KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

KUMASI, GHANA

COLLEGE OF AGRICULTURE AND NATURAL RESOURCES

FACULTY OF AGRICULTURE

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EFFECT OF STAGES OF RIPENING AND TRAY FERMENTATION METHOD ON THE QUALITY OF COCOA (*Theobroma cacao*) BEANS

BY

ADU THEODORE OTOMFO

AUGUST, 2014

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EFFECT OF STAGES OF RIPENING AND TRAY FERMENTATION METHOD ON THE QUALITY OF COCOA (*Theobroma cacao*) BEANS

A THESIS SUBMITTED TO THE DEPARTMENT OF HORTICULTURE, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF PHILOSOPHY IN POST HARVEST TECHNOLOGY

BY

ADU THEODORE OTOMFO

AUGUST, 2014

DECLARATION

I, Adu Theodore Otomfo, do hereby declare that except for references to other researchers duly cited, this is my original research conducted at Sentia near WassaMpohor in the Western Region while the laboratory work was carried out at the Quality Control Company (COCOBOD) laboratory, Tema and that no part of this thesis has been in whole or part presented for a degree elsewhere.

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Adu Theodore Otomfo …….. …….

(STUDENT) Signature Date

Certified by

Dr. Francis Appiah …… ……

(SUPERVISOR) Signature Date

Certified by

Dr. Francis Appiah …… ……

(HEAD OF DEPARTMENT) Signature Date

DEDICATION

This work is dedicated to Almighty God, my lovely wife Irene AdiAdu, my children, nephews and nieces, friends and entire family for their support, prayers and care shown to me throughout my academic pursuit.

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ABSTRACT

Tray fermentation method as a cocoa postharvest technology has remained limited in use in Ghanaian cocoa preparation and the need to explore its comprehensive value has become imperative to derive its benefits. The major objective of this study was to assess the effect of different stages of pod ripening on quality of fermented cocoa beans using the tray fermentation method. Three treatments namely, Half ripe, Full ripe and Over ripe were distributed over three sets of trays namely (T_1, T_2 and T_3) with each set of tray representing tray replication. Traditional leaves (Heap) method was used as control involving the full ripe stage. The results indicated a significant difference between the over ripe beans and the other three treatments with a percentage mould (1.78%) which was within acceptable maximum level of 4% for grade 2 cocoa. The over ripe beans tray fermented drifted beyond grade 2 with the 6.56% germinated beans content exceeding the 6% upper limit and was rendered substandard. There was also a significant difference between the half ripe tray fermented in terms of slaty (7.45%) which narrowly fell within the acceptable (8%) for grade 2 cocoa, purple (17.33%) was within the grade 1 limit of (20%), and pH (5.77) which was within what could be termed unfermented (5.5-5.8) compared to the other three treatments which were within acceptable limits. The tray fermented over ripe beans also showed a significant difference in terms of pH (4.47) and free fatty acids (0.99%), however, they were within acceptable levels (1.75%) for good quality cocoa.

The tray fermentation method was found to be less cost effective than the traditional heap method in the short run. However, the tray method had numerous advantages over the traditional method in the long run.

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CHAPTER ONE

1.0 INTRODUCTION

Cocoa, *Theobroma cacao* (Linnaeus) is an important perennial small forest tree crop. It belongs to the Genus *Theobroma* and the family *Sterculiaceae* (Wood and Lass, 1985) but recently, molecular marker techniques has re-classified *cacao* has being in the family *Malvaceae* (Alvenson*et al.*, 1999; Fagbohun*et al.*, 2011) and has been widely studied as a cash crop in world trade (Acquaah, 1999). Annual world cocoa bean production is approximated to be 3.6 million metric tonnes, major producers being the Ivory Coast, Ghana, Indonesia, Brazil, Nigeria, Cameroon, Ecuador and Malaysia (Schwan and Wheals, 2004; ICCO, 2009; Afoakwa, 2010).

Ghana plays a major role as the second largest cocoa producing country with production suddenly rising to about 540 000 metric tonnes during the 2003/2004 crop year and reaching 720, 000 metric tonnes which constituted 20.7% of world production as at the end of 2009. Its production was reported to have reached 1.0 million metric tonnes by end of 2011 according to Ghana Cocoa Board (2012). However, in 2012 production was later reported to have fallen to about 879,380 metric tonnes and a further drop by 5% to 835,410 metric tonnes in the 2012/2013 Crop year as reported by (ICCO, 2013). According to the ICCO (2007),cocoa provides direct employment to up to 800 000 families and about 3.2 million of the population spread over six of the ten regions of Ghana. It also contributes on the average 6% of Ghana's Gross Domestic Product (GDP).

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In the food beverage and confectionery industry, cocoa plays a key role by providing essential raw materials such as fermented dry beans for the production of semi-finished products like cocoa mass, liquor, butter, cake and powder for further processing into finished products like chocolate, confectionery, various beverages and cosmetics (Lopez & Dimick, 1995; Thompson *et al*., 2001; Ouattara *et al*., 2008; Rodriguez-Campos *et al*., 2011).

Ghanaian cocoa generally are of the *Forastero* type which constitutes 95% of total volume in international trade and are cultivated mainly in West Africa, Brazil and South East Asia. They are potentially astringent and acidic in taste and require good fermentation over a longer period than the *Criollo* type (Are and Gwynne-Jones, 1974; Dand, 1997). Poor fermentation activity as a postharvest challenge depicted by the presence of purple, slaty and germinated beans in marketed cocoa has had a number of adverse effects on the industry. Until recently, the purple bean factor was not a bother till its partial inclusion as a defect criterion in quality assessment

with attendant economic and social implications at the local (Ghanaian) market frontier (QCD, 2006). The main remote cause resulting in poor fermentation practices in Ghana is the multi-buying policy that replaced the unitary-buying system of internal marketing. Licensed Cocoa Buying Companies (LBCs) competing for cocoa beans among farmers has presented a temporal burden on them leading to tendering partially if not poorly fermented cocoa beans for sale. The scramble for the cocoa beans by LBCs forces the farmers to deliver to them whatever stock they have at any stage of preparation, thus affecting the quality of the beans. Aggravating the problem further is the increased harvested volumes in recent times as a result of the introduction of fertilizers in cocoa production and the integrated pest management that has improved on the yield of the crop on farms under the Cocoa Hi-Tech and CODAPEC programmes and increased the pressure on the few equipment required for fermentation (COCOBOD, 2007).

The cocoa industry has continued to advocate for the maintenance of quality and the further improvement in the preparation of cocoa beans for export and processing into finished products by reducing the current levels of defective beans. Assessment of the potential contributing factors in the postharvest chain, to enable policy makers and extension services tailor appropriate methodologies to address such quality challenges has been on-going in Ghana. The quality attributes of dried cocoa varies widely as Ghanaian farmers harvest cocoa pods at different maturity/ripening stages as well as pod resting periods prior to breaking. Where huge volumes from large farms usually held by households rather than commercial firms are involved, labour stress adds to the temporal extension of preparatory activities and unsatisfactory quality (Acquaah, 1999). The processes of determining maturity by ripeness of pods coupled with safe harvesting that ensures maintenance of healthy trees that continue to give high yields and pod

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resting are essential for the maintenance of the industry including efficiency of fermentation of heaps of cocoa beans to contribute to the quality of such beans (Schwan *et al*., 1995; Adeyeye *et al*., 2010). Various farmers from different communities upon personal interaction about the challenges of traditional heap fermentation involving banana leaves indicated a significant need for changes in fermentation practices. It is becoming imperative to identify fermentation practices among other technologies that might compensate for the increasing demands and consequently ensure premium quality.

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Tray fermentation has been studied widely as a potential alternative for heap fermentation, however, the quality of dried tray fermented beans as affected by stages of ripening and period of pod resting has not been ascertained in Ghana. Tray fermentation, most popular and frequently used in Nigeria in addition to the box method (Hamzat, 2005; Aroyeun *et al*., 2006; Lagunes – Gálvez *et al*., 2007; Mounjouenpou *et al*., 2008)may have the potential to improve efficiency of fermentation and as a result quality, over a shorter period compared to the traditional heap, popular in Ghana. A study to identify the prospects of tray fermentation and the influence of ripening in Ghana cannot be important at any other time than now. The over dependence on the foliage of banana and plantain plants for various purposes including cocoa fermentation does threaten their fruit bearing to provide the staple food for the populace. The defoliation of the plants has resulted in the dwindling availability of the foliar material during peak harvest. Tray fermentation could modernize and maximize revenue generation in the cocoa industry hence this study. In Ghana, tray fermented cocoa is exported under special client certificates under various initiatives including sustainable agriculture and traceability strategies facilitated by agencies such as Armajaro Ghana Limited (Peace FM, 2014) among others. The marketing of cocoa certified to

be either organically produced, free of child labour involvement during production on farms and other special farmer welfare tailored initiatives dubbed 'Cocoa Abrabopa' (COCOBOD, 2010) has included the possibility of exploring the tray option in fermentation. International buyers of such specially certified cocoa attract clients and grinders who are willing to offer the extra prices that are associated with them (FCC, 2007). Poor fermentation, a postharvest outcome depicted by the presence of purple, slaty, mouldy and germinated beans in marketed cocoa has had a number of adverse effects on the industry with its attendant economic and social implications (QCD, 2006). The over dependence on banana and plantain leaves may subside with the adoption of the tray method of fermentation beyond its current confinement to the experimental and project farms of the Cocoa Research Institute of Ghana (CRIG) and the Seed Production Unit (SPU, COCOBOD).

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1.1 OBJECTIVE

The main objective therefore of this study was to assess the effect of different stages of pod ripeness on quality of cocoa beans fermented by the tray fermentation method.

The specific objectives were to determine:

1. farmers' knowledge and their willingness to adopt the tray fermentation method.
2. the effect of stages of ripeness on fermentation and drying of cocoa beans.
3. the effect of stages of ripeness and tray fermentation method on cut test attributes of cocoa beans.
4. the effect of stages of ripeness and tray fermentation method on chemical attributes of cocoa beans.

5. the cost effectiveness of using the tray method compared to the heap method of fermentation.

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CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 World cocoa production

The cocoa tree belongs to the genus *Theobroma cacao* and the family *Sterculiaceae*(Wood and Lass, 1985), recently, with molecular marker technique *cacao* has been classified to belong to the family Malvaceae (Alvenson *et al.*, 1999 and Fagbohun *et al.*, 2011). Cocoa has been widely cultivated by the Maya-speaking people of tropical Central America before the region was conquered by Spain in the 16th century. The ancient Mayan cocoa industry is presumed to ultimately originate from the wild cocoa from the forests of the Amazon Basin. In the 17th century with its European market expanded swiftly and cocoa production expanded to most

Caribbean islands and subsequently to mainland Venezuela and Colombia. Within the same hundred years span, the transferring of a few live plants to Manila in the Philippines by the Spanish added to the volumes. Cocoa cultivation began to spread to the south through the East Indies and to Sri Lanka by the 19th century. In the early 20th century a succession of introduction were made into Sri Lanka from Trinidad by the British, the Dutch to Java and the Germans to Papua New Guinea from various parts of Latin America which gave rise to the cocoa industry in these new places. Ecuador and the Province of Bahia in Brazil independently developed major cocoa areas in the 19thcentury, the first planting in Bahia however, had been in place by the mid-18th century (Afoakwa *et al*., 2007; Fowler, 2009).

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2.2 Constraints to cocoa production in Ghana

Having been introduced as an exotic or stranger crop in most cocoa producing areas, cocoa has been exposed to a number of serious 'new encounter diseases', which originate from the indigenous host flora but to which this new crop has not developed defense mechanism(s). It has been suggested that when cocoa is in its natural environment in the upper zones of the Amazon forest, it enjoys some amount of protection from being infected by a range of co-evolved naturally beneficial organisms. This assertion has exceptions where cocoa has faced serious disease threats in the Central and South Americas such as the Witches' Broom and Frosty Pod (Vos *et al*., 2003). It has become obvious that cocoa has been attacked by some pest or disease introduced wherever the crop has been introduced to which it has been increasingly susceptible. West African cocoa farmers for example have had to grapple with a range of some pathogenic

and pest organisms, such as Black Pod causing *Phythophthora palmivora* and its more virulent relative *P. megakarya*, Cocoa Swollen Shoot Virus, Mirids, Stem Borers, Termites, Mistletoe and Weeds (Thresh *et al.*, 1998). The increasing movement of plant materials around the globe exposes cocoa to a looming threat of Witches' Broom and Frosty Pod diseases from South American locations. Further to problems with crop health, farmers have to grapple with a volatile world market, reducing labour availability due to growing disinterest of youth in agriculture, inconsistent land tenure systems, cost of farm input and difficulty in accessing credit facilities.

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2.3 Types of Cocoa

Cocoa has been classified under three large groups namely, the *Criollo*, Amazonian *Forastero* and the *Trinitario* types. These three are inter-fertile and result in fertile hybrids such as the C 70 (CRIG, 1992; Dand, 1997) and others upon genetic crossing, most of which has now become the cultivars in commercial plantations around the world (Mossu, 1992)

2.3.1 Criollo Types

This type has been domesticated for over 4000 years now by the Maya Indians representing only 5% of global cocoa production, and grown in Ecuador (Acquaah, 1999; Afoakwa *et al*., 2007 and Fowler, 2009).

They have pale pink staminodes. The pods are green or red before ripening, (Plate 2.1a) varied in shape but usually resembling the *Cundeamor* type which is fairly long and ridged with protruding or slightly reduced tips both top and bottom. They generally are with a very warty and thin pericarp and a mesocarp which is only slightly woody, and thin.

They have plump beans (Plate 2.1b), almost round in cross section, white or slightly pigmented cotyledons. Examples of the Criollo include the *Pentagona* or *Lagarto* cocoa which has typical pods with pentagonal cross-section as well as the Real and Porcelana cocoa. However this type is less vigorous, slow growing, have small leaves, vulnerable to diseases and have been less and less produced over recent years (Mossu, 1992; Afoakwa *et al*., 2007 and Fowler, 2009). It is also reported as being very much sought after because of its strong chocolate aroma with less bitterness, though fermented over shorter periods. It is very high in importance to the Biscuit, Chocolate and Confectionery Association (BCCCA) in the chocolate industry for luxury products (BCCCA, 1996).

Plate 2.1a: Criollo Type Pod **Plate 2.1b: Cocoa beans from criollo pod**

2.3.2. Forastero Type

This type which belongs to the Amelonado and Amazonia among others is a widely varied group found in an indigenous or semi-indigenous state in the High Amazonia (Peru, Ecuador and Colombia) is now mostly cultivated in West Africa. These are now widely involved in commercial plantations around the world. This group constitutes about 90% of the bulk of world production (Afoakwa *et al*., 2007 and Fowler, 2009), examples are the West African 'Amelonado',' Maranhao', 'Comun' and Para. Interesting to note are the 'Almeida' and 'Catongo' cocoa types of this group which are mutations with white cotyledons. The Forastero is characterized by the purple-pigmented staminodes with pods (Plate 2.2a) being green before ripening and varying enormously in shape. They have thick pericarp and very woody mesocarp. The beans are more or less flat in appearance with dark-purple cotyledons (Plate 2.2b), yielding a cocoa with relatively bitter flavour and often acid taste (astringent) even after fermentation as a result of the presence of some amounts of less fermented cotyledons. (BCCCA, 1996)

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Plate 2.2a: Pod of Forastero type **Plate 2.2b: Cocoa beans of Forastero**

2.3.3 Trinitario Group

This group consists of very different and heterogeneous types, probably resulting from *Forastero* and *Criollo* cross (Afoakwa *et al*., 2007; Fowler, 2009).Their botanical characteristics have all the intermediate features of the *Criollo* and *Forastero* groups (Plate 2.3a). They produce a cocoa which is also of intermediate quality. These were originally selected through crosses at the Imperial College in Trinidad, hence their name *Trinitario*. Examples are the ICS type from Trinidad, UF type from United Fruit Selection in Costa Rica, SNC type from the Nkoemvone Station in Cameroon and the WACRI Series II hybrids from the Cocoa Research Institute of Ghana (CRIG) (Mossu, 1992). These have fast replaced the original varieties on most plantations due to their advantageous characteristics inherited from their ancestors (Wood and Lass, 1985; Dand, 1997).

Plate 2.3a: Trinitario Type Pod **Plate 2.3b: Cocoa beans from Trinitario pod**

2.4 Pod Ripeness

The pod may be green, more or less intense in shade or reddish-purple or a combination of these in various degrees. Mostly the *Forasteros* are green and ripen into yellow when fully mature, *Criollo* on the other hand have reddish-purple pod becoming bright red or orange when mature. This is also characteristic of the *Trinitario* which is a hybrid of *Criollo* and *Forastero* in varied degrees (Biehl *et al*., 1990 and Voigt *et al*., 1994). At maturity, various stages of ripeness of pods are harvestable with little effect on quality of marketed beans after fermentation and drying except when pods overripe through long delays in harvesting where significant levels of diseases, pest attacks and germination become of concern (Wood and Lass, 1985).

The shape of the pod is described by determining the ratio between the pod length and its width and also by the shape of the two ends of the pods lengthwise. These may be spherical, regular oval-shaped or intermediate of these two shapes. Five to ten regularly spaced furrows run along

the length of the pod from end to end being marked in other cultivars than others. The fruit surface may be either smooth or extremely warty. A mature pod varies in length from 10 to 35 cm, the average being between 15 cm to 30 cm in length. They vary in weight from about 200g to 1kg with average pod weight being within 400 and 500g. An average mature pod contains between 100 to 120g of fresh seeds that vary in the number of seeds from about 20 to 60 per pod (Dand, 1997 and Wood and Lass, 1985)

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2.5 Postharvest handling of cocoa beans

The post-harvest handling of cocoa produced by smallholders varies a great deal depending on the location and season. The preferred quality of cocoa depends on various factors, fundamental being the variety and the post-harvest handling. Poor post-harvest handling may cause cocoa beans to grow mouldy and germinated which reduces the cocoa quality. Ghana Cocoa has superior quality specifications attributable to excellent post-harvest handling procedures maintained by the Ghanaian farmer. These postharvest handling processes involve, harvesting, fermentation, drying, transportation and storage.

2.5.1 Harvesting

Harvesting is preferably due when the cocoa pod is fully ripe on the tree showing a complete pale to deep yellow colouration. The cocoa pods attain maturity between 110 to 130 days (four to five months) sometimes extending to 120 to 150 days (five to six months) depending on the variety and prevailing weather condition, from pollination to pod ripening (Opeke, 1992; Sanusi and Oluyole, 2005). An essential requirement to ensure the production of quality beans is the harvesting of only matured and ripe pods and carrying out prompt processing (Hamzat, 2005). In West Africa there exists two fruit (pod) production seasons by cocoa farms, the main crop season – July to December and light crop season – January to April (Motamayor, 2002). Pod harvesting exercise is carried out regularly and frequently as possible to prevent excessive ripening. All pods do not ripen simultaneously either on a single tree or whole plantation thus, it is imperative that a scheduled tree inspection, preferably fortnightly, be put in place to identify ready pods for harvest. Ripe pods should not be left on trees for long to avoid pest and disease attacks and also the depletion of vital contents due to advancement in senescence. The seeds may germinate inside the pod and the weight reduced as well as the commercial value (Dand, 1997). Worse than the over ripe pod is the harvesting of unripe pods which yields poorly fermented beans with unfavourable aroma (Bitter and astringent) referred to in commerce as 'Slaty bean' due to the lesser sugar content of the mucilage surrounding the bean at this stage. If harvesting is done when pod is immature the beans may not only be smaller but also contain less fat; a factor of the quality requirements which has been widely studied and found to range on the average from 51% in dry nib for the Indonesian type to as high as 58% in the West African types (BCCCA, 1996; Dand, 1996). For optimal processing of cocoa, only ripe, undamaged and un-diseased pods are harvested and processed. Sub optimal practices have the potential to affect quality (Sukha, 2003).

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The harvesting process requires the clean cut through the stalk with a well sharpened blade or cutting edge (Machete or cutlass) and fruits high up the tree are harvested using a pruning- hook type of tool with handle at the end of a long pole. Through a push-pull mechanism the stalk is cut clean without damaging the branches (Mossu, 1992).

2.5.2 Pod Storage

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The technique of pod storage (as a means of pulp preconditioning) of cocoa beans has been reported to be beneficial to fermentation outcomes (Meyer *et al*., 1989; Sanagi, 1997; Nazaruddin*et al*., 2006). Reports have shown that, pod storage results in decreases in pulp volume relative to seed due to the loss of water by evaporation and inversion of sucrose which advantageously diminishes total sugar content leading to reduced acid production during fermentation. This practice varies in duration and depending on the volume harvested, may last favourably up to seven days or longer, though too long resting periods have attendant quality challenges (Biehl *et al*., 1989).

2.5.3 Pod Breaking

Harvested and 'rested' ripe cocoa pods (Mossu, 1992) are carefully broken with a short and blunt cutlass or club and the contents of fresh beans with mucilaginous pulp cover scooped out, piled and prepared for fermentation. This process is usually carried out at the same spot year after year and recommendations are that a pit be dug into which debris of broken pods and placenta may be buried or burnt to reduce microbial activity that may present disease hazards to the plantation and future yields. Pod opening or breaking can be an arduous task that requires a lot of labour

and the tools used have evolved to include some pod opening machines like the Cacaoette, Zumex and Pinhalense developed in France, Spain and Brazil (Mossu, 1992). Beans found to have germinated should ideally be isolated from non-germinated ones upon pod breaking in order to reduce the percentage in prepared produce for the market. This has not been the case due to the additional labour and loss of weight most farmers vehemently abhor.

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2.5.4 Fermentation

This is the process whereby microbiological and chemical activity on fresh cocoa beans over a period results in the development of preferred chocolate flavours and characteristics in the nib(Voigt *et al.*, 1994 and Schwan *et al*., 2004). The presence of relatively high amounts of flavonoids and anthocynidines which are contributory factors for the extreme bitter, acidic and astringent tastes are drastically reduced through good fermentation to levels acceptable to industry. The presence of grey or slaty beans is an indication of poorly fermented cocoa. Germinated beans which are regarded as defects due to physical and physiological changes to the bean, hold the potential of increasing the amounts of mouldy beans due to susceptibility to microflora infection. Enzymatic activity and nutrient breakdown predisposes beans to less effective fermentation (Dand, 1997).

2.5.4.1 Essential factors required for good fermentation

The degree of ripeness of the pods, type or cultivar of cocoa, diseases, climatic and seasonal variations (humidity, temperature and sometimes altitude) partly or collectively influence the speed of the process due to their bearing on metabolism of microorganisms and the reactions of compounds and enzymes (Hansen *et al*., 1998). The biodiversity factors useful to efficient fermentation (Camu *et al.,* 2007). The quantity of cocoa in a heap is also an indicator of efficiency as well as the duration. This further depends on some of the factors mentioned earlier. Ideally, fermentation volumes are recommended to be of a minimum of 90-100 kilograms and maximum of 2000 kilograms in a single heap beyond which it may be difficult to manage for good results (Mossu, 1992).

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2.5.4.2 Materials and Methods of fermentation

Fermentation methods adopted vary from fermenting on banana leaves in baskets as receptacles or on banana leaves alone according to (Jinap *et al*., 2003) in most traditional settings.

Most large plantations adopt the use of wooden boxes of definite dimension and procedures. Fermentation is said to be a basic process that can take care of itself if kept simple. This has been described as being more of an art than a science and the end-point of fermentation proposed to be best judged through experience when the external appearance of the bean indicates the expected features of readiness for drying (BCCCA, 1996). All the factors influencing fermentation quality considered favorable, a fermentation process is expected to be complete within 96 and 120 hours for the tray and banana leaves heap respectively (Kirchhoff *et al*., 1989; Lagunes-Galvez, 2007 and Lopez**,** 1995).

2.5.5 Box and Tray Fermentation

The box or tray fermentation method which is quite popular among Nigerian cocoa farmers is on the other hand in Ghana currently restricted in use on research, seed production and demonstration farms of the Cocoa Research Institute of Ghana (CRIG) and the Seed Production Unit of Ghana Cocoa Board (COCOBOD, 2010). The boxes or trays for fermentation of cocoa beans come in various shapes and sizes with attendant degrees of effectiveness of yielding the preferred fermentation results of marketable cocoa of premium quality. A typical box has a square base of length of 1.2 meters and depth of 0.9 meters to hold 1 tonne of wet beans and has perforations of 15mm diameter at 10 to 15 cm intervals at the floor to allow aeration and flow of sweating. Various arrangements are possible, such as the rows, cascades, vertical or columns. The particular arrangement comes with the advantage of ease of handling the produce under fermentation from stage to stage through the process. Aeration is a vital requirement of the fermentation process and any method such as the box or tray method must facilitate either turning of the cocoa beans or must allow the ease of air diffusion through the mass of beans. Ideally, the depth of the cocoa beans fermented should allow such aeration and the tray method in practice come handy (Zahouli *et al*., 2010).

The dimension of the tray for fermentation is preferably 0.9 m × 0.6 m × 0.13 m with 0.03m of the depth covered by battens at close intervals of about 0.5 cm to hold a maximum of 45 kilograms of wet beans (Dongo *et al*., 2008). Trays can be stacked one on the other up to twelve high. The bottom tray is usually raised slightly above ground or left empty for aeration. The filled and stacked trays are allowed to stand for 24 hours then covered with sacking to retain heat. These are left unmoved until the end of the fermentation. According to trials carried out on

Amelonado type cocoa in Ghana, a four day treatment gave a superior result to that of result of the normal heap fermentation using banana leaves (Wood and Lass, 1985).

2.5.6 Effect of Fermentation on Free Fatty Acids in dried cocoa beans

Although fermentation process play an important role in achieving good chocolate flavor, the duration of fermentation can also affect the quality of beans. Several works has shown different fermentation periods. Work done by Kirchhoff *et al*., (1989); Lopez and Dimick**,** (1995) and Dand, (1997), shows that three to six days period of fermentation with 48-hourly turnings for aeration under favourable conditions, are essential for best results. The duration of the fermentation process has been observed to be for 96 hours for the tray method and 120 hours generally for Forasteros with about 48 hours less for Criollo types. Simplice *et al*., (2008) revealed that cocoa beans fermentation duration seemed to have a critical effect of increasing the chances for FFA formation. He recorded slight increases in FFA in cocoa beans with varying increases in duration of fermentation. The initial and final FFA contents in cocoa beans fermented over 3 days were found to be higher than those in cocoa beans fermented below 3 days (Guehi *et al*., 2008). It is not advisable to extend fermentation beyond recommended periods for a particular method, due to the fact that off flavours may begin to develop due to increase in activity of fungal mould in the nib that may increase amounts of Free Fatty Acids breaking from the fat molecules through oxidation and the introduction of mycotoxins (Lagunes-Galvez *et al*., 2007).

2.5.7 Effect of fermentation duration on pH of dried cocoa beans.

Fermentation requires the increase in rate of diffusion of organic acids into the cotyledons, timing of the initial entry of these acids, duration or the period at which optimum pH and final pH are crucial for optimum flavour formation (Biehl *et al*., 1985). Beans of higher pH (5.5-5.8) are considered unfermented, having low fermentation index and cut test score - and those of lower pH (4.75- 5.19), well fermented. Fermentation techniques applied can reduce acid notes and maximize chocolate flavours (Holm *et al*., (1993); Beckett, (2008) and Afoakwa and Paterson, (2010). Studies by Biehl *et al*., (1990) revealed that varying conditions during fermentation such as duration affected the acidity of cocoa beans. Results from Biehl's study further confirmed work done by Simplice *et al*., (2010) who worked on the effect of turning beans and fermentation method on the acidity and physical quality of raw cocoa beans recorded pH values being greater than the standard Malaysian state beans, which was 4.4-4.7 (Nazaruddin *et al*., 2006) after four days of fermentation.

2.5.8 Microbial and chemical activities during fermentation

Fresh cocoa beans and the pulp during fermentation undergo the following important changes. Micro-organisms such as yeast *Saccharomyces cereviseae* first develop on the mucilaginous pulp on the beans (Jespersen *et al*., 2005; Schwan *et al.*, 1995) and are suspected to be borne by insects that are attracted to the heap especially *Drosophila melanogaster* the 'vinegar fly' (Nielsen *et al*., 2005). Initially the moisture content of the pulp is about 85% and 11% sugars with a pH of 3.5 due to Citric acid. The action of the yeast leads to the conversion of sugar to alcohol with further washing off of Citric acid with the flow out of water from the pulp. Bacteria activity increases with the development of congenial environment enhanced by the occurrence

mentioned above (Hashim *et al*., 1998; Ardhana *et al.*, 2003).Two main bacteria groups are important at this stage and these are the Lactic Acid Bacteria (LAB) and the Acetic Acid Bacteria (AAB) **(**Cleenwerck *et al*., 2007) the former being anaerobic and the latter aerobic, converting sugar and other compounds such as alcohol to lactic acid and acetic acid (Holm *et al.*, 1993; Hashim *et al*., 1998). A diffusion of oxygen through the pile in aid of the acetic acid bacteria activity converts the sugar and other compounds accumulating, into acetic acid as Lactic acid bacteria anaerobic activity which converts sugar to Lactic acid and presents the rather acidic taste in beans is reduced.

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The bacteria oxidation involved is exothermic, warming the heap up to a temperature range of between 40 and 45°C. The heat in addition to the acetic acid (volatile short-chain fatty acid) present in the bulk diffuses through the beans to kill the seed, leading to the collapse of cells and the ease of absorption of pulp liquid into the cotyledons (Hashim *et al*., 1998). The bean increases in volume slightly through bloating leading to reactions that change the nature and concentration of peptides, amino acids (Kirchhoff *et al*.,1989; Lopez**,** 1995; Lagunes-Galvez, 2007) pyrazines, alkaloids, and polyphenols in the cocoa bean, mainly through endogenous enzymatic activities and other earlier mentioned factors (Hansen *et al*., 1998; Brito *et al*., 2000; Camu *et al*., 2007).

2.5.9 Reduction of purple pigment during fermentation

The turning of the beans at 48 hour intervals within the five to six-day period of large heaps of cocoa beans that are greater than the ideal minimum of 90 kilograms, facilitates the adequate exposure of beans to oxygen for efficient aerobic bacteria activity important for proper fermentation and reduction in proportion of purple beans (Dand, 1997). He also recommended

the removal of the placenta from the bulk of beans to be fermented. In some larger box or tray fermentation this step is carried out by special cascade arrangement of various units that are tipped from one level into the next lower level following the 48 hour interval. Other types do not require the turning step at all as a result of their design thus making them convenient to handle in terms of labour (Wood and Lass, 1985). Work done by (Guehi *et al*., 2010) shows purple beans decreased to about 12% for cocoa fermented in wooden box with turning.

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Further, from work done by (Guehi *et al*, 2010) indicated that fermentation with wooden box for 4 days without turning, resulted in pH of dried cocoa beans ranging between 4.75 and 5.30 while those that were turned within boxes resulted in a higher pH range of 4.92 to 5.66. Chong *et al*., (1978) and Duncan (1989) concluded that titratable acidity was a better indicator of the acidity in cocoa liquor than pH and have been correlated with taste scores or flavour acidity.

2.6 Drying

Drying involves the exposure of the fermented beans to the sun mostly in the regions with the favourable weather for this purpose or using artificial drying methods at an ambient temperature of 40°C in areas with high humidity condition to reduce the moisture content of the beans from about 60% to the ideal range of 6% to 7.5% at which point a couple of beans squeezed in the palm gives a crackling noise. Beans with more than 8% moisture may grow mouldy quicker with time in storage (Kirchhoff *et al*., 1989; Lagunes, 2007; Lopez**,** 1995) The drying process is recommended to be mild enough to avoid the fast hardening of outer tissue of the nib which locks up some moisture in the middle portions of the bean that may aid fungal growth and

introduce off flavours through oxidation which germinated beans might exhibit an aggravated situation. Rapid drying can also result in excessive acidity, thus low pH, as a result of the presence of volatile and non-volatile acids such as acetic, citric and lactic acids that might be locked in, instead of evaporating slowly through the moderately slow rate of drying (Wood *et al.*, 1985). The drying exercise should ideally be completed between 4 and 10 days depending on prevailing conditions and thickness of the spread of beans on the mat (Duncan, 1984). Slow or delayed drying can cause off flavours from fungal or other deterioration. The artificial drying system should be such that it does not introduce any smoky or other fuel taint into the beans. When the drying is efficiently done it enhances the development or achievement of the preferred chocolate flavour (Dand, 1997).

In Ghana, the traditional practice of drying is by using raised platforms of raffia palm frond woven together either by the same material (Wood *et al.*, 1985) or with nylon twine into mats. The beans are spread thinly on the mat to about a depth of 7.5 centimeters (3 inches) and not more than 9 centimeters (6 inches) to ease the drying. Frequent stirring of the beans is recommended for free flow of warm air through the mass and removal of debris of pods, placenta, flat beans, germinated and black beans together with other foreign materials. The beans must be protected from rodents and other pests and domestic animals who may introduce foreign matter droppings and pathogens that may reduce the quality (Wood *et al.*, 1985). The mat or drying method adopted must incorporate a facility that aids covering and protection from the rummages of rain or adverse weather including dust. The traditional mats are usually rolled in the evenings and spread out again in the morning to meet the above requirement.

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On large plantations elsewhere, drying may involve the use of more elaborate drying systems, some of which are still under trial, but the key objective has been the production of good quality dried beans (Wood *et al*., 1985).

2.7 Storage

Maintenance of the dried beans in good condition until utilized is very essential in the cocoa industry and this is achieved by the way they are stored in the supply chain. The dry beans which are highly hygroscopic do absorb moisture quickly when exposed to humid conditions (Wood *et al*., 1985). The moisture thus absorbed if protracted under that condition may trigger fungal growth and other reactions that lead to rancidity and other deteriorations reducing the quality. If favourable conditions are restored or such damp beans are exposed to warm conditions by re-drying, they lose the moisture hitherto absorbed to the outside environment but onset of deterioration to any extent is irreversible (Dand, 1997).

Cocoa if exposed in storage to other items including foodstuff with odour can get tainted by these unwanted scents to reduce the quality. Smoke, mineral oils and other materials are detrimental to cocoa quality during storage or transport (Jonfia- Essien, 2001).Storage pests such as insects and rodent pests can damage produce both externally and internally to reduce both quantity and quality and these must be prevented from getting near produce by all means possible, physical or chemical. Some of the interventions put in place to ensure the safety of the beans based on international standards of cocoa commerce are; Storage in ambient humidity of not higher than 70 per cent, Storage in dry hessian (jute) sacks that maintain adequate ventilation around the beans, weight of bag of cocoa accepted in international commerce is 62.5kg, placing sacks on dry gratings (well cured wood) at least 7 cm from the floor and allows free air

circulation, sacks of cocoa bags must be placed at least 60 cm away from walls of the store and between stacks. Different types of cocoa must be stored separately in different stacks (Powell and Wood, 1959; Jonfia- Essien, 2001).

Disinfection with fumigants such as phosphine and spraying with pyrethrin-based insecticides and protection against rodents and other pests and avoidance of contamination with odours, off-flavours and dust are additional requirements as well as regular inspection of the storage facility and the produce in store (Wood and Lass, 1985).

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2.8 Fat

The cocoa bean contains a high amount of fat to about 45-55% of its weight with some new varieties containing higher amounts being developed through research. There are variations in the fatty acid composition of the triacylglycerides in cocoa beans which may attributable to the ambient temperatures prevailing at where cocoa was grown. Other factors that might affect the fat composition include edaphic factors and shading. The composition of fatty acids of the triacylglycerides are mainly 26.5 % palmitic, 35.4% stearic, 34.7% oleic and 3.4% linoleic and others which are available in traces (Quao, 2010).

2.9 Free fatty acids (FFA) in cocoa

Free fatty acids (FFA) are carboxylic acids released from Triglycerides (Selamat*et al*., 1996) through the effects of lipase (E.C 3.1.1.3) or an oxidation reaction. Cocoa beans or butter contains low amounts of unsaturated fatty acids (Whitefield, 2005) hence lower amounts of free fatty acids relatively, with high amounts of polyphenols and natural anti-oxidants therefore, exposed to negligible risk of oxidation (Nickless, 1996). It has been detected that plant lipase

activity is usually high during seed germination (Wanasundara *et al*., 2001) and cocoa beans may not be an exception as in the over ripe pods. Over ripe pods may contain some amount of black and rotten beans due to senescence. Wood and Lass (1985), Pontillon (1998), Fowler (1999) Hiol (1999) and Afoakwa *et al*., 2011 suggested that FFA may occur in stored cocoa beans due to the activity of microflora, particularly moulds and their associated lipases activity under humid condition. In the trade and industry of cocoa the maximum allowed limit of percentage free fatty acid content is 1.75 Wood and Lass (1985).

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2.10 Polyphenols

The polyphenols present include; tannins, *cathechin, anthocyanin, leucoanthocyanin* and purines present include *theobromine* and caffeine. The anthocyanin content, commonly called 'cocoa red' or 'cocoa purple' give the cotyledons their purple colour. The tannins which have an astringent taste oxidize rapidly, giving coloured products which are commonly referred to as 'cocoa brown' *Theobromine* (3-7 dimethylxanthine) and *caffeine* (1-3-7-trimethylxanthine) are bonded to the tannins in a way that form compounds in the fresh cotyledons. *Theobromine* among other compounds, have been identified to be responsible for the bitter taste in fermented cocoa beans found in commerce. These essential compounds have been proven to be affected by the oxidative reactions that prevail during fermentation and drying of cocoa (McDonald *et al.*, 1981). Compounds associated with the characteristic chocolate flavor have been found in the majority of unfermented cocoa beans (Mossu, 1992; Lopez**,** 1995 and Lagunes-Galvez, 2007).

2.11 Development of the characteristic aroma, flavour and colour of the beans

These properties are developed further during drying, roasting, and final processing of well-fermented cocoa beans (Voigt *et al.,* 1994 and Thompson *et al*., 2001). Resultant product quality of the fermentation process however depends on the raw material.

2.12 Bean count and moisture content of cocoa beans

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The grading of cocoa involves a number of procedures which assess both quantitative and qualitative attributes of the commodity as well may be external and maintain the bean intact or be destructive as in the cut test and in laboratory analysis where required. Quantitative attributes may include the bean weight which is assessed by the bean count per 100 grams weight of beans as well as the moisture content of beans which gives an idea of the available dry weight as well as safety of beans for storage. The weight of beans therefore is directly related to its moisture and dry matter content which the extent of maturity and ripening of the pods are a factor at harvesting and pod breaking for fermentation (Mossu, 1992). These parameters therefore form part of initial procedures for quality assessment of cocoa beans.

2.12.1 Moisture Content Determination

Determination of the Moisture content of cocoa beans has been based on the ISO 2291 Laboratory methodology in which samples are dried by hot air in an oven set at 105^0C for some hours till it attains a stable weight. This has been simulated electronically in moisture meters used on the field such as the "Aqua Boy" moisture meter which gives accurate results. (Dand, 1997). With this equipment a metal probe or a cup electrode which senses the amount of

moisture present in the sampled produce as electrical conductivity measurable as current on a calibrated scale by a pointer or cursor based on the ISO 2291 laboratory results for cocoa.

2.12.2 Selective Grading and bean count determination

The marketing of cocoa in Ghana and other producing countries incorporated selective grading or sale of cocoa beans by bean weight or size based on the bean count by 1995 and categorization of this specification has continued. A representative sample of beans to be marketed is drawn and 100 grams weighed and counted. The weighing and counting is done in triplicate and the average bean count determined (QCC, 2011).

2.13 Terminologies used in assessing the quality of fermented cocoa.

Cocoa beans with internal and external fungal infection are described as mouldy (Plate 2.3). When over ripe pods are harvested, the beans may have already germinated or do so during the beginning of fermentation. The embryo may protrude or later fall out leaving a round hole in the shell. Germinated beans are more likely than normal beans to develop serious defects such as internal mould or insect infestation during storage due to either the more nutritious germ or the open entry point for agents of infestation or infection (Appiah, 2001). Slaty beans can be recognized by their darker cut surface with more compact cotyledon with slaty and "cheesy" texture. Chocolate made from them is dark grey, extremely bitter, astringent and lacks the typical chocolate flavor. Slaty beans generally result from inadequate ripeness of pods which does not allow the beans to undergo effective fermentation. Over-fermented beans tend to give a rancid flavor due to oxidation and chocolate flavor suffers as a result. Some over-fermented beans are dark brown.

Smoky beans are beans contaminated by smoke during drying. They have objectionable flavor which is impossible to remove from the chocolate due to the high solubility of aromatic carbons in cocoa butter. Off-smell caused by one or two smoky beans in a lot can destroy the quality of the entire lot for processing (Dand, 1993).

Flat or shriveled beans are imperfectly developed beans containing very little of the useful cotyledons. Their presence reduce yield of nib and they are removed by sieving and grading machine. The cotyledons are too thin to be cut to give a surface for observation in analysis.

Purple beans are objectionable because they produce bitter and astringent flavor. They exhibit a bright purple colour associated with inadequate fermentation. Normal fermentation will however give a proportion of beans described as partly brown and partly purple. Such beans are not defective; in fact it is desirable that the samples contain at least 20% of beans in this category. As the proportion increases, the bitter and astringent flavor of inadequately fermented cocoa will tend to dominate and 50% is regarded as the upper limit for the class of beans (Appiah, 2001) Insect-damaged Bean: A cocoa bean the internal parts of which are found to contain insects at any stage of development or show signs of damage caused thereby, which are visible to the naked eye. Thoroughly Dry Cocoa: Cocoa which has been dried throughout. The moisture content must not exceed 7.5% (Jonfia- Essien, 2010).

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Plate 2.4: Cross section of cut cocoa bean. SOURCE: QCC Research Laboratory, 2010

2.13.1 Grading of cocoa beans (Cut Test)

Cocoa as a food material and export commodity is marketed under internationally defined quality standards and its grading involves steps and methods based on the count of defective beans in the 'cut test'. The cut test exposes the presence of defects which may cause off-flavours and indicates the extent of success in fermentation of the beans and has a bearing on the flavour and quality of the products from further processing. The International Cocoa Organization (2004) cut test procedure requires that a complete determination of bean quality be done on a composite sample drawn from a bag or batch (30 bags at buying centers and 300 bags at port). The sample is thoroughly mixed and then 'quartered' down to leave a collection slightly more than 100 beans for a bag and 300 beans for more than one bag. The first 100 or 300 beans are

counted off regardless of size, shape or condition in the particular case. Beans are cut lengthwise (longitudinal) through the middle, a maximum cut surface must be exposed of the cotyledons. Both halves of each bean are visually examined but only one half is factored in the analysis. Each defective type of bean shall be counted separately, and the result for each kind of defect shall be expressed as a percentage of the beans examined. The number of defective beans is recorded as percentage of each defect being either, mouldy, slaty and other defects namely, germinated, insect damaged, flat or shriveled. The cut test is done on samples per batch of cocoa under inspection or examination (Wood and Lass, 1985; Dand 1993; BCCCA, 1996; Acquaah, 1999). Gourieva and Tserrevitinov (1979) and Kongor *et al*., (2013) provide a fermentation index (FI) with respect to purple colour presence in fermented and dried cocoa beans ranging between deep purple through pale purple to the preferred brown (chocolate) colour to complement the cut test as a measure of the effectiveness of fermentation and drying over varied periods.

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2.13.2 Grade Standards

Cocoa is graded on the basis of the count of defective beans in the cut test. Defective beans shall not exceed the following limits within a particular grade (Table 2.1). Other defects as appears in the table implies defects regarded as minor relative to mould and slaty and includes germinated, flat, weevily among others. On a lighter note, percentage purple content levels of up to 20% is set for Grade I cocoa while up to 30% is acceptable for Grade II with any higher amounts in a parcel of cocoa beans given a critical look with regards to acceptability in quality (QCC, 2010).

Table 2. 1: Quality Specification for Ghana Cocoa Beans

	Maximum defect levels		
Grade	**Mouldy**	**Slaty**	**All Other defects**
Grade 1	3%	3%	3%
Grade 2	4%	8%	6%
Sub-Standard(SS)	>4%	-	-

Source: COCOBOD (2010)

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2.14 Uses of Cocoa

The "food of the gods" as cocoa has been named, through West Indian folklore, ancient courts of the Aztec dynasties of Mexico held the cocoa tree, fruits and products in very high esteem. Locally referred to as "*quachahuatl*" tree, products like the *xocoatl*, a beverage which was preserved for royalty and presumed to have aphrodisiac properties and from which the history of chocolate evolved. Various modifications of the original recipe were developed by early explorers and merchants in their home countries to which the crop was exported (Knapp, 1934; Acquaah, 1999). Dried fermented beans are chewed like kola by other interested persons on a rather low scale. The butter from the beans at the local level have been used as skin smears and moisteners but this was not popularized like shea butter until industrial cosmetic products from it became prominent. Cooking fat, medicinal balm and ointment, hard soap for laundry, soft soap for toiletry, candle fat, dipped candle, moulded candle are other products locally derived from cocoa butter.

Cocoa Research Institutions like the one at Tafo in the Eastern Region of Ghana has in recent times been developing new products under its New Products Development Unit. Products like cocoa cream, wine, brandy, whiskey, vinegar among others derived from the juice from the mucilage. In a factory at Calabar, Nigeria, it has been reported that by-products from the manufacture of the earlier mentioned beverages have been used to produce floor tiles, ceiling boards and shoe polish (Ake, 1974).

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Modernization of industry through technological advancement has led to a swift development and improvement of the products of cocoa, chief among these are cocoa liquor, butter, cake and powder produced by a group of manufacturers called cocoa processors and further products of these by chocolate, confectionery, cosmetic and pharmaceutical companies. Cocoa and chocolate products constitute a great number of pleasure and luxury products for ordinary as well as special occasions which list is in-exhaustive (Dand, 1997).

For good quality cocoa products, the chocolate flavor (aroma and taste) and colour are very important attributes that are required by manufacturers. Good fermentation practices carried out on harvested beans results in well cured cocoa which has the potential of developing the favourable chocolate aroma when beans are roasted during the manufacturing process (Wood and Lass, 1985).

2.15 Nutritional Value of Cocoa

Cocoa is reputed as food of very high nutritional content that holds the potential of meeting various body needs for which its consumption has been reported as having enhanced a lot of functions. Laboratory analysis on cocoa and cocoa products has revealed a lot of remarkable

nutritional facts to the extent that the rate of absorption of most of these nutrients by the human body is about 90% compared to other food sources like tea and coffee which discharge three-quarters of the weight as waste. It has further been observed that for the same quantity of these food substances, cocoa yields thirteen times the nutrients of tea and four and half times that of coffee.

Cocoa powder can contain between 8 to 36% of cocoa butter depending on preference of manufacturers and consumers and this percentage is further raised for chocolate manufacture. Theobromine and caffeine content of cocoa give a mild stimulating effect and its high digestibility and calories content reputes it as a high energy food. In situations of war, famine and disaster management, cocoa products have featured prominently in emergency food aid.Its value in infant food and ability to enhance longevity, fertility among men and muscular strength cannot be over emphasized (Acquaah, 1999).

This study may not be exhaustive without the mention of chocolate, probably the most popular of cocoa products among a varied category of persons. Chocolate is a product of cocoa liquor, cocoa butter and other ingredients like sugar, milk and other additives such as different kinds of essence, usually vanilla. Chocolates play an important role during special occasions especially the romantic part of valentine days (Wood and Lass, 1985).

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CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Site

This study was conducted on a 6-acre (2.4 hectares) cocoa farm at 'Sentia', near 'Wassa Mpohor' in the Western Region of Ghana while the laboratory work was carried out at the laboratory of Quality Control Company (COCOBOD) at Tema.

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3.2 Materials for Field Experiment

3.2.1 Survey

An initial survey was carried out to ascertain the extent of challenges that traditional heap fermentation presented to farmers, their awareness of tray fermentation method and willingness to adopt this technology. To achieve this objective questionnaire (APPENDIX I) were administered to fifty (50) cocoa farmers within the Wassa Mpohor community. Open and close ended questions were used to solicit information from the farmers in line with the objective of the study. Information gathered included, type of fermentation, knowledge on tray fermentation, challenges on the use of heap fermentation and tray method and their willingness to adopt the tray method.

3.2.2 Crop Type

Cocoa beans at different stages of ripening (half-ripe, full ripe and over ripe) (Plate 3.1) used in this trial were collected from fruits of Hybrid C 70 clonal type developed by the Cocoa Research Institute of Ghana (CRIG, 1984) and had been planted in 1997 (16 year old cocoa trees). Seven

thousand cocoa pods were randomly harvested (2013/2014 main crop season) and their beans extracted from them. Pods were considered **half ripe** when they had pale yellow and green patches, **full ripe** whencompletely yellow or orange in colour with or without minimal patches and **over ripe** when fully covered with deep yellow to orange colour with dark brown patches.

Plate 3.1: Cocoa pods at different stages of ripening

3.2.3 Wooden tray

Wooden trays, of 45 kg wet beans capacity, and of dimensions (L=0.9m× B=0.6m× H=0.13m) (Wood and Lass, 1985) were used for fermentation (Plate 3.2a).Three sets of three tier trays were used with each set on a stand representing a replication. The sets were labelled as T_1, T_2 and T_3 (Plate 3.2b).

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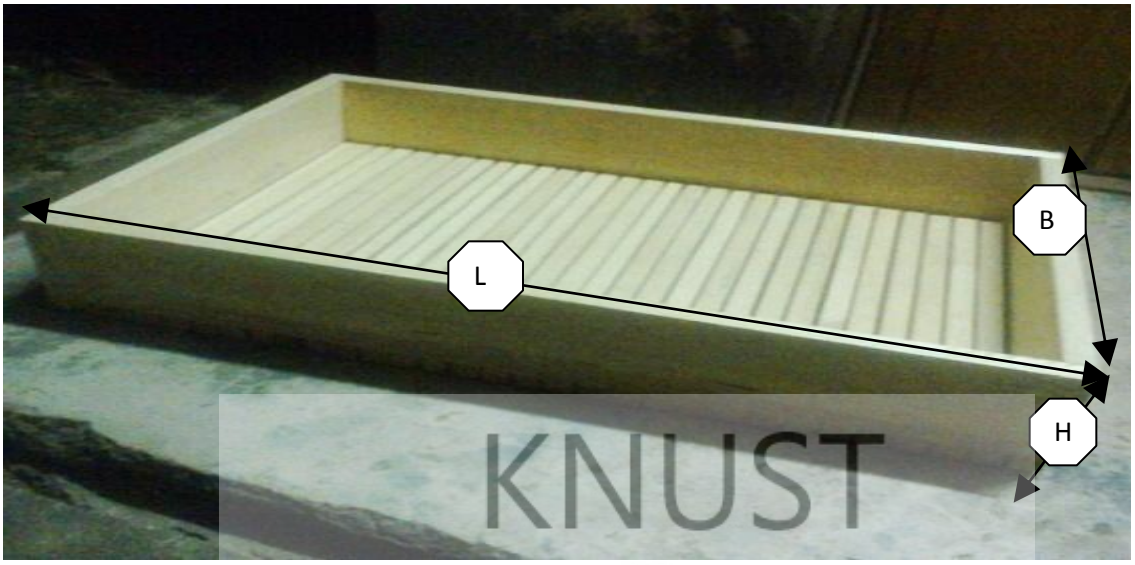

Plate 3.2a: Wooden Tray

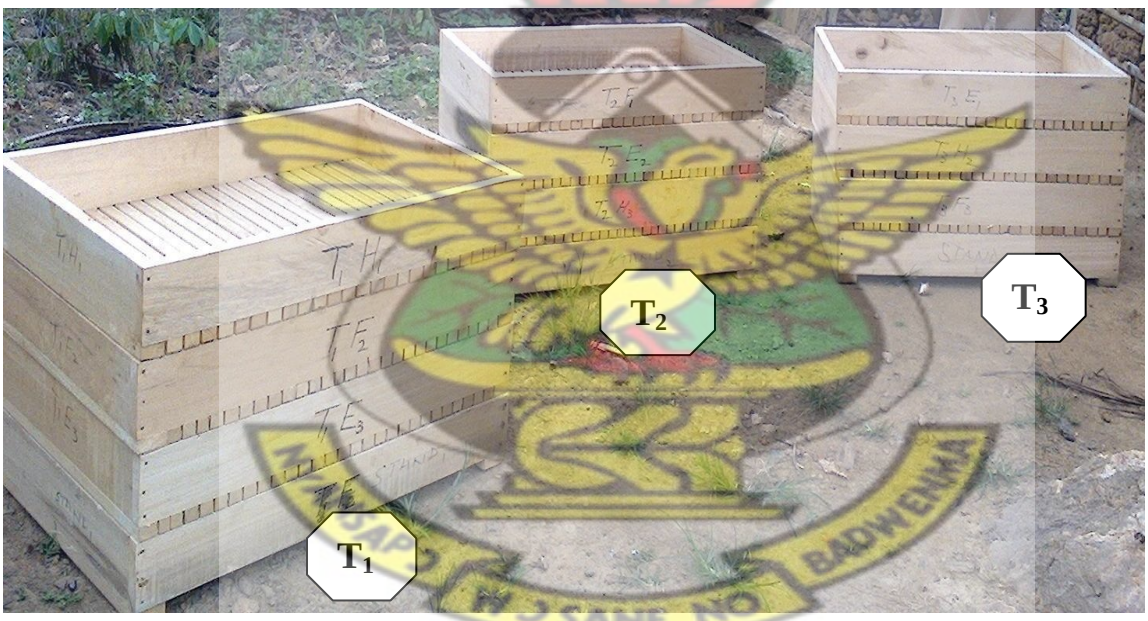

Plate 3.2b: Tray Sets

3.2.4 Kenaf Jute Sacks

Jute sacks made of Kenaf and originally treated with vegetable oil according to industry specifications by manufacturers (COCOBOD, 1995) and imported from India, were used to cover the tray sets containing fresh cocoa beans during the fermentation (Plate 3.3).

Plate 3.3: Jute Sack

3.2.5 Drying Mats

Drying mats made of raffia palm fronds with each unit having a dimension of 2m × 2.5m and raised to about 1 meter high on wooden and bamboo frame was used to dry the fermented beans (Plate 3.4).

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Plate 3.4: Drying Mats made from raffia palm fronds

3.3 Experimental Design

The experiment was conducted using Completely Randomized Design (CRD) for the field work. Three treatments (stages of ripeness) namely, half ripe, full ripe and over ripe were distributed over three sets of trays namely (T_1, T_2 and T_3) with each set of tray representinga replicate. Heap method with the full ripe stage fermented for six days was used as control.

3.4 Field Experiment

3.4.1 Harvesting, Sorting and Resting of Pods

Cocoa pods were harvested over a period of four days, gatheredand the three ripening stages of interest were sorted. Debris and blemished pods were removed from the harvested stock in addition to sorting over three more days within which the pods were resting, consistent with farmer practice according to personal enquiry from some farmers.

3.4.2 Pod Breaking

Blunt machete was used to break pods open to facilitate bean-scooping from pods (Appendix A).

3.5 Filling of Trays

The trays were filled with 45 Kg each of the designated categories of cocoa beans according to the experimental design (Plate 3.5). The filled trays were then arranged according to the three sets in the design and left uncovered for 24 hours before covering with the jute sacks and allowed to ferment for four days (96 hours) (Appendix B).

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Plate 3.5: Fresh Half Ripe Beans in Tray

3.6 Fermentation and drying

The traditional heap fermentation method was used as control for ripe stage (Appendix C). The beans in each tray and heap (45 kg) cocoa beans each representing the three ripe stages was set and allowed to ferment for 96 hours for the tray as scientifically recommended (Wood and Lass, 1985) and 144 hours for the heap according to common practice. All the treatments were dried on a mat after their respective completion period.

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3.7 Monitoring of Temperature in Trays and Heaps

Temperature was monitored (Appendix D) every morning (6am) and evening (5pm) in all treatments at about 15 centimeters deep (Wood and Lass 1985) during the fermentation period using a thermo hygrometer (HANNA instruments: HI 9161C; -20.0 °C to 60.0°C) in both heap and trays for the first four days.

3.8 Drying of Fermented Beans

The fermented beans from each tray and heap were dried separately (Appendix E &F) for a period of five days (Plate 3.8). Temperature and relative humidity (RH) of the environment were monitored using the thermo hygrometer (HANNA instruments; HI 9161C: RH range 5.0% to 95.0%).

The following parameters were assessed in triplicates during the study:

3.9 Bean Count and Moisture Content Monitoring during Drying of beans

The bean count per 100 g (QCC, 2011) and moisture content of fermented beans were monitored during the drying process to observe how different ripening stages affected this quantitative quality factor (Plate 3.6 & 3.7).

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Plate 3.6 Bean Count during drying

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Plate 3.7: Determination of moisture content

3.10 Sampling from each criteria of fermented cocoa beans

One (1) kilogram each of dried fermented cocoa beans were sampled from each experimental unit and labeled for further analysis (QCC, 2011) (Plate 3.8).

Plate 3.8: Sampling dry fermented beans for analysis

3.11 Cut Test

Three hundred beans from each treatment sample were cut longitudinally across the broader surface (Plate 3.9) and the defects of the various beans were picked (Plate 3.9).

Plate 3.9a: Cross longitudinal section of cut cocoa beans before picking of defect.

Plate 3.9b: Defective beans picked from the cutting in Plate 3.9a.

The following data were collected during the cut test;

3.11.1 Average mouldy beans

Mouldy beans as a defect were observed from 100 beans from each tray for each ripe stage and the number of beans found to exhibit the features of mouldiness was counted. This was expressed as a percentage using the formula (QCC, 2011).

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$$\% \text{ Mouldy beans (M)} = \frac{Number\ of mouldy\ beans}{Total\ number\ of\ beans\ cut} \times 100$$

3.11.2 Average slaty beans

Slaty bean, as a defect, was observed from 100 beans for each treatment and expressed as a percentage using the formula (QCC, 2011).

$$\textbf{\% Slaty beans (S)} = \frac{Number\ of\ slaty\ beans}{Total\ number\ of\ beans\ cut} \times 100$$

3.11.3 Average germinated beans

Germinated beans as a defect were observed from 100 beans cut from each tray (T1, T2, T3) for each ripe stage and the number of beans found to exhibit the features of germination counted. This was expressed as a percentage for each treatment by the formula (QCC, 2011):

$$\textbf{\% Germinated beans (G)} = \frac{Number\ of\ germinated\ beans}{Total\ number\ of\ beans\ cut} \times 100$$

3.11.4 Other defects

Other defective beans such as Weevily, Flat, Foreign Matter among others were observed from 100 beans cut from each tray (T1, T2, T3) for each ripe stage and the number of beans found to exhibit the features of other defects counted. This was expressed as a percentage for each treatment by the formula (QCC, 2011):

$$\textbf{\% Other defective beans} = \frac{Number\ of\ \ other\ defective\ beans}{Total\ number\ of\ beans\ cut} \text{ x } 100$$

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3.11.5 Purple beans

Purple beans, as a defect, were determined from100 beans from each tray for each ripe stage and the number of beans found to exhibit the features of purpleness counted. This was expressed as a percentage using the formula (QCC, 2011).

$$\textbf{\% Purple beans (PP)} = \frac{Number\ of\ purple\ beans}{Total\ number\ of\ beans\ cut} \times 100$$

3.11.6 Percentage Purity

Purity as a measure of the overall effect of the observed defects on the quality of cocoa, was expressed as a percentage by the formula (QCC, 2011).

% Purity (P) = 100 – [M + S + AOD]

Where,

M = the percentage Mouldy beans found

S = the percentage Slaty beans found

G = the percentage germinated beans found

OD = (Weevily, Flat, Foreign Matter etc.)

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AOD = the percentage of germinated and all other defective beans found

3.11.7 Percentage Purity with purple factor

Percentage purity as a measure of the overall effect of the observed defects on the quality of cocoa, has always been expressed without the purple factor in practice but for the purpose of this study and to enable a proper measure of the results of fermented stages of ripening and tray method, a modified formula (QCC, 2011) is included as below.

% Purity (P') = 100 – [M + S + AOD+PP]

Where,

PP = the percentage purple beans found

3.12 Laboratory Work

Samples taken in triplicates were assessed for the following;

Fat Content, Free Fatty Acid (FFA) and pH, according to the recommendations of AOAC (2012).

3.12.1 Determination of Fat content

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A 5.0g portion of powdered cocoa beans from each treatment was weighed into an extraction thimble and defatted using standard procedure for cocoa powder fat extraction by soxhlet method. Petroleum ether was used as the solvent and evaporated off after extraction. The residue (fat extracted) together with the Erlenmeyer flask were dried in an oven at 105^{o}C for at least 2 hours. The flask with the fat were allowed to cool in desiccators for 30 minutes and weighed again with the residue. The fat content was expressed as a percentage of the weight of the 5.0g using the formula (AOAC, 2012):

$$\% \text{ Fat} = (M_3 - M_1)/M_2 \times 100$$

Where:

M_1= mass in grams of the Erlenmeyer flask

M_2= mass in grams of the cocoa powder sample

M_3= mass in grams of the flask with the fat residue

3.12.2 Determination of Free Fatty Acids (FFA)

The FFA for each treatment was determined by adding 25 ml of 95% ethanol and 25 ml diethyl ether to the extracted fat and gently swirled to obtain a homogenous mixture. The mixture was titrated against 0.1M NaOH using phenolphthalein as an indicator and the titre value was recorded. The free fatty acid (FFA) was calculated as Oleic acid and expressed as a percentage by the formula (AOAC, 2012):

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$$\%FFA = (V \times N \times F \times 100)/ (SW \times 1000)$$

Where:

V = volume of NaOH required

N = Normality of the NaOH

F = equivalent weight of the FFA expressed in oleic acid equivalents

SW = sample weight

3.12.3 Determination of pH

A 10g portion of fine milled cocoa nib from each category of sample was weighed into a kilner jar appropriately labeled. Distilled water was boiled to about $100^{O}C$. 100 ml of the boiled distilled water was poured into the kilner jar containing the sample. The content was stirred continuously for about 5mins in each case and then filteredinto another kilner jar through a

Whatman Filter paper. The filtrates were allowed to cool to 20^{O}C. The pH of the cocoa beans was determined in each case with the pH meter, (AOAC, 2012).

3.13 Data Analysis

Data collected numerically in both the field and laboratory work were subjected to statistical analyses using analysis of variance, GenStat version 9.2 (Lawes Agricultural Trust, 2007). Where significant differences were observed, the Least Significant Difference (LSD) was used to separate the means at 5% level of confidence. Tables, graphs and pictures were used to present the results.

3.14 Determination of the cost effectiveness of the tray method compared to the traditional heap fermentation method

Thecost of constructing the ten (10) trays of dimension 2m x 1m x 0.13m to handle an average harvest of 10 bags of cocoa assuming a farm size of 10 acres or more. The estimated cost of materials for constructing the trays were obtained from the Bibiani wood market. A tray was expected to last forseven years and this was used to determine the depreciated value over the period. The operational cost of handling cocoa from harvesting through fermentation to drying was determined using the minimum wage per day per man hour for the estimated volume of cocoa for both the heap and tray method.

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CHAPTER FOUR

4.0 **RESULTS**

4.1 Results of survey

4.1.1 Farmers knowledge of tray method of fermentation

The results of the survey indicated that 74% (Figure 4.1) of the farmer respondents were familiar with thetray method of fermentation while 26% were not.

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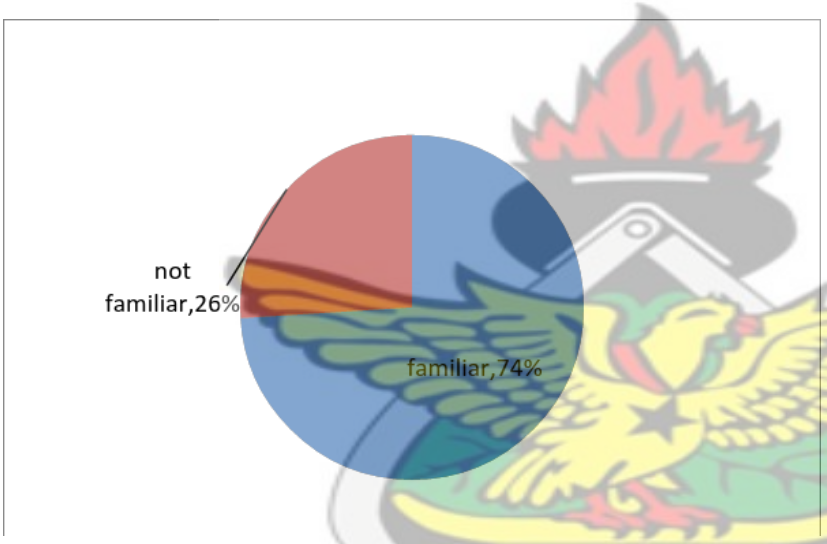

Figure 4.1: A pie chart showing farmers familiarity with tray method

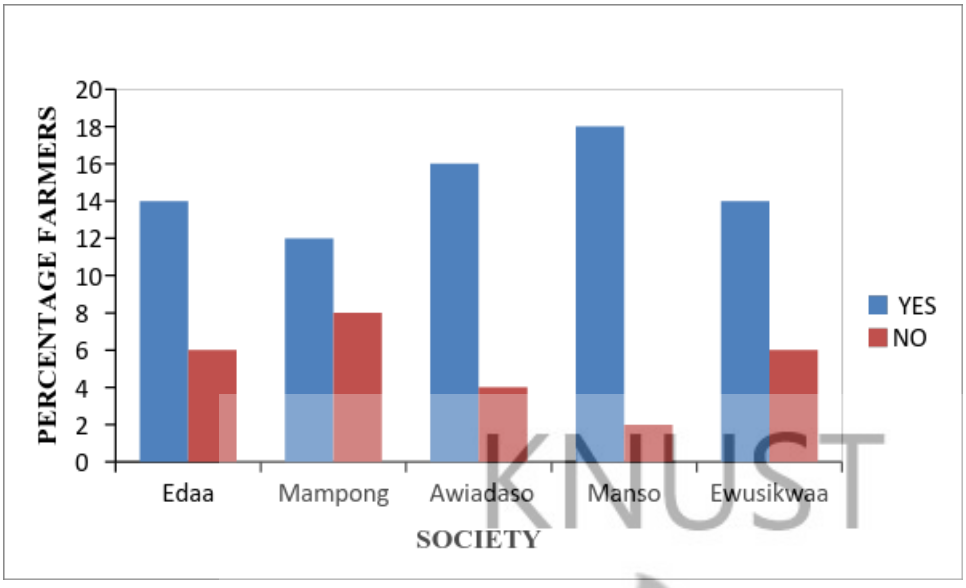

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Figure 4.2: A graph showing the distribution of respondents among the societies

As far as the communities were concerned, 14%, 12%, 16%, 18% and 14% (Figure 4.2) of respondents from were familiar with tray method of fermentation in Edaa, Mampong, Awiadaso, Manso and Ewusikwaa, respectively.

4.1.2 Farmers willingness to adopt tray method of fermentation

The results of the survey indicated that 42 farmers representing 84% of the entire population (farmers) expressed their willingness to adopt the tray method of fermentation over the heap method. Out of this, 18% were from Edaa, 16% from Mampong, 18% from Awiadaso, 14% from Manso and 16% from Ewusikwaa. However, 16% were not willing to adopt the tray method of fermentation.

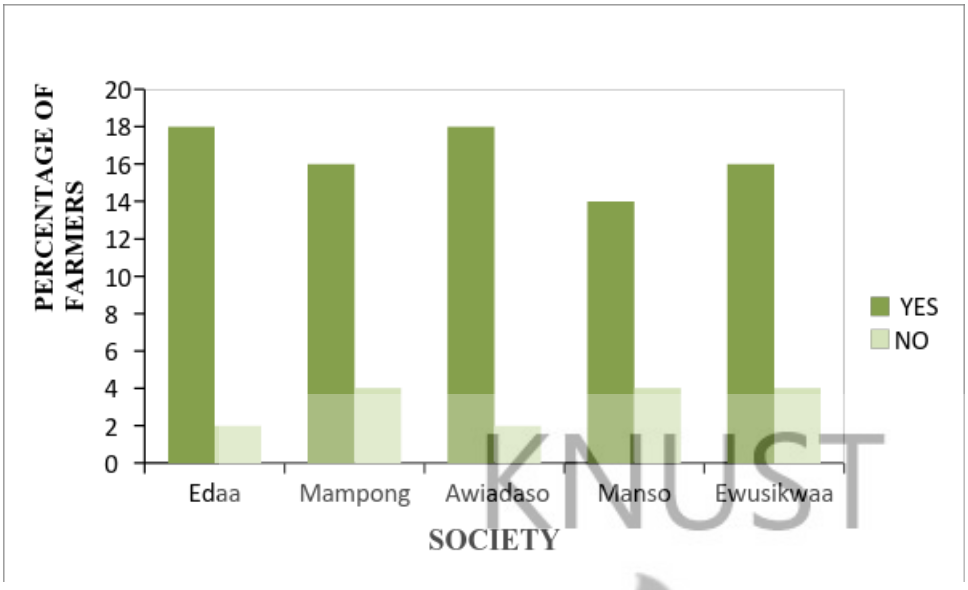

Figure 4.3: A graph showing farmers willingness to adopt tray method

4.2 Effect of stages of ripeness on fermentation method and drying of cocoa beans.

4.2.1 Moisture Content

Figure 4.1 shows variation in moisture content of the cocoa beans during drying. It was observed that generally, moisture content declined sharply from an average of 56.4% on Day 1 to an average of 11.3% on Day 3 for all the treatments. By the third day moisture levels had significantly reduced and became relatively constant (6.6%).

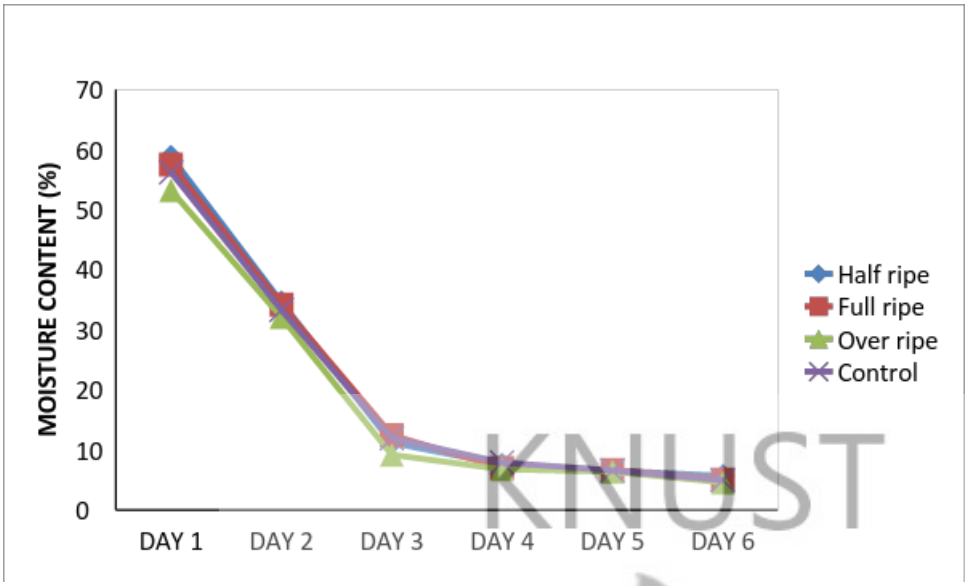

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Figure 4.4: A graph showing the change in moisture content during days of drying

4.2.2 Bean Count

The result of the average bean count as indicated in Table 4.2 below shows that the average bean count increased drastically from Day 1 to Day 6,by which time all beans were favorably dried for all the various ripening stages and the control. It was observed that there was a no significant difference ($p>0.01$) in bean count between the full ripe tray fermented and the control. The over ripe showed a higher significant difference ($p<0.01$) in bean count than all the other treatments suggesting a possible faster drying and attainment of lighter weight beans after fermentation and drying thanless ripe beans. No significant difference was observed between the full ripe, half ripe tray fermented and the control.

Table 4.1: Average Bean Count based on ripening

TREATMENT	MEAN	
	DAY 1	DAY 6
OVER RIPE	49	97
FULL RIPE	42	88
CONTROL	41	86
HALF RIPE	39	84
LSD(P≤0.05)	2.7	2.1

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4.2.3 Temperature during fermentation

Figure 4.5 shows the temperature changes during fermentation in both the tray and heap (control) methods. Temperature increased drastically by from 35oC to 40°C in 24 hours of fermentation and remained steady for 72 hours.

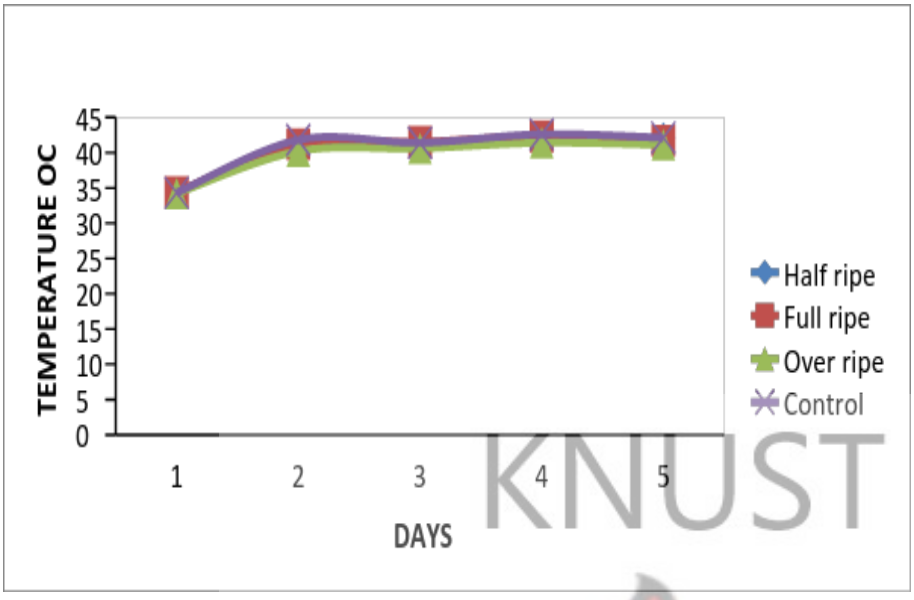

Figure 4.5: A graph showing the temperature changes during fermentation

4.3 Effect of stages of ripeness and tray fermentation method on cut test attributes of cocoa beans.

4.3.1 Cut test attributes of cocoa beans after fermentation

Table 4.2 shows the means of various defective cocoa beans revealed through the cut test.

4.3.2 Percentage Mould

The results on mouldiness of beans showed that there was no statistical difference (P> 0.05) between half ripe and full ripe tray fermented beans and those fermented using heap method (control). There was however, a significant difference between the over ripe treatment and the rest in terms of percentage mould content with over ripe beans being higher in mouldy beans (1.8%).

4.3.3 Percentage Slaty

Results of percentage slaty for tray-fermented half ripe beans were found to be significantly different ($P < 0.05$) from all the other treatments. Tray fermented full ripe however was similar to the heap (control) in terms of slaty content and the two together were significantly different ($P < 0.05$) from the over ripe tray-fermented being higher. Over ripe cocoa beans and the half ripe beans in tray method were significantly different ($P < 0.05$) from the tray fermented full ripe cocoa beans and the control. The half ripe beans recorded a high slaty percentage (7.5%) whereas the over ripebeans had a low percentage of 0.6%. The full ripe cocoa beans in the tray method and the control were however not significantly ($P \leq 0.05$) different. It was observed that as the pod ripened fully and further advanced to over ripe, the slaty levels gradually reduced.

4.3.4 Percentage germinated

The results further showed that there was a significant difference ($P < 0.05$) between tray-fermented over ripe beans and all the other treatments, namely, tray fermented half ripe and full ripe as well as the heap fermented (control). There was a marked increase in percentage germinated beans in the over ripe beans than all the treatments.

4.3.5 Percentage Purple beans

From Table 4.2,a significant difference ($P<0.05$) was observed between the over ripe beans and full ripe in the tray fermentation as well as the heap (control) with regard to percentage purple bean content. The full ripe and the control were statistically similar and lower in purple content

than that of the half ripe. It could be seen that stages of ripeness might have a significant effect on the percentage purple content. The results showed that the more ripened the pod towards senescence (over ripe) the lower the purple content (4.2%) appeared to become with fermentation when compared to the half ripe (17.3%).

4.3.6 Percentage Purity

Percentage purity as a cumulative measure of the effect of the various defects on the quality of cocoa beans from the cut test under the various treatments gave the following results. There was a high purity recorded for the control (Heap fermented full ripe) and full ripe fermented in tray with no significant difference ($P > 0.05$), the former however were significantly different ($P < 0.05$) from the over ripe and half ripe which were tray fermented. They were statistically similar in terms of purity however, by different quality defect factors.

4.2.7 Percentage Purity with purple factor (P^I)

The results of the percentage purity with purple factor indicated a statistical similarity between the tray fermented full ripe, over ripe and the control and these were statistically different from the half ripe.

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Table 4.2: Cut test results based on ripening

Treatment	TM	TS	G	AOD	Purple	P'	Purity(P)	Grade
Half ripe	0.4	7.5	0.3	0.33	17.3	74.5	91.7	II
Full ripe	0.4	1.8	0.6	0.55	7.1	90.1	97.2	I
Over Ripe	1.8	0.6	6.6	6.56	4.2	86.9	91.1	Sub Standard
Control	1.0	1.9	0.9	0.89	7.4	89.3	96.8	I
LSD(0.05)	0.67	0.77	1.32	1.32	2.87	2.61	0.88	

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Where,

T**M** = percentage Total Mouldy beans

T**S**= percentageTotal Slaty beans

G= percentage germinated beans

AOD= percentage of germinated and all other defective beans

P'= percentage Purity with purple factor

4.4 Effect of stages of ripeness and tray fermentation method on chemical attributes of cocoa beans.

4.4.1 Free Fatty Acids

Table 4.3 shows the results of chemical analysis carried out on cocoa beans after fermentation. The results showed a significant difference in free fatty acids ($P \leq 0.05$) between the full ripe and half ripe tray fermented and the control (heap fermented) and that of the over ripe beans.

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4.4.2 pH determination

As cocoa pods ripen the pH of fermented beans decreased (more acidic) compared to half ripe cocoa (high pH). A significant difference ($P<0.05$) was shown between the full ripe in the tray and the heap (control) on one hand and the. Over ripeand half ripe beans in traywere also different from each other. The half ripe tray fermented beans recorded a higher pH (5.8), less acidic.

4.4.3 Fat content

A lower percentage fat content (53.6%)was recorded for the half ripe in tray fermented, showing a significant difference ($P<0.05$) between the tray fermented full ripe, over ripe and the control (heap fermented full ripe) which recorded high percentage fat contents (Table 4.3).

Table 4.3: Chemical attributes of cocoa beans after fermentation

TREATMENT	MEAN		
	Free fatty acids (%)	Fat (%)	pH
Control (heap method)	0.5	58.8	5.2
Half ripe (tray method)	0.5	53.6	5.8
Full ripe (tray method)	0.5	60.7	5.1
Over ripe (tray method)	0.9	59.6	4.5
LSD (0.05)	**0.25**	**4.03**	**0.58**

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4.5 COST ANALYSIS FOR TRAY AND TRADITIONAL HEAP

The cost of fermenting 10 bags of cocoa constituting an average harvest at a time from a 10 acre farm using the tray method was found to be less cost effective in the short run than that of the traditional heap method due to the initial high cost of constructing the wooden trays(Table 4.4).

Table 4.4: Cost analysis for tray and traditional heap methods

OPERATIONAL COST	HEAP METHOD (GH¢)	TRAY METHOD (GH¢)
*Estimated cost of constructing wooden trays	-	700.00
Depreciated operational cost per annum.	-	93.00
Harvesting/Gathering of pods	50.00	50.00
Breaking of pods	50.00	50.00
Miscellaneous	20.00	20.00
TOTAL OPERATING COST	**120.00**	**213.00**

Depreciated cost of tray = Capital Cost-Expected Salvage/ Expected lifespan

Expected Salvage Value = 7% of Capital Cost (John Francis, 2006)

*Refer to Appendix J for details of estimated cost of constructing wooden trays

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CHAPTER FIVE

5.0 DISCUSSION

5.1 Field survey

The results of the survey showed a high perception and enthusiasm of farmers to adopt the tray fermentation method. It was obvious that most of them (74%) had either seen the tray fermentation method at the farmer field school at the Bunso Cocoa College or had the method introduced to them byvarious extension officers of the Cocoa Health and Extension Division (CHED) formerly Cocoa Swollen Shoot Virus Disease Control Unit (CSSVDCU) and the Seed Production Unit (SPU).

The 84% of farmers who expressed the desire to adopt the method cited the size of their farms being bigger than 5 acres and their harvesting and fermenting of more than ten bags of cocoa beans with attendant high demand for banana leaves. The farmers further gave reasons of insecurity of the beans under fermentation due to thefts as a reason why they may adopt the tray method that allowed the luxury of mounting at home instead of within the farm. The shorter fermentation duration (4 days) was also cited as an advantage they would want to explore over the traditional banana heap that takes six days to complete fermentation.

The 16% who were unwilling to adopt the tray method cited reasons such as not knowing anything about it, inability to foot the cost of construction and not having problems with gathering banana leaves for their small volumes of harvest.

The results of the survey therefore formed the basis for the study of the effects of tray fermentation and different ripening stages within the Wassa Mpohor cocoa production area on quality of cocoa.

5.2 Climatic conditions prevailing and moisture content during drying

The favourable temperature and relative humidity (RH) conditions that prevailed during the drying period with averages of 24°C and 83% RH in the mornings and 31°C and 82% RH in the afternoons allowed moisture content of the beans of the various treatments to drop favourably during the drying period within the first 4 days. The over ripe beans lost moisture faster than the full ripe followed by the heap fermented (control) with the half ripe trailing in speed of moisture loss probably because the cotyledons could not open effectively due to lesser ripening compared to completely ripe beans as reported by Jonfia- Essien, (2010). Moisture levels at the end of the first 4 days for all ripe stages lost moisture at a slower and steady rate with the variation of the different ripening stages remaining in a similar order as in the first case of the first 4 days of drying. This observation agreed with the trendsreported by McDonald *et al.,* (1982) where the percentage rate of change in moisture content in different duration of fermentation of cocoa beans prior to drying showed differences.

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5.3 Bean count

The bean count per 100g was found to show a reverse of the moisture characteristics thus, as the drying days advanced bean count increased for all the ripening stages rapidly until the fourth day and remained steady for the remaining two days of drying. The high increase of bean count in the over ripe from 49% to 97% may be due to the high loss of nutrient components as a result of senescence. This finding indicated that over ripe beans were faster to ferment and dry and was consistent with an earlier work where degree of ripening was a determining factor in which the more ripened the beans the faster they fermented and dried (Wood and Lass, 1985). It can be deduced that the fermentation method used had no significant effect on the bean count when the same ripening stage is involved. The entire results indicated that bean count values were less than 100 beans per 100 grams in all treatments implying, beans were favourably heavier than 1 gram on the average as required for export market (ICCO, 2009). The lesser number of beans per 100 grams of cocoa were observed in the half ripe and full ripe beans indicating heavier beans at favourable moisture content (7.5%). The optimal values were those of the full ripe tray fermented and the control which levels were as preferred by industry and commerce (ICCO, 2009).

5.4 Temperature of cocoa during fermentation

It was observed that the temperature of the cocoa beans under tray and heap (control) method of fermentation rose rapidly from an average of 34°C to about 43°C by the end of the first 24 hours of the expected 96 hours of the fermentation, an environment which probably resulted from the metabolic and respiratory activities of microbial organisms in the cocoa pod supported by enzymes during the fermentation process. The over ripe beans hada slightly lesser temperature

build up compared to the other ripe stages probably due to reduced respiratory substrates (Biehl*et al*., 1990). Hashim*et al*., (1998) reported values of 40°C to 45°C temperature build up and stabilization by 24 hours for cocoa during fermentation. The temperature attained prevailed for the remaining 72 hours within the tray and heap (control). For fermentation trials carried out beyond 96 hours, it was reported by Guehi*et al*., (2008) that different stages of ripeness had no marked difference in temperature build up. A study carried out by Barel (1998) revealed that excessive exposure of beans to high temperatures (>50° C) could be disturbing to smooth microbial activity necessary for fermentation of cocoa while it advantageously inhibits bean germination.

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5.5 Cut Test Attributes of cocoa beans

The results of the cut test revealed interesting observations with respect to percentage mould, slaty, germinated and purple content of a sample of 300 beans drawn from the various treatments: tray fermented half ripe, full ripe, over ripe and control (heap fermented full ripe). These defect criteria together determined the quality of cocoa expressed as the percentage purity.

5.5.1 Percentage mould content

The results showed a remarkable rise in mould content of the tray fermented over ripe cocoa (1.8%) with the tray fermented half ripe showing the reverse with a lower percentage mould content, while the control (heap fermented full ripe) and the tray fermented full ripe were similar in mould content. The differences may be attributable to the extent of ripening in which degree of respiration, chemical and enzymatic activity of the beans and microbial content increased with senescence **(**Lagunes-Gálvez*et al.*, 2007). The handling of over ripe and other ripening stages of

cocoa beans during primary processing might have predisposed them to different extents of such microbial and biochemical activities due to ageing. It has been reported by (Guehi*et al*., 2008) that extended delay of pods prior to fermentation increases the amount of quality defects. Poisson *et al*., (1979) concluded that moisture activities around cocoa beans under fermentation may aid this microbial (mould) activity. The results were all within the acceptable grade 1 limit of 3% mould for industry and commerce with the tray fermented over ripe beans however registering a fairly higher mould content of 1.8%, compared to the other tray fermented ripening stages and the control. Mould in cocoa poses a high health risk as in other oil-rich foods like cereals and legumes (Dongo*et al*., 2008). The mycotoxin produced in high amounts in such food materials has carcinogenic properties that must be avoided (Dongo*et al*., 2008).

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5.5.2 Percentage slaty content

The slaty bean content as a defect observed from the cut test showed a higher value in tray fermented half ripe beans than for full ripe and the control with the over ripe containing a lower amount. This could be attributed to the higher amounts of anthocyanin content in under ripe beans which renders their fermentation more demanding compared to full ripe and over ripe beans It has been reported in work done on effects of pulp preconditioning and over fermentation on slaty and purple presence in cocoa that, the longer pods are delayed prior to fermentation, pulp and nib interactivity commences to shorten the duration of fermentation by optimum generation of fermentative quality and the desired chocolate colour (Guehi *et al.,* 2008). The levels attained by tray fermented full ripe and over ripe as well as the control were within acceptable limits for industry and commerce, falling within the grade 1 limit of 3%. The tray

fermented half ripe beans however almost fell outside the acceptable grade 1 or grade 2 cocoa which has a maximum acceptable value of 8% at the recorded 7.5%.

5.5.3 Percentage purple content

The study found out that purple bean content of less ripened pods were higher, indicating a lesser fermentation response over the same duration recommended for tray method by Wood and Lass, (1985) than full ripe and over ripe beans in tray fermentation, recording very encouraging and minimal values of purple. Though the entire study resulted in every ripening stage having acceptable levels of purple, which was less than the maximum 20% for grade 1 cocoa, half ripe recorded a high of 17.3% in tray and over ripe in tray showed as low as 4.22% purple content.

5.5.4 Percentage Germinated beans

Germinated beans have been considered as a defect because the void left by the emerging radicle provides an opportune entrance for insects and moulds. They are also considered to lack good chocolate flavour (Wood and Lass, 1985). When pods over ripe through long delays in harvesting, significant levels of germination become of concern (Wanasundara *et al*., 2001) and (Afoakwa*et al*., 2011). Results of this study revealed a higher amount of germinated beans in tray fermented over ripe beans than the full ripe and half ripe tray fermented as well as the control respectively. The overall outcome of the study showed the over ripe beans drifting beyond grade 2 with the 6.56% germinated beans content being more than the 6% upper limit and rendered substandard. The other treatments however indicated more preferred grade 1 levels acceptable for commerce and industry.

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5.5.5 Percentage Purity

Percentage purity which is the overall assessment of the impact of all the defects on the quality of the cocoa under consideration indicated an overall good performance of the tray fermentation method as the heap fermentation method. The tray fermented full ripe compared favourably with the heap fermented full ripe beans. The half ripe and full ripe beans were statistically similar in overall quality under tray fermentation but as a result of different quality defects namely, slaty and germinated, respectively. The high slaty in the half ripe criterion however was less serious than the presence of high amount of germinated in the over ripe going by the commerce and industry requirements. The most serious defect in the grading system, percentage mould, was refreshingly low for all the studied situations with the most affected criterion over ripe, remaining within grade 1 limits of (≤ 3%).

5.4.6 Percentage Purity with purple factor (P^I)

This result was assessed to provide a measure of the immediate effect of fermentation on the various stages of ripening using percent purple bean content as an indicator. The significant difference between the tray fermented full ripe, over ripe, the control and the tray fermented half ripe was attributable to the high purple bean content in the half ripe. High purple in cocoa beans is due to the amounts of anthocyanins which present the purple pigmentation and in less ripe beans this is pronounced as observed in the case of the half ripe (Mossu, 1992; Lopez**,** 1995; Lagunes-Galvez *et al.*, 2007).

5.6 Chemical attributes of cocoa

5.6.1 Percentage Fat Content

Percentage fat content of all the category of ripening observed gave favourable values which were quite encouraging for the particular variety and ambient condition of the farm location and clonal hybrid type utilized in the study (Quao, 2010). The half ripe tray fermented recorded 54% and was significantly different from the remaining treatments of tray fermented full ripe, over ripe and the heap fermented full ripe (control) which recorded higher amounts of fat. The fat contents obtained, favourably met and exceeded the expected levels of 45-55% of bean weight. Most of the ripening stages, especially full ripe tray fermented recorded as high as 60.7% fat content. The half ripe which recorded the lowest amount was also within the stated range, an encouraging observation for industry and commerce (Dand, 1993).

5.6.2 Free Fatty Acids

Free fatty acid content which is the chemical attribute that reveals the extent of oxidation of the fat content of cocoa beans is also an indicator of the extent of microbial impact by way of mould presence. The level of FFAs in the fat of cocoa beans gives the measure of rancidity of cocoa, and high levels of FFA (> 1.75% in dried beans) in cocoa are not acceptable (Dand, 1997). In this study the results indicated a high amount (0.9%) of free fatty acid in over ripe beans which were corroborated by the corresponding high mould content than other ripening stages. The findings however were all lower than the maximum acceptable limit of 1.75% in cocoa beans (ICCO, 2009). Raghavendra and Prakash (2002) indicated that foodstuffs exposed to humid conditions were easily attacked by moulds. These moulds in their metabolism produce enzymes capable of breaking down lipids (lipase) which, when in contact with cocoa butter

of broken cocoa nibs released FFA from triglycerides (Wood and Lass, 1985). Black decayed beans which probably originate from over ripe pods infected by fungal diseases, *Phytophthora sp*. could create congenial conditions for the development of moulds which in turn would lead to increases in FFA formation (Wanasundara *et al*., 2001).

5.6.3 pH

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Less aerated cocoa under fermentation has a build-up of anaerobic conditions that aid lactic acid bacteria action as in box and tray fermentation when there is no turning, while aerobic conditions aid acetic acid bacteria (AAB) activity achieved when cocoa under fermentation is turned to aerate the masse of beans. The biochemical interactivity informs the pH of cocoa meant for the market and industry. In this trial, the trays had in-built aeration system to aid aerobic conditions and maintain levels of anaerobic conditions as well. The efficiency of these systems was revealed by the overall quality of fermented beans under all the ripening stages as well as the pH levels of beans from the chemical attributes analysis. The pH observed in this study revealed lower levels (4.4 – 5.2) for tray fermented over ripe and full ripe as well as full ripe heap fermented (control) than the tray fermented half ripe (5.8) which was less fermented as revealed by the high purple and slaty content from the cut test results. Beans of higher pH (5.5-5.8) are considered unfermented - with low fermentation index and cut test score - and those of lower pH (4.8- 5.2), well fermented (Holm *et al*., 1993; Beckett, 2008; Afoakwa and Paterson, 2010). Results from this study confirmed work done by Simplice *et al*. (2010) who worked on the effect of turning beans and fermentation method on the acidity and physical quality of raw cocoa beans and recorded pH values being greater than the standard Malaysian state beans, which is 4.4 - 4.7

(Nazaruddin*et al*., 2006) after four days of fermentation. The result was probably due to the high anthocyanin contents and the lesser amounts of sugars in the bean environment of under ripe category leading to lesser microbial activity and acetic and lactic acid production (Lagunes-Gálvez*et al.*,2007). The reverse was the higher amounts of sugars in the full ripe and over ripe which were readily oxidized through microbial and pod content respiration to give the acidic conditions as well as their residual low pH. The tray fermented over ripe beans however recorded the lowest pH, probably indicating the effect of greater pulp preconditioning beside other senescence related factors that were associated with other quality indicators.

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5.7 Cost analysis for tray and traditional heap methods

Although the use of tray fermentation method was less cost effective than the traditional heap method in the short run, it had many latent advantages over the traditional method.

The useof traditional heap method which is mostly done under cocoa trees and quite away from the cottage is usually exposed to theft, rodents and other external factors that may affect the quantity and quality of beans. However, in the case of the tray fermentation method, the setup can be mounted at the cottage under close observation of the farm family which will deter intruders from succeeding in any attempts to affect quantity and quality. The labour intensive factor of turning of cocoa beans during the traditional heap fermentation is eliminated in the case of the tray method due to the inclusion of an aeration system factored in the design. Lesser number of days are required in the tray fermentation method with the added benefit of quicker availability of cocoa for marketing and allows further harvesting and preparation of other ready

pods. It provides clean and hygienic beans comparatively with versatility in handling of equipment. It further has the advantage of possible collection of swertings for distilling alcohol for added income. Finally, it is a more precise technology friendly to the youth.

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CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

It could be concluded from the outcome of the survey that farmers had challenges with the heap method but lacked the encouragement and sensitization to carry them beyond the mostly distant or vague knowledge about tray fermentation. The willingness to use other better technology was expressed but the empowerment to carry this willingness to actual use was required. Considering the effect of ripening on fermentation and drying, it could be concluded that the more ripened the beans, the more efficient the fermentation as indicated by the percentage slaty and purple found compared to the amount found in the control. The more ripened the beans the faster the response to drying with the full ripe giving superior results.

It could be concluded that tray fermentation method compared favourably with the heap method for the fermentation of considerably ripened cocoa beans, especially, the full ripe. The overall effect of the treatments on the quality attributes from the cut test revealed that, the full ripe treatment resulted in superior beans quality than the other ripening treatments under tray fermentation than under the traditional heap method. The full ripe beans had a higher percentage fat content from the results obtained from the chemical attributes.

The pH of the half ripe beans was found to be higher compared to the other treatments depicting less fermented beans. The percentage free fatty acid contents of extracted fat from the treatments revealed a higher percentage from the over ripe beans than those of the full ripe which was also higher than that of the half ripe. In conclusion it is obviousthat in spite of the initial capital cost

of the tray method which makesit less cost effective in the short run, there are enough benefits associated with its use to offset the extra cost in the long run, compared to the traditional heap method.

6.2 Recommendations

It is recommended that a much more detailed study of the economic viability of the tray fermentation method should be carried out.

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Further study could also be carried out to reduce the amount of purple and slaty beans observed.

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APPENDICES

Appendix A **QUESTIONNAIRE**

SURVEY ON CHALLENGES OF HEAP FERMENTATION

This questionnaire is administered among randomly selected cocoa farmers in the WassaMpohor District of the Western Region of Ghana to gather information on the challenges of the traditional banana and plantain heap fermentation method and their knowledge of tray method.

Farm location……
……..

1. What is the approximate size of your farm? □ Less than 1 Acre □ About 1 Acre
   □ About 2 Acres □ More than 2 Acres
2. How many bags of cocoa do you harvest for a particular fermentation in the peak period?
   □ Less than1 bag □ About 2 bags □ Between 2 and 5 bags
   □ Between 5 and 10 bags □ More than 10 bags
3. How do you ferment your cocoa? □ Basket and leaves □ Heap in banana leaves
   □ OTHER
   Specify……
   ……
   ……
4. Do you encounter any difficulties in obtaining the leaves when banana or plantain leaves have to be used for fermentation? □ YES □ NO
5. Does obtaining the leaves have any effect on the yield of your plantain and banana?
   □YES □ NO

6. Would you like to ferment your cocoa for a shorter number of days with the banana leaves heap method? □ YES □ NO
7. Does the quick demand for your cocoa by the buyers affect your days of fermentation? □ YES □ NO
8. Does your need for cash quickly affect your number of days of fermentation? □ YES □ NO
9. Do buyers complain about the quality of your cocoa because it is not well fermented? □ YES □ NO
10. How often do they complain? □ Less often □ Often □ Very often
11. Would you prefer another method of fermentation that takes a shorter time? □ YES □ NO
12. Would you prefer another method of fermentation that does not involve banana or plantain leaves? □ YES □ NO
13. Do you know of any of such a method? □ YES □ NO
14. If answer to 13 is yes, specify the material and method used.
    ……
    ……
    ……..
15. Have you used some before? □ YES □ NO
16. Have you heard of or seen tray fermentation before? □ YES □ NO
17. Specify where and when you saw or heard about it.
    ……
    ……
18. Would you like to change your fermentation method from banana leaves method to tray if it is available? □ YES □ NO
19. Are you ready to bear the cost of the tray if it is helpful? □ YES □ NO
20. Will you be willing to use it if it was provided for free? □ YES □ NO

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Appendix B:

COST ANALYSIS FOR TRAY AND TRADITIONAL HEAP

ESTIMATED COST OF CONSTRUCTING WOODEN TRAY OF DIMENSION (2m x 1m x 0.13m)

ITEM	QUANTITY	UNIT COST (GHC)	TOTAL COST (GHC)
*Wawa board (red wood)	20 pieces	12.00	240.00
Nails	1 box	50.00	50.00
Cost of (sawing, machine cutting)	20 boards	3.00	60.00
Workmanship (constructing of tray box)	10 boxes	20.00	200.00
Transportation	-	-	50.00
Miscellaneous	-	-	100.00
TOTAL			**700.00**

*The prices of items used for the construction were obtained from the Bibiani market. Prices may differ at different locations.

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Appendix C: Cut test analysis

Analysis of variance

Variate: GERMINATED_G

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	1.0545	0.5272	1.72	
REPLICATION.*Units* stratum					
TREAT	3	80.5145	26.8382	87.67	<.001
Residual	6	1.8367	0.3061		
Total	11	83.4057			

Tables of means

Variate: GERMINATED_G

Grand mean 2.08

TREAT	CONT	FULL	HALF	OVER
	0.89	0.55	0.33	6.56

Standard errors of means

Table	TREAT
rep.	3
d.f.	6
e.s.e.	0.319

Standard errors of differences of means

Table	TREAT
rep.	3
d.f.	6
s.e.d.	0.452

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Least significant differences of means (5% level)

Table	TREAT
rep.	3
d.f.	6
l.s.d.	1.105

Analysis of variance

Variate: MOULD_M

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	0.2178	0.1089	0.97	
REPLICATION.*Units* stratum					
TREAT	3	3.5839	1.1946	10.68	0.008
Residual	6	0.6712	0.1119		
Total	11	4.4729			

Tables of means

Variate: MOULD_M

Grand mean 0.916

TREAT	CONT	FULL	HALF	OVER
	1.000	0.443	0.443	1.777

Standard errors of means

Table	TREAT
rep.	3
d.f.	6
e.s.e.	0.1931

Standard errors of differences of means

Table	TREAT
rep.	3
d.f.	6
s.e.d.	0.2731

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NYANSAPO WO SANE NO BADWENMA

Least significant differences of means (5% level)

Table	TREAT
rep.	3
d.f.	6
l.s.d.	0.6682

Analysis of variance

Variate: PURITY_P1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	21.657	10.829	1.53	
REPLICATION.*Units* stratum					
TREAT	3	126.694	42.231	5.97	0.031
Residual	6	42.467	7.078		
Total	11	190.818			

Message: the following units have large residuals.

REPLICATION 1 *units* 1 -4.56 s.e. 1.88

Tables of means

Variate: PURITY_P1

Grand mean 92.64

TREAT	CONT	FULL	HALF	OVER
	93.78	97.22	88.45	91.11

Standard errors of means

Table	TREAT
rep.	3
d.f.	6
e.s.e.	1.536

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Standard errors of differences of means

Table	TREAT
rep.	3
d.f.	6
s.e.d.	2.172

Least significant differences of means (5% level)

Table	TREAT
rep.	3
d.f.	6
l.s.d.	5.315

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Analysis of variance

Variate: PURITY_P2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	0.295	0.147	0.06	
REPLICATION.*Units* stratum					
TREAT	3	509.256	169.752	67.73	<.001
Residual	6	15.039	2.506		
Total	11	524.590			

Message: the following units have large residuals.

REPLICATION 2 *units* 1 2.33 s.e. 1.12

Tables of means

Variate: PURITY_P2

Grand mean 81.70

TREAT	CONT	FULL	HALF	OVER
	76.33	90.11	74.45	85.89

Standard errors of means

Table	TREAT
rep.	3
d.f.	6
e.s.e.	0.914

Standard errors of differences of means

Table	TREAT
rep.	3
d.f.	6
s.e.d.	1.293

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Least significant differences of means (5% level)

Table	TREAT
rep.	3
d.f.	6
l.s.d.	3.163

Analysis of variance

Variate: PURPLE_PP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	0.236	0.118	0.05	
REPLICATION.*Units* stratum					
TREAT	3	294.760	98.253	43.63	<.001
Residual	6	13.513	2.252		
Total	11	308.509			

Message: the following units have large residuals.

REPLICATION 2 *units* 1 -2.39 s.e. 1.06

Tables of means

Variate: PURPLE_PP

Grand mean 9.03

TREAT	CONT	FULL	HALF	OVER
	7.44	7.11	17.33	4.22

Standard errors of means

Table	TREAT
rep.	3
d.f.	6
e.s.e.	0.866

Standard errors of differences of means

Table	TREAT
rep.	3
d.f.	6
s.e.d.	1.225

Least significant differences of means (5% level)

Table	TREAT
rep.	3
d.f.	6
l.s.d.	2.998

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Analysis of variance

Variate: SLATEY_S

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	0.0176	0.0088	0.05	
REPLICATION.*Units* stratum					
TREAT	3	83.7015	27.9005	152.15	<.001
Residual	6	1.1002	0.1834		
Total	11	84.8194			

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Tables of means

Variate: SLATEY_S

Grand mean 3.53

TREAT	CONT	FULL	HALF	OVER
	4.33	1.78	7.45	0.56

Standard errors of means

Table	TREAT
rep.	3
d.f.	6
e.s.e.	0.247

Standard errors of differences of means

Table	TREAT
rep.	3
d.f.	6
s.e.d.	0.350

Least significant differences of means (5% level)

Table	TREAT
rep.	3
d.f.	6
l.s.d.	0.856

Analysis of variance

Variate: SLATEY_S_1 SLATEY_S

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	0.0176	0.0088	0.05	
REPLICATION.*Units* stratum					
TREAT	3	83.7015	27.9005	152.15	<.001
Residual	6	1.1002	0.1834		
Total	11	84.8194			

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Tables of means

Variate: SLATEY_S_1 SLATEY_S

Grand mean 3.53

TREAT	CONT	FULL	HALF	OVER
	4.33	1.78	7.45	0.56

Standard errors of means

Table	TREAT
rep.	3
d.f.	6
e.s.e.	0.247

Standard errors of differences of means

Table	TREAT
rep.	3
d.f.	6
s.e.d.	0.350

Least significant differences of means (5% level)

Table	TREAT
rep.	3
d.f.	6
l.s.d.	0.856

Appendix D: Chemical attributeanalysis

Analysis of variance

Variate: %FAT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	0.975	0.488	0.12	
TREATMENT	3	90.488	30.163	7.43	0.019
Residual	6	24.373	4.062		
Total	11	115.836			

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Tables of means

Variate: %FAT

Grand mean 58.16

TREATMENT	Control	Tray Full ripe	TRAY Half ripe	Tray over ripe
	58.82	60.72	53.55	59.56

Standard errors of means

Table	TREATMENT
rep.	3
d.f.	6
e.s.e.	1.164

Standard errors of differences of means

Table	TREATMENT
rep.	3
d.f.	6
s.e.d.	1.646

Least significant differences of means (5% level)

Table	TREATMENT
rep.	3
d.f.	6
l.s.d.	4.027

Stratum standard errors and coefficients of variation

Variate: %FAT

Stratum	d.f.	s.e.	cv%
REPLICATION	2	0.349	0.6
REPLICATION.*Units*	6	2.015	3.5

Analysis of variance

Variate: pH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	0.11762	0.05881	0.70	
REPLICATION.*Units* stratum					
TREATMENT	3	2.79476	0.93159	11.14	0.007
Residual	6	0.50192	0.08365		
Total	11	3.41429			

Tables of means

Variate: pH

Grand mean 5.216

TREATMENT	Control	Tray Full ripe	TRAY Half ripe	Tray over ripe
	5.307	5.350	4.440	5.767

Standard errors of means

Table	TREATMENT
rep.	3
d.f.	6
e.s.e.	0.1670

Standard errors of differences of means

Table	TREATMENT
rep.	3
d.f.	6
s.e.d.	0.2362

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Least significant differences of means (5% level)

Table	TREATMENT
rep.	3
d.f.	6
l.s.d.	0.5778

Stratum standard errors and coefficients of variation

Variate: pH

Stratum	d.f.	s.e.	cv%
REPLICATION	2	0.1213	2.3
REPLICATION.*Units*	6	0.2892	5.5

Analysis of variance

Variate: %_%FREE_FATTY_ACIDS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPLICATION stratum	2	0.08187	0.04093	2.70	
REPLICATION.*Units* stratum					
TREATMENT	3	0.53163	0.17721	11.68	0.006
Residual	6	0.09107	0.01518		
Total	11	0.70457			

Tables of means

Variate: %_%FREE_FATTY_ACIDS

Grand mean 0.628

TREATMENT	Control	Tray Full ripe	TRAY Half ripe	Tray over ripe
	0.517	0.540	0.467	0.990

Standard errors of means

Table	TREATMENT
rep.	3
d.f.	6

e.s.e. 0.0711

Standard errors of differences of means

Table	TREATMENT
rep.	3
d.f.	6
s.e.d.	0.1006

Least significant differences of means (5% level)

Table	TREATMENT
rep.	3
d.f.	6
l.s.d.	0.2461

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Stratum standard errors and coefficients of variation

Variate: %_%FREE_FATTY_ACIDS

Stratum	d.f.	s.e.	cv%
REPLICATION	2	0.1012	16.1
REPLICATION.*Units*	6	0.1232	19.6

Appendix E: Bean count

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Completely Randomized AOV for BC day 6

Source	DF	SS	MS	F	P
Trt	3	278.250	92.7500	159.00	0.0000
Error	8	4.667	0.5833		
Total	11	282.917			

Grand Mean 88.917 CV 0.86

Homogeneity of Variances	F	P
Levene's Test	1.89	0.2089
O'Brien's Test	0.84	0.5082
Brown and Forsythe Test	1.22	0.3630

Welch's Test for Mean Differences

Source	DF	F	P
Trt	3.0	M	0.0000
Error	M		

Component of variance for between groups 30.7222
Effective cell size 3.0

Trt	Mean
CONTROL	86.000
FULL RIPE	88.000
HALF RIPE	84.667
OVER RIPE	97.000

Observations per Mean 3
Standard Error of a Mean 0.4410
Std Error (Diff of 2 Means) 0.6236

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Completely Randomized AOV for BC day 1

Source	DF	SS	MS	F	P
Trt	3	170.250	56.7500	56.75	0.0000
Error	8	8.000	1.0000		
Total	11	178.250			

Grand Mean 42.750 CV 2.34

Homogeneity of Variances	F	P
Levene's Test	0.00	1.0000
O'Brien's Test	0.00	1.0000
Brown and Forsythe Test	0.00	1.0000

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Welch's Test for Mean Differences

Source	DF	F	P
Trt	3.0	43.65	0.0010
Error	4.4		

Component of variance for between groups 18.5833
Effective cell size 3.0

Trt	Mean
CONTROL	42.000
FULL RIPE	41.000
HALF RIPE	39.000
OVER RIPE	49.000

Observations per Mean 3
Standard Error of a Mean 0.5774
Std Error (Diff of 2 Means) 0.8165

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