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EFFECT OF PACKAGING MATERIALS AND STORAGE PERIODS ON THE QUALITY OF REFERENCE COCOA BEANS.

BY

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SEPTEMBER, 2015

DECLARATION

I hereby declare that the work herein presented is the result of my own investigations, and that, except for specific references which have been duly acknowledged, this project has not been submitted either in part or whole for any other degree elsewhere.

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DEDICATIONS

This work is dedicated foremost to God Almighty. Secondly to my lovely wife, Mrs. Happy Ewe and children Favour, Promise, Mercy and Matthew for their support and prayers during the course of my studies.

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ABSTRACT

Reference cocoa beans are cocoa samples that are kept in glass bottles and stored for four months to address problems of discrepancies in quality of beans shipped to their destinations abroad. The beans are later analysed for biochemical, physical and entomological properties for arbitration resolution if the cocoa is found to be inferior at their destinations abroad. During storage, the quality of the beans could be affected by moulds, insects and moisture. This study was, therefore, carried out at the Cocoa Research Institute of Ghana (CRIG) to determine the effect of packaging materials and storage durations on the physical and biochemical quality of reference cocoa beans fermented for six days, dried and stored for four months in a 4 x 5 factorial arrangement in completely randomized design with three replications. Cocoa beans kept for reference were packaged in transparent glass bottles, transparent plastic bottles, transparent high density polyethylene bags and jute sack bags and stored for 30, 60, 90 and 120 days. Physical characteristics of the cocoa beans were studied using the cut test method. AOAC (2005) method was used to determine pH, free fatty acid, fat and moisture contents of the beans. Results from the cut test analyses showed that all the treatments had effect on percentage deep purple, pale purple and brown beans. However, beans packaged in jute sacks and stored for 120 days developed significantly (p = 0.01) the least (13.57%) deep purple beans, than those in glass bottle, plastic bottle and high density polyethylene bag. Jute sacks produced significantly higher (80.51%) amount of brown beans. Beans kept in jute sack bags produced the most desirable physical quality (deep purple, pale purple and brown) of beans. Among the packaging

materials tested, jute sack again produced the most desirable biochemical properties in terms of bean pH, free fatty acid, fat and moisture contents.

Storing beans for 60 days gave the best physical quality whilst beans stored for 90 days produced the most desirable biochemical quality. Mean temperature and relative humidity did not correlate with biochemical characteristics of cocoa beans kept in the different packaging materials. Overall, beans packaged in jute sack bag and stored during the entire period of 120 days produced the most physical and biochemical qualities. From the study, to maintain quality towards/defend any discrepancies which may arise regarding the quality of beans shipped, reference beans should be stored in jute sacks but in dry cool conditions and protected from insects and dust.

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CHAPTER ONE

1.0 INTRODUCTION

Commercial cocoa is obtained from the beans as seeds from the ripe pods of the plant *Theobroma cacao*, which is native to the Amazon region of South America and cultivated in the tropical regions of the world (Ardhana and Fleet, 2003).

More than two thirds of the world's cocoa beans are produced in West Africa, and Ghana in the year 2010/2011 cocoa season produced, an unprecedented level of 1,025,000 tons of cocoa beans. This makes Ghana the second largest cocoa beans producer in the world. Ghana's neighbouring country, Côte d'Ivoire, the largest world producer, produced 1,511,000 tons of cocoa beans in 2010/2011 (ICCO, 2011).

The quality of cocoa beans is dependent on the complex chemical and biochemical changes which occur in the beans during fermentation and drying (Afoakwa *et al*., 2007; Fowler, 2009) and cocoa fermentation is the most important stage in postharvest processing that mostly governs ultimate product quality.

Good packaging enhances marketing of the goods, being itself attractive, displaying label and contents to advantage, and being of suitable size as a unit of sale. It also gives protection from dirt, dust and infection. However, by keeping humidity high, it may favour disease causing organism in stored products (Ellis, 1993).

Generally, cocoa beans are packed in jute bags upon drying after the beans are sorted and eliminated of flat, broken, germinated and other impurities to improve the quality of the beans (Mossu, 1992).

Reference cocoa beans are sampled cocoa beans that are kept for inferences to be made on them by the exporting countries. The beans are kept to address problems of discrepancies in quality of beans shipped to their destinations abroad. However, they are hermetically stored in glass jars (Klinar jar). The jars which are well-labeled/tallied have the following information; destination of the beans, name of vessel, date of dispatch, country of origin of the beans and port of exit. The recommended biochemical conditions of reference cocoa beans include 6-7.5% moisture content, free fatty acid (FFA) content of less than 1.75% and pH of 5-7 (Mossu, 1992; Dand, 1997; Wood and Lass, 1985; Gorkeh-Sekyim, 2011).

The beans are later analyzed for biochemical, physical and entomological properties for arbitration resolution if the cocoa is found to be inferior at destinations abroad (Quarmine *et al*., 2012). Cocoa beans of good quality should be free from insect attack, smoky and flat beans. They should not be excessively acidic, bitter or astringent, and they should have uniform sizes (Mossu, 1992).

Although, it is known that proper fermentation duration produces beans of good quality little is known about the effect of packaging materials and length of storage on the quality of these reference cocoa beans. The present study, therefore, sought to evaluate the effect of different packaging materials and storage periods on the quality of dried cocoa beans kept as reference material.

Specifically, this study sought to determine the:

1. effect of different packaging materials and storage periods on the physical characteristics of reference cocoa beans;

2. effect of different packaging materials and storage periods on the biochemical properties of reference cocoa beans; and
3. relationship between storage environmental factors (relative humidity and temperature) and biochemical quality of reference cocoa beans samples.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 ORIGIN AND DISTRIBUTION

The cultivated cocoa plant, *Theobroma cacao L*. belongs to *Sterculiaceae* family (Mossu, 1992). Cocoa is a lower storey rainforest tree. Cocoa has been cultivated for centuries in Central America and the northern part of South America. The crop presumably originated in the equatorial rainforests to the Andes Mountains in South America. It was an early introduction into Mexico where the potential of the crop was fully realized (Onwueme and Sinha, 1991).

Cocoa spread rapidly into New World countries such as Venezuala, Trinidad, Jamaica, Haiti and Brazil during the 16th century after the arrival of the Spaniard. The Spanish and Portuguese introduced cocoa to islands in the Gulf of Guinea in the 17th century and from there it spread to many West African countries. In the 17th century it was also introduced to South-East Asia. The Germans took it to New Guinea and it was introduced to Uganda in 1901 (Onwueme and Sinha, 1991).

The cocoa plant which is native to the Central and Western Amazon regions has been widely distributed throughout the tropics, with major commercial production in Cote d'Ivoire, Ghana, Indonesia, Nigeria, Togo, Brazil and Cameroun.

In Ghana, cocoa was first introduced in the Eastern Region in 1879 by Tetteh Quarshie. Cocoa production in the region reached a peak during the early 1930's and started to decline ten years later as a result of severe outbreak of cocoa swollen shoot virus disease (CSSVD) and capsid pests.

The region remained as the centre of cocoa production in the country until the early 1940's when its enviable position shifted to Ashanti and Brong Ahafo regions where fresh lands had been planted to cocoa (Anon, 2000).

2.2 BOTANY

Cocoa is a lower storey tree of the evergreen rain forest of the western hemisphere from 18^0 N to 15^0 S. The mature cocoa tree can grow up to 12–15 m high in the wild. The cocoa tree is traditionally grown under shade trees, although it can also be grown in full sunlight when the canopy is closed and water and mineral supplies are adequate. The stem of the cocoa tree grows vertically (orthotropically) for about 14 to 18 months. The first branches develop in the form of a whorl of five branches, growing horizontally (plagiotropically). These fan branches form the framework of the tree and are called the *jorquette.* At this stage of growth, the trunk is about 1.5 m tall. One of the dormant axillary buds on the trunk below the branches of the *jorquette* develops and produces an orthotropic shoot termed the "Chupon" which behaves like the main stem. The morphology of the leaves depends on the type of stem on which they arise. The first leaves arising on chupons have long petioles and are symmetrical whilst those on fan branches have shorter petioles and are slightly asymmetrical.

The young leaves are soft and have green midribs and veins. When mature, the leaves become dark green. The leaves are usually produced in flushes in March–April and September-October in West Africa. Cocoa is cauliflorous thus; the flowers are borne on small flower stalks in clusters. The flowers are only produced on the tree of a certain minimum physiological age, usually two or three years old under favourable growing conditions (Opoku-Ameyaw *et al*., 2010).

2.3 GROUPS OF COCOA

Cocoa can be divided into three large groups namely, the Criollo, Forastero and Trinitario. Criollo (*Theobroma cacao var cacao*) is noted for its strong aroma with slightly bitterness. This group of cocoa is not vigorous, slowly growing and have small leaves. They are highly susceptible to diseases. Forastero (*Theobroma cacao var. shaerocarpum*) most of the production currently coming from Brazil, West Africa and South East Asia come from this group. The West African 'Amelonado' cocoa belongs to this group (Mossu, 1992). Trinitario, a hybrid of Forastero and Criollo is more disease resistant (Beckett, 2009). The Trinitarios which are now found almost everywhere were originally selected in Trinidad. They produce cocoa beans which are of intermediate quality (Mossu, 1992).

2.4 USES

Cocoa is grown primarily for chocolate production, but the edible pulp is delicious and often consumed in the tropics. Cocoa butter is used medicinally in Brazil for healing bruises, and is used by the cosmetic and pharmaceutical industries. The seeds contain about 2% of the alkaloid theobromine, which is a central nervous system stimulant, similar to caffeine. Theobromine is used as a diuretic and to lower blood pressure, since it dilates the blood vessels (Mossu, 1992).

Dry cocoa seeds (also known as "beans") may contain as much as 12-18% polyphenols, known as cocoa polyphenols or cocoa flavonoids. Cocoa baking, chocolate and milk chocolate all contain polyphenols (Onwueme and Sinha, 1991).

2.5 HARVESTING AND PROCESSING OF COCOA

The first stage in the processing of cocoa is harvesting. Ripe, healthy pods, which are yellow or orange in colour, are removed from the trees at three weekly intervals by cutting through the short pod stalk with a sharp cutlass. Pods borne high up in the leaf canopy are removed with sharp knives tied on long or short sticks known as harvesting hooks. During harvesting care must be taken not to injure the flower cushion since this may reduce subsequent pod yield (Are and Gwynne-Jones, 1974). After plucking the pods, the commonest practice is to gather the pods to one or more convenient places in the field and to open them when the harvesting round has been completed (Wood and Lass, 1985).

2.6 FERMENTATION

Fermentation is done to develop the chocolate flavour and aroma in the beans. It is a heating process, for fermentation to be successful there must adequate aeration. The temperature of the beans rises to between 47^{o}C and 50^{o}C; efforts should be made to keep the temperature within this range. Sudden drops in temperature are experienced during the turning and mixing of the beans which help to remove the carbon dioxide produced during fermentation (Wood and Lass, 1985).

The aims of fermentation are:

- To remove the mucilaginous pulp surrounding the seeds
- To cause the death of the embryo and prevent it from germinating
- To bring about biochemical changes inside the cotyledons, resulting in a reduction in the bitterness and astringency to enable the precursors of the chocolate flavour to develop and

- To reduce the water content of the fermented beans from about 60 per cent to 6-7 per cent, to enable the beans to be stored safely, free from pests and diseases (Mossu, 1992).

According to Are and Gwynne-Jones (1974) the duration of fermentation varies with the variety of cocoa, the batch size and the particular method used. Under-fermented beans usually develop deep purple colour whilst unfermented beans are slaty, giving bitter taste. Over-fermented beans lose the desired quality. There are various methods that are used for fermenting cocoa in West Africa and are described below.

2.6.1 Heap Fermentation

This method of fermentation accounts for most of the cocoa beans that enter world trade due to its widespread use in West Africa which alone produced about 60% of the world's cocoa in 2009 (Baker *et al*., 1994; Aneani and Takrama 2006; ICCO 2011).

It is a cheap method of fermentation, practised in West Africa which produces wellfermented cocoa when it carried out well. Banana or plantain leaves are spread on a raised platform of sticks. The bases of the leaves overlap and the raised sticks form a slope that facilitates drainage during fermentation.

The leaves may also be perforated in a number of places to allow the drainage of sweating. Beans are poured on to form a heap in the centre of the leaves which are folded over to enclose the beans.

A piece of wood is placed on top to hold the leaves in place so as to conserve heat inside the heap. According to Takrama and Adomako (1996); Cudjoe *et al*. (2009). The heap also conserves moisture and protects the beans from rain. The heap is opened on the third and fifth days to allow turning and mixing of the beans.

Takrama and Adomako (1996); Dahl (2006); Amoa-Awua (2007a) recommended that the heap be allowed to ferment spontaneously for six days. The beans are fermented and removed for drying on the seventh day (Are and Gwynne-Jones, 1974).

Plate 1: Heap fermentation

2.6.2 Box Method

This method gives good fermentation results, however it is costly and laborious. Each unit consists of three boxes arranged in steps to allow for easy transfer of beans from one box to the next. The boxes which are constructed with durable wood, have perforations at the bottom to facilitate the drainage of excess liquid during fermentation. The boxes have a removable sliding front for easy turning of the beans. Fresh beans are poured in the topmost box, covered with banana or plantain leaves.

After two days, the leaves are removed and the beans are turned into the middle box by removing the sliding front of the box. The beans at the top in the topmost box fall into the bottom of the middle box; those at the bottom in the topmost come to the top in the middle box. This practice encourages a thorough mixing of the beans, which is necessary for an even fermentation.

The beans are again covered and left to ferment for two days before they are emptied into the bottom box. The beans are left to ferment for another two days after which they are removed for drying on the seventh day (Are and Gwynne-Jones, 1974).

Plate 2: Box fermentation

2.6.3 Tray Fermentation

With this method of fermentation the beans are loaded into the trays after pod opening and the trays are stacked up to twelve or fourteen trays high. The bottom tray is often left empty to improve aeration and the whole stack may be raised slightly for the purpose of allowing sweating to drain off. The stack of trays is covered with banana or plantain leaves in order to retain heat. The trays are not moved until the end of fermentation (Wood and Lass, 1985).

Plate 3: Tray fermentation

2.6.4 Basket Fermentation

The basket method is used to ferment small quantities of cocoa beans. The baskets are lined with banana or plantain leaves. The cocoa beans are poured inside the basket and the protruding ends of the leaves are folded over to cover the beans and then secured with a piece of wood. The baskets are placed on sticks or a raised wooden platform to allow drainage of the excess liquid. The package is opened and the beans turned and mixed thoroughly on the third and fifth days. The fermented beans are removed for drying on the seventh day (Are and Gwynne-Jones, 1974).

Plate 4: Basket fermentation

2.7 DRYING OF FERMENTED COCOA BEANS

Fermented cocoa beans are dried for two main reasons: First, to reduce their moisture content from about 40-55% to a level, which is safe for storage and shipment; that is, between 4% and 8%. Second, to complete the oxidative stage of fermentation and thereby reduce astringency, bitterness, and acidity, while enhancing flavour development and the brown colour associated with well-fermented beans (Wood, 1985; Garcia-Alamilla *et al.*, 2007; Sukha 2009). According to Lopez and Dimick (1995) moisture content above 8% might yield mould growth during prolonged storage and moisture of below 5% is very brittle.

2.7.1 Natural Drying

Sun drying is the simplest and the most widely used method in most of the producing countries. This method is depended on the climatic conditions and beans have to be exposed for one or two weeks (Mossu, 1992). This method over the years produces good quality cocoa beans in traditional areas of cocoa production such as Ghana where the weather is sunny. In Ghana, the beans are spread in a thin layer on bamboo mats in the sun raised off the ground and the mats can be rolled up to protect the beans when it rains. The beans are stirred regularly and foreign materials are easily identified and hand-picked and there is also a lesser risk of contamination (Afoakwa *et al.*, 2011a; 2011b).

2.7.2 Artificial Drying

This method of drying is used where cocoa beans are produced during the rainy season and under humid conditions. The drying is achieved via hot air or heating by induction.

Dryers are relatively expensive to acquire and to run because of high fuel consumption (Are and Gwynne-Jones, 1974). The use of wood, as a source of heating fuel, poses the danger of smoky beans leading to off-flavours when the smoke produced if not well controlled. This will severely affect the value of the beans (Wood and Lass, 1985;

Thompson *et al.*, 2001).

2.8 MOISTURE CONTENT

The moisture content of the wet cocoa beans is about 40 per cent which should be reduced to 6.0 – 7.5 per cent for the beans to be stored safely. It is important that the moisture content of the beans is reduced to prevent mould growth and subsequent development of off-flavours. Moisture content above 8 per cent encourages the growth of moulds; below 5 per cent the beans will be brittle and unsuitable for factory processing. Dry cocoa beans are hygroscopic and absorb moisture under humid conditions (Wood and Lass, 1985).

2.9 HERMETIC STORAGE

"Hermetic storage", comprises a sealed storage system containing a modified atmosphere. Generally, there is the development of low oxygen and high carbon dioxide as a result of respiration effects in the sealed storage ecosystem. The low permeability envelope maintains a constant moisture environment.

Hermetic storage system has resulted in the broad use of safe, pesticide-free storage that is suitable for many commodities and seeds, particularly in hot, humid climate. These hermetic storage systems are used primarily in Africa, Asia, South and Central America for a growing variety of both high and medium value commodities.
The commodities include; seeds, cocoa and coffee as well as large stores of staple grains (Calderon and Navarro 1980; Navarro *et al*., 1989; Navarro and Calderon 1980).

Problems associated with cocoa beans storage are the harmful effects of moulds, microflora and oxidation. Oxidation leads to the increase of free fatty acids (FFAs), which have a negative impact on the quality of cocoa. With hermetic storage of cocoa, oxygen levels typically go down to 2% or less in a week, protecting the commodity against insects, oxidations effects, and the growth of moulds (De Bruin and Murali, 2006).

2.10 CUT TEST

Mouldy and unfermented beans can be estimated from the cut test which is the standard method of assessing quality. Other defects which can affect the keeping quality of the beans can be identified through cut test.

The cut test is made on 300 beans taken from a random sample of cocoa whose quality is to be assessed. The beans are cut lengthwise through the middle using a penknife to expose the maximum cut surface of the cotyledon. Both halves of each bean are examined in full daylight according to the cross sectional colour of the beans. The beans are observed and placed in one of the following categories: fully brown (fermented), partly brown, partly purple (partly fermented), purple (under fermented), slaty (not fermented), insect damaged, mouldy and germinated.

The results are expressed as a percentage of each type.

Some defects of cocoa beans are as follows:

- Mouldy bean: A cocoa bean on the internal parts of which mould is visible to the naked eye.

- Slaty bean: A bean which shows a slaty colour over half or more of the surface exposed.
- Insect-damaged bean: A bean that has its internal parts of which are found to contain insect at any stage of development, or show signs of damage caused, which are visible to the naked eye.
- Germinated bean: A bean in which the shell has been pierced, slit or broken by the growth of the seed germ.
- Flat bean: A bean whose cotyledons are too thin to be cut to give a surface of cotyledon (Wood and Lass, 1985).
- Fragment: A piece of bean equal to or less than half the original bean.
- Smoky bean: A bean which has a smoky smell or taste or which shows signs of contamination by smoke.
- Broken bean: A bean in which a fragment is missing, the missing part being equivalent to less than half the bean (Boateng, 2012).

Cocoa beans are graded, according to the proportion of defective beans determined by the method of test specification. The grade types comprise:

GRADE I: Cocoa which is thoroughly dry, free from foreign matter, smoky beans and any evidence of adulteration, and which contains not more than 3% by count of mouldy beans, not more than 3% by count of slaty beans, and not more than 3% by count of all other defects.

GRADE II: Cocoa which is thoroughly dry, free from foreign matter, smoky beans and any evidence of adulteration, and which contains not more than 4% by count of mouldy beans, not more than 8% by count of slaty beans, and not more than 6% by count of all other defects.

SUB GRADE: Cocoa which fails to reach the standard Grade II. This is not purchased by the Ghana Cocoa Board. Only grades I and II cocoa are purchased at the full price (Boateng, 2012).

2.11 OFF-FLAVOURS

The major off-flavour in cocoa beans is due to mould, smoke, under-fermentation and acidity. Mould causes off-flavour because it cannot be removed during manufacture. Mouldy beans can increase the free fatty acid (FFA) content of the cocoa butter; this is normally low less than 1 per cent. If the free fatty acid in a sample of beans exceeds 1 per cent, it is likely that the FFA in the cocoa butter derived from them will exceed 1.75 per cent (Wood and Lass, 1985).

FFAs are carboxylic acids released from triglycerides (Selamat *et al*., 1996) through the effect of a lipase (E. C. 3.1.1.3) or an oxidation. The quality of raw cocoa beans depends largely on their FFAs content as it gives the measure of rancidity of cocoa beans (Afoakwa *et al*., 2011b) and high FFAs content is reported to be a serious quality defect which reduces the technical and economic value of the cocoa beans (Guehi *et al*., 2008).

The hardness of cocoa fat (butter) is reported to depend on the saturated and unsaturated fatty acid contents bound in triglycerides, and on free fatty acids (FFAs) content (Guehi *et al*., 2008) and a high FFAs content leads to a decrease in hardness of cocoa butter which reduces the commercial value for both processors and chocolate manufacturers. High FFA content in cocoa beans might result from black beans which originate from rotten pods or germinated beans. Microflora, particularly moulds, can cause similar problems during storage (Hiol, 1999). According to Wood and Lass (1985) and Pontillon (1998) FFA occurrence in stored cocoa beans is linked to the action of microbial lipase.

Smoke, distinctive off-flavours which are described as smoky are usually attributed to contamination by smoke during drying or storage. This off-flavour is currently associated with cocoa beans from Brazil and in the past with cocoa from West Cameroon (Wood and Lass, 1985).

2.11.1 Under-Fermentation

Beans which are dried without being fermented have slaty colour of the cotyledons and a cheesy texture. Chocolate made from slaty beans has a bitter, astringent and thoroughly unpleasant flavour.

2.11.2 Acidity

Cocoa beans are acid to a certain degree to an extent that is acceptable for chocolate manufacture. However, when the amount of acids in the beans is excessive there will be an adverse effect on the flavour of the finished product. The acids involved are acetic and lactic.

Acidity in cocoa beans can be measured in terms of pH, West African cocoa beans are not acidic and have a pH of 5.5, while acid beans have a pH below 5.0 (Wood and Lass, 1985).

2.12 FAT

Cocoa butter or fat constitutes about half the weight of the cocoa bean and its quantity and quality are critical to chocolate manufacture. Ranging from 45 – 55% the majority of the lipid profile exists as triacylglycerides (95%) with a minute amount of approximately 5% existing as mono- and di-glycerides, glycolipids, sterols and phospholipids (Belitz *et al.*, 2009).

2.13 PACKAGING

Packaging is used for several purposes:

- Contain products, defining the amount the consumer will purchase.
- Protects products from contamination, from environmental damages and from theft.
- Facilitates transportation and storing of products.
- Carry information and colourful designs that make attractive displays.

2.13.1 Packaging Material

According to Ellis (1993) the material used for packaging must satisfy certain criteria such as having low vapour transmission rates and preventing changes in moisture content. Therefore, for the selection of packaging material, certain factors should be taken into consideration such as the gas and moisture barrier properties, adequate strength, damaging corners or surfaces and mechanical injury should be absent.

2.13.2 Types of Packaging Materials

2.13.2.1 Jute sack bag

Jute sack bag is popular and environmentally friendly packaging material for agricultural industry. Jute sack bag also called jute hydro carbon bag which is specially made from agro-based product has no contamination of hydrocarbons and it is completely free from kerosene smell. Woven jute sacks, which are chemically treated to proven rotting and to reduce their flammability, are non– slip, have a high tear resistance, and good durability.

They are used to store and transport a wide variety of bulk foods including vegetables, grain, flour, sugar and salt (Ellis, 1993).

2.13.2.2 Glass

This is an ideal packaging material for foods, especially liquids. It is strong and easy to recycle. It is the traditional vessel in the home (jars, glasses, jugs etc). Its weight and shape may involve some difficulties for transport and storage (Wills *et al.*, 1989).

2.13.2.3 Plastic

This is the most common packaging material however; one of the most difficult to dispose of.

The common characteristics to all plastics are that they are light, strong and cheap to manufacture. It is for these reasons that they are used so much, as an alternative to other packaging materials. Among the plastic films are cellulose, polypropylene and polyethylene (low and high density) (Meir *et al.*, 1995). Low – density polyethylene is heat sealable, inert, odour free and shrinks when heated.

It is a good moisture barrier but has relatively high gas permeability. It is less expensive than most films and is therefore widely used. High – density polyethylene is stronger, thicker, less flexible and more brittle than low – density polyethylene and has lower permeability to gases and moisture. It has higher softening temperature (121°C) and can therefore be heat sterilized.

Bags made from 0.03 – 0.15mm high – density Polyethylene have high tear strength, penetration resistance and seal strength. They are water proof and chemically resistant and are used instead of paper bags (Lisboa *et al*., 1983).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 LOCATION OF EXPERIMENT

The experiment was carried out at the fermentation laboratory of the Cocoa Research Institute of Ghana (CRIG), New Tafo-Akim in the Eastern Region between October, 2014 and April, 2015. The laboratory analysis of cocoa bean samples for pH, free fatty acid, fat and moisture contents was conducted at the Department of Horticulture, Kwame Nkrumah University of Science and Technology, Kumasi.

3.2 SOURCE OF EXPERIMENTAL MATERIALS

Ripe, fresh pods of mixed hybrid cocoa were obtained from cocoa plantation of the Cocoa Research Institute of Ghana (CRIG), New Tafo-Akim in the Eastern Region of Ghana for the study. The cocoa pods were stored for four (4) days and cut open with a cutlass and the beans extracted from the pods with hands in gloves.

3.2.1 Fermentation and Drying of Cocoa Beans

The heap method of fermentation was used. Banana leaves perforated in a number of places were arranged closely in a circular pattern. The heap was made up of 500kg wet cocoa beans which were poured in the centre of the heap; the banana leaves were folded over to enclose the beans very well in order to prevent entry of air.

Pieces of wood were placed on top to hold the leaves in place so as to conserve heat inside the heap. The heap was opened on the third and fifth days to allow turning and mixing of the beans. The heap was allowed to ferment spontaneously for six days (Takrama and Adomako 1996; Dahl, 2006 and Amoa-Awua, 2007a).

The beans were fermented and 200kg wet cocoa beans were removed for drying on the seventh day in the open sun on raised platforms using the traditional process (Afoakwa, 2010).

Drying of the beans started at 8.00a.m and ended at 3.00p.m each day for thirteen days. The beans were stirred constantly each day and covered with raffia mats in the evening till the next morning. During stirring of the beans debris, flat beans, placenta and all foreign materials were removed leaving uniformly sized beans. The drying and stirring processes continued until the beans were well-dried and had reached the ideal moisture content of 6-7.5%. At this point, a couple of beans squeezed in the palm gave a 'cracking' noise (Opoku-Ameyaw *et al.*, 2010).

3.2.2 Sample preparation, Storage and Sampling

The well-dried cocoa beans were conveyed to the store room. About 350 g dried cocoa beans were weighed with a digital top-loading balance (CAMRY, China) into each of the following four packages; transparent glass bottle, transparent plastic bottle, transparent high density polyethylene bag and sewn jute sack bag (37.5cm x 25cm) for the physical (cut test) analysis. However, for the biochemical analysis 700 g cocoa beans were weighed into each of the four packages. The set-up was repeated three times.

The packages were sealed and stored for four months. Daily temperature and relative humidity at 9.00a.m, 12.00p.m and 3.00p.m in the storage environment were taken with a Thermo-hygro meter (EAI TMH–250, China). The unstored beans, which constituted the first set of sample consisted of 12 sample beans each, were sent for physical (cut test) and biochemical analyses. The second, third, fourth and fifth sets of samples were sent for analyses at 30, 60, 90 and 120 days, respectively. In all, 120 sample cocoa beans were used for both the physical and biochemical analyses.

3.3 EXPERIMENTAL DESIGN

The study was conducted using a 2-factor (4x5) factorial experiment which was laid out in completely randomized design with 3 replications. The factors were packaging materials at 4 levels (Transparent Glass Bottle, Transparent Plastic Bottle, Transparent High Density Polyethylene Bag and Jute sack bag) and storage periods at 5 levels (0 day, 30 days, 60 days, 90 days and 120 days).

There were (twenty) 20 treatment combinations as follows:

1. Cocoa beans in glass bottle stored for 0 day
2. Cocoa beans in glass bottle stored for 30 days
3. Cocoa beans in glass bottle stored for 60 days
4. Cocoa beans in glass bottle stored for 90 days
5. Cocoa beans in glass bottle stored for 120 days
6. Cocoa beans in plastic bottle stored for 0 day
7. Cocoa beans in plastic bottle stored for 30 days
8. Cocoa beans in plastic bottle stored for 60 days
9. Cocoa beans in plastic bottle stored for 90 days
10. Cocoa beans in plastic bottle stored for 120 days
11. Cocoa beans in high density polyethylene bag stored for 0 day
12. Cocoa beans in high density polyethylene bag stored for 30 days
13. Cocoa beans in high density polyethylene bag stored for 60 days
14. Cocoa beans in high density polyethylene bag stored for 90 days

15. Cocoa beans in high density polyethylene bag stored for 120 days
16. Cocoa beans in jute sack bag stored for 0 day
17. Cocoa beans in jute sack bag stored for 30 days
18. Cocoa beans in jute sack bag stored for 60 days
19. Cocoa beans in jute sack bag stored for 90 days
20. Cocoa beans in jute sack bag stored for 120 days.

3.4 PHYSICAL ANALYSIS

3.4.1 Cut Test

The cut test was performed according to the International method described by Guehi *et al*. (2008). The test was performed on sixty (60) different samples. A total of 300 beans per sample were cut vertically through the middle to expose the maximum cut surface of the cotyledon. Both halves of each bean were examined in full daylight according to the cross sectional colour of the beans.

Beans were observed and placed in one of the following categories: deep purple (under fermented), pale purple, fully brown (fermented), slaty (not fermented), mouldy, germinated and other defects. The results were expressed as a percentage of each type.

3.5 BIOCHEMICAL ANALYSIS

3.5.1 Parameters Studied

3.5.1.1 Determination of pH

The pH meter (METTLER TOLEDO, UK) was calibrated at 20^{o}C using two buffer solutions (pH 4.00 and 7.00). 40g of powdered cocoa beans was weighed into 100ml beaker and 60mls of boiling distilled water was added.

The mixture was stirred occasionally and allowed to cool. The pH was measured when the suspension had cooled to 20^{o}C and the experiment was performed in triplicate.

3.5.1.2 Determination of free fatty acid (FFA)

Fat from the samples was extracted with petroleum ether (40–60^{o}C) in a Soxhlet apparatus using the AOAC (2005) method 963.15. FFA of the oils extracted was determined using the IOCCC (1996) method 42-1993. 25ml of 95% ethanol was added to the oil in the flask and 25mls of diethyl ether was added to it. 3 drops of phenolphthalein indicator was stirred to mix uniformly. The solution was titrated against 0.1M KOH by swirling constantly until a faint pink colour persisted for 30 seconds. The percentage FFA was determined. The analysis was conducted in triplicates and the mean values reported.

$$\text{Acid value} = \frac{56.1 \times T \times V}{W}$$

Where T = Concentration of Standardized KOH = 0.1M

V = Volume of KOH used in ml (Titre value)

W = Weight of fat sample (g)

$$\text{Free Fatty Acid} = \frac{\text{Acid Value}}{M}$$

Where M = Molecular weight of fat sample

M = 2.82

3.5.1.3 Determination of fat content

Cocoa beans sample was ground and mixed thoroughly. 2g of the sample was weighed and placed in a filter paper. The filter paper was folded to hold the sample.

A piece of cotton wool was placed at the top which evenly distributed the solvent as it dropped on the sample during extraction. The sample packet was placed in the butt tubes of the Soxhlet extraction apparatus. The extraction flask was placed in an oven for about 5 minutes at 110^{o}C it was then cooled and weighed. The fat was extracted with petroleum ether for 2-3 hours without interruption by gentle heating. It was allowed to cool and the extraction flask dismantled. The ether was evaporated on a water bath until no odour of ether remained. It was then cooled at room temperature.

The extraction flask and its extract were re-weighed and the weight recorded.

Calculations

(A + B) – A = B % ether extract = B/c x 100

Where A = flask weight, B = ether extract weight, C = sample weight

3.5.1.4 Determination of moisture content (%MC)

A moisture can was weighed and 2g of granular sample was weighed into the moisture can. This was allowed to dry overnight in an air oven (Wagtech, UK) at 110^{o}C for 24 hours, the can plus the sample was cooled in desiccators and re-weighed.

Calculations

(A+B) – A = B

(A+B) – (A+C) = B – C = D % Moisture = D/B x 100

Where A = can wt., B = sample wt., C = dry sample wt., D = moisture wt.

3.6 DATA ANALYSIS

Data collected on all parameters studied were statistically analysed using the Statistix (version 9) statistical software for Analysis of variance (ANOVA). Means separation of the treatments were performed by the Honestly Significant Difference (HSD) test at 5% (p = 0.05) and 1% (p = 0.01) levels for the physical and biochemical analyses respectively. Correlation analysis was also performed.

CHAPTER FOUR

4.0 RESULTS

4.1 PHYSICAL (CUT TEST) ANALYSIS OF DRIED COCOA BEANS

The cut test which is a qualitative standard test assesses the degree of fermentation of cocoa beans for purchase and chocolate processing. According to Wood and Lass (1985) the test is a standard method used to assess quality as defined in grade standard. The test is also used to determine two major off-flavours thus; mouldy and unfermented beans. The cut test was performed on cocoa beans that had been fermented for 6 days. The beans were dried, packaged in different materials and stored for a period of 4 months. In order to determine the degree of fermentation, the cut beans were divided into 7 different categories; deep purple, pale purple, brown, slaty, mouldy, germinated and other defects.

4.1.1 Percentage Deep Purple Beans

The effect of packaging materials and storage durations on deep purple beans is presented in Table 4.1. Significant differences (p = 0.01) in percentage (%) deep purple beans occurred among the packaging materials. The mean percentage deep purple beans for the packaging materials ranged from 13.57% to 19.06% whilst the mean for the storage durations ranged from 15.68% to 18.30%. Jute sack bag recorded the least (13.57%) whilst high density polyethylene bag recorded the highest (19.06%) deep purple beans during the entire storage duration of 120 days.

Significant differences occurred between the jute sack bag and plastic bottle which recorded the second least mean deep purple beans of 16.71%. Storage duration did not affect (p = 0.20) percentage deep purple beans. The interaction effect was statistically significant (p = 0.01).

Cocoa beans packaged in jute sack and stored for 60 days recorded the least (11.70%) deep purple beans, but did not differ from beans packaged in glass bottle and stored during the same duration of 60 days.

Beans packaged in high density polyethylene bag which was not stored recorded the highest (22.20%) deep purple beans. However, this was not different from beans packaged in glass bottle and not stored.

Table 4.1: Effect of packaging materials and storage duration (days) on deep purple bean of cut test on dried cocoa beans.

	Storage duration(days)					
Packaging materials	0	30	60	90	120	**Mean**
Glass Bottle	22.10^{a*}	13.80^{abc}	14.10^{abc}	13.53^{abc}	21.57^{ab}	**17.02**^{a}
Plastic Bottle	14.43^{ab}	16.13^{abc}	19.67^{abc}	19.10^{abc}	14.20^{abc}	**16.71**^{a}
High Density polythene Bag	22.20^{a}	21.47^{ab}	18.43^{abc}	16.97^{abc}	16.23^{abc}	**19.06**^{a}
Jute Sack Bag	14.47^{abc}	13.10^{bc}	11.70^{bc}	13.10^{bc}	15.47^{abc}	**13.57**^{b}
Mean	**18.30**^{a}	**16.13**^{a}	**15.98**^{a}	**15.68**^{a}	**16.87**^{a}	
CV(%) 17.47						

*Means in columns carrying the same superscript letter are not significantly different at p = 0.05

4.1.2 Percentage Pale Purple Beans

Table 4.2 shows that pale purple beans were significantly (p = 0.03; p = 0.01) affected by both packaging materials and storage durations. Cocoa beans packaged in plastic bottle recorded the least mean value of 3.21% whilst the highest (4.40%) was recorded by glass bottle, but did not differ significantly from high density polyethylene bag.

Beans stored for 60 days recorded the least mean value of 2.89% whilst non-storage of beans resulted in the highest pale purple beans with mean value of 5.22% Table 4.2.

No significant difference occurred between plastic bottle and jute sack bag.
During the entire period of storage significant differences did not occur among days 30, 60, 90 and 120 for the pale purple beans. The percentage pale purple beans for all packaging materials at the end of the storage period ranged from 2.23% to 7.80%.

The combined effect of packaging materials and storage durations resulting in pale purple beans was significant (p = 0.02). Interaction between reference beans kept in glass bottle and stored for 60 days recorded the least (2.23%) pale purple bean which was not significantly different from beans packaged in plastic bottle, high density polyethylene and jute sack bags and stored for the same 60 days Table 4.2.

Table 4.2: Effect of packaging materials and storage duration (days) on pale purple beans of cut test on dried cocoa beans.

	Storage durati)					
Packaging materials	0	30	60	90	120	**Mean**
Glass Bottle	7.80^{a*}	4.23^{abc}	2.23^{c}	3.33^{bc}	4.43^{abc}	**4.40**^{a}
Plastic Bottle	2.90^{bc}	2.67^{c}	3.80^{bc}	3.90^{abc}	2.77^{bc}	**3.21**^{a}
High Density polythene Bag	6.63^{ab}	4.13^{abc}	2.87^{bc}	3.67^{bc}	3.57^{bc}	**4.17**^{a}
Jute Sack Bag	3.53^{bc}	3.10^{bc}	2.67^{c}	4.10^{abc}	2.97^{bc}	**3.27**^{a}
Mean	**5.22**^{a}	**3.53**^{b}	**2.89**^{b}	**3.75**^{ab}	**3.43**^{b}	
CV(%) 34.07						

*Means in columns carrying the same superscript letter are not significantly different at p = 0.05

4.1.3 Percentage Brown Beans

The effect of packaging materials and storage duration resulting in brown beans is presented in Table 4.3. The mean value of brown beans among the packaging materials were significantly different (p = 0.01). Brown beans ranged from 71.91% to 80.51% for the packaging materials and 70.49% to 81.22% for the storage durations. Jute sack bag recorded the highest mean value of (80.51%) brown beans with high density polyethylene bag recording the lowest mean value of (71.91%).

There were no significant differences in mean values obtained from glass and plastic bottles. Significant differences (p = 0.01) occurred among the duration of storage for brown beans.

Beans stored for 60 days recorded the highest mean value of 81.22% whilst storage for 120 days recorded the least value of 70.49% (Table 4.3). Interaction between packaging materials and storage durations significantly (p = 0.02) affected percentage brown beans.

The combination that recorded the highest value (86.33%) of brown beans was jute sack bag at storage duration of 60 days, which was not significantly different from glass bottle at the same storage duration. The least value (63.90%) was recorded for 120 days of storage in glass bottle.

Table 4.3: Effect of packaging materials and storage duration (days) on brown beans of cut test on dried cocoa beans.

	Storage duration(days)					
Packaging materials	0	30	60	90	120	**Mean**
Glass Bottle	69.87^{abc*}	81.90^{ab}	83.57^{a}	83.10^{a}	63.90^{c}	$\mathbf{76.45}^{ab}$
Plastic Bottle	82.57^{ab}	81.20^{ab}	76.30^{abc}	75.53^{abc}	76.57^{abc}	$\mathbf{78.43}^{a}$
High Density polythene Bag	71.00^{abc}	74.00^{abc}	78.67^{abc}	66.00^{bc}	69.90^{abc}	$\mathbf{71.91}^{b}$
Jute Sack Bag	81.77^{ab}	83.43^{a}	86.33^{a}	79.43^{abc}	71.57^{abc}	$\mathbf{80.51}^{a}$
Mean	$\mathbf{76.30}^{ab}$	$\mathbf{80.13}^{a}$	$\mathbf{81.22}^{a}$	$\mathbf{76.02}^{ab}$	$\mathbf{70.49}^{b}$	
CV(%) 7.14						

*Means in columns carrying the same superscript letter are not significantly different at p = 0.05

4.1.4 Percentage Slaty, Mouldy, Germinated and other Defective Beans before Storage

Table 4.4 shows slaty, mouldy, germinated and other defective beans. The results indicated that apart from glass bottle which recorded 0.3% germinated beans there were no slaty, mouldy and other defective beans in all the packaging materials before storage.

Table 4.4: Cut test score of dried cocoa beans in different packaging materials before storage

Packaging materials	Slaty (%)	Mouldy (%)	Germinated (%)	OD (%)
Glass Bottle	0	0	0.3	0
Plastic Bottle	0	0	0	0
High Density Polyethylene Bag	0	0	0	0
Jute Sack Bag	0	0	0	0

4.1.5 Percentage Slaty, Mouldy, Germinated and other Defective Beans Thirty (30) Days after Storage

Thirty (30 days) after storing cocoa beans there were no slaty, mouldy and other defective beans Table 4.5. High density polyethylene bag and jute sack bag recorded 0.3% germinated beans, respectively.

Table 4.5: Cut test score of dried cocoa beans in different packaging materials 30 days after storage.

Packaging materials	Slaty (%)	Mouldy (%)	Germinated (%)	OD (%)
Glass Bottle	0	0	0	0
Plastic Bottle	0	0	0	0
High Density Polyethylene Bag	0	0	0.3	0
Jute Sack Bag	0	0	0.3	0

4.1.6 Percentage Slaty, Mouldy, Germinated and other Defective Beans Sixty (60) Days after Storage

Table 4.6 shows slaty, mouldy, germinated and other defective beans 60 days after storage. There were no slaty, mouldy and other defective beans during the 60-day storage period. However, 0.3% each of germinated beans was recorded by Plastic bottle and Jute sack bag.

Table 4.6: Cut test score of dried cocoa beans in different packaging materials 60 days after storage

Packaging materials	Slaty (%)	Mouldy (%)	Germinated (%)	OD (%)
Glass Bottle	0	0	0	0
Plastic Bottle	0	0	0.3	0
High Density Polyethylene Bag	0	0	0	0
Jute Sack Bag	0	0	0.3	0

4.1.7 Percentage Slaty, Mouldy, Germinated and other Defective Beans Ninety (90) Days after Storage.

Slaty, mouldy, germinated and other defective beans 90 days after storage are shown in Table 4.7. There were no slaty, mouldy, germinated and other defective beans. Cocoa beans packaged in plastic bottle and high density polyethylene bag recorded 0.3% each of germinated beans.

Table 4.7: Cut test score of dried cocoa beans in different packaging materials 90 days after storage

Packaging materials	Slaty (%)	Mouldy (%)	Germinated (%)	OD (%)
Glass Bottle	0	0	0	0
Plastic Bottle	0	0	0.3	0
High Density Polyethylene Bag	0	0	0.3	0
Jute Sack Bag	0	0	0	0

4.1.8 Percentage Slaty, Mouldy, Germinated and other Defective Beans One Hundred and Twenty (120) Days after Storage

The results of slaty, mouldy, germinated and other defective beans of cut test score 120 days after storing of the beans are presented in Table 4.8. The results indicated that cocoa beans packaged in plastic bottle, high density polyethylene bag and jute sack bag recorded 0.3% each of germinated beans. There were no slaty, mouldy and other defective beans.

Table 4.8: Cut test score of dried cocoa beans in different packaging materials 120 days after storage

Packaging materials	Slaty (%)	Mouldy (%)	Germinated (%)	OD (%)
Glass Bottle	0	0	0	0
Plastic Bottle	0	0	0.3	0
High Density Polyethylene Bag	0	0	0.3	0
Jute Sack Bag	0	0	0.3	0

4.2 BIOCHEMICAL ANALYSIS OF DRIED COCOA BEANS

4.2.1 pH of Dried Cocoa Beans

The effect of packaging materials and storage duration resulting in pH is presented in Table 4.9. The pH of the dried cocoa beans were significantly (p = 0.01; p = 0.01) affected by both packaging materials and storage durations.

Cocoa beans packaged in glass bottle, plastic bottle and high density polyethylene bag recorded a lower mean pH value of 5.0 which was significantly different from beans in jute sack bag which recorded a mean pH value of 5.3. Beans stored for 30 and 120 days recorded a lower mean pH value of 5.0 respectively whilst unstored beans and beans stored for 60 and 90 days produced higher mean pH value of 5.1 respectively. The combined effect of packaging materials and storage duration resulting in pH of the dried cocoa beans was significant (p = 0.01).

Interaction between beans packaged in jute sack bag and stored for 90 days recorded the highest (5.5) pH value which was significantly different from beans in glass bottle, plastic bottle and high density polyethylene bag and stored for the same 90 days Table 4.9. The combination with the least pH value of 4.9 was recorded by beans in glass bottle stored for 120 days; beans in plastic bag stored for 30 and 60 days respectively and beans in high density polyethylene bag stored for 120 days.

Table 4.9: Effect of packaging materials and storage duration (days) on pH of dried cocoa beans

	Storage duration(days)					
Packaging materials	0	30	60	90	120	**Mean**
Glass Bottle	5.0^{c*}	5.0^{c}	5.0^{c}	5.0^{c}	4.9^{c}	**5.0**^{b}
Plastic Bottle	5.0^{c}	4.9^{c}	4.9^{c}	5.0^{c}	5.0^{c}	**5.0**^{b}

High Density polythene Bag	5.0^{c}	4.9^{c}	5.0^{c}	5.0^{c}	4.9^{c}	**5.0^{b}**
Jute Sack Bag	5.3^{ab}	5.1^{c}	5.4^{ab}	5.5^{a}	5.3^{b}	**5.3^{a}**
Mean	**5.1^{a}**	**5.0^{c}**	**5.1^{ab}**	**5.1^{a}**	**5.0^{bc}**	
CV(%) 1.02						

*Means in columns carrying the same superscript letter are not significantly different at p = 0.01

4.2.2 Percentage Free Fatty Acid of Dried Cocoa Beans

Table 4.10 shows the effect of packaging materials and storage duration on FFA of dried cocoa beans. The FFA of the dried cocoa beans was significantly (p = 0.01) affected by storage durations. The mean FFA for the storage durations ranged from 1.58% to 2.28% whilst the mean for the packaging materials ranged from 1.77% to 2.12%. Beans which were not stored produced the least (1.58%) mean FFA whilst beans stored for 90 days recorded the highest (2.28%) mean FFA. Significant differences were observed between beans which were not stored and beans stored for 90 days. Packaging materials did not affect (p = 0.04) FFA. The combined effect of packaging materials and storage durations resulting in FFA was significant (p = 0.01).

Interaction between beans not stored and in glass bottle recorded the least (1.05%) FFA but was not significantly different from beans which were not stored and in plastic bottle, high density polyethylene and jute sack bags. The combination which recorded the highest (2.80%) FFA was beans packaged in high density polyethylene bag and stored for 90 days which was not significantly different from beans packaged in plastic bottle, glass bottle and jute sack bag stored for the same 90 days.

Table 4.10: Effect of packaging materials and storage duration (days) on FFA of dried cocoa beans

	Storage duration(days)					
Packaging materials	0	30	60	90	120	**Mean**

Glass Bottle	1.05[c*]	2.55[a]	1.98[abc]	2.25[abc]	1.80[abc]	**1.93**[a]
Plastic Bottle	1.09[bc]	1.91[abc]	1.88[abc]	2.33[ab]	1.83[abc]	**1.81**[a]
High Density polythene Bag	2.15[abc]	1.92[abc]	1.82[abc]	2.80[a]	1.92[abc]	**2.12**[a]
Jute Sack Bag	2.01[abc]	1.63[abc]	1.75[abc]	1.75[abc]	1.70[abc]	**1.77**[a]
Mean	**1.58**[b]	**2.00**[ab]	**1.86**[ab]	**2.28**[a]	**1.81**[ab]	
CV(%) 18.47						

*Means in columns carrying the same superscript letter are not significantly different at $p = 0.01$

4.2.3 Fat Content of Dried Cocoa Beans

Table 4.11 shows the effect of packaging materials and storage durations on fat content of dried cocoa beans. The fat content of the cocoa beans were significantly ($p = 0.01$; $p = 0.01$) affected by the packaging materials and storage durations. The fat content of the beans ranged from 29.50% to 51.33%. Cocoa beans in glass bottle recorded the least mean value of 38.65% whilst the highest (45.43%) mean value was recorded by plastic bottle which was significantly different from the mean value of 40.20% recorded by jute sack bag. Beans stored for 60 days recorded the least (36.75%) mean whilst storage at 120 days recorded the highest (45.01%) mean value which was not significantly different from beans stored for 30 days.

The combined effect of packaging materials and storage durations was significant ($p = 0.01$). The combination that recorded the highest (51.33%) fat content value was beans in plastic bottle stored for 30 days which did not differ significantly from beans packaged in glass bottle and jute sack bag and stored at the same duration of 30 days. The least value of 29.50% was recorded by interaction between high density polyethylene bag and beans which were not stored.

Table 4.11: Effect of packaging materials and storage duration (days) on percentage fat content of dried cocoa beans.

	Storage duration(days)

Packaging materials	0	30	60	90	120	Mean
Glass Bottle	44.17^{abcd*}	43.00^{abcde}	31.00^{de}	31.73^{cde}	43.33^{abcde}	**38.65**^{b}
Plastic Bottle	45.67^{abc}	51.33^{a}	37.17$_{abcde}$	44.83^{abcd}	48.17^{ab}	**45.43**^{a}
High Density polythene Bag	29.50^{e}	35.50^{bcde}	42.33^{abcde}	46.27^{ab}	46.03^{abc}	**39.93**^{b}
Jute Sack Bag	40.50^{abcde}	39.00^{abcde}	36.50^{bcde}	42.50^{abcde}	42.50^{abcde}	**40.20**^{b}
Mean	**39.96**^{ab}	**42.21**^{ab}	**36.75**^{b}	**41.33**^{ab}	**45.01**^{a}	
CV(%) 9.87						

*Means in columns carrying the same superscript letter are not significantly different at p = 0.01

4.2.4 Percentage Moisture Content of Dried Cocoa Beans

Table 4.12 shows the effect of packaging materials and storage durations on percentage moisture content of dried cocoa beans. The moisture content of the cocoa beans was significantly affected by storage duration (p = 0.01). The moisture content of the beans ranged from 4.5% to 7.0%. Cocoa beans packaged in plastic bottle recorded the least mean value of 5.7% whilst the highest (6.3%) was recorded by jute sack bag. Beans stored for 30 days recorded the least mean value of 5.3% whilst beans which were not stored recorded the highest moisture content value of 6.3% which was significantly different from beans stored for 30 days. Packaging materials did not affect (p = 0.05) moisture content of the beans. The combined effect of packaging materials and storage durations resulting in moisture content was statistically significant ((p = 0.01).

Interactions between beans packaged in glass bottle and high density polyethylene bag that were stored for 90 and 60 days respectively recorded the least (4.5%) moisture content. The combination that recorded the highest (7.0%) moisture content was beans packaged in jute sack bag and stored for 90 days which was not significantly different from beans packaged in high density polyethylene bag and plastic bottle stored for the same period. Significant differences were however observed between beans packaged in jute sack bag and glass bottle which were stored for 90 days.

Table 4.12: Effect of packaging materials and storage duration (days) on percentage moisture content of dried cocoa beans

	Storage duration(days)					
Packaging materials	0	30	60	90	120	**Mean**
Glass Bottle	6.0_{abc*}	6.0^{abc}	6.8^{ab}	4.5^{c}	5.5^{abc}	**5.8^{a}**
Plastic Bottle	5.8^{abc}	5.3^{abc}	5.3^{abc}	6.0^{abc}	6.3^{abc}	**5.7^{a}**
High Density polythene Bag	6.5^{abc}	5.3^{abc}	4.5^{c}	6.5^{abc}	6.3^{abc}	**5.8^{a}**
Jute Sack Bag	6.8^{ab}	4.8^{bc}	6.5^{abc}	7.0^{a}	6.3^{abc}	**6.3^{a}**
Mean	**6.3^{a}**	**5.3^{b}**	**5.8^{ab}**	**6.0^{ab}**	**6.1^{ab}**	
CV(%) 10.02						

*Means in columns carrying the same superscript letter are not significantly different at p = 0.01

4.3 CORRELATION ANALYSES

4.3.1 Relationship between Environmental Factors and Biochemical Properties of Stored Dried Cocoa Beans

Even though the relationship between temperature and moisture content of dried cocoa beans in glass bottle shown in Figure 4.1 was not statistically significant (r^2= 0.18; p= 0.47), there appeared to be a decreasing trend in moisture content of the beans as temperature increased.

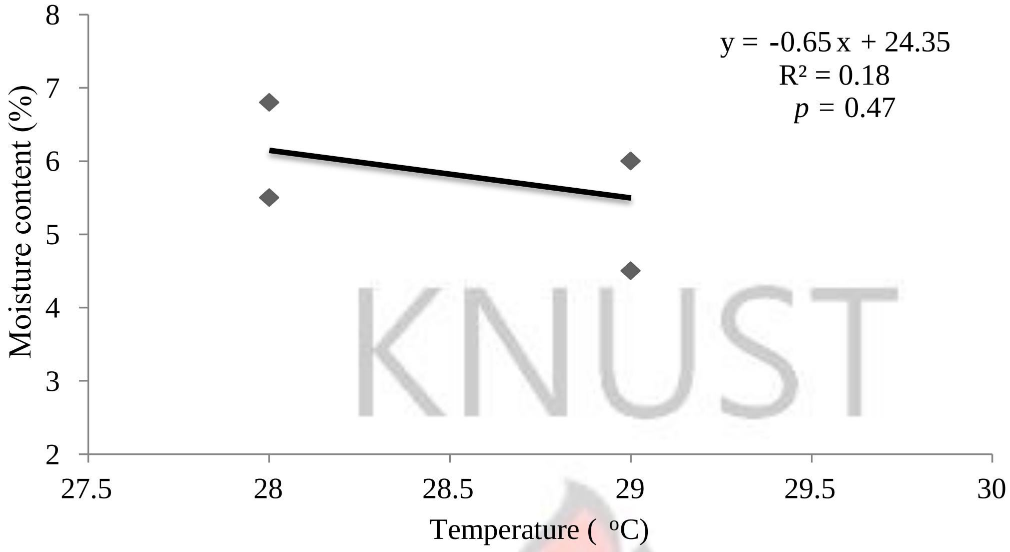

Figure 4.1: Relationship between mean temperature and moisture content in the storage environment of cocoa beans kept in glass bottles.

The relationship between relative humidity and moisture content of dried cocoa beans in glass bottles was not statistically significant (r^2= 0.12; p= 0.10), but there appeared to be an increasing trend in moisture content of the beans as relative humidity increased Figure 4.2.

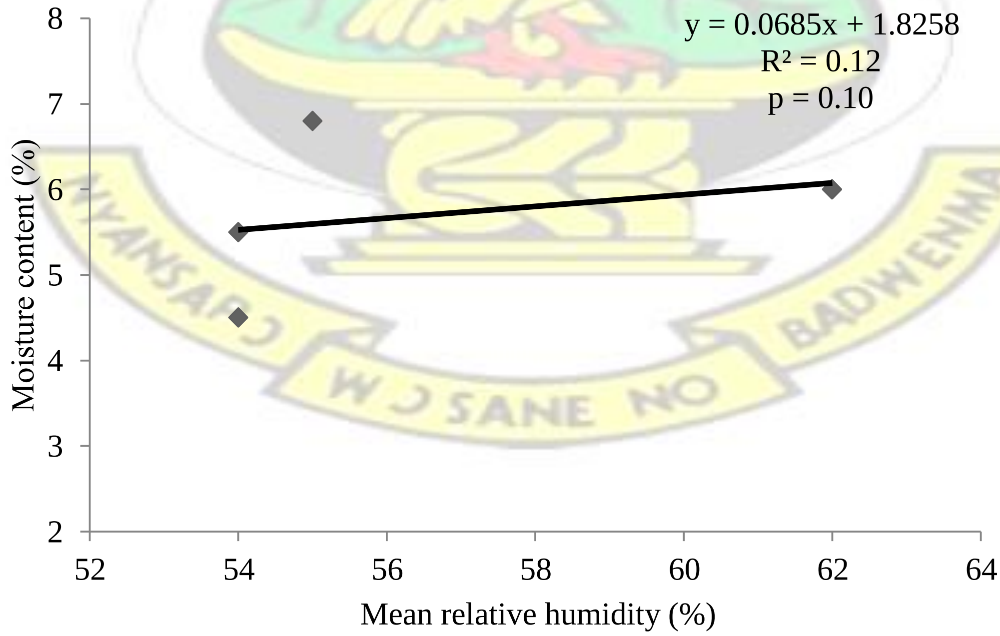

Figure 4.2: Relationship between mean relative humidity and moisture content in the storage environment of cocoa beans kept in glass bottles.

The relationship between relative humidity and FFA content of dried cocoa beans in jute sack bags as shown in Figure 4.3 was not statistically significant (r^2= 0.11; p= 0.58), however, there appeared to be an increasing trend in FFA content of the beans as relative humidity increased.

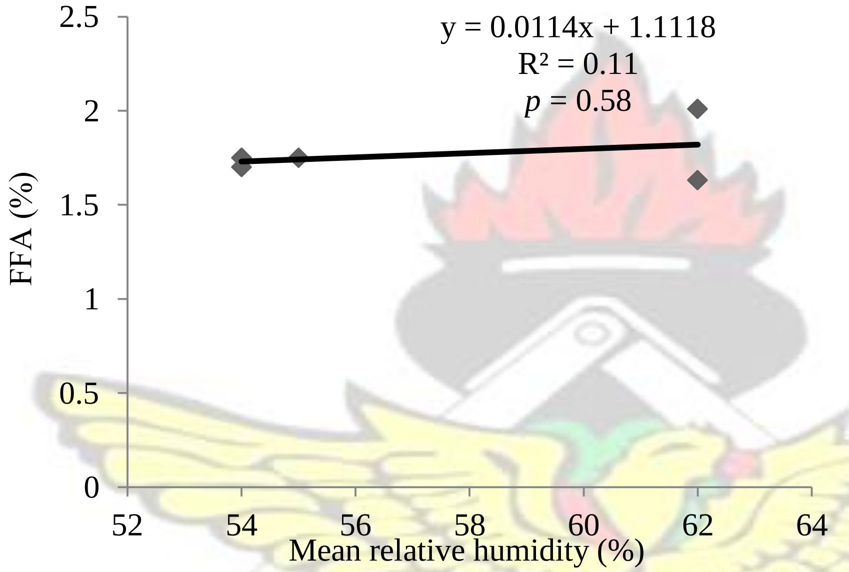

Figure 4.3: Relationship between mean relative humidity and FFA content in the storage environment of cocoa beans kept in jute sacks

Generally, there was no relationship between storage environmental factors (temperature and relative humidity) and biochemical properties (pH, FFA, fat and moisture contents) of stored dried cocoa beans in the different packaging materials.

4.4 MEAN TEMPERATURE (º C) AND RELATIVE HUMIDITY (%) OF THE STORAGE ENVIRONMENT

Figure 4.4 shows the mean temperature and relative humidity pattern of the storage environment of the dried cocoa beans from December, 2014 to April, 2015. The months of December and January recorded a constant mean temperature and relative humidity of 29^{o}C and 62%, respectively.

In February the mean temperature declined marginally to 28^{o}C. However, relative humidity declined from 62% to 55%. Temperature increased slightly to 29^{o}C in March and decline again to 28^{o}C in April. The months of March and April recorded a steady relative humidity of 54%.

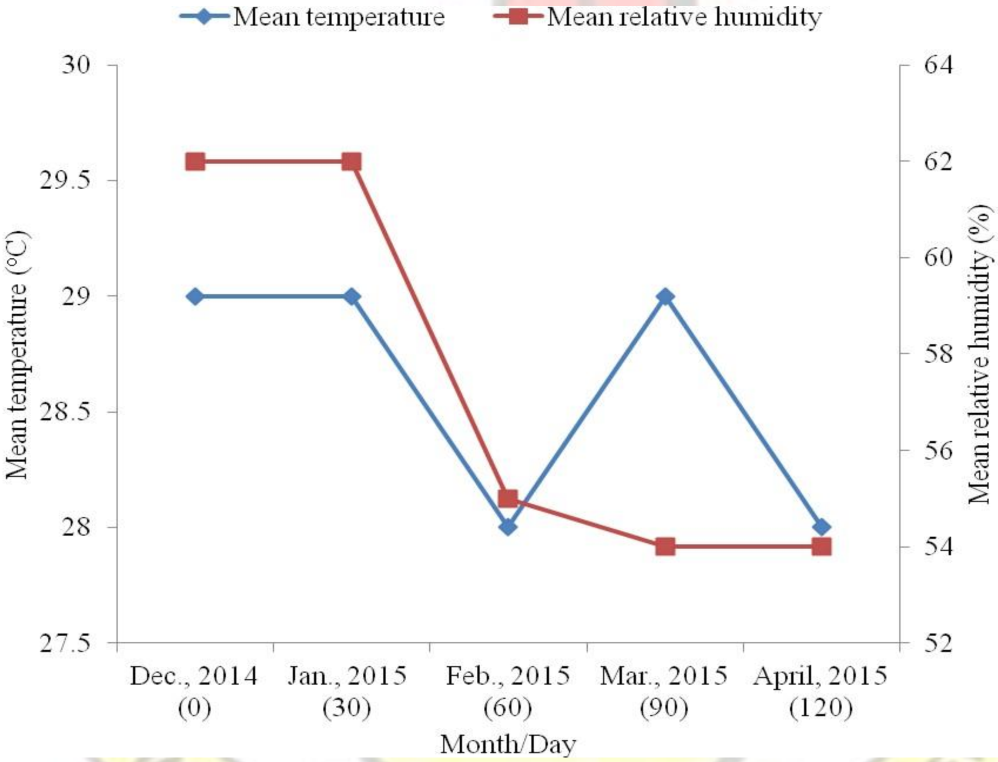

Figure 4.4: Mean temperature and relative humidity of the storage environment

CHAPTER FIVE

5.0 DISCUSSION

5.1 PHYSICAL CHARACTERISTICS (CUT TEST) OF DRIED COCOA

BEANS

5.1.1 Percentage (%) Deep Purple Beans

Cocoa beans kept as reference in jute sack bags and stored for 120 days recorded the lowest mean deep purple as compared to reference beans kept in glass bottle. The lowest percentage of deep purple beans was expected in beans kept in the jute sacks because of the very high proportion of brown beans that they recorded. It could therefore be explained that as the percentage of brown beans in a parcel of cocoa increases the percentage deep purple decreases, as the percentage of brown beans decreases the percentage deep purple increases. The least deep purple produced by the beans kept in jute sacks could be attributed to the exchange of gases particularly oxygen between the storage environment and the beans in the jute sacks because of the air spaces in the sacks. This suggested that the beans in the sacks had sufficient oxygen and were therefore well-aerated.

However, mean deep purple beans recorded by all the treatments in the study were all within the acceptable limits of lower than 20% to be considered as grade I cocoa. The result from the study is a reflection of the high degree of fermentation attributed to the long period of six days of fermentation. Takrama and Adomako (1996); Dahl (2006); Amoa-Awua (2007a) recommended that during fermentation of cocoa beans by the heap method, the heap be allowed to ferment spontaneously for six days. This result also confirms the assertion by Opoku-Ameyaw *et al.* (2010) that purple beans result from insufficient fermentation.

5.1.2 Percentage (%) Pale Purple Beans

Reference beans kept in glass bottles and stored for 120 days produced the highest mean pale purple beans than beans kept in the other receptacles. The lowest mean pale purple beans were recorded by beans kept in plastic bottles followed by beans kept in jute sacks. The highest pale purple beans value recorded by beans in glass bottle could be attributed to inadequate oxygen in the bottles therefore the beans were not wellaerated. Jute sack bags have air spaces which facilitated exchange of gases. Beans in the jute sacks have access to oxygen for better aeration.

Generally, increasing storage duration decreased the percentage of pale purple beans for all the treatments. This was prominent for beans stored up to 60 days. According to Takrama *et al*. (2006) pale purple beans are not defective beans as they change to brown beans upon storage and the International trade accepts up to 30% to 40%. However, samples which contain over 50% are unacceptable. Results from this study showed that the proportion of pale purple beans did not exceed 50% for the treatments indicating that the beans were adequately fermented.

The low pale purple beans produced by the treatments could be attributed to the long period of six days fermentation. Low purple beans will not have bitter and astringent flavours.

5.1.3 Percentage (%) Brown Beans

The highest percentage of brown beans during the storage duration of 120 days was recorded by beans kept in jute sacks. This could be due to air spaces in the jute sacks therefore the beans were well-aerated because of adequate availability of oxygen.

The lower percentage of brown beans produced by reference beans kept in glass bottles could be attributed to the hermetic conditions under which the beans were kept. Hermetic storage technology involves the bio-generation of an oxygen-deficient and carbon dioxide-enriched atmosphere in a sealed storage environment (Calderon and Navarro 1980). This implies that the beans in the glass bottle had insufficient oxygen and therefore were not well-aerated.

For good cocoa flavour to be developed the degree of fermentation (% fully brown beans) should be above 60% (Afoakwa, 2006). The very high values (above 60%) of brown beans for all the treatments are an indication of proper fermentation of the beans and adequate oxidation of the polyphenols in the beans. Very high percentage of brown beans reduces bitterness and astringency of cocoa liquor which is a good quality characteristic (Wood, 1985).

5.1.4 Percentage (%) Slaty, Mouldy, Germinated and other Defective Beans before Storage of Dried Cocoa Beans

The problem of slaty beans arises where the beans are not well-fermented (Are and Gwynne-Jones, 1974). There were no slaty beans before they were stored. The results are indications that the beans were adequately fermented (six days) before they were dried. From the results there were no mouldy beans either before storage. Internal moulds are the major causes of off-flavours in their finished products during cocoa processing and samples of beans which contain as little as 4% of internal moulds can produce off-flavour in their finished products. Moulds inside cocoa beans can increase the free fatty acid (FFA) content of the cocoa butter (Wood and Lass, 1985). The results suggest that the beans were adequately fermented and dried.

Germinated beans are considered a defect because the hole left by the emerging radicles provides an easy entrance for insects and moulds. They also lack good chocolate flavour.

Reference cocoa beans kept in glass bottle recorded 0.3% germinated beans. Germinated beans were absent in plastic bottle, high density polyethylene bag and jute sacks.

Germinated beans observed in the glass bottle could be attributed to some cocoa pods that were over-ripe before harvesting and the beans from them used for fermentation. Other defect of cocoa beans includes insect infested and flat beans. From the results there were no other defective beans before they were stored.

5.1.5 Percentage (%) Slaty, Mouldy, Germinated and other Defective Beans Thirty (30) Days after Storage of Dried Cocoa Beans

The packaging materials did not record slaty, mould and other defective beans thirty (30) days after storing cocoa beans in them. However, 0.3% each of germinated beans was observed for beans packaged in high density polyethylene and jute sack bags respectively. This could be due to some germinated beans that were used for fermentation. During fermentation of cocoa beans high temperature (40^{o}C-50^{o}C) is generated. Acetic and lactic acids enter the cotyledon of the cocoa beans.

These processes cause the death of the embryo and prevent it from germinating. Thus, after proper fermentation cocoa beans cannot germinate.

5.1.6 Percentage (%) Slaty, Mouldy, Germinated and other Defective Beans Sixty (60) Days after Storage of Dried Cocoa Beans

Sixty days after storing of cocoa beans slaty, mouldy and other defective beans were absent. Cocoa beans packaged in plastic bottle and jute sack bag recorded 0.3% each of germinated beans. Slaty beans arise because of improper fermentation and such beans are bitter to taste (Are and Gwynne-Jones, 1974). The results of the study indicated that the beans were adequately fermented.

5.1.7 Percentage (%) Slaty, Mouldy, Germinated and other Defective Beans Ninety (90) Days after Storage of Dried Cocoa Beans

Slaty, mouldy, germinated and other defective beans were absent 90 days after storing the cocoa beans. However, beans in plastic bottle and high density polyethylene bag recorded 0.3% each of germinated beans indicating that some cocoa pods were overripe before harvesting was done.

5.1.8 Percentage (%) Slaty, Mouldy, Germinated and other Defective Beans 120 Days after Storage of Dried Cocoa Beans

There were no slaty, mouldy and defective beans after 120 days of storing the beans. Cocoa beans packaged in plastic bottle, high density polyethylene and jute sack bags recorded 0.3% each of germinated beans. Germinated beans observed in these materials could be attributed to the already germinated beans that were used for fermentation.

5.2 BIOCHEMICAL PROPERTIES OF DRIED COCOA BEANS

5.2.1 pH of Dried Cocoa Beans

Generally, cocoa beans kept in jute sack bags recorded higher pH values with increasing storage durations than reference beans kept in glass bottle as well as beans kept in plastic bottle and high density polyethylene bag. The lower pH values recorded by beans kept in glass and plastic bottles and high density polyethylene bag could be attributed to low gaseous exchange particularly oxygen, in sealed storage environment of the beans.

Acidity in cocoa beans can be measured in terms of pH, West African beans have a pH of 5.5 and not acidic, whilst acid beans have a pH below 5.0 and have reduced commercial value because of their higher acidity (Wood and Lass, 1985). GorkehSekyim (2011) recommended that the pH of commercial bean should range between

5.0 and 7.0.

5.2.2 Free Fatty Acid (FFA) Content of Dried Cocoa Beans

Reference beans kept in glass bottle and stored for 30, 60, 90 and 120 days recorded unacceptable FFAs as compared to beans kept in jute sacks which produced the most desirable FFAs. The European parliament and European council directive 73/241/EEC limits the maximum FFAs content to 1.75% oleic acid equivalent in cocoa butter. According to Dand (1997) for this acceptable level to be met, FFAs levels should be less than 1% in fresh cocoa beans and less than 1.75% in dried cocoa beans.

Cocoa beans which were packaged in jute sack bag and stored during the period between 30 and 120 days recorded FFAs content that were not above the maximum acceptable limits of 1.75 % oleic acid equivalent in cocoa butter. This could be due to better aeration of the beans in the jute sacks and absence of moulds. Mouldy beans can increase the free fatty acid (FFA) content of the cocoa butter (Wood and Lass, 1985). However, beans in glass bottle, plastic bottle and high density polyethylene bag and stored for the same period recorded FFA contents that exceeded the maximum acceptable limits. Generally, beans kept in jute sacks and stored for 120 days recorded the most desirable quality product in terms of free fatty acid.

5.2.3 Fat Content of Dried Cocoa Beans

Fat content or yield is an important quality index for cocoa processors during purchasing of fermented cocoa beans. The fat contents produced by all the treatments in the current study were very low. The observed fat contents of the beans for the packaging materials and storage durations could probably be attributed to the relatively lower sizes of cocoa beans used in this study. The fat content of West African fermented and dried cocoa beans ranges from 56 to 58% and most *Forastero* cocoas fall between 55 and 59% (Wood and Lass, 1985).

The fat content of the beans as observed in this study were slightly lower than the reported values. Differences in the bean sizes could also account for the observed relatively lower fat content. According to Wood and Lass (1985) and Dand (1997) smaller bean sizes result in lower fat content.

5.2.4 Moisture Content

The highest moisture content observed between the combinations of beans in jute sack bag and stored for 90 days could be attributed to the air spaces in the jute sacks. Cocoa beans are hygroscopic and absorb moisture from the surrounding environment. The air spaces in the sacks suggested that the beans might have absorbed moist air thereby increasing the moisture content to 7%. However, for cocoa beans to be stored safely the threshold level of moisture content is 7.5%.

The lowest moisture content of 4.5% observed between the reference beans kept in glass bottle and stored for 90 days could be attributed to the impermeable nature of the glass bottle. This suggested that cocoa beans in the glass bottles could not absorb moist air from the surrounding environment. Higher moisture content beyond 8% promote the growth of moulds but excessively low moisture content below 5% makes the cocoa beans too brittle and turn to break up during roasting for product processing (Wood and Lass, 1985; Jonfia-Essien, 2004).

5.3 RELATIONSHIP BETWEEN ENVIRONMENTAL FACTORS AND BIOCHEMICAL PROPERTIES OF STORED DRIED COCOA BEANS

The results showed no correlation between temperature of the storage environment and moisture content of dried cocoa beans kept in glass bottles. This implied that the moisture content of dried cocoa beans kept in glass bottles was not influenced by temperature. However, individual weights of dried beans may vary from bottle to bottle but this difference was not statistically significant. Any difference in magnitude of the moisture content of dried beans stored in glass bottle may be due to chance.

Moisture content of cocoa beans observed in the current study for glass bottle treatments was within the acceptable limits (6-7.5%) for the beans to be stored safely.

There was no relationship between relative humidity of the storage environment and moisture content of dried cocoa beans kept as reference material in glass bottles. The results implied that the moisture content of dried beans kept in glass bottle was not influenced by the relative humidity. Any differences in magnitude of the moisture content of beans stored in glass bottle may be due to chance. However, cocoa beans will absorb moisture from its surrounding environment if the relative humidity in the environment increases. On the contrary, the beans will lose moisture to the environment if the relative humidity of the environment decreases (Wood and Lass, 1985).

The results also indicated that there was no correlation between relative humidity of the storage environment and FFA content of dried cocoa beans kept in jute sack bags. The results implied that the FFA content of cocoa beans kept in jute sack bags was not influenced by the relative humidity. Any differences in magnitude of the relative humidity of the beans stored in jute sack bags may be due to chance. However, as the relative humidity in a storage environment increases, cocoa beans absorb moisture from the surrounding environment thereby increasing the moisture content of the beans because cocoa beans are hygroscopic. Moisture content of cocoa beans exceeding 7.5% encourages the development of moulds

The metabolic activities of moulds 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). Mouldy beans therefore increase the free fatty acid content of the cocoa butter.

It is recommended that the free fatty acid content of dried cocoa beans should not exceed 1.75% (Dand, 1997). FFA content observed in beans kept in jute sack did not exceed the maximum level.

5.4 EFFECT OF TEMPERATURE AND RELATIVE HUMIDITY ON STORED DRIED COCOA BEANS

Cocoa beans are hygroscopic and absorb moisture under humid conditions until the beans reach equilibrium. Cocoa beans with moisture content higher than 8% will turn mouldy and such beans are in equilibrium at a relative humidity of 80-85%.

The relative humidity in cocoa stores should not exceed 80% for any length of time (Wood and Lass, 1985). Preferably, cocoa beans should have a moisture content of not more than 6%, in equilibrium with relative humidity of 65% at temperature of 30^{o}C.

During storage of the cocoa beans from December, 2014 to April, 2015 the relative humidity of the storage environment ranged from 54% to 62% whilst temperature ranged between 28^{o}C and 29^{o}C. This suggests that the optimum environmental conditions during the storage of dried cocoa beans were favourable.

The relatively low moisture content of the cocoa beans observed in this study could probably be attributed to the optimum storage environmental conditions that were met during the storage period.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The effect of packaging materials and storage periods on the physical and biochemical qualities of reference cocoa beans has been studied, and the following conclusions can be drawn from the results.

1. Packaging materials significantly affected quality of reference cocoa beans. The quality of the beans changes with duration of storage of the beans. The results from the current study revealed that the quality of reference beans kept in glass bottles degraded with increasing storage durations. Beans kept as reference materials in jute sack bags produced beans with physical and biochemical qualities that fall within the standard recommended physical appearance and biochemical parameters of a reference cocoa bean.

2. Storing beans for 60 days resulted in the best physical properties whilst beans stored for 90 days produced the most desirable biochemical quality.

3. Mean temperature and relative humidity did not correlate with biochemical characteristics of cocoa beans kept in the different packaging materials.

Overall, reference beans kept in jute sack bags and stored for 120 days produced the most physical and biochemically desirable qualities.

6.2 RECOMMENDATIONS

Based on the study the following recommendations are made:

- Further studies should be carried out on durations of fermentation and storage periods.
- To maintain quality to dispute any discrepancies in quality of beans shipped, reference beans should be stored in jute sacks but in dry cool conditions and protected from insects and dust.

REFERENCES

Afoakwa, E. O. (2006). Cocoa Production and Processing Technology. CRC Press p.248.

Afoakwa, E.O., Paterson, A. and Fowler, M. (2007). Factors influencing rheological and textural qualities in chocolate – a review. Trends in Food Science and Technology 18: 290-298.

Afoakwa, E. O. (2010) Chocolate Science and Technology. Wiley-Blackwell Publishers, Oxford UK p. 3-22.

Afoakwa, E. O., Quao, J.,Takrama, J., Budu, A. S. and Saalia, F. K. (2011a). Chemical Composition and Physical Quality Characteristics of Ghanaian Cocoa Beans as affected by Pulp Pre-Conditioning and Fermentation. *Journal of Food Science Technology*, *47*, (1), 1 – 11.

Afoakwa, E. O., Quao, J., Takrama, J., Budu, A. S. and Saalia, F. K. (2011b). Effect of pulp preconditioning on acidification, proteolysis, sugars and free fatty acids concentration during fermentation of cocoa (*Theobroma cacao*) beans. *International Journal of Food Sciences and Nutrition 62*, (7): 755–764.

Amoa-Awua, W. (2007a). Cocoa and Coffee Fermentation, CRC, Press. Taylor and Francis Group.

Aneani F, Takrama JF. (2006). The Microbiology of Cocoa Fermentation and its Role in Chocolate Quality. *Critical Reviews in Food Science and Nutrition* 44, 205–222.

Anonymous, (2000). A report on causes of recent decline in cocoa production in Ghana and measures to revamp the industry. Office of the President, Accra: pp. 103.

AOAC (2005). Official methods of analysis, Association of Official Analytical

Chemists, 18th ed., Washington, D.C USA.

Ardhana, M. M. and G. H. Fleet, (2003). The microbial ecology of cocoa beans fermentation in Indonesia. *International Journal Food Microbiol*ogy 86: 87-99.

Are, L. A., & Gwynne Jones, D. R. G. (1974). *Cacao in West Africa*. Oxford University Press.

Baker, D.M., K.I. Tomlins, and C. Gay (1994): Survey of Ghanaian cocoa farmer fermentation practices and their influence on cocoa flavour. *Food Chemistry,* 51, 425–431.

Beckett, S. T. (2009). Industrial Chocolate Manufacture and Use.4TH Ed. Blackwell Publishing Ltd, UK. Pp. 10 – 12, 20 – 28.

Belitz, H. D., Grosch, W., and Schieberle, P. (2009). *Food Chemistry* 4th Ed. Springer-Verlag, Berlin. 173, pp. 959 – 966.

Boateng D. O. (2012), insect science and crop protection strategies in the global world: cocoa quality control and grading.

Calderon, M., Navarro, S., (1980). Synergistic effect of CO_2 and O_2 mixture on stored grain insects. Pages 79-84. In: Controlled Atmosphere Storage of Grains. J. Shejbal, Ed. Elsevier, Amsterdam.

Cudjoe, A.R., Johnson, V., Wiafe, W.M., Opoku-Arneyaw, K., Ansah, F.O.,Gyasi, M., Bhat, R. J.F. Takrama, M. Assuah, F.Y. Asuamah, K. Holmes & D. Preece (2009): *Ghana Cocoa Farmers Newspaper*, Issue No. 5, Cocoa Research Institute of Ghana. July 2009.

Dahl, M.W. (2006). Development of a quality management system for the primary processing of cocoa. MSc thesis, Royal Veterinary and Agricultural University, Copenhagen, Denmark.

Dand (1997). The International Cocoa Trade. Oxford, UK: Wiley Publishers Inc.

De Bruin, T., Murali, V., 2006. Quality Preservation of Stored Cocoa Beans in the Tropics. (unpublished). GrainPro Document Number SL2299TB0905. GrainPro, Inc. Concord, MA USA.

Ellis,W.O.(1993). Effect of Modified Atmosphere packaging on the growth and Aflatoxic Production by Aspergillus flavus and Aspergillus parasificus under tropical environment storage conditions. Department of Food Science and Agriculture Chemistry. PhD Thesis.Mc Gill University, Montreal. pp. 287- 288.

Essien, W.A.J., 2004. Cocoa Storage in Ghana. In: Crop Post Harvest: Science and Technology, Hodges, R.J. and G. Farrell (Eds.). Blackwell Science Ltd., UK., pp: 274.

European Economic Community (1973). Directive 73/241/EEC by European Parliament and the European Council relating to cocoa and chocolate products intended for human consumption. Official Journal of the European Communities L 228 of 16/08/1973, pp. 0023-0035.

Fowler, M. S. (2009). Cocoa beans: From Tree to Factory. In: Industrial Chocolate manufacture and use. Fourth Edition. Beckett ST (eds) Wiley-Black Science, Oxford, UK. pp 137-152.

Garcia-Alamilla, P., Salgado-Cervantes, M. A. Barel, M., Berthomia, G., RodriguezJiminnes, Garcia-Alvarado, M. A. (2007). Moisture, acidity and temperature evolution during cacao drying, *Journal of Food Engineering*, 79: 1159-1165.

Gorkeh-Sekyim, K. (2011): Different steps that COCOBOD has put in place to monitor the quality of cocoa from the farm level to the port. (Presentation at Seminar for WCF and QCC officers, Accra. March, 2011).

Guehi, S. T., Dingkuhn, M., Cros, E., Fourny, G., Ratomahenina, R., Moulin, G. and Vidal, A. C. (2008). Impact of cocoa processing technologies in free fatty acids formation in stored raw cocoa beans. *African Journal of Agricultural Research* 3(3): 174–179. *Nutrition* 1-10.

Hiol A. (1999). Contribution à l'etude de deux lipases extra cellulaires issues de souches fongiquesisolées à partir du fruit de palme PhD Dissertation, Universitéd'Aix, Marseille, France.

ICCO (2011). ICCO document: Quarterly Bulletin of Cocoa Statistics, Vol. XXXVII, No. 4, Cocoa year 2010/2011. *International Cocoa Organization, London, U. K.*

International Office of Cocoa, Chocolate and Sugar Confectionery (IOCCC) Determination of free fatty acids (FFA) content of cocoa fat as a measure of cocoa nib acidity. *Analytical Methods*. 1996; 42: 130–136.

Lisboa, P., Ben-Yehoshua, S., Shapiro, B., Chein, J.E. and Lurie, S. (1983). *Mode of action of plastic films in ex-tending life of lemon and bell pepper fruits by alleviation of water stress*. Plant Physiology 73: 87–93.

Lopez, A.S., and Dimick, P. S. (1995). Cocoa fermentation In: Reed, G.,Nagodawithana, T.W.(Eds.), Enzymes, Biomass, Food and Feed. VCH, Weinheim, pp. 561–577.

Meir, S., Rosenberger, Y., Aharon, Z., Grienber, S. and Fallik, E.(1995). Improvement of the postharvest keeping quality and colour development of bell pepper by packaging with polyethylene bags at a reduced temperature. Postharvest Biology and Technology **5:** 303–309.

Mossu, G. (1992). *The Tropical Agriculturalist*. Chapter 6: Harvesting and preparation of Commercial cocoa. *The Macmillan press ltd.* London, United Kingdom.

Navarro, S., Calderon, M., 1980. Integrated approach to the use of controlled atmospheres for insect control in grain storage. Pages 73-78. in: Controlled Atmosphere Storage of Grains. J. Shejbal, Ed. Elsevier, Amsterdam.

Navarro, S., Donahaye, E., Dias, R., Jay, E., 1989. Integration of modified atmospheres for disinfestation of dried fruits. Final Scientific Report of Project No: I-1095-86, submitted to US-Israel Bi-national Agricultural Research and Development Fund (BARD) 86 pp.

Onwueme, I. C. and Sinha, T. D. (1991). *Field Crop Production in Tropical Africa* pp. 447- 450.

Opoku-Ameyaw, K., Baah, F., Gyedu-Akoto, E., Anchirinah, V. M., Dzahini-Obiatey, H., Cudjoe, A. R., Acquaye, S., and Opoku, S. Y. (2010). *Cocoa Manual. A Source Book for Sustainable Cocoa Production*. Cocoa Research Institute of Ghana.

Pontillon J. (1998). *Le beurre de cacao et les matieres grasses en chocolaterie. In: Pontillon J. (ed) Cacao, chocolat, production, utilisation, caracteristiques* (p326). *Techniques et documentation*, Lavoirsier, Paris, pp. 257-269.

Quarmine, W., Haagsma, R., Sakyi-Dawson, O., Asante, F., van Huis, A. and ObengOfori, D. (2012). Incentives for cocoa bean production in Ghana : Does quality matter ? Wageningen *Journal of Life Sciences*, 60-63 (2012) 7-14.

Selamat, J., Hamid, M. A., Mohamed, S. and Man, C. Y. (1996). Physical and chemical characteristics of Malaysian cocoa butter. In: Selamat, J., Lian, B. C., Lai, T. K., Ishak, W. R. W., and Mansor, M. (Eds.), Proceeding of the Malaysian international cocoa conference, Kuala Lumpur. pp. 351–357.

Sukha, D.A (2009). Primary processing of high quality Trinidad and Tobago cocoa beans - targets, problems, options. Proc. of Seminar/Exhibition on the revitalisation of the Trinidad and Tobago Cocoa Industry – Targets, Problems and Options. The Association of Professional Agricultural Scientists of Trinidad and Tobago (APASST), Faculty of Science and Agriculture, The University of the West Indies,St. Augustine, pp. 27-31.

Takrama, J.F. and Adomako, D. (1996): Raw Cocoa processing in Ghana. Cocoa Research Institute of Ghana, New Tafo. Ghana.

Takrama, J.F., Aculey, P.C., Aneani, F. (2006). Fermentation of cocoa with placenta: A scientific study.Posters presentation. Chemistry, technology and quality. *15th International Cocoa Research Conference.* Cocoa Research Institute of Ghana.

Thompson, S.S., Miller, K. B.and Lopez, A. S. (2001). Cocoa and coffee In: Doyle, M.P., Beuchat, L.R. and Montville, T.J. (Eds.), Food Microbiology Fundamentals and Frontiers. ASM Press, Washington, DC, pp. 837-850.

Wills R.B.H, Mcglasson, W.B, Graham. D., Lee, T.H. and Hall, E.G. (1989). *Postharvest: An Introduction to the Physiology and Handling of fruits and vegetables*. South China Printing Company Limited 3rd edn; pp. 170-190.

Wood, G.A.R. (1985). In Wood, G.A.R., Lass, R.A. 1985. *Cocoa*, 4th edn. Tropical Agriculture Series, Longman Scientific and Technical, Longman Group Ltd., Harlow, UK.

Wood, G. A. R. and R. A. Lass, (1985). Cocoa . 4th Edn., Longman Inc., New York.

APPENDICES

APPENDIX A: ANALYSIS OF VARIANCE (ANOVA) TABLES Appendix A1: Analysis of Variance Table for percentage (%) Deep purple beans

Source	DF	SS	MS	F	P
Packaging	3	231.599	77.1997	9.19	0.0001

Duration	4	53.188	13.2969	1.58	0.1976
Packaging*Duration	12	368.482	30.7068	3.66	0.0010
Error	40	336.013	8.4003		
Total	59	989.282			

Grand Mean 16.588 CV 17.47

Tukey HSD (p=0.05); Critical Value for Comparison
Packaging materials = 2.83, Storage Duration = NS
Packaging*Duration = 8.95

Appendix A2: Analysis of Variance Table for percentage (%) Pale purple beans

Source	**DF**	**SS**	**MS**	**F**	**P**
Packaging	3	16.979	5.65972	3.44	0.0257
Duration	4	36.407	9.10183	5.53	0.0012
Packaging*Duration	12	48.977	4.08139	2.48	0.0157
Error	40	65.833	1.64583		
Total	59	168.197			

Grand Mean 3.7650 CV 34.07

Tukey HSD (p=0.05); Critical Value for Comparison
Packaging materials = 1.25, Storage Duration = 1.49
Packaging*Duration = 3.96

Appendix A3: Analysis of Variance Table for percentage (%) Brown beans

Source	**DF**	**SS**	**MS**	**F**	**P**
Packaging	3	605.91	201.971	6.71	0.0009
Duration	4	856.53	214.132	7.11	0.0002
Packaging*Duration	12	888.25	74.021	2.46	0.0165
Error	40	1204.17	30.104		
Total	59	3554.87			

Grand Mean 76.830 CV 7.14

Tukey HSD (p=0.05); Critical Value for Comparison
Packaging materials = 5.37, Storage Duration = 6.39
Packaging*Duration = 16.95

Appendix A4: Analysis of Variance Table for pH

Source	DF	SS	MS	F	P
Packaging	3	1.20183	0.40061	150.23	0.0000
Duration	4	0.20267	0.05067	19.00	0.0000
Packaging*Duration	12	0.19733	0.01644	6.17	0.0000
Error	40	0.10667	0.00267		
Total	59	1.70850			

Grand Mean 5.0550 CV 1.02

Tukey HSD (*p*=0.01); Critical Value for Comparison
Packaging materials = 0.06, Storage Duration = 0.07
Packaging*Duration = 0.18

Appendix A5: Analysis of Variance Table for FFA

Source	DF	SS	MS	F	P
Packaging	3	1.1362	0.37872	3.06	0.0392
Duration	4	3.2380	0.80950	6.53	0.0004
Packaging*Duration	12	5.1357	0.42797	3.45	0.0015
Error	40	4.9549	0.12387		
Total	59	14.4647			

Grand Mean 1.9052 CV 18.47

Tukey HSD (*p*=0.01); Critical Value for Comparison
Packaging materials = NS, Storage Duration = 0.50
Packaging*Duration = 1.25

Appendix A6: Analysis of Variance Table for Fat

Source	DF	SS	MS	F	P
Packaging	3	404.61	134.870	8.22	0.0002
Duration	4	441.27	110.316	6.72	0.0003
Packaging*Duration	12	1136.96	94.747	5.77	0.0000
Error	40	656.69	16.417		
Total	59	2639.53			

Grand Mean 41.052   CV 9.87

Tukey HSD (*p*=0.01); Critical Value for Comparison
Packaging materials = 4.91, Storage Duration = 5.76
Packaging*Duration = 14.43

Appendix A7: Analysis of Variance Table for Moisture content

Source	DF	SS	MS	F	P
Packaging	3	2.8875	0.96250	2.77	0.0537
Duration	4	6.2813	1.57031	4.53	0.0041
Packaging*Duration	12	23.2687	1.93906	5.59	0.0000
Error	40	13.8750	0.34688		
Total	59	46.3125			

Grand Mean 5.8750 CV 10.02

Tukey HSD (*p*=0.01); Critical Value for Comparison
Packaging materials = NS, Storage Duration = 0.83
Packaging*Duration = 2.09

APPENDIX B: ANALYSIS OF VARIANCE (ANOVA) TABLES ON REGRESSION

Appendix B1: Analysis of Variance Table for Linear Regression of Moisture Content

Source	DF	SS	MS	F	P
Regression	1	0.50700	0.50700	0.65	0.4795
Residual	3	2.34500	0.78167		
Total	4	2.85200			

Cases Included 5   Missing Cases 0

Appendix B2: Analysis of Variance Table for Linear Regression of Moisture Content

Source	DF	SS	MS	F	P
Regression	1	0.33447	0.33447	0.40	0.5727
Residual	3	2.51753	0.83918		
Total	4	2.85200			
Lack of Fit	1	2.01753	2.01753	8.07	0.1048
Pure Error	2	0.50000	0.25000		

Cases Included 5   Missing Cases 0

Appendix B3: Analysis of Variance Table for Linear Regression of FFA

Source	DF	SS	MS	F	P
Regression	1	0.00931	0.00931	0.38	0.5815
Residual	3	0.07357	0.02452		
Total	4	0.08288			

APPENDIX C: STORAGE ENVIRONMENTAL DATA

Month	Mean Temperature (^oC)	Mean Relative Humidity (%)
December	29	62
January	29	62
February	28	55

March	29	54
April	28	54

Source: Field Data using Thermo-Hygro meter (EAI TMH – 250).