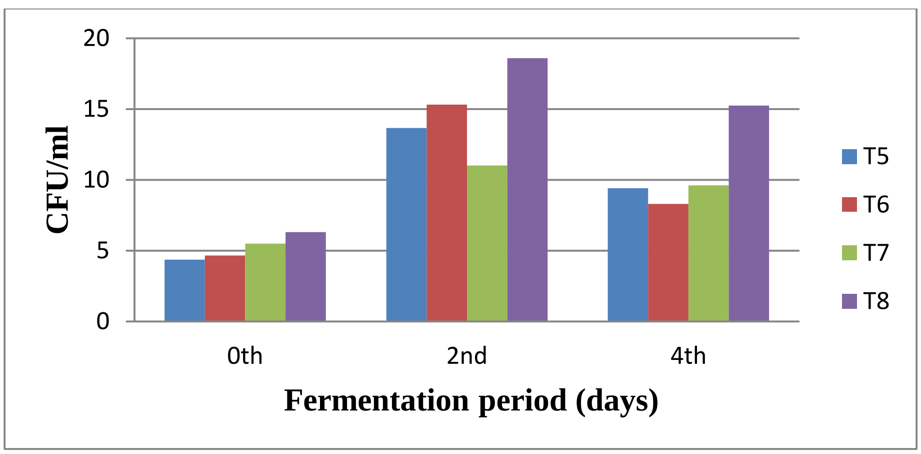


Fig. 4.20. Bacteria population kept under poly house

The maximum population of yeast estimated on tray, box, heap and basket method under artificial fermentation chamber at the second day of fermentation was 20.33×10^5, 27.33×10^5, 25.33×10^5 and 26.33×10^5 cfu/ml, respectively. Similarly, the bacteria population estimated on tray, box, heap and basket method artificial fermentation chamber at the second day of fermentation was 5.34×10^5, 15.33×10^5, 9.60×10^5 and 12.60×10^5 cfu/ml, respectively. The population of yeast and bacteria during fermentation under artificial fermented chamber is shown in Fig 4.21 and Fig 4.22.

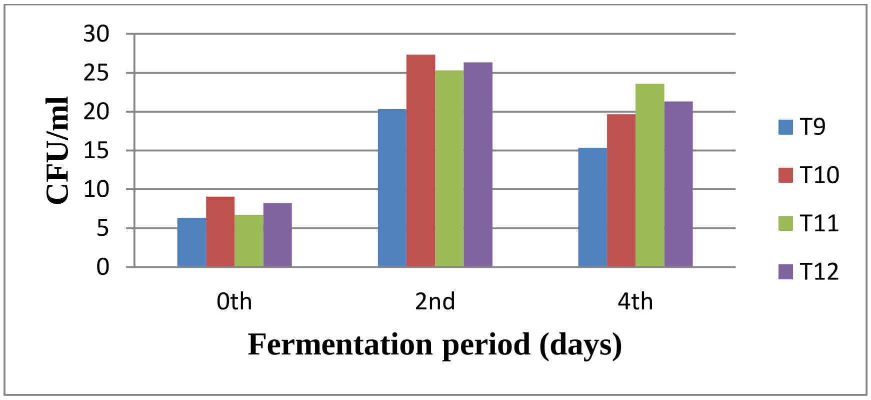


Fig. 4.21. Yeast population kept under artificial fermentation chamber

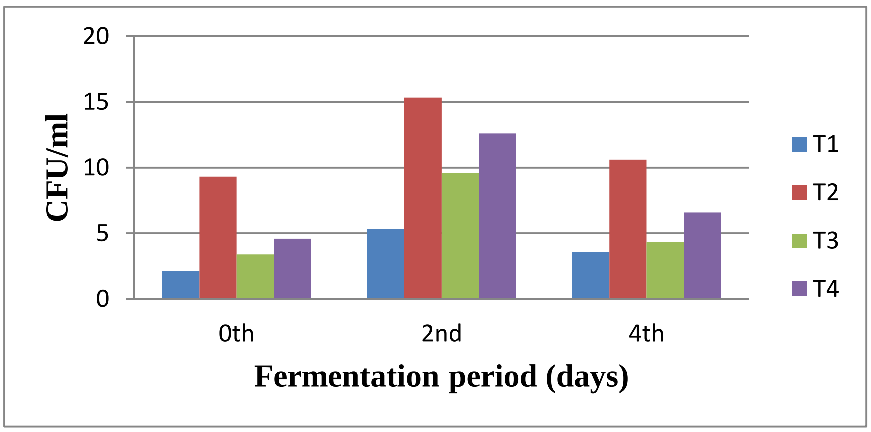


Fig. 4.22. Bacteria population kept under artificial fermentation chamber

Plate 4.4. Colour change during fermentation (a) fresh beans, (b) second day fermented sample and end day fermented samples in (c) poly house, (d) ambient condition and (e) fermented chamber

The increase of the microbial load during fermentation is due to the proliferation of dominating microfloras especially filamentous fungi, yeasts or those lactic and acetic acid producing bacteria. Moreover, the excellent nutrients contained in the cocoa beans as well as the biochemical changes inside in the beans also play significant role in the increase of microbial population. (Camu *et al.*, 2007).

According to above results, the yeast population is more in artificial fermentation chamber as compared to other two conditions (poly house and ambient condition). The yeast growth and activity were essential for cocoa bean fermentation and the development of chocolate characteristics (Graham *et al.*, 2014).

In this study, fermentation of cocoa beans kept under artificial fermentation chamber found the best among the other conditions for the production of good quality cocoa. Also, the box method was found the best among the other fermentation methods.

4.6. Cost Economics

The cost of operation of cocoa pod breaker and manual method was estimated as Rs.74.42 /h and Rs. 150/h, respectively. The benefit-cost of operation of cocoa pod breaker and manual method was estimated as 1.67:1 and 1.62:1, respectively. The detailed cost economics is given in Appendix D

CHAPTER V

SAMMARY 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 is the main raw material in the production of chocolates, cosmetics, health drinks, pharmaceuticals etc. It contains about 50 per cent fat, which is useful in the production of candle, soap, ointments, etc. Cocoa butter is also used in the production of pharmaceutical products. The cocoa bean powder is the raw material for the preparation of chocolates, ice cream, soft drinks and confectionaries.

At present the process of breaking cocoa pods is done manually and crudely by the use of wood and cutlass. This is a strenuous task, apart from the large labour requirement and time consumed during the operation. The cutlass damages the beans, resulting to increased losses leading to reduced profit. Hence, cocoa production and processing must be properly improved and mechanized to increase profits and reduce losses. Hence an attempt was made to develop a cocoa pod breaker.

Before the fabrication of the machine, the engineering properties of cocoa *viz*., physical, mechanical and frictional properties of fresh cocoa pod were studied. Physical properties studied were size, shape, mass and density. The mechanical and frictional properties *viz.,* compression test, angle of repose and co-efficient of friction were determined as per the standard procedures.

The developed cocoa pod breaker consists of cocoa pod breaking unit and cocoa bean separation unit. Cocoa pod breaking unit and cocoa bean separation unit comprise of hopper, metal rollers, chute and rotating cylindrical strainers, frame, prime mover, pulleys, respectively. Cocoa fruit was fed manually in to the breaker unit through a hopper. Gap between the rollers was set so that the cocoa kernels were not damaged during the pod breaking process. Tangential force of the roller pushed the cocoa pod towards the gap resulted in breakage. Cocoa pod, kernels and placenta then discharged to strainer through chute. Rotation of strainer separated the cocoa kernels from cocoa pod and placenta, and passed through the pores of the strainer. It was then collected and could be directly sent to fermentation process. The broken pods remained above the strainer and got separated.

The field evaluation of the developed machine was done with two cocoa varieties *viz*., *Criollo* and *Foraste*ro of three different sizes-large, medium and small in the farmer's field at Karuvarakundu village in Malappuram district. The performance of the machine was evaluated based on its capacity, per cent bean damage, efficiency of cocoa pod breaker and energy requirement.

The fermentation studies were conducted in ambient condition, poly house and artificial fermentation chamber. Fermentation methods selected were tray, box, heap and basket methods. Cocoa beans were covered with plantain leaves to prevent any heat and moisture loss during fermentation. The parameters were optimized based on pH, temperature, moisture content and microbial load of fermenting mass.

The results of the above experiments are summarized as following:

The average moisture content of fresh cocoa husk of *Criollo* and *Forastero* variety was 81.21±1.88 per cent (wb) and 79.45±1.25 per cent (wb), respectively. Similarly, the moisture content of fresh cocoa beans of *Criollo and Forastero* varieties were 57.66±1.10 per cent (wb) and 58.33±2.05 per cent (wb), respectively.

Two varieties *viz*., *Criollo* variety and *Forastero* variety were used for the study. The average length of small, medium and large cocoa pod of *Criollo* variety was measured as 124.6±11.12, 159.3±7.19 and 188.55±7.85 mm, respectively. For

Forastero variety cocoa pods, the average lengths were 130.6±9.01, 158.9±8.51 and 187.2±10.17 mm, respectively. The average diameter of cocoa pod of *Criollo* variety and *Forastero* variety for small, medium and large pods was measured as 73.19±7.262, 83.44±5.06, 97.01±6.16 mm and 73.70±7.48, 83.32±9.97 and 92.63±7.34 mm, respectively. The average geometric mean diameter (D_{gm}) of *Criollo* variety pods for small, medium and large cocoa pods was 87.19±6.11, 103.44±4.5 and 120.95±5.24 mm, respectively. The average geometric mean diameter for *Forastero* variety cocoa pods was 89.13±7.75, 103.00±8.26 and 117.05±7.54 mm, respectively.

The average sphericity of *Criollo* variety and *Forastero* variety cocoa pods for small, medium and large pods was estimated as 0.70±0.06, 0.65±0.0.01, 0.64±0.03 and 0.68±0.03, 0.65±0.06, 0.62±0.02, respectively. The aspect ratio of *Criollo* variety and *Forastero* variety cocoa pods were 0.59±0.08, 0.52±0.07, 0.51±0.04 and 0.56±0.04, 0.52±0.07, 0.49±0.03, respectively.

The mass of cocoa pod of *Criollo* variety for small, medium and large cocoa pods were 244.95±40.35, 358.59±63.36 and 630.47.04±104.9 g, respectively. For *Forastero* variety cocoa pods, the mass of cocoa pods was 254.12±30.19, 304.48±56.16 and 488.34±53.30 g, respectively for small, medium and large pods. The average volume of cocoa pod of *Criollo* variety and *Forastero* variety for small, medium and large pods was measured as 307.7±45.33, 410.8±61.48, 785.7±143.01 cm^3 and 293.3±43.57, 394.9±63.15, 634.5±74.69 cm^3, respectively.

The true density of *Criollo* variety and *Forastero* variety cocoa pod for small, medium and large pods was 795.57±53.31, 871.78±80.90, 809.4±87.88 kg/m^3 and 861.97±48.53, 864.23±56.48, 774.11±73.31 kg/m^3, respectively. The average bulk density of *Criollo* variety and *Forastero* variety cocoa pod was 417.24±6.64, 384.94±19.45, 406.53±32.08 and 413.9±9.3, 395.15±8.56, 400.28±16.01 kg/cm^3, respectively. The porosity of *Criollo* variety and *Forastero* variety cocoa pod for small, medium and large pods was 47.50±10.08, 55.95±15.57, 49.77±12.49 and 51.90±8.08, 54.27±8.48 48.29±7.80 per cent, respectively.

The average compression force of *Criollo* variety and *Forastero* variety cocoa pods for small, medium and large size was 5.2, 5.9, 6.3 kgf and 5.5, 6.1, 6.5 kgf, respectively. The coefficient of friction values on stainless steel sheet, aluminum sheet, galvanized iron sheet and plywood of *Criollo* variety and *Forastero* variety cocoa pods for small size were 0.31, 0.32, 0.35, 0.33 and 0.31, 0.32, 0.34, 0.33, respectively. The coefficient of friction of *Criollo* variety and *Forastero* variety cocoa pods for medium size cocoa pods and large size cocoa pods on various surfaces were 0.33, 0.35, 0.36, 0.34; 0.3, 0.32, 0.36, 0.34 and 0.35, 0.39, 0.42, 0.37; 0.29, 0.34, 0.43, 0.38, respectively. The average angle of repose of *Criollo* variety and *Forastero* variety for small, medium and large pods was 23.21±1.18°, 22.76±1.57°, 20.91±0.87° and 25.15±1.17°, 22.32±0.96°, 20.07±1.25°, respectively.

Performance of the machine was evaluated in terms of capacity, percent bean damage, power requirement and machine efficiency. The maximum capacity of the developed machine was found to be 626.81 kg/h for small size cocoa pods at a speed of 460±10 rpm. The minimum capacity was found to be 512.33 kg/h for large size cocoa pods at speed 260±10 rpm. The capacity of the machine at three different speeds *viz*., S_1, S_2 and S_3 for small size cocoa pods was 586.95, 610.67 and 626.81 kg/h, respectively. The capacity of the machine for medium and large size cocoa pods at different speeds was 553.56, 579.71, 610.16 kg/h and 512.33, 535.55, 564.21 kg/h, respectively.

The maximum breaking efficiency of the machine was found to be 96.97 per cent at 460±10 rpm for large size cocoa pods. The minimum breaking efficiency of 94.53 per cent was obtained at 260±10 rpm for small size cocoa pods. The average breaking efficiency of the machine at three different speeds (260±10 rpm, 360±10 rpm and 460±10 rpm) for small, medium and large size cocoa pods was 94.53, 95.30, 95.54; 94.93, 95.63, 95.97 and 96.16, 96.43, 96.67 per cent, respectively.

The maximum energy requirement of cocoa pod breaker was found to be 13.10 kJ for large size cocoa pod at speed 260±10 rpm. The minimum energy requirement of cocoa pod was measured to be 10.71 kJ for small size cocoa pods at speed 460±10 rpm. The energy requirement of the machine at three different speeds (260±10 rpm, 360±10 rpm and 460±10 rpm) for small, medium and large size cocoa pods was 11.43, 11.15, 10.71; 12.12, 11.58, 11.00 and 13.1, 12.86, 11.38 kJ, respectively.

The shelling efficiency of the strainer at inclinations, 40°, 45° and 50° were 94.3, 96.42 and 94.4 per cent, respectively. The beans separation efficiency of the strainer at inclinations, 44°, 45° and 46° were 83.5, 86.5 and 84.5 per cent, respectively. The total time required to break 100 kg cocoa pods and collect the beans for mechanical and manual method was 10.44 and 50.17 minutes, respectively.

The field evaluation of the developed machine for *Criollo* variety, the total time required to break 100 kg of small, medium and large size cocoa pods was 9.58, 9.83, 10.16 and 9.71, 10.15, 10.35 min, respectively. Similarly, the efficiency and energy requirement of the cocoa pod breaker for three size were 96.32, 97.12, 98.00 and 107.20, 110.84, 113.72 kJ, respectively. Similarly, for *Forastero* variety, the total time required to break 100 kg of small, medium and large size cocoa pods was 9.71, 10.15 and 10.35 min, respectively. Similarly, the efficiency and energy requirement of the cocoa pod breaker for three size were 95.25, 95.85, 96.90 and 108.60, 113.54, 115.82 kJ, respectively.

The fermentation parameters were optimized based on pH, temperature, moisture content and microbial load of fermenting mass during fermentation. The temperature of fermenting mass increased with increase in fermentation period. The temperature of fermenting mass in ambient, poly house and artificial fermentation chamber was risen from 35.5°C to 40.54 °C, 38.1°C to 42.01°C and 40.5°C to 43.07°C, respectively. The maximum temperature of fermenting mass was recorded on box method in three environmental conditions. The maximum temperature recorded on tray, box, heap and basket method in ambient condition at the fourth day of fermentation was 39.94, 40.54, 39.54 and 39.98°C, respectively. Similarly, the maximum temperature recorded in poly house and artificial fermentation chamber was 41.85, 42.04, 41.74, 41.52°C and 42.93, 43.07, 42.82, 42.80°C, respectively.

The maximum pH of mucilage pulp of 4.99 was recorded on box method in artificial fermentation chamber. The maximum pH recorded on tray, box, heap and basket method in ambient condition at the end of fermentation was 4.31, 4.39, 4.32 and 4.37, respectively. Similarly, the maximum pH recorded in poly house and artificial fermentation chamber was 4.37, 4.42, 4.33, 4.29 and 4.96, 4.99, 4.82, 4.90, respectively. The least pH of beans 4.09 was recorded on box method in poly house. The minimum pH of beans recorded on tray, box, heap and basket method in poly house at the end of fermentation was 4.37, 4.09, 4.19, and 4.22, respectively. Similarly, the minimum pH recorded in ambient condition and artificial fermentation chamber was 4.33, 4.21, 4.38, 4.36 and 4.45, 4.32, 4.43, 4.49, respectively.

The minimum moisture content of beans recorded on tray, box, heap and basket method in ambient condition at the end of fermentation was 51.27, 51.18, 51.95 and 52.05 per cent (wb), respectively. Similarly, the minimum moisture content recorded in poly house and artificial fermentation chamber was 51.85, 51.03, 52.94, 52.94 and 50.94, 50.17, 50.64, 50.25 per cent (wb), respectively. The mean moisture content decreased from the initial value of 57.81 to 51.43 on fifth day of fermentation.

The microbial population (yeast and bacteria) was increased significantly during the first 3 days of fermentation process and then decreased at the end of fermentation. The maximum population of yeast was observed on third day of fermentation. The maximum population of yeast estimated on tray, box, heap and basket method under ambient condition at the third day of fermentation was 3.31×10^5, 5.3×10^5, 3.3×10^5 and 4.3×10^5 cfu/ml, respectively. Similarly, the maximum bacteria population estimated on tray, box, heap and basket method under ambient condition at the third day of fermentation was 47.34×10^5, 27.65×10^5, 23.34×10^5 and 28.36×10^5 cfu/ml, respectively. The maximum yeast count measured on tray, box, heap and basket method under poly house at the third day of fermentation was 19.33×10^5, 25.60×10^5, 14.36×10^5 and 21.61×10^5 cfu/ml, respectively. Similarly, the maximum bacteria population estimated on tray, box, heap and basket method under poly house at the third day of fermentation was 13.67×10^5, 15.32×10^5, 11.02×10^5 and 18.6×10^5 cfu/ml, respectively. The yeast count measured on tray, box, heap and basket method under artificial fermentation chamber at the third day of fermentation was 20.33×10^5, 27.33×10^5, 25.33×10^5 and 26.33×10^5 cfu/ml, respectively. Similarly, the bacteria population estimated on tray, box, heap and basket method under artificial fermented chamber at the third day of fermentation was 5.34×10^5, 15.33×10^5, 9.60×10^5 and 12.60×10^5 cfu/ml, respectively. The final recommendation like fermentation of cocoa beans on all methods in the artificial fermentation chamber found the best among the other conditions for the production of good quality cocoa. Similarly, the box method was found the best among the other fermentation methods.

The cost of operation of cocoa pod breaker and manual method was estimated as Rs.74.42 /h and Rs. 150/h, respectively. The benefit-cost of operation of cocoa pod breaker and manual method was estimated as 1.67:1 and 1.62:1, respectively.

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APPENDIX – A

Table A-1. Physical properties of criollo variety cocoa pod (Small)

S.No.	Length (mm)	Diameter (mm)	Geometric Mean diameter (mm)	Sphericity	Aspect ratio	Mass (g)	Volume (cm^3)
1	113.00	86.36	94.45	0.83	0.76	274.80	340.00
2	140.00	71.95	89.82	0.64	0.51	215.00	288.50
3	109.00	60.21	73.38	0.67	0.55	301.30	350.50
4	138.00	73.34	90.54	0.65	0.53	264.40	380.00
5	116.00	71.34	83.88	0.72	0.61	166.40	216.00
6	120.00	69.21	83.14	0.69	0.57	254.00	295.00
7	140.00	67.86	86.38	0.61	0.48	231.70	288.00
8	115.00	83.36	92.79	0.80	0.72	221.90	276.00
9	125.00	78.10	91.35	0.73	0.62	218.00	292.00
10	130.00	70.24	86.23	0.66	0.54	302.00	351.00
Mean	124.60	73.20	87.19	0.71	0.59	244.90	307.70
SD	11.12	7.26	6.11	0.06	0.08	40.35	45.33

Table A-2. Physical properties of criollo variety cocoa pod (Medium)

S.No.	Length (mm)	Diameter (mm)	Geometric mean diameter (mm)	Sphericity	Aspect ratio	Mass (g)	Volume (cm^3)
1	165.00	81.63	103.21	0.62	0.49	501.10	570.00
2	145.00	83.21	100.13	0.69	0.57	401.80	448.00
3	167.00	92.31	112.47	0.67	0.55	351.60	368.00
4	155.00	83.57	102.67	0.66	0.53	379.60	428.00
5	152.00	84.78	102.99	0.67	0.57	300.70	384.00
6	153.00	79.49	98.87	0.64	0.51	388.80	375.00
7	163.00	78.98	100.55	0.61	0.48	300.40	395.00
8	162.00	86.00	106.21	0.65	0.53	281.00	348.00
9	168.00	74.23	97.45	0.58	0.44	293.40	362.00
10	163.00	90.21	109.87	0.67	0.55	387.50	430.00
Mean	159.30	83.40	103.40	0.65	0.52	358.50	410.80
SD	7.19	6.16	5.24	0.18	0.07	63.36	61.48

Table A-3. Physical properties of criollo variety cocoa pod (Large)

S.No	Length (mm)	Diameter (mm)	Geometric mean diameter (mm)	Sphricity	Aspect ratio	Mass (g)	Volume (cm^3)
1	179.00	101.65	122.75	0.68	0.56	879.70	1111.00
2	176.00	104.80	124.56	0.70	0.59	588.00	795.00
3	190.00	105.44	128.30	0.67	0.55	506.40	683.00
4	195.00	94.10	119.96	0.61	0.48	501.00	611.00
5	187.00	96.21	120.06	0.64	0.51	581.00	652.00
6	189.00	91.34	116.39	0.61	0.48	593.50	971.00
7	193.00	90.63	116.60	0.60	0.46	611.10	731.00
8	196.00	89.63	116.33	0.59	0.45	648.30	759.00
9	201.00	105.31	130.63	0.64	0.52	683.50	742.00
10	179.00	91.00	114.01	0.63	0.50	712.20	802.00
Mean	188.50	97.10	120.95	0.64	0.51	630.47	785.70
SD	7.85	6.16	5.24	0.03	0.04	104.90	143.01

Table A-4. Physical properties of forastero variety cocoa pod (Small)

S.No	Length (mm)	Diameter (mm)	Geometric mean diameter (mm)	Sphricity	Aspect ratio	Mass (g)	Volume (cm^3)
1	139.00	74.40	91.63	0.65	0.53	318.50	391.00
2	120.00	62.75	77.88	0.64	0.52	274.60	318.00
3	121.00	71.75	85.40	0.70	0.59	247.60	296.00
4	139.00	74.03	91.32	0.65	0.53	247.40	281.00
5	123.00	60.13	76.33	0.62	0.48	262.20	274.00
6	130.00	73.27	88.70	0.68	0.56	222.80	237.00
7	140.00	84.10	99.67	0.71	0.60	279.20	336.00
8	118.00	74.84	87.10	0.73	0.63	219.20	255.00
9	130.00	76.45	91.24	0.70	0.58	214.50	257.00
10	146.00	85.31	102.04	0.69	0.58	255.20	318.00
Mean	130.60	73.70	89.13	0.68	0.56	254.12	296.30
SD	9.01	7.48	7.75	0.03	0.04	30.19	43.57

Table A-5. Physical properties of forastero variety cocoa pod (Medium)

S.No	Length (mm)	Diameter (mm)	Geometric mean diameter (mm)	Sphericity	Aspect ratio	Mass (g)	Volume (cm^3)
1	153.00	71.33	91.99	0.60	0.46	317.30	349.00
2	165.00	74.15	96.80	0.58	0.44	352.10	416.00
3	170.00	62.63	87.36	0.51	0.36	489.10	524.00
4	168.00	85.31	106.93	0.63	0.50	311.60	351.00
5	155.00	91.55	109.11	0.70	0.59	329.00	378.00
6	150.00	84.94	102.66	0.68	0.56	318.00	369.00
7	142.00	87.24	102.62	0.72	0.61	270.00	334.00
8	157.00	86.78	105.74	0.67	0.55	300.00	319.00
9	164.00	93.27	112.57	0.68	0.56	354.80	479.00
10	165.00	95.13	114.29	0.69	0.57	362.90	430.00
Mean	158.90	83.20	103.00	0.65	0.52	340.48	394.90
SD	8.51	9.97	8.26	0.06	0.07	56.16	63.14

Table A-6. Physical properties of forastero variety cocoa pod (Large)

S.No	Length (mm)	Diameter (mm)	Geometric mean diameter (mm)	Sphericity	Aspect ratio	Mass (g)	Volume (cm^3)
1	209.00	90.34	119.48	0.571	0.43	531.60	671.00
2	182.00	88.94	112.91	0.62	0.48	418.80	628.00
3	178.00	92.14	114.75	0.64	0.51	434.40	643.00
4	183.00	90.81	114.70	0.62	0.49	480.00	683.00
5	179.00	83.00	107.23	0.59	0.46	481.00	599.00
6	180.00	86.08	110.07	0.61	0.47	577.10	703.00
7	193.00	103.70	127.55	0.66	0.53	421.40	515.00
8	189.00	101.20	124.62	0.65	0.53	515.00	631.00
9	178.00	85.75	109.38	0.61	0.48	559.40	762.00
10	201.00	104.4	129.87	0.64	0.51	464.70	510.00
Mean	187.20	92.60	117.05	0.62	0.49	488.30	634.50
SD	10.17	7.34	7.54	0.02	0.03	53.30	74.69

APPENDIX – B

Table B-1. Optimized parameters of cocoa pod breaker

Speed	**Size**	**Efficiency (per cent)**	**Capacity (kg/h)**	**Energy requirement (kJ)**
260 ±10	small	94.53	586.95	11.43
	medium	94.93	553.56	12.12
	large	96.16	512.33	13.10
360±10	small	95.30	610.67	11.15
	medium	95.63	579.71	11.58
	large	96.43	535.55	12.86
460±10	small	95.54	626.81	10.71
	medium	95.97	610.16	11.00
	large	96.67	564.21	11.38

Table B-2. Field Trail of developed cocoa pod breaker

Variety of cocoa pod	Size of cocoa pod	Weight of cocoa pods (kg)	Capacity of machine (kg/h)	Efficiency of machine (%)	Energy requirement (kJ)	Bean damage percentage (%)
Criollo	Small	100.00	626.08	96.32	107.20	<1
	medium	100.00	610.16	97.12	110.84	<1
	large	100.00	590.16	98.00	113.72	<1
Forastero	Small	100.00	617.68	95.25	108.60	<1
	medium	100.00	591.13	95.85	113.54	<1
	large	100.00	579.30	96.90	115.8	<1

Table B-3. Analysis of variance for efficiency of cocoa pod breaker

Source	df	SS	MS	F	PROB
S	2	3.321474	1.660737	10.1058	0.001 **
D	2	10.143474	5.071737	30.8623	0.000 **
SD	4	0.839393	0.209848	1.2770	0.320 NS
Err	16	2.629348	0.164334	1.0000	

Source	SED	CD (0.05)	CD (0.01)
S	0.19110	0.40512	0.55818
D	0.19110	0.40512	0.55818
SD	0.33099	0.70168	0.96680

CV = 0.44%

** Significant at 1% level

NS - not significant

Table B-4. Analysis of variance for capacity of cocoa pod breaker

Source	df	SS	MS	F	PROB
S	2	16030.607874	8015.303937	8004.8458	0.000 **
D	2	18718.176052	9359.088026	9346.8765	0.000 **
SD	4	1955.362815	488.840704	488.2029	0.000 **
Err	16	16.020904	1.001306	1.0000	

Source	SED	CD (0.05)	CD (0.01)
S	0.47171	1.00000	1.37782
D	0.47171	1.00000	1.37782
SD	0.81703	1.73205	2.38646

CV = 0.16%

** Significant at 1% level

Table B-5. Analysis of variance for energy requirement of cocoa pod breaker

Source	df	SS	MS	F	PROB
S	2	6.736385	3.368193	8229.9728	0.000 **
D	2	8.411585	4.205793	10276.5973	0.000**
SD	4	1.191948	0.297987	728.1131	0.000**
Err	16	0.006548	0.000409	1.0000	

Source	SED	CD (0.05)	CD (0.01)
S	0.00954	0.02022	0.02786
D	0.00954	0.02022	0.02786
SD	0.01652	0.03502	0.04825

CV = 0.16%

** Significant at 1% level

APPENDIX – C

Table C-1. Effect of ambient conditions on temperature profile of basket, box, and heap and tray fermentation

Fermentation conditions	**Treatments**	**Fermentation days**					**Mean**
		1st	**2nd**	**3rd**	**4th**	**5th**	
Open condition	T1	35.50	37.87	38.90	39.94	39.14	38.27
	T2	36.54	38.70	39.10	40.54	39.90	38.96
	T3	35.52	36.97	38.53	39.54	38.95	37.90
	T4	35.50	36.9	38.80	39.98	39.50	38.14
Polyhouse	T5	38.50	39.07	40.24	41.85	41.15	40.16
	T6	39.42	39.85	40.75	42.01	41.78	40.10
	T7	38.10	39.04	40.35	41.74	41.25	40.76
	T8	38.53	39.00	40.53	41.52	41.00	40.12
Fermented chamber	T9	40.54	41.53	42.23	42.93	42.75	42.00
	T10	41.03	42.16	42.33	43.07	42.95	42.31
	T11	40.70	42.14	42.20	42.82	42.71	42.11
	T12	40.80	41.75	42.06	42.80	42.85	42.05
	Mean	38.39	39.58	40.50	41.56	41.16	40.24

Table C-2. Effect of ambient conditions on pulp pH of basket, box, heap and tray fermentation

Fermentation conditions	Treatments	Fermentation days					Mean
		1st	2nd	3rd	4th	5th	
Open condition	T1	3.86	3.99	4.11	4.20	4.31	4.09
	T2	3.95	4.07	4.16	4.25	4.39	4.16
	T3	3.85	3.96	4.12	4.23	4.32	4.10
	T4	3.96	4.05	4.14	4.21	4.37	4.15
Polyhouse	T5	3.86	4.15	4.19	4.21	4.37	4.16
	T6	3.92	4.21	4.22	4.32	4.42	4.22
	T7	3.91	4.11	4.23	4.29	4.33	4.17
	T8	3.79	3.96	4.11	4.19	4.29	4.07
Fermented chamber	T9	3.85	4.12	4.33	4.66	4.96	4.38
	T10	3.91	4.30	4.51	4.78	4.99	4.50
	T11	3.82	4.11	4.27	4.57	4.82	4.32
	T12	3.90	4.25	4.37	4.71	4.90	4.43
	Mean	3.88	4.11	4.23	4.39	4.50	4.23

Table C-3. Effect of ambient conditions on beans pH of basket, box, heap and tray fermentation

Fermentation conditions	**Treatments**	**Fermentation days**					**Mean**
		1st	**2nd**	**3rd**	**4th**	**5th**	
Open	T1	5.30	5.18	4.75	4.42	4.33	4.80
	T2	5.15	5.05	4.58	4.32	4.21	4.66
	T3	5.20	5.11	4.60	4.49	4.38	4.76
	T4	5.26	5.16	4.62	4.45	4.36	4.77
Polyhouse	T5	5.33	5.18	4.72	4.51	4.37	4.82
	T6	5.21	5.09	4.50	4.27	4.09	4.63
	T7	5.23	5.14	4.63	4.39	4.19	4.72
	T8	5.30	5.19	4.54	4.39	4.22	4.73
Fermented chamber	T9	5.60	5.43	4.85	4.61	4.45	4.99
	T10	5.41	5.21	4.71	4.58	4.32	4.85
	T11	5.55	5.31	4.89	4.68	4.43	4.97
	T12	5.58	5.25	4.82	4.6	4.49	4.95
	Mean	5.34	5.19	4.68	4.48	4.32	4.80

Table C-4. Effect of ambient conditions on moisture content of beans on basket, box, heap and tray fermentation

Fermentation conditions	**Treatments**	**Fermentation days**					**Mean**
		1st	**2nd**	**3rd**	**4th**	**5th**	
Open	T1	59.95	57.53	55.23	52.98	51.27	55.39
	T2	57.00	56.40	54.00	52.82	51.18	54.28
	T3	58.20	57.92	55.75	53.09	51.95	55.38
	T4	59.75	57.54	56.90	53.19	52.05	55.89
Polyhouse	T5	57.50	56.23	55.13	53.19	51.85	54.78
	T6	57.22	56.12	54.23	52.98	51.03	54.32
	T7	57.40	56.80	54.31	53.62	52.94	55.01
	T8	58.85	56.92	55.03	54.98	52.94	55.74
Fermented chamber	T9	57.50	55.45	54.12	52.09	50.94	53.12
	T10	56.27	55.24	52.89	51.05	50.17	54.02
	T11	56.86	55.31	54.65	52.13	50.64	53.92
	T12	57.27	56.50	54.87	52.15	50.25	54.21
	Mean	57.81	56.50	54.76	52.86	51.43	54.67

Table C-5. Analysis of variance for temperature profile of fermented mass

Source	**df**	**SS**	**MS**	**F**	**PROB**
T	11	652.776063	59.343278	71212071.9280	0.000**
D	4	201.017380	50.254345	60305330.7262	0.000**
TD	44	190.440700	4.328198	5193847.3259	0.000**
Err	59	0.000049	0.000001	1.0000	

Source	SED	CD(0.05)	CD(0.01)
T	0.00041	0.00082	0.00109
D	0.00026	0.00053	0.00070
TD	0.00091	0.00183	0.00243

CV = 0.00%

** Significant at 1% level

Table C-6. Analysis of variance for pulp pH of fermented mass

Source	**df**	**SS**	**MS**	**F**	**PROB**
T	11	2.436889	0.221535	203.1408	0.000**
D	4	4.789470	1.197368	1097.9474	0.000**
TD	44	3.515890	0.079907	73.2718	0.000**
Err	59	0.06432	0.001091	1.0000	

Source	**SED**	**CD (0.05)**	**CD (0.01)**
T	0.01477	0.02955	0.03931
D	0.00953	0.01908	0.02538
TD	0.03302	0.06608	0.08790

CV = 0.78%

** Significant at 1% level

Table C-7. Analysis of variance for beans pH of fermented mass

Source	**df**	**SS**	**MS**	**F**	**PROB**
T	11	1.143469	0.103952	24614.6603	0.000**
D	4	13.608003	3.402001	805557.3946	0.000**
TD	44	0.333477	0.007579	1794.6297	0.000**
Err	59	0.000249	0.000004	1.0000	

Source	**SED**	**CD (0.05)**	**CD (0.01)**
T	0.00092	0.00184	0.00245
D	0.00059	0.00119	0.00158
TD	0.00206	0.00411	0.00547

CV = 0.04%

** Significant at 1% level

Table C-8. Analysis of variance for moisture content of fermented mass

Source	**df**	**SS**	**MS**	**F**	**Prob**
T	11	1172.959320	106.632665	693896.4215	0.000**
D	4	693896.4215	438.975568	2856569.0863	0.000**
TD	44	538.733488	12.243943	79675.6617	0.000**
Err	59	0.009067	0.000154	1.0000	

Source	**SED**	**CD (0.05)**	**CD (0.01)**
T	0.00554	0.01109	0.01476
D	0.00358	0.00716	0.00953
TD	0.00953	0.02481	0.03300

CV = 0.02%

** Significant at 1% level

Table C-9. Population of yeast and bacteria of different treatments

Fermentation conditions	Treatments	Yeast (10^5 cfu/ml)			Bacteria (10^5 cfu/ml)		
		Fermentation days			Fermentation days		
		1st	3rd	5th	1st	3rd	5th
Ambient condition	T_1	1.21	3.33	2.10	6.66	47.34	33.24
	T_2	2.60	5.33	4.20	7.33	27.65	20.33
	T_3	1.40	3.30	2.60	5.66	23.34	13.60
	T_4	2.50	4.63	3.30	5.30	28.36	18.66
Poly house	T_5	7.30	19.33	14.66	4.36	13.67	9.40
	T_6	4.34	25.60	12.30	4.66	15.32	8.30
	T_7	4.15	14.36	9.29	5.50	11.02	9.60
	T_8	5.30	21.61	11.35	6.30	18.60	15.24
Fermentation chamber	T_9	6.34	20.3	15.3	2.13	5.34	3.60
	T_{10}	9.07	27.30	19.61	9.33	15.33	10.6
	T_{11}	6.70	25.32	23.60	3.40	9.60	4.33
	T_{12}	8.25	26.33	21.30	4.60	12.60	6.60

Appendix-D

1. Cost Economic of Cocoa Pod Breaker

Capacity of cocoa pod breaker = 550.5 kg/h

Life span of cocoa pod breaker = 7 years

Annual usage = 120 days

Daily usage = 6 hours

Interest rate = 10.5 % per annum

Total cost of equipment = Rs. 27,600/-

A) Fixed cost

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

$= \dfrac{0.105(0.105+1)^7}{(0.105+1)^7+1} \times 27600$

= Rs. 1934.10/-

ii) Housing charge = Rs. 100/month

Housing charges/year = Rs.1200/year

Total fixed cost/year = Rs. 1934.10 + 1200

= Rs. 3134.10/ year

B) Variable cost

i) Reapir and maintenance, 5% = Rs. 27,600 × 5/100

= Rs.1380 /year

ii) Labour cost,

Labour cost per day = Rs.400

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

iii) Power consumption

Power consumption/day	=	1.49 KWh
Power consumption/year	=	1.49 × 120
	=	179 KWh
Cost of 1 KWh	=	Rs. 6.00
	=	179 × 6
	=	Rs. 1072.8 / year

Total variable cost	=	Rs. 1380 + Rs. 48000
		+ Rs.1072.8
	=	Rs. 50,452.8 / year
Total cost of cocoa pod breaker	=	Fixed cost + variable cost
	=	3134.10+ 50,452.8
	=	Rs. 53,586.6/ year
	=	Rs. 446.55 / day
	=	Rs. 74.42 / h

1.1. Benefit – cost ratio

1.1.1. Assumptions

Cost of raw cocoa pods per kilogram	= Rs.25/-
Machine working hours per day	= 6 h
Machine working days per year	= 120 days

Selling price of processed beans per kilogram = Rs. 120/-

1.1.2. Actual performance of the machine

Operating cost of machine per hour = Rs. 74.42/-

Actual capacity of machine = 550.5kg/h

Beans obtained from 100 kg of cocoa pod = 30.50 kg

1.1.3 Calculation

Cost of raw cocoa pods per year = 25×120×6×550.5

= Rs. 9909000/-

Actual operating cost of machine per year = 74.42×6×120

= Rs. 53,582.4/-

Weight of cocoa pods processed per year = 550.5 ×6×120

= 396360 kg

Total weight of beans obtained per year = 138726 kg

Total Cost of obtained beans per year (gross income) = Rs.16647120 /-

Net income = (Total gross income – Actual processing cost)

= 16647120 - 53,582.4

= Rs. 16593538/-

Benefit – cost ratio $= \frac{16593538}{9909000}$

= **1.67:1**

2. Manual method

Number of labour required	= 3
Cost of labour	= Rs. 400 / day.
The total cost of labour	= 1200 / day.
The total cost of labour per one hour	= Rs. 150 /h

2.1. Benefit - cost ratio

2.1.1. Assumptions

Cost of raw cocoa pods per kilogram	= Rs. 25 /-
Manual working hours per day	= 6 h
Manual working days per year	= 120 days
Selling price of processed beans per kilogram	= Rs.120 /-

2.1.2 Actual performance

Cost of manual operation per hour	= Rs. 150 /-
Actual capacity of worker	= 107.40 kg/h
Beans obtained from 100 kg of cocoa pod	= 30.50 kg

2.1.3 Calculation

Cost of raw cocoa pods per year	= 25×120×107.4×6
	= Rs. 1933200 /-
Actual cost of manual operation per year	= 150×6×120
	= Rs. 108000 /-
Weight of beans processed per year	= 107.4×6×120
	= 77328 kg

Total weight of beans obtained per year = 27064.8 kg

Total Cost of obtained beans per year (gross income) = Rs. 3247776 /-

Net income = (Total gross income - Actual processing cost)

= 3247776 - 108000

= Rs. 3139776 /-

Benefit – cost ratio $= \frac{3139776}{1933200}$

= **1.62:1**

3. Payback period

Cost of equipment = Rs 27,600/-

Cost of raw cocoa pod = Rs 99, 09,000/-

Labor charge per year = Rs 1, 44,000/-

Interest rate = 10.5 % per annum

Net income = (Total gross income – Actual processing cost)

= 16647120 - 53,582.4

= Rs. 16593538/-

$$\text{Payback period} = \frac{\text{Investment required for a project}}{\text{Net annual cash inflow}}$$

$$= \frac{11088660}{5504878}$$

= 2.01 year

ABSTRACT

Cocoa (*Theobroma cacao*) is a commercial plantation crop in India. It is the main raw material in the production of chocolates, cosmetics, health drinks, pharmaceuticals etc. The cocoa beans which are embedded in a mucilaginous pulp inside the pod consist of two parts- seed coat and seed cotyledon. Seed cotyledon is the material in which characteristic flavour and aroma produced during fermentation.

At present, cocoa pod breaking and bean extraction from crust pod are done manually by using sickle which is a labour intensive method. Manual chopping could increase the number of damage bean which leads to fungal attack. In order to eliminate the drudgery involved in manual cocoa pod breaking, avoid injury to workers, increase efficiency and to ensure high quality products, an attempt was made to develop a continuous cocoa pod breaker. Before the fabrication of machine, the engineering properties of cocoa *viz*., physical, mechanical and frictional properties of fresh cocoa pod were determined. Physical properties studied were size, shape, mass and density. The mechanical and frictional properties *viz.*, compression test, angle of repose and co-efficient of friction were determined as per the standard procedures.

The continuous cocoa pod breaker consists of hopper, metal rollers, chute, rotating cylindrical strainers, frame, prime mover and pulleys. Cocoa fruit was fed manually in to breaker unit through hopper. Gap between the rollers was set so as the cocoa kernels were not damage during the pod breaking process. Tangential force of the roller pushed the cocoa pod towards the gap resulted in breakage. Cocoa pod, kernels and placenta then discharged to strainer through chute. Rotation of strainer separated the cocoa kernels from cocoa pod and placenta, and passed through the pores of the strainer. It was then collected and could be directly send for fermentation process. The broken pods were remained above the strainer and got separated.

Performance of the machine was evaluated in terms of capacity, energy requirement, percent bean damage, per cent bean recovery, shelling efficiency and machine efficiency. The average capacity and breaking efficiency of cocoa pod breaker was 550.5 kg/h and 95-98 percent, respectively. Bean damage percentage was 0.5 per cent. The shelling efficiency and beans separation efficiency of the strainer at inclination, 45° 96.42 and 86.5 per cent, respectively. The performance of the developed cocoa pod breaker was compared with traditional method of pod breaking, the total time required to break 100 kg cocoa pods and collect the beans for mechanical and manual method was 10.44 and 50.17 minute, respectively.

The field evaluation of the developed machine was done with two cocoa varieties viz., *Criollo* and *Foraste*ro. The performance of the machine was evaluated based on its capacity, per cent bean damage, efficiency of cocoa pod breaker and energy requirement. From the field trail it is understood that, the efficiency of the machine is higher for *Criollo* variety as compared to *Forastero* variety.

The fermentation studies were conducted in artificial fermentation chamber, poly house and ambient condition and it was compared with three different environmental conditions (ambient, poly house and fermentation chamber). The effects of treatments on dependent variables like temperature, pH, moisture content and microorganisms during fermentation process were studied. In this study, fermentation of cocoa beans on all methods in the artificial fermentation chamber found the best among the other treatments for the production of good quality cocoa. Similarly, the box method was found the best among the other treatments for the production of good quality cocoa.

The cost of operation of cocoa pod breaker of 550 kg/h capacity was estimated as Rs.74.42 /-