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DETERMINATION OF POSTHARVEST LOSSES IN COCOA (*Theobroma cacao*) FROM HARVEST TO THE DEPOT

BY

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DETERMINATION OF POSTHARVEST LOSSES IN COCOA (*Theobroma cacao*) FROM HARVEST TO THE DEPOT

A THESIS SUBMITTED TO THE SCHOOL OF RESEARCH AND GRADUATE STUDIES, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER OF PHILOSOPHY (MPhil. POSTHARVEST PHYSIOLOGY) DEGREE

BY

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DECLARATION

I hereby declare that this submission is my own work towards the award of MPhil Postharvest Physiology and that to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in text.

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DEDICATION

I dedicate this book to my parents, Dr. and Mrs. F.M. Amoah, and my siblings, Linda, Derrick and Dennis.

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ABSTRACT

Cocoa production is a major source of income that sustains the livelihood of millions of farmers and their dependants, contributes significantly to Ghana's GDP and avenue for foreign exchange earnings. Even though Ghana is a recognized leader in the cocoa industry, its cocoa production faces problems such as postharvest losses which are a major cause of concern to stakeholders. Unfortunately, available information on postharvest losses in cocoa in Ghana is very scanty. This makes it virtually impossible to carry out effective prevention measures. This study was therefore, conducted to assess causes, nature and identify major areas along the production chain where losses occur. The study also sought to examine the effect of fermentation method and number of days of fermentation on the quality and chemical properties of dried cocoa beans. Structured questionnaires were used to collect primary data from farmers to ascertain their perception on extent of postharvest losses on their farms. Field visits were carried out on cocoa farms in the Eastern Region including farms of Cocoa Research Institute of Ghana (CRIG) to qualitatively and quantitatively determine losses along the chain. Responses from the farmers indicated that the major causes of pre-harvest losses in cocoa were capsid attack, black pod attack and rodent infestation. Major postharvest losses occurred at the pod breaking stage and losses were mainly attributed to germinated and caked beans. As to how caked beans affected quality it was observed that they produced higher free fatty acid (8.4%) content and pH (6.8). The study showed that both CRIG and farmers' farms produced Grade 1 cocoa according to the standards of Quality Control Company (QCC) of Ghana Cocoa Board. Generally, fermenting beans for six days using the heap and basket fermentation methods resulted in Grade 1 cocoa and also produced beans with lower free fatty acids (0.41% and 0.58% respectively). Fermenting beans for six days using tray method produced the best (36.83mg/g) results of polyphenol content in dried beans. The study designed a model that could be used in estimating losses when the quantities of germinated and caked beans are known.

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CHAPTER ONE

1.0 INTRODUCTION

Cocoa, *Theobroma cacao*, is a small (4–8m tall) evergreen tree in the family *Sterculiaceae* (alternatively *Malvaceae*). The word "cocoa", *Theobroma* ("food of the gods") *cacao*, is derivative of "cacao". In order of annual production size, the eight largest cocoa-producing countries at present are Côte d'Ivoire, Ghana, Indonesia, Nigeria, Cameroon, Brazil, Ecuador and Malaysia (UNCTAD 2008). These countries represent 90% of world production. The demand for cocoa in the world market is said to be increasing and this is shown in the table:

Table 1. World Production of cocoa beans (2008 – 2011)(thousan

Country	2008/09		2009/2010 Estimates		2010/20 Forecas
Africa	2519.4	69.9%	2482.5	68.4%	3100.2
Cameroon	226.6		205.0		215.0
Cote d'Ivoire	1223.2		1242.3		1470.0
Ghana	662.4	18.4	632.0	17.4	1010.0
Nigeria	250.0		235.0		240.0
Others	157.2		168.2		165.2
America	485.4	13.5%	516.7	14.2%	536.1
Brazil	157.0		161.2		195.0
Ecuador	135.0		149.8		140.0
Others	193.4		205.7		200.1
Asia & Ocenia	597.7	16.6%	632.8	17.4%	559.0
Indonesia	490.0		550.0		470.0
Papua New Guinea	59.4		38.7		45.0
Others	48.3		44.1		44.0
World Total	3602.5		3632.0		4195.3

(Reference: ICCO Quarterly Bulletin of Cocoa Statistics. Vol. XXXV Year 2010/2011)

Immature cocoa pods have a variety of colors, but most often are green, red, or purple, and as they mature their colour changes to yellow or orange, particularly, in their creases (Hui, 2006). The ripe and near-ripe pods, as judged by their colour, are harvested from the trunk and branches of the cocoa tree with a curved knife on a long pole and care must be taken when harvesting. However, on several occasions, care is not taken when cutting the stem of the pod and this causes injury at the junction of the stem with the tree, as this is where future flowers and pods emerge. Cocoa beans are excessively bitter and astringent without the flavour of chocolate when processed, therefore there is the need to ferment the cocoa beans (Lopez and Dimick, 1995).The pods (or the seeds extracted from them) are transported to the area where beans are to be fermented. The beans are removed and subjected sequentially to fermentation and drying processes that are generally carried out at the farm level. Naturally, fresh beans with the surround mucilage are contaminated by a wide range of microorganisms from the pods surface, insects, hands of labourers, tools and containers used for opening of pods and fermentation of beans (Grimadldi, 1978). Climatic factors may influence the sequence of microorganisms involved in cocoa fermentation. After fermentation of the beans, during the process of drying, transportation and storage, there is a quantitative and qualitative loss in the beans.

Postharvest losses in cocoa are many and varied, ranging from losses due to diseases, rodent damage, unpicked pods, spillage, germinated and mouldy beans, but no quantitative estimation of these losses have been documented in the literature or by the Cocoa Research Institute of Ghana, hence there is the need to do a detailed evaluation, quantification and modeling of these losses. Despite the increasing demand of cocoa in the world market, the cocoa industry experiences postharvest losses during the various stages of the primary processing of cocoa.

Cocoa is a major source of income for many people in Ghana (Mingle, 2010). It is estimated that about eight hundred thousand farmer families are involved in cocoa production and about two million hectares of land is used in the cultivation of cocoa in Ghana. Also, according to Ghana Cocoa Board (1998), the livelihood of about six million people depends on cocoa. Ghana is the second highest producer of cocoa in the world. Cocoa produced in Ghana is considered premium and is used as the worlds standard.

Even though Ghana is a recognized leader in the cocoa industry, the industry faces myriads of problems. Important problems confronting the industry include diseases and postharvest concerns such as bad beans (i.e. caked beans, mouldy beans, purple beans, germinated beans and wet beans). Information on postharvest handling and losses are important in charting and informing policy direction for stakeholders in the cocoa industry.

Although, extensive reports are available on postharvest handling practices of cocoa in Ghana there is insufficient information on the postharvest losses in the cocoa industry. Postharvest losses along the cocoa production chain could be addressed if they are empirically estimated. This can be done if the losses that occur along the postharvest chain are identified and quantified.

This study will therefore seek to bridge the knowledge gap by providing empirical data on postharvest losses of cocoa in Ghana. In addition, it will enable government and stakeholders to plan to mitigate losses by putting in place strategic interventions that will reduce the losses and enhance the production target for cocoa. The model that will be generated in this study will help in estimating losses in cocoa producing areas in the Eastern region of Ghana.

The main objective of this study therefore was to assess the postharvest losses in cocoa from harvest to the sales depot. Specifically to;

- Determine farmer perception on pre-harvest and postharvest losses of cocoa.
- Identify the causes of losses in cocoa beans along the chain.
- Estimate quantitative and qualitative losses of cocoa along the production chain.

- Determine the effect of season of harvest and type of farm on the quality and chemical properties of dried cocoa beans.
- Develop a model to predict losses based on the loss factors identified.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin

The word ‘cocoa’ is derived from "cacao". The cocoa tree is believed to have originated from the Americas. It is said to have originated in the foothills of the Andes in the Amazon and Orinoco basins of South America and cultivated in the tropical regions of the world (Ardhana and Fleet, 2003).

However, it may have had a larger range in the past, evidence for which may be obscured because of its cultivation in these areas long before, as well as after, the Spanish arrived.

It was first cultivated by the Olmec at least 1500 BC in Central America. The cocoa tree was also introduced into the West Indies and the Philippines by the Spaniards. The Europeans also introduced it into West Africa and the rest of Asia. Commercial cocoa which is obtained from the beans originated as seeds from the ripe pods of the plant, *Theobroma cacao*, which is native to the Amazon region of South America.

2.2 Botany

Cocoa is typically known to be an evergreen tree. It is also an understory tree and could grow to a height of 25 meters. In its early life it develops as a vertical shoot with a single trunk and later branches at the jorquettes. The upright-growing shoots of the cocoa tree are called chupons. Cocoa trees exhibit a flushing-type growth habit, with two to four growths of flushes yearly. Leaves are short-lived for a tropical evergreen and generally drop after two flushes. Leaves have an average length of 0.1 to 0.2 meters and are 0.05 to 0.12 meters wide and glabrous, with entire margins and acute to acuminate tips. Leaves on new flushes are pink to red in colour and hang down vertically. The leaves of cocoa are alternate, entire and unlobed. Cocoa is extremely well adapted to shade and most often grown with an overstory tree crop.

Cocoa is cauliflorous, with its flowers arising on old wood at the site of a former leaf, called a “cushion”. Usually flowers are produced in clusters directly on the trunk and on older branches; and are small with in diameter (0.01–0.02m), with pink calyx. Whilst many of the world's flowers might be pollinated by several insect groups, the flowers of cocoa are mainly pollinated by midges (Hernández, 1965). The cocoa pod is ovoid in shape, with a length and width of about 0.15–0.3m and 0.08–0.01m respectively, ripening from yellow to orange. The pod contains about 20 to 60 beans, embedded in a white pulp.

The beans are the main ingredient used in chocolate processing, while the pulp is used to prepare juice in some countries. Each seed contains a significant amount of fat (40–50%) and the fruits are either red or yellow at maturity, mature year-round, and are self-thinning.

2.3 Varieties

Generally, there are three varieties of cocoa namely criollo, forastero and trinitario.

Criollo *(T. cacao var. cacao):* The word *criollo* means “native”, as it is distributed from southern Mexico to South America, north and west of the Andes. The fruits are oblong to ovoid in shape, tapering to a point and have five or ten longitudinal ridges. Seeds have yellowish white cotyledons.

Forastero *(T. cacao var. sphaerocarpum)*: The word *forastero* means “foreign”, as it was introduced to Mesoamerica from the Amazon basin. The fruits are ellipsoid to round in shape, lacking a pointed tip, and may be furrowed but have a smooth surface. The seeds have violet cotyledons. Forasteros are considered to have inferior quality despite the fact that they are higher yielding and more vigorous than criollos. About 80 to 90 percent of global cocoa production is based on the forastero, due to its superior yield, vigour, and disease resistance. ‘Amelonado’ which is the major West African cultivar, was until recently the predominant type grown worldwide

Trinitario: These are hybrids of criollo and forastero forms, which originated in Trinidad, and are sometimes classified as a subgroup of the forasteros. Since they are hybrids, they are highly variable in seed, unless the seed is derived from known crosses. The seed quality is intermediate between that of the criollos and the forasteros.

(Rieger, 2012)

2.4 Ecology

About 70% of the world cocoa is cultivated in West Africa. Cocoa trees are found to grow in a limited geographical zone, (approximately between latitudes 20º to the north and south of the Equator) and require a good well drained soil to sustain its growth. Soils required for growth usually have a neutral to very slightly acid pH balance.

Cocoa trees are also tropical trees grow best at altitudes with between 0 to 3,000 feet above sea level. Because cocoa has a small stature, it typically grows in the shade of the larger canopy trees of the rainforests. Cocoa is sometimes referred to by ecologist as an understory tree because it exists in the shade of taller trees. This may account for why young cocoa trees require shade for their growth.

2.5 Uses and nutritional values

Cocoa contains a high level of flavonoids, specifically epicatechin, which is reported to have beneficial cardiovascular effects on health. Prolonged intake of flavanol-rich cocoa has been linked to cardiovascular health benefits, (Schroeter *et al.;* 2006, Taubert *et al.;* 2007) though it should be noted that this refers to raw cocoa and to a lesser extent, dark chocolate, since flavonoids degrade during cooking and alkalizing processes (BBC news,2007). It is believed also that the consumption of flavanol-rich cocoa improves blood flow and this may help to achieve health benefits in hearts and other organs. Foods rich in cocoa appear to also reduce blood pressure (Taubert *et al*, 2007). In particular, the benefits extend to the brain and have important implications for learning and memory (Bayard *et al*, 2007). Cocoa is used primarily in making pebbles, chocolate and cocoa powder. Also, wines, soaps and creams are obtained from cocoa sweatings and butter when they are processed. The husk is also burnt and processed into potash used in making a local soap called “alata samina”.

2.6 Production

Cocoa is grown in West, Central and East Africa, Central and South America, and Asia. The eight largest cocoa producing countries are presently Côte d'Ivoire, Ghana, Indonesia, Nigeria, Cameroon, Brazil, Ecuador and Malaysia (UNCTAD 2008). These countries represent 90% of world production. In the early 1970s production was concentrated on Ghana, Nigeria, Côte d'Ivoire and Brazil, but it has now expanded to areas such as the Pacific region, where countries like Indonesia have shown spectacular growth rates in production. In Ghana cocoa is grown in Eastern, Ashanti, Brong-Ahafo, Central, Western North and Western South regions.

2.7 Pre-harvest activities

2.7.1 Land preparation

Cocoa requires suitable land, with climatic conditions and specific soil conditions in order to obtain better growth and production. The soil used in cultivation of cocoa usually has the capacity to hold water, is well aerated and has good drainage ability. The soil pH should also be about 6-7 and be high in nutrients. Temperature affects the formation of a flushes and flowers, and causes leaf damage hence a favourable temperature is required. Shade is also provided for seedlings planted and planting is done early in the morning with the required spacing. An initial shading of about 70% is considered ambient for the growth and development of young plants and this is gradually reduced to approximately 25% for plants over 5 years old (CRC , 2004).

2.7.2 Planting of seedlings

The most commonly used planting materials are the beans which are obtained from healthy cocoa pods. Seeds are nursed in a nursery which is usually sited near a water source. Seeds are either sown on nursery beds or in poly bags containing fertile soil. In order to prevent seedlings from drying out and also to protect them against heavy rains and direct sunlight it is necessary to provide shade for the seedlings. Seedlings are watered twice in a day and are raised in the nursery for about 3-6 months before transplanting. The recommended planting distance is 3m x 3m. Care is usually taken during transplanting to avoid damage of seedling.

2.7.3 Cultural practices

The length of time that a cocoa farm remains productive and financially viable is determined by, the application of good maintenance practices, in particular pest and disease control (ICCO, 2008). Cultural (good agricultural) practices in cocoa towards increased production include weeding, pruning, thinning, mistletoe removal, removal of infected pods, spraying among other things. It is therefore important to maintain a high standard of farm management to prevent diseases and insect attacks, as well as to ensure an appropriate response to specific outbreaks when they do occur (ICCO, 2008).

The presence of weeds surrounding the cocoa trees minimizes its growth since it provides an environment that favours the establishment and spread of diseases such as the black pod disease. It is therefore necessary to adopt weed control measures to keep the cocoa farms free from weeds. Weeds are controlled either manually by the use of cutlasses or chemically by spraying with herbicides.

Pruning is also an important cultural practice to be carried out on cocoa trees since it can affect yield, as well as the shape and structure of the tree. Pruning also helps to reduce the attack of insects and diseases on the cocoa tree since insects and diseases multiply more on un-pruned cocoa trees with dense canopies. Pruning can be carried out properly by using good tools such as bow saw, secateurs, a chupon knife and a long-handle pruner (ICCO, 2008).

It is also necessary to apply fungicides and insecticides periodically to reduce the attack of pest and diseases. The attack of pest and diseases on the cocoa pods causes an increase the rate at which losses occur.

2.8 Pest and diseases

2.8.1 Pest

Cocoa pest can be classified as either major or minor. There are a number of pests that attack cocoa and these include mirids (capsids), stem borers, shield bugs, leaf defoliators, pod bearers, rodents and termites.

Mirids, also known as capsids, are major pests that affect cocoa in Ghana. These insects pierce the surface of cocoa stems, branches and pods using their needle-like mouthpart and also suck the sap of the cocoa tree. In the process of sucking, they inject toxic spit into the plant and this causes the dying of internal cocoa tissues. (Boateng, 2011).There are four species found on cocoa but the most common types found in Ghana are *Distantiella theobroma* (black capsid) and *Sahlbergella singularis* (brown capsid). *Helopeltis species* (cocoa mosquito) and *Bryocoropsis species* are less important, except in instances of occasional localized outbreaks. They attack crops from the establishment stage.

Stem borers are now a very seriously and widespread pest in Ghana (Adu-Acheampong *et al*; 2001). They are considered to be an emerging pest of cocoa in Ghana. Losses from this insect are usually low but a high number can seriously affect yield and tree health.

The shield bugs (*Bathycoelia thalassina)* are insects that feed on cocoa pods. They pierce the pod husk with their mouth parts and suck out the sap of the beans. As a result young pods turn yellow and then black, large pods stop growing and becomes yellow (Boateng, 2011). When the sap is sucked from the pods, the beans remain caked in the pods thereby making it difficult to remove and this contributes to postharvest losses.

The leaf defoliators are the most common insects that feed on soft leaves of cocoa. When they feed on the leaves, they prevent them from receiving adequate sunlight, which aids in the process of photosynthesis.

Cocoa pod borer attacks both young and matured pods. A common symptom of infested pods is unevenness and premature ripening. Infestation of young pods results in heavy losses because the quantity and quality of the bean becomes seriously affected (COPAL, 2011).

Rodents that attack cocoa include mice, rats and squirrels. They chew the cocoa husk and feed on the beans within the pods. Rodents are mostly found in farms with a lot of overhead shade trees and farms that are not well maintained, such as those with lots of undergrowth which provides hiding places for them.

Termites may live either in the canopy or in the underground. They attack seedlings or young trees at the base and this makes the trees wilt and die when not controlled. The damage also extends to suckers of full-grown trees. In full-grown trees, some types of termites attack injured and dead wood, whist other types chew into the roots and tunnel up into the branch. Termites can attack living cocoa wood by chewing the wood, and this causes openings for diseases such as the stem canker. (Boateng, 2011)

2.8.2 Diseases

Disease is one of the major reasons for loss of cocoa production in the world .A list of these diseases includes black pod, swollen shoot, witches broom, frosty pod rot and vascular steak dieback.

Cocoa Swollen Shoot Virus (CSSV) Disease still poses a serious threat to Ghana's cocoa industry. The disease has caused enormous devastation of cocoa farms in Ghana since its discovery in 1936 and over 200 million visibly infected and 'contact' trees have been cut out from about 130,000 hectares of land during the past fifty (50) years as control measure (Ampofo, 1997). The swollen shoot disease is an infectious virus disease which spreads in cocoa farms if not controlled early, and also affects cocoa trees causing defoliation, reduction in yield and death of the cocoa tree. It also causes swellings on the chupons and fan branches of the cocoa tree.

Black pod disease is caused by the fungus *Phytophthora* species. Pod losses due to Black pod diseases are 4.9-19% in infections caused by *Phytophthora palmivora* and 60-100% when caused by *Phytophthora megakarya.* Generally, losses due to *P. megakarya* range from 60-80% in newly affected farms to about 100% in old affected farms in the black pod season (Opoku, 2004). The black pod disease results in the browning, blackening and rotting of cocoa pods and beans (Boateng , 2011).

Witches broom disease which is a fungal disease, attacks actively growing tissues such as the shoots, pods and flowers, causing cocoa trees to produce branches with no fruits and ineffective leaves The pods show distortion and present green patches that give the appearance of uneven ripening.(COPAL, 2011).

Frosty pod rot infects only actively growing pod tissues, especially young pods. The time from infection to the appearance of symptoms is about 1-3 months. The most outstanding symptom is the white fungal mat on the pod surface (COPAL, 2011).

'Chlorosis' of a leaf on the second or third flushes behind the tip is the initial characteristic symptom of the vascular- streak dieback disease. The fungus may spread internally to other branches or the trunk, usually causing death of the tree. When an infected leaf falls during the rainy season, hyphea may emerge from the leaf scar and develop into a basidiocarp, evident as a white, flat, velvety coating over the leaf scar and adjacent bark (COPAL, 2011).

2.9 Postharvest activities

2.9.1 Harvesting

Cocoa pods are harvested regularly to prevent pods from becoming over-ripe. During harvesting, only ripe and matured pods are picked. Unripe pods cannot undergo the fermentation process, and over ripe pods also often become dry (Barclays Bank 1970). Diseased and damaged pods are also discarded and not included in the harvest. The ripe pods are judged by their colour and are harvested using harvesting hooks. It is necessary to use sharp harvesting tools, in order not to cause damage to the cushions of the tree (Mikkelsen, 2010). Damaging the cushions serve as a potential point of entry for fungi. Care is taken when cutting the stem of the pod to avoid injuring the junction of the stem with the tree, as this is where future flowers and pods will emerge (Dand, 1999; wood and lass, 2001). While harvesting, the farmer may spread fungal diseases from contamination by the hook or knife (Vos *et al.,* 2003). Different harvesting equipment should therefore be used to remove diseased pods from the tree in order to help prevent the spread of the disease. Also when pods are left too long on trees, beans start to germinate and this affects the quality and flavour of the cocoa after fermenting and drying.

2.9.2 Pod breaking

Pods should not be opened more than six days after harvesting (Are and Gwynne-Jones, 1974; Mossu, 1992). Harvested pods should be kept for about three days before breaking. Pods are usually opened using a cutlass, however, care is taken in order not to cut beans since this affects their quality after fermenting and drying. During pod breaking, beans that are caked in pods, germinated beans and wet beans are sorted out and dried separately. Also placental materials are also removed.

2.9.3 Fermentation

Cocoa beans are excessively bitter and astringent without the flavour of chocolate when processed; hence cocoa beans need to be fermented (Lopez and Dimick, 1995). Fermentation is brought about by micro-organisms. The most prominent ones are the yeast and the acetic acid bacteria. During this process, the yeast converts the sugar (i.e. the pulp surrounding the beans which is sugary) into alcohol and the acetic acid bacteria converts alcohol into acetic acid. During this reaction, a lot of heat is generated and this kills the living cells in the beans including the eye which would have germinated.

There are several methods used in fermenting cocoa beans and these include the heap, basket, tray and box fermentation methods. Cocoa beans are fermented in order to:

- Kill the embryo and stop germination.

- Remove pulp to enable beans dry properly.
- Get the proper taste, colour and flavour associated with cocoa products

Beans are fermented for a six days depending on the fermentation method used. With the exception of the tray fermentation method, beans are turned every two days (i.e. using the box, heap and basket method) until fermentation is complete.

Basket fermentation is usually used when beans are in smaller volumes. Before the fermentation begins, the sides of the basket are lined with banana leaves, but the bottom remains uncovered to let the sweating drain away easily. The basket is mounted on a board. Beans are then poured into the basket and covered with banana leaves. Short sticks are placed on the leaves to support them and hold them in place.

Heap fermentation is mostly used by farmers because it is a cheap method that produces well fermented beans, when it is done properly (Are & Gwynne-Jones, 1974). With this method, short sticks are arranged in a circular form on the ground with banana leaves placed on them to overlap each other. The sticks are used to raise the centre to enhance easy drainage of the sweating. Beans are poured in the centre and covered with banana leaves. This is supported by placing short sticks on them from behind.

Tray fermentation is done by arranging the trays in stack on a slab. The bottom tray is placed on a slab to avoid the ground absorbing the produced heat, to allow the sweating to drain away, and to promote air circulation. The trays are stacked in piles, 3 - 12 trays high since less than three trays will not produce enough heat. The top tray is covered with banana leaves and supported with short sticks placed on them. No turning is done with this fermentation method and beans are fermented for five days.

Finally, with the box fermentation method, boxes are arranged in a form of tiers (3 tiers). The beans to be fermented is put in the uppermost box and covered with banana leaves with pieces of wood placed on them to hold them in place. After two days of fermentation, the beans is scraped into the second box in a horizontal pattern and covered again with banana leaves. On the fourth day, beans are scraped again into the third box which is the last box in a vertical pattern and covered. On the sixth day, beans are sun dried.

Figure 2.1: Basket fermentation **Figure 2.2:** Heap fermentation

Figure 2.3: Tray fermentation **Figure 2.4:** Box fermentation

2.9.4 Drying

After fermentation, the water content of the beans is about 60 %, and it must be reduced to less than 7.5% during drying to avoid spontaneous mould and bacterial growth under storage and transport (Takrama and Adomako, 1996). Drying of beans takes a period of about 10 -14 days depending on the atmospheric conditions and volume of beans per square area on drying mat. Well dried beans will crack easily when squeezed between the fingers and can easily be cut with a knife (Amoa-Awua *et al*., 2006). Methods of drying cocoa beans are usually either by sun-drying or artificial drying.

Sun drying is the natural means of drying beans in the sun on raffia mats. It is simple and cheap but it is also labour-intensive and there is much concern for a stable weather condition. The mats are placed on a raised platform to protect the cocoa beans against animals and foreign materials. There is also the frequent stirring of beans on mat to facilitate drying. At night and whenever the rain comes, the mats should be rolled up (Are and Gwynne-Jones, 1974: Mossu, 1992).

Artificial dryers include the use of ovens in drying cocoa beans. The beans are spread in trays, allowing the air to permeate through a ladder system (Mossu, 1992). Using this method, it is very important that the cocoa beans are not contaminated with smoke from the fire, since dry beans easily absorb flavours and aromas from the environment (Barclays Bank, 1970).

2.9.5 Storage

After the beans have been completely dried, they are bagged and stored in jute sacks under favourable weather conditions. Old sacks are usually not used because of the weevil attack. Beans are then transported to individual buyers or buying companies.

2.9.6 Warehouse storage

Bags of dried cocoa beans are stored in the warehouse in stacks. The roofs of the warehouse should also not have any signs of leakage. The temperature in the warehouse is made favourable to enable proper storage of beans. The warehouse is fumigated prior to evacuation and shipment regularly in order to control insect pests. Bags may be covered with polyethylene during storage. However, bags are not stored in the warehouse for very long period of time since they may be attacked by weevils.

2.10 Postharvest losses in cocoa

Postharvest losses in cocoa are many and may include losses due to diseases, rodent damage, unpicked pods, spillage, germinated and mouldy beans. During the process of harvesting, some of the cocoa pods may fall on the ground and these are collected later on by the farmers. However, in situations where the farmers' farms are covered with bushes, to the extent that the fallen pods cannot be noticed, the farmers loose these pods to the ground.

Losses could also be due to unharvested pods which may be higher up in the canopy outside the reach of the farmer. These pods are eventually attacked by rodents, insects, as well as certain diseases thereby contributing to post harvest losses.

Harvested pods are broken in order to remove the good beans. However during the stage of pod breaking, some bad beans such as germinated, caked, black and wet beans are sorted out. During the process of sun drying, germinated beans as well as other bad beans such as mouldy beans, purple beans, and slaty beans are sorted out. The germinated beans have their embryo attached to them and when the embryo is removed, it creates a hole which serves as an entry for pathogens hence such beans must be sorted out. Some of the beans also fall from the mat and remain unnoticed to the farmers and all these contribute to post harvest losses.

Figure 2.5: Postharvest losses caused

Figure 2.6: Postharvest losses caused

by Black Pod Disease

by rodent damage

Figure 2.7: Postharvest losses caused by seed germination

Figure 2.8: Postharvest losses caused by caked beans

2.11 Chemical, Biochemical and Polyphenolic compounds in cocoa beans

2.11.1 Carbohydrates

Carbohydrates are a class of natural organic substance which includes sugars, starch and cellulose. Total sugars comprise of sucrose, fructose, glucose, mannitol and inositol. Unfermented beans contain up to 2% sucrose and almost all the sucrose is hydrolyzed by native cocoa seed invertase into the reducing sugars glucose and fructose (Hensen *et al.*, 1998).

The sucrose concentration of the unfermented beans generally comprised about 90% of the total sugars (2.4-8.0%), whereas both fructose and glucose made up to 6%, other sugars were found to be less than 4% (Berbert, 1979).

2.11.2 Proteins

There are two types of proteins in cocoa namely albumin and globulin and these are usually classified according to their solubility and electrophoretic mobility. Proteins are a significant component of cocoa beans, both in quantity (1.5%-2.0%) and their role in the development of flavour precursors (Wright *et al.,* 1982).

2.11.3 Fat

Cocoa bean has a high fat content of about 45-55%. The variation in the fatty acid composition of triacylglycerides in cocoa beans may be caused by ambient temperatures at which cocoa beans are grown. Other factors that may affect the composition may 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 limiting (Quao, 2010).

2.11.4 Polyphenols

Cocoa is rich in polyphenols, specifically catechins (flavan-3-ols) and procyanidins, stored in cotyledon pigment cells and cocoa leaves (Osman *et al*., 2004). Nazaruddin *et al*. (2001) reported total polyphenols ranged from 45 to 52 mg/g in cocoa liquor, 34 to 60 in beans and 20 to 62 in powder: epicatechin contents were 2.53, 4.61 and 3.81 mg/g, respectively. Polyphenols have bitter, astringent flavours and their antioxidant properties help protect the seed from damage and disease (Kim and Keeney, 1984; Kyi *et al.,* 2005).

2.11.5 Organic acids

Organic acids found in cocoa beans are both volatile and non-volatile acids. The volatile acids which include acetic, propionic, butyric, isobutyric and isovaleric acids are affected when the bean is roasted. The non-volatile acids are oxalic, citric, malic, succinic, lactic and tartaric. These acids are usually formed during the process of fermentation (AFJ, 1994).

2.12 Quality of cocoa

2.12.1 Quality parameters

The quality of cocoa beans exported is an important factor to consider in the cocoa industry since this will affect the quality of the final product. Dried Cocoa beans should be of good quality and free from all forms of off flavours and defectiveness. Defectiveness among cocoa beans includes flat, mouldy and geminated beans (Are and Gwynne-Jones, 1974). Off flavours in dried cocoa beans also include mouldy and smoky flavours. In other to produce good quality chocolate, it is necessary that the dried cocoa beans should not be excessively acidic, bitter or astringent, have a free acid content of less than 1%, moisture content should also be between 6-8 % and beans must be free from live insects, foreign objects, pest residue and harmful bacteria (Amoa- Awua *et al.*,2006). The quality of cocoa can be determined physically by performing a cut test on the dried cocoa beans.

2.12.2 Cut test

The cut test is a physical analysis performed on the dried cocoa beans to assess their quality. Before this is performed, it is necessary that, the cocoa beans are:

- Properly fermented and completely dried.
- Uniform in size and shape
- Free from broken beans, fragments and small pieces

- Free from foreign materials
- Free from beans of abnormal odour or flavor
- Free from admixture of any other seeds and impurities
- Have a moisture content of 6 – 7%. Beans become mouldy when their moisture content is over 8% and brittle when their moisture content falls below 5%.

(Boateng, 2012)

The cut test is performed on 300 beans of cocoa in every given sample. In the determination, beans are cut lengthwise through the middle, in order to expose the maximum cut surface of cotyledons. After cutting the beans lengthwise, the beans are placed on a white board to be examined and graded. Beans are examined for any form of defect.

Listed below are some defects of cocoa beans:

- Mouldy Bean: A bean on the internal parts of which mould is visible to the naked eye.
- Slaty Bean: A bean which shows a grey or purple colour over half or more of the surface exposed.
- Insect Damage Bean: Beans that have internal parts of which contains insects at any stage of development, or have been attacked by insects which have caused damage visible to the naked eye.
- Germinated Bean: A bean in which the shell of which has been pierced, slit or broken by the growth of the seed germ.
- Flat Bean: A bean of which the two cotyledons are so thin that it is not possible to obtain a cotyledon surface by cutting.

- 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.
- Fragment: A piece of bean equal to or less than half the original bean.
- Black bean: Bean which is black in appearance.
- Decayed or rotten beans: cocoa beans which appears to be decayed.
- Cocoa cluster: cocoa beans which have formed clusters.

(Boateng, 2012)

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

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 (Boateng,2012).

GRADE II: This describes cocoa which is thoroughly dry, free from foreign matter, smoky beans and evidence of adulteration, and 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(Boateng,2012).

SUB GRADE: These are cocoa which fail to reach the standard of Grade II. Sub Grade cocoa is usually not purchased by the Ghana Cocoa Board but only Grades I and II cocoa are purchased at the full prices (Boateng, 2012).

2.12.3 Free fatty acid

In order to produce good quality chocolate, the free fatty acid content of the dried cocoa beans to be processed should be less than 1%. The free fatty acid content in cocoa usually becomes higher (i.e. >1%) if the cocoa is stored improperly for a long period of time. The activity of bacteria or mould could also be a factor that can cause an increase in the free fatty acid content in cocoa since the enzyme lipase acts on the beans by breaking down the triglyceride into separate groups of fatty acids. The final product produces a rancid flavor if the free fatty acid present is in significant amount.

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1. Experimental location

The research was carried out in the East Akim District in the Eastern Region of Ghana. The field studies were carried out on farmer fields and Cocoa Research Institute of Ghana (CRIG) fields. The farmer fields selected included fields from Akooko, Nobi, Ohenenkwanta, Kwasiaku, Bosomponso No.1, Oguaa, Sakodie Juaso, Mampong-Akuapem and Adonkwanta. The C.R.I.G. fields also served as the control.

The laboratory analysis of the cocoa samples for free fatty acids, total sugars, total polyphenols and proteins were conducted in the physiology/biochemistry laboratory of the Cocoa Research Institute of Ghana, New Tafo-Akim.

3.2 Questionnaire administration

A total number of fifty (50) questionnaires were administered to farmers in towns in the East Akim district. The questionnaires administered were to find out the sources, causes and extent of postharvest losses in cocoa production system.

3.3 Experiments

Three experiments were conducted and physical, chemical, biochemical and physico-chemical analysis were also performed on the dried cocoa beans. The experimental procedures under the different experiments are as described below.

3.3.1 Experiment 1

Determination of postharvest losses in cocoa from harvest through to the depot

The total number of pods at each harvest on each farm was recorded and the quantity of good pods was separated from the bad pods. During the process of pod breaking, bad pods (i.e. black pods, rodent damaged pods and immature ripe pods) as well as pods which contained bad beans (i.e. germinated beans, wet beans and caked beans) were separated from the good pods.

The good beans obtained from the good pods were weighed and the wet weight determined. Beans were fermented for six days or four days depending on the method of fermentation (i.e. Tray, basket, box or heap), after which beans were sun dried on raffia mat. The cocoa beans were sun dried for about fourteen days depending on the weather conditions. The dried beans were weighed and the dry weight determined after which beans were bagged and sold.

The control experiment was done by selecting a number of good and healthy pods only, depending on the harvest obtained. The pods were broken and the beans obtained from these pods weighed. The beans were fermented for six days after which they were sun dried.

Experimental design

A 2 x 2 factorial design in a completely randomized design with four treatments was used. There were two factors and each factor had two levels. Factor 'A' comprised the cocoa seasons (i.e., major and minor seasons) and factor 'B', cocoa farms where data was taken (i.e., CRIG and farmer farms).

3.3.2 Experiment 2

Determination of the effect of number of days of fermentation of cocoa using the heap, tray and basket method of fermentation

The research was carried out at the Cocoa Research Institute of Ghana (C.R.I.G.). The methods of fermentation are described below:

3.3.2.1. Basket fermentation

A total of four baskets of equal sizes were used. The sides of the baskets were lined with banana leaves and each of these baskets was filled with cocoa beans which weighed 25kg. The baskets were arranged on a slab to facilitate easy drainage of the sweating and were also covered with banana leaves with short sticks placed on them to prevent easy penetration of air and also to allow proper fermentation of the cocoa beans. In order to maintain a uniform temperature within the beans, beans were turned on the second day of fermentation after which they were covered again. The beans were allowed to ferment for 3, 4, 6 and 7 days and on each of these days, a basket (containing 25kg cocoa beans) was emptied on a separate raffia mat and sun dried.

3.3.2.2. Heap fermentation

The total weight of beans used was 200kg and four heaps were used. Each heap was created by arranging leaves of banana closely in a circular pattern. Short sticks were also arranged underneath the banana leaves but in the centre to raise the heap to facilitate easy drainage of the sweating. Each heap was filled with cocoa beans which weighed 50kg and beans were poured in the centre of each heap and covered very well to prevent the entry of air.

Short sticks were also placed on the heap after covering to prevent the heap from opening up thereby allowing the entry of air. In order to maintain the temperature and also to enable beans ferment properly, beans were turned on the second day of fermentation and covered again. Fermentation was done for 3, 4, 6 and 7 days and on each of these days, a heap of beans was sun dried on a raffia mat.

3.3.2.3. Tray fermentation

The total weight of beans which were used for the tray fermentation was 400kg and four different trays were used with each tray filled with cocoa beans weighing 100kg. The lower tray was placed on a wooden platform, about 30 cm high. The bottom tray was placed on a wooden platform to allow the sweating to drain away, and to promote air circulation. The cocoa beans were poured into the first tray and distributed evenly before the next tray was positioned on top. Same procedure was repeated till the stack was four trays high. The trays were filled so the surface of the cocoa beans was higher than tray level. The top tray was covered with banana leaves and held in place by sticks. Beans were allowed to ferment for 3, 4, 6 and 7 days and on each of these days, a tray was removed. The cocoa beans were sun dried on a raffia mat.

Experimental design

A 3 x 4 factorial design in a completely randomized design was used. There were two factors. Factor 'A' had three levels (i.e. basket, heap and tray method of fermentation) and factor 'B', four levels (i.e. 3,4,6,7 days of fermentation).There were twelve treatments and three replicates for this experiment.

3.3.3 Experiment 3

Determination of postharvest losses associated with caked beans of cocoa using the basket fermentation method

Cocoa pods which contained caked beans were gathered and left for three days. This was because; the beans could not be removed from the pods immediately. On the third day, beans were removed from the pods and allowed to ferment. The basket fermentation method was used and baskets were of the same sizes. The sides of the two baskets were lined with banana leaves and each of these baskets was filled with the caked beans which weighed 25kg. The baskets were arranged on a slab and were also covered with banana leaves and short sticks were placed on them to give support. The beans were allowed to ferment for 4 days after which they were poured on a raffia mat and sun dried. A control experiment was also set up. In the control only good pods which contained only good beans was used.

Experimental design

A completely randomized design was used. The experiment had two treatments and three replicates.

3.5 Laboratory Analysis

3.5.1 Biochemical and physico- chemical analysis

3.5.1.1 pH determination

The pH was determined on dried cocoa beans and these included samples from three farmer fields. About 50g of dried cocoa beans was weighed from each sample. Each of these beans was peeled, blended and bagged using different sample bags. Ten grams (10g) of each blended sample was put in different conical flasks and 90ml of boiling distilled water added. Samples were allowed to cool in a cold room to a temperature of about 20ºC and the pH readings were taken using the pH meter. Each sample was replicated three times.

3.5.1.2 Free fatty acids determination

Fat was extracted from the cocoa bean samples with petroleum ether (60ºC -80 ºC) using a Soxhlet apparatus. Melted fat samples (5g) were weighed into a 250ml conical flask and 25ml of Diethyl Ether added to the weighed sample. The sample was swirled to mix and titrated against 0.1M KOH with phenolphthalein as indicator till a faint pink colour was obtained.

Figure 3.1: Soxhlet apparatus

3.5.2 Chemical Analysis

3.5.2.1 Total Sugars determination

The Dubois method (Dubois *et al.*,1979) was used in the determination of the total carbohydrates in the cocoa samples. Blended cocoa sample (0.5g) was weighed into a round bottle flask. The sample was allowed to boil in 30ml of 80% ethanol under reflux for 30 minutes in the soxhlet apparatus. After the first 30 minutes of reflux, more of the 30ml of 80% ethanol was added to the residue and heating continued under reflux for further 30 mins to remove supernatant. This was repeated three times. The ethanol was evaporated from the supernatant under reduced pressure using the rotary evaporator. The extract was de-proteinized with 10ml of 5% zinc sulphate and 9.3ml of 0.3N barium hydroxide and filtered. This was then de-ionized with chlorine and sodium resins for soluble sugars.

In the acid digest determination, 25ml of 1.5N sulphuric acid was added to the residue remained after the soluble extraction and digested under reflux for one hour using the same extraction mantle. The extract was neutralized with barium carbonate and centrifuged at high speed to remove any precipitate. The supernatant was filtered and de-proteinized and de-ionized as mentioned above for the soluble extract. The final volumes of both the soluble and insoluble extracts were recorded and the absorbance determined using the spectrophotometer.

Absorbance Determination

The final soluble extract (0.5ml) was taken and diluted with 0.5ml of distilled water and 0.2ml of the final acid extract, diluted with 0.8ml of water. 1ml of 10% phenol and 5ml of concentrated sulphuric acid was added to each extract (soluble and acid) and shaken till an orange colour was developed which is an indication of the presence of sugar. The resulting solution was allowed to cool down for a while and a measured amount was poured into a cuvette (a small transparent rectangular test tube) and placed in the spectrophotometer to be read at the absorbance of 490nm.

3.5.2.2 Proteins determination

This determination was done using the Kjeldahl method. Three stages were involved: digestion, neutralization and titration stage. Each of the blended cocoa samples (0.5g) to be analyzed was weighed into a digestion flask and 0.5g of the catalyst (a mixture of 0.2g Selenium + 5g K_2SO_4 + 1g $Cuso_4$) added. Sulphuric acid (12ml) was added to the sample and digested in a digestor at a temperature of 350ºC for at least two hours under a fume chamber until a clear solution is obtained. The solution was allowed to cool and the digested sample was transferred into a conical flask and 5ml of 40% sodium hydroxide added. The ammonia in the resulting solution is distilled off into a conical flask containing 20ml of 2% boric acid solution. The resulting solution was then titrated against sulphuric acid using methylene blue and methyl red as indicators until a purple colour was obtained.

3.5.3 Phenolic Composition

3.5.3.1 Total Polyphenols

Cocoa samples were defatted by extracting the fat with petroleum ether (60ºC -80 ºC) using a Soxhlet apparatus. The total polyphenols in the samples were determined using the Folin-Ciocalteau method. The defatted cocoa samples (0.2g) were weighed into a 50ml falcon tube and 30ml of 1% hydrochloric acid and 80% methanol added. The samples were placed in an orbital shaker to shake for two hours at maximum speed. After two hours filtrates were decanted into other falcon tubes.

Absorbance determination

The filtrate (1ml) was collected into a falcon tube and 9ml of 80% methanol added. The resulting filtrate (1ml) was collected into a test tube and 5ml of 10% of Follin Ciocalteu's Phenol reagent added. Sodium carbonate (4ml of 0.075g/ml) was added and sample allowed to settle down at room temperature for one hour. A required amount of the sample was poured into a cuvette and placed in the spectrophotometer to be read at the absorbance of 760nm.

3.5.4 Physical analysis

3.5.4.1 Cut Test

The cut test was performed on twenty seven different samples of dried cocoa beans and these included samples from three farmer fields. For the cut test determination 300 beans were used. The beans were cut lengthwise through the middle in order to expose the maximum cut surface of cotyledons. Both halves of each bean were visually examined in daylight. Beans were categorized into the following: mouldy, germinated, slaty, purple, weevil, other defects, total mouldy, total slaty, total purple, all other defects and tolerance level. Each defective bean was counted separately, and the result for each kind of defect was expressed as a percentage of the 300 beans examined.

3.4 Statistical analysis

Questionnaires were analyzed using Statistical Package for Social Science (SPSS, Version 16). The data on postharvest losses in cocoa after harvest through to the depot were analysed using General Linear Model (GLM) on Statistical Package for Social Science (SPSS, Version 16) instead of Analysis of Variance (ANOVA) because the data were unbalanced.

All other data collected was entered into Microsoft excel to calculate the means and data were analysed using Student Edition of Statistix (Statistix , version 9) .

The least significant difference (LSD) and highest significant difference (HSD) were used to separate the means for the parameters studied. The level of significance was defined at $p < 0.05$.

CHAPTER FOUR

4.0 RESULTS

This chapter presents results on the responses given by the farmers in the East Akim district on the sources, causes and extent of postharvest losses in the cocoa production system. It also presents results obtained from the field to depot on the determination of postharvest losses in cocoa (in both CRIG and farmer fields) after harvest to the depot. Results on the laboratory analyses to determine the pH, free fatty acid, proteins, carbohydrates and polyphenol content on the dried cocoa beans obtained from all experiments conducted are also presented. Cut test results on the quality of beans produced are also presented.

4.1 Results on survey

Table 4.1: Educational level of farmers

EDUCATIONAL LEVEL	FREQUENCY	PERCENTAGE
NONE	8	16.0
BASIC EDUCATION	34	68.0
SECONDARY EDUCATION	4	8.0
TERTIARY	4	8.0

Results presented in Table 4.1 showed that, majority of the respondent (cocoa farmers) in the East Akim District who responded in this study obtained education at the basic level (68%). Sixteen percent (16%) of the respondents also had no formal education and the total number of respondents who obtained secondary education was the same as those who obtained tertiary education (8%).

Table 4.2: Type of labour used for postharvest activities in the cocoa production chain

Labour	Harvesting		Pod Gathering		Pod Breaking		Fermentation		Head Porterage		Drying	
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%
Family	13	26	9	18	19	38	23	46	17	34	29	58
Hired	31	62	36	72	28	56	23	46	30	60	17	34
Abusa	5	10	4	8	3	6	4	8	3	6	4	8
Abunu	1	2	1	2	-	-	-	-	-	-	-	-

Abusa and Abunu- systems of land tenure in Ghana

Results presented in Table 4.2 showed that most of the farmers used hired labour for their postharvest activities (harvesting; 62%, pod gathering; 72 %, pod breaking; 56%, fermentation; 54%, head porterage; 60%) with the exception of drying of the beans, which is done mostly by the family members (58%).

4.1.1 Farmers' perception on the major causes of pre-harvest losses in cocoa.

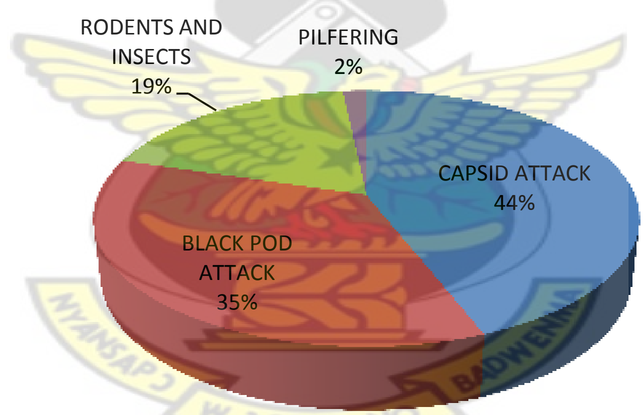

Figure 4.1: Farmers' perception on the major causes of pre-harvest losses in cocoa

According to the farmers, capsid and black pod attack were the major causes of pre-harvest losses in their cocoa farms (44% and 35% of the respondents respectively). On the other hand, 19% of the respondents reported that rodents were among the pests of cocoa causing pre-harvest losses and this could be attributed to poor maintenance of farms. Pilfering was a minor cause of pre-harvest losses.

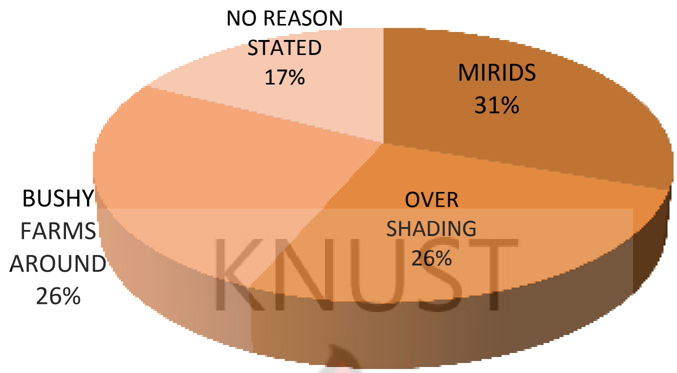

Figure 4.2: Farmers' perception on the causes of capsid attack

According to the farmers (83%), excessive shade on their cocoa farms, bushy farms nearby and mirids were the main causes of the capsid attack on their farms. Over shading and bushy farms nearby were also reported by 52% of the respondents to be major causes of the capsid attack. Seventeen percent (17%) of the respondents could not give any specific reasons on the causes of the capsid attack even though they found the capsid attack to be a major cause of pre-harvest losses in cocoa.

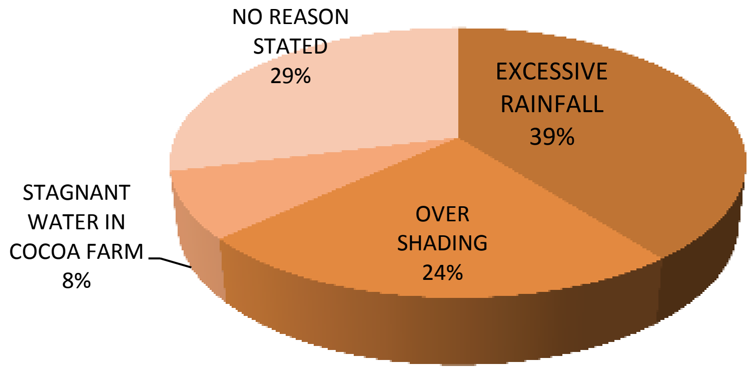

Figure 4.3: Farmers' perception on the causes of black pod attack

Excessive rainfall was reported by 39% of the respondents as the major cause of the black pod attack. Farmers also reported other causes to be too much shade and stagnant water found in their farms. However, 29% of the respondents could not give any specific reasons on the causes of the black pod attack even though they found the black pod attack to be a cause of pre-harvest losses in cocoa.

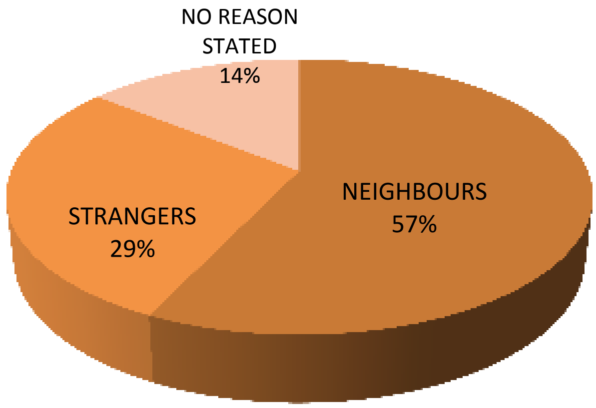

Figure 4.4: Farmers' perception on the causes of losses due to pilfering.

Although pilfering was not considered a major cause of pre-harvest losses in cocoa, farmers identified neighbours within their communities and strangers outside their communities as the causes of this loss. Farmers (57%) reported that most of their pods on the farms were stolen by their neighbours. However, 14% of the respondents could not give any specific reasons on the causes of losses due to pilfering.

4.1.2 Farmers' perception on the stages in the cocoa production chain where major postharvest losses occur.

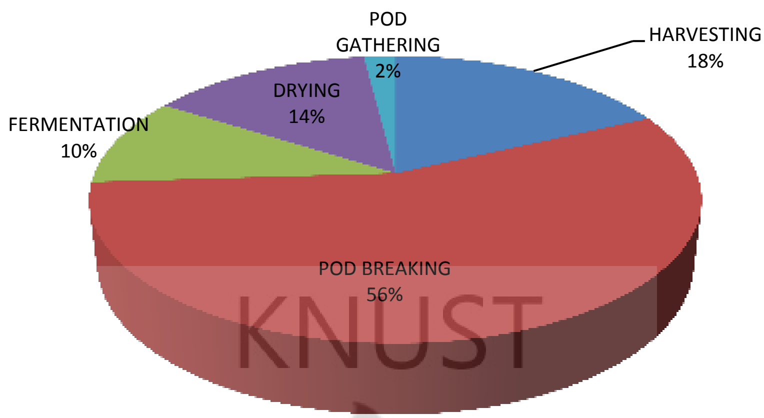

Figure 4.5: Farmers' perception on the stages in the cocoa production chain where major postharvest losses occur.

Harvesting, pod gathering, pod breaking, fermentation and drying stages are the postharvest stages in the cocoa production chain. According to the farmers (56%), major losses incurred during the pod breaking stage. During the pod breaking stage, most of the pods are found to contain bad beans and these are not included during the fermentation process. Pod gathering stage was reported to be the stage in the production chain with the least losses occurring.

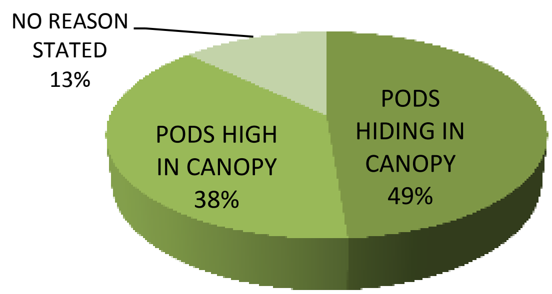

Figure 4.6: Farmers' perception on the causes of losses at harvest.

According to the farmers, they are unable to harvest all their ripe and matured pods due to the fact that some of their pods are found hiding in the canopy, whilst others are located high in the canopy. Thirteen percent (13%) of the respondents could not give any specific reason on the causes of the losses at harvest.

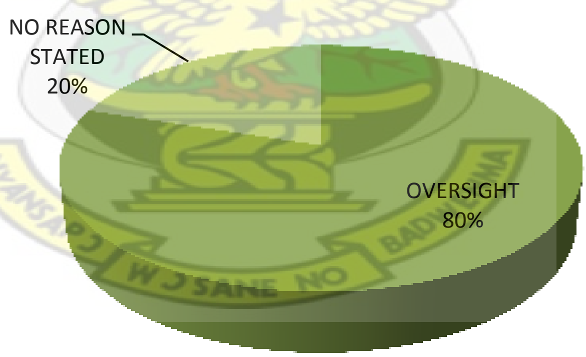

Figure 4.7: Farmers' perception on the causes of losses at pod gathering.

Figure 4.7 presents results on the causes of losses at pod gathering. Farmers (80%) who experienced losses at pod gathering reported oversight as a major cause of losses at this stage. However 20% of the respondents did not give any specific reason on the cause of this loss.

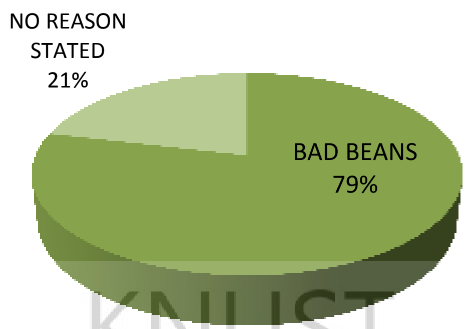

Figure 4.8: Farmers' perception on the causes of losses at pod breaking.

Result on the causes of losses at pod breaking is presented in Figure 4.8. Most respondents (79%) reported that most of the losses they incurred during the pod breaking stage were due to bad beans. Bad beans included germinated beans, caked beans, wet beans and black beans. Some of the respondents could not assign specific reasons for the causes of the losses at pod breaking although they reported losses at this stage.

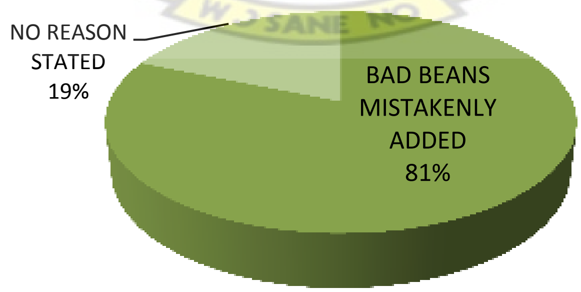

Figure 4.9: Farmers' perception on the causes of losses at fermentation.

Usually during the process of fermentation only good beans are used. However, farmers mistakenly include bad beans and these are sorted out when the beans are being turned during the fermentation process. Eighty one percent (81%) of farmers reported the bad beans which were mistakenly added, (most of which were sorted out during turning) as losses at fermentation.

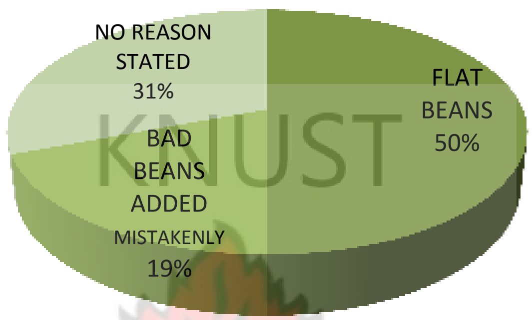

Figure 4.10: Farmers' perception on the causes of losses at drying.

According to 50% of the respondents, a lot of flat beans were sorted out during the drying stage. Flat beans are considered to be low in quality hence, not added to the completely dried good beans. Thirty one (31%) of the respondents could not give the exact causes of loses at the drying stage though they reported losses at this stage.

4.2 Experiment 1

Determination of postharvest losses in cocoa from harvest to the depot

Table 4.3 summarizes the models of the dependent variables with farm types as factors for the major cocoa season. The model for the proportion of pods with germinated beans was statistically significant ($F_{0.05}$ (1,7) = 9.940, P = 0.016). The R^2 was 0.587, implying that the farm types were able to explain 58.7% of the variation in this response variable. The intercept was positive and statistically significant (P = 0.0001). The intercept is the mean difference when no factor is affecting the dependent variable. Also the coefficient (mean difference) of CRIG experimental plot compared to farmer's cocoa farm as a reference category was negative and statistically significant (P = 0.016). This means that CRIG experimental plot tended to reduce the proportion of pods with germinated beans by 4.067 relative to farmer's cocoa farm. In other words, the reverse is also true for farmer's cocoa farm category.

The model for the proportion of pods with caked beans variable was statistically significant ($F_{0.05}$ (1,7) = 6.668, P = 0.036). The R^2 was 0.488, meaning that farm types accounted for 48.8% of the variation in this response variable. The intercept was also positive and statistically significant (P = 0.0001). Additionally, the coefficient (mean difference) of CRIG experimental plot factor compared to farmer's cocoa farm was positive and statistically significant (P = 0.036). This means that the conditions of the CRIG experimental plots appeared to increase the proportion of pods with caked beans by 30.350 relative to farmer's cocoa farm. However, the models for the following response variables were not statistically significant as indicated by the corresponding f-statistics and p-values: proportion of pods with black pod disease, proportion of pods with wet beans and proportion of rodent damaged pods.

All the models were also not statistically significant in the minor season as indicated by the F-statistics and their p-values (P > 0.05).

Table 4.3: Models of the dependent variables with farm types as factors for the major cocoa season

Dependent variable	Farm type	coefficient	Std Error	t-value	p-value	
Proportion of pods with germinated beans	Intercept	7.967	0.745	10.698	0.000	$F_{0.05}(1,7)$ =9.940 p-value = 0.016 R^2 = 0.587
	CRIG experimental plot	-4.067	1.290	-3.153	0.016	
	Farmer's cocoa farm	0#				
Proportion of pods with caked beans	Intercept	48.983	6.786	7.218	0.000	$F_{0.05}(1,7)$ = 6.668 p-value = 0.036 R^2 = 0.488
	CRIG experimental plot	30.350	11.753	2.582	0.036	
	Farmer's cocoa farm	0#				

The parameter is set zero because it is redundant.

4.3 Quantitative estimation of losses in the major season

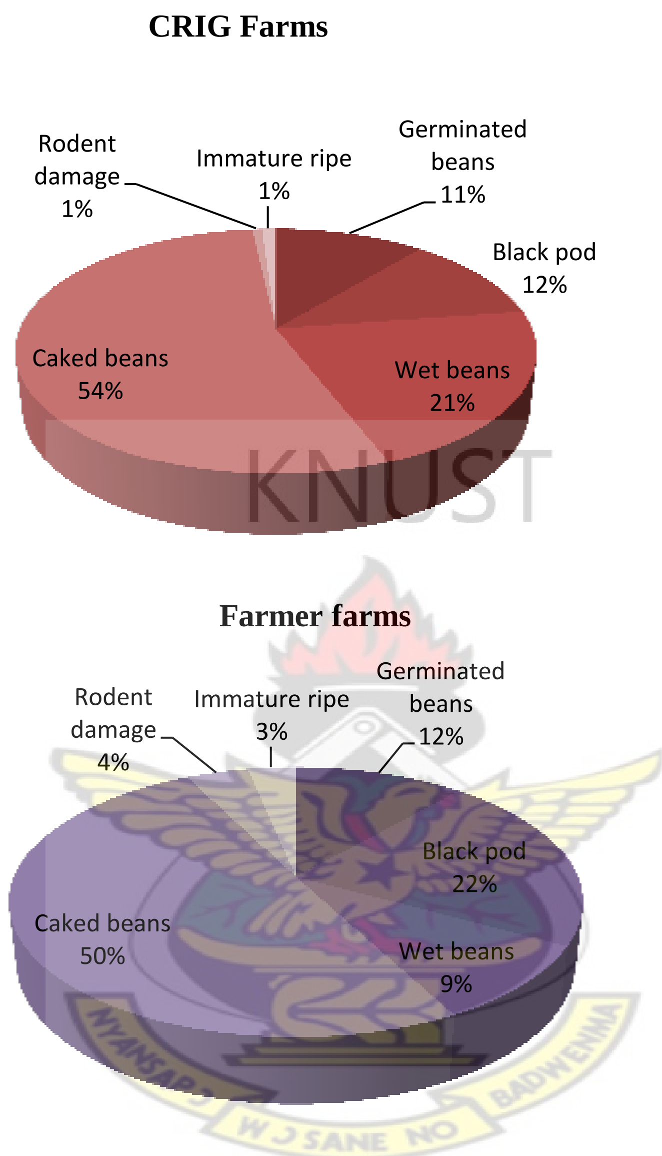

Figure 4.11: Mean postharvest losses in cocoa from both CRIG and Farmer farms (major season)

In the major season, both farms lost a majority of their beans as a result of beans caked in the pods although CRIG farms experienced higher loss (54%) as compared to the farmer farms (50%). Pods from the farmer farms were also mostly attacked by the black pod disease (22%) as compared to pods from the CRIG farms (12%). However, in both farms, pods that were harvested immature ripe were the least losses encountered.

4.4 Quantitative estimation of losses in the minor season

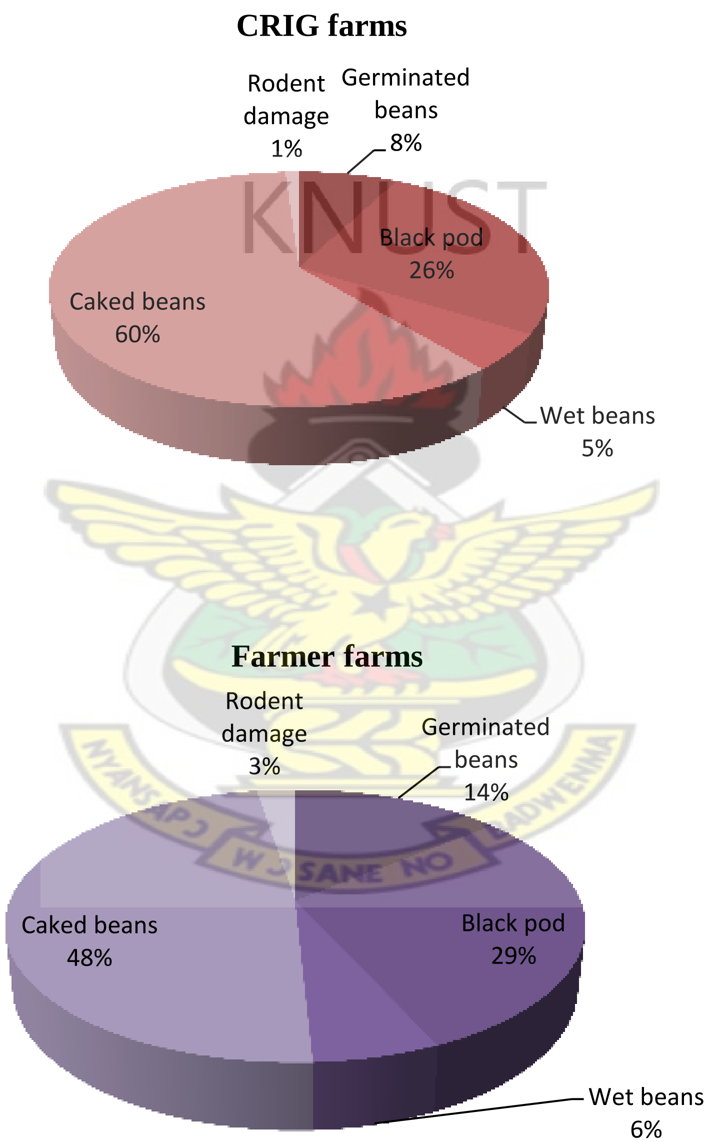

Figure 4.12: Mean postharvest losses in cocoa from both CRIG and Farmer farms (minor season)

In the minor season, majority of the pods obtained from the CRIG farms had most of their beans caked within (60%) as compared to pods obtained from the farmer farms (48%). Pods were also largely attacked by black pod disease in both farms. Cocoa pods obtained from the farmer farms also had a higher percentage of germinated beans (14%) as compared to pods from the CRIG farms (8%).

4.5 Physical assessment of dried cocoa beans by the cut test

Table 4.4: Cut test results of dried beans from some experimental plots

EXPERIMENTAL PLOTS	M	G	S	P	W	OD	TM	TS	TP	AOD	TL	GRADE
CRIG A	-	-	-	-	1.0	-	-	-	-	1.0	99%	1
CRIG B	-	-	-	3.7	-	-	-	-	3.7	-	96.3%	1
CRIG C	-	0.7	-	11.7	-	-	-	-	11.7	0.7	87.7%	1
CRIG D	-	-	-	2.0	0.3	-	-	-	2.0	0.3	97.7%	1
KWASIAKU	-	-	0.3	7.3	-	-	-	0.3	7.3	-	92.0%	1
OHENENKWANTA	-	-	0.3	7.0	-	-	-	0.3	7.0	-	92.7%	1
OGUAA	-	-	0.7	8.0	-	-	-	0.7	8.0	-	91.3%	1

M-Mould, **G**-Germinated, **S**-Slate, **P**-Purple, **W**-Weevil, **OD**-Other defects ,**TM**-Total mould, **TS**- Total slate, **TP**- Total purple, **AOD**- All other defects, **TL**- Tolerance level.

Table 4.4 presents the cut results of the dried cocoa beans from four CRIG farms and three farmer farms. From the table, both farms produced grade 1 cocoa which means that beans were of very good quality hence acceptable according to the quality standards. None of the beans from both farms showed any signs of mould and other defects.

Table 4.5: Cut test results of dried beans obtained from using different methods and days of fermentation

METHOD OF FERMENTA-TION	DAYS OF FERMEN-TATION	M	G	S	P	W	OD	TM	TS	TP	AOD	TL	GRADE
TRAY FMT	3	-	-	-	14.7	-	-	-	-	14.7	-	85.3 %	1
	4	-	2.3	0.3	17.7	-	-	-	0.3	17.7	2.3	79.7 %	1
	6	0.7	0.3	0.7	18.0	0.3	0.3	0.7	0.7	18.0	1.0	79.7 %	1
	7	0.7	0.7	-	14.3	-	-	0.7	-	14.3	0.7	84 %	1
HEAP FMT	3	-	0.3	0.7	38.0	-	-	-	0.7	38.0	0.3	61 %	SS
	4	-	-	-	33.3	-	-	-	-	33.3	-	66.7 %	SS
	6	-	-	0.3	-	0.3	-	-	0.3	-	0.3	99.3 %	1
	7	-	1.0	-	0.7	0.3	-	-	-	0.7	1.3	98 %	1
BASKET FMT	3	0.3	-	-	37.0	-	-	0.3	-	37.0	-	62.7 %	SS
	4	-	-	-	33.3	-	-	-	-	33.3	-	66.7 %	SS
	6	0.3	0.7	-	-	-	-	0.3	-	-	0.7	99 %	1
	7	-	-	-	3.3	0.3	-	-	-	3.3	0.3	96.3 %	1

M-Mould, **G**-Germinated, **S**-Slate, **P**-Purple, **W**-Weevil, **OD**-Other defects, **TM**- Total mould, **TS**- Total slate, **TP**- Total purple, **AOD**- All other defects, **TL**- Tolerance level, **SS**-Sub-standard.

From the Table, beans fermented for 3 and 4 days using the heap and basket fermentation method, produced sub-standard grade of cocoa and such beans are usually rejected since they are of low quality. However using the tray fermentation method produced grade 1 cocoa irrespective of the number of days of fermentation. Fermenting beans for 6 and 7 days using the heap and basket method of fermentation also produced grade 1 cocoa.

Laboratory methods of quality assessment

4.6 Determination of protein content in dried beans.

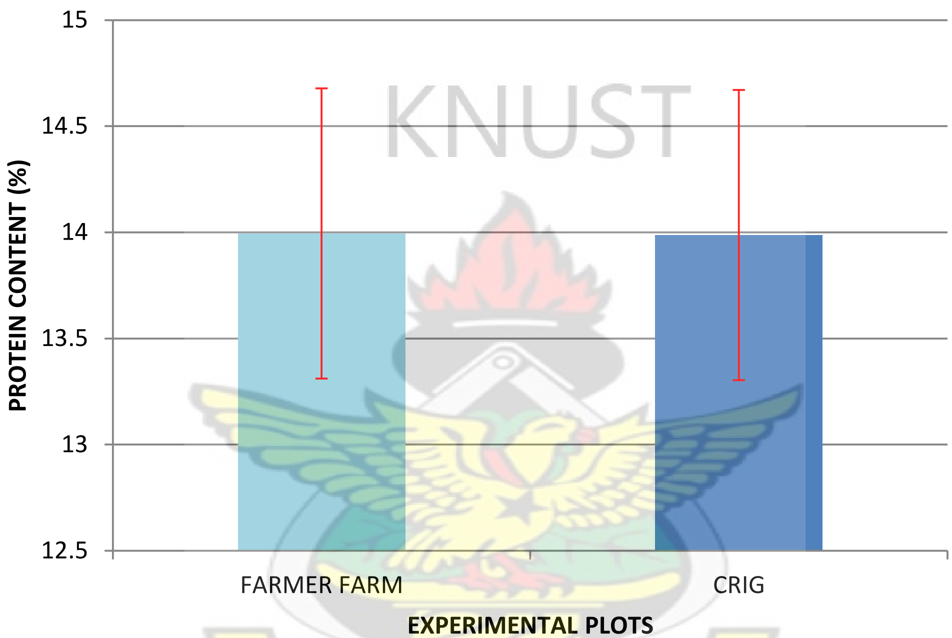

Figure 4.13: Protein content in beans from CRIG and Farmers' farms.

There were no significant differences in the protein content of beans obtained from both CRIG and farmers' farms.

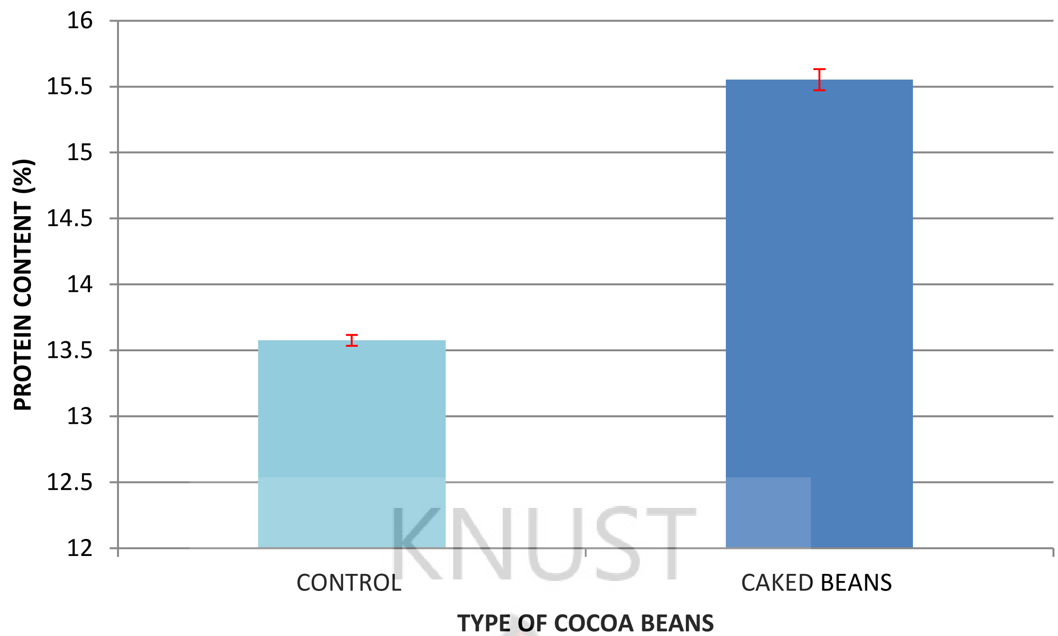

Figure 4.14: Protein content in caked beans and beans obtained from the control experiment.

The protein content in the caked beans was significantly different from that of the control. Beans obtained from the control had lower protein content (13.6 %) than the caked beans (15.6%).

4.7 Determination of free fatty acid content in beans.

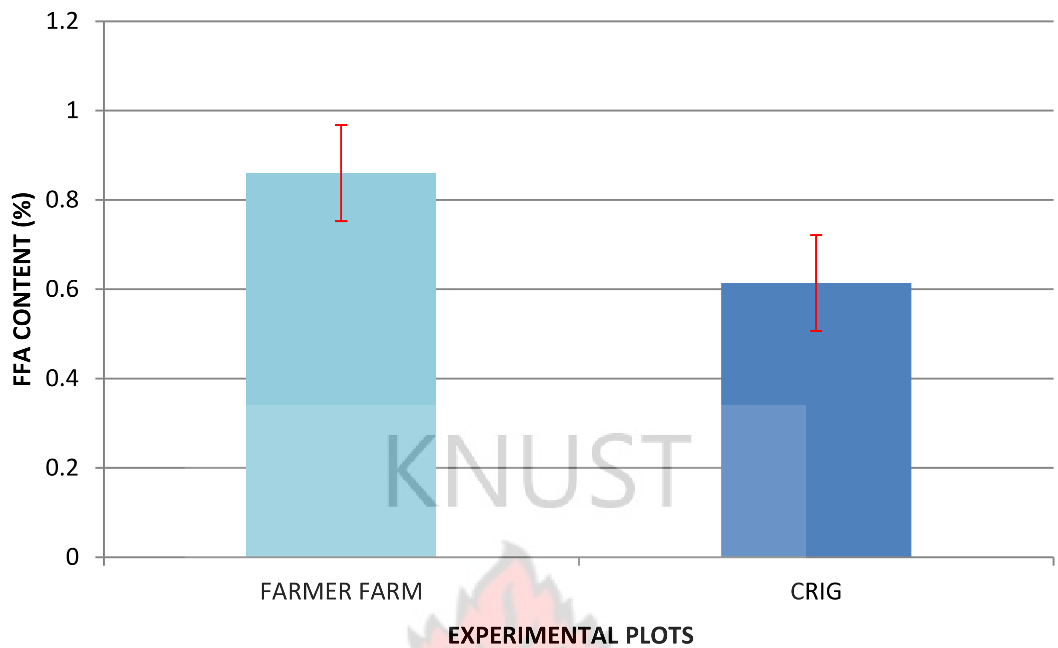

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Figure 4.15: Free fatty acid content in beans from CRIG and Farmers' Farm

There was a significant difference in the free fatty acid (FFA) content of the beans obtained from both farms. Beans from the CRIG farms had lower free fatty acids (0.61%) than those from the farmers' farms (0.86 %).

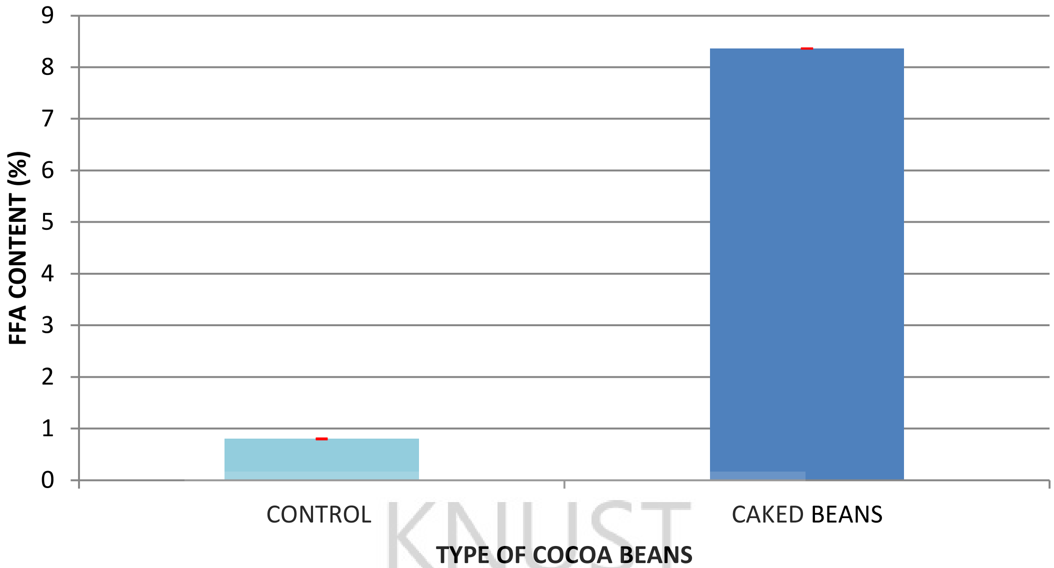

Figure 4.16: Free fatty acid content in caked beans and beans obtained from the control experiment.

The free fatty acid (FFA) content in the caked beans was significantly different from that of the control. Beans obtained from the control had lower free fatty acid content (0.8%) as compared to the caked beans (8.4%).

4.8 Determination of polyphenol content in beans.

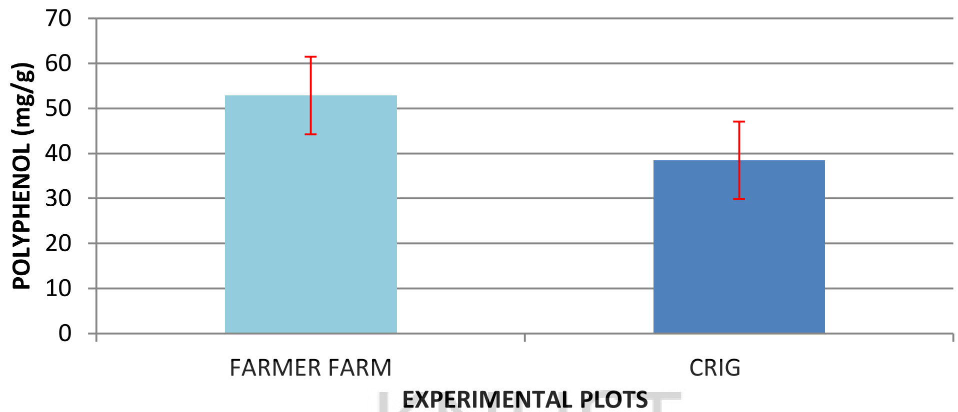

Figure 4.17: Polyphenol content in beans from CRIG and Farmers' farms.

There were no significant differences in the polyphenol content of beans obtained from both CRIG and farmers' farms even though beans from the farmer farms had higher polyphenol content (52.9mg/g) as compared to the CRIG farms (38.5mg/g).

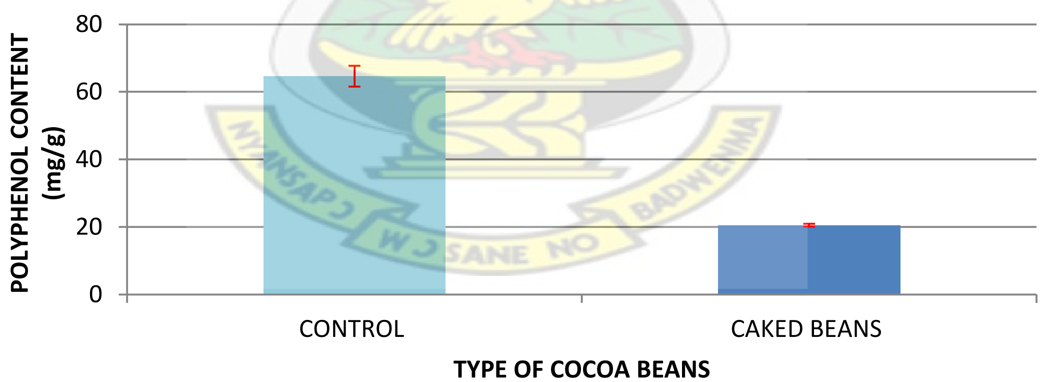

Figure 4.18: Polyphenol content in caked beans and beans obtained from the control experiment.

Beans from the control experiment had higher polyphenol content (64.6mg/g) than that of the caked beans (20.5mg/g). Also there were significant differences in polyphenol content in beans from both the control and caked beans.

4.9 Determination of carbohydrate content in beans.

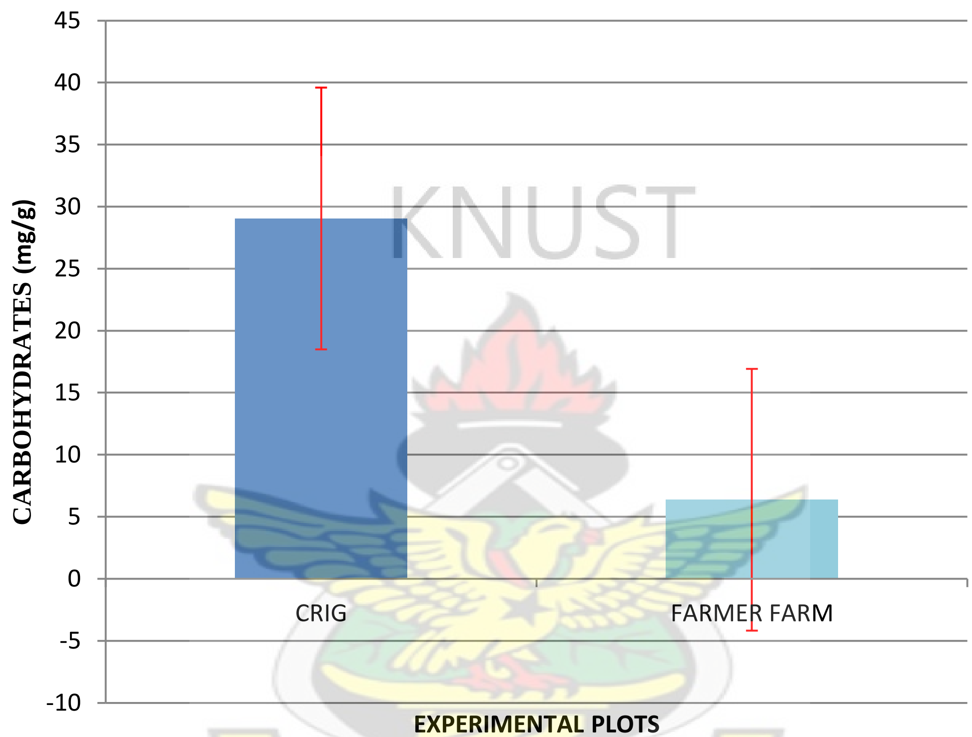

Figure 4.19: Carbohydrate content in beans from CRIG and Farmers' farms.

Cocoa beans obtained from CRIG farms had higher carbohydrate levels (29.0 mg/g) than beans from farmers' farms (6.4 mg/g) and there were significant differences in the carbohydrate levels in beans obtained from both farms.

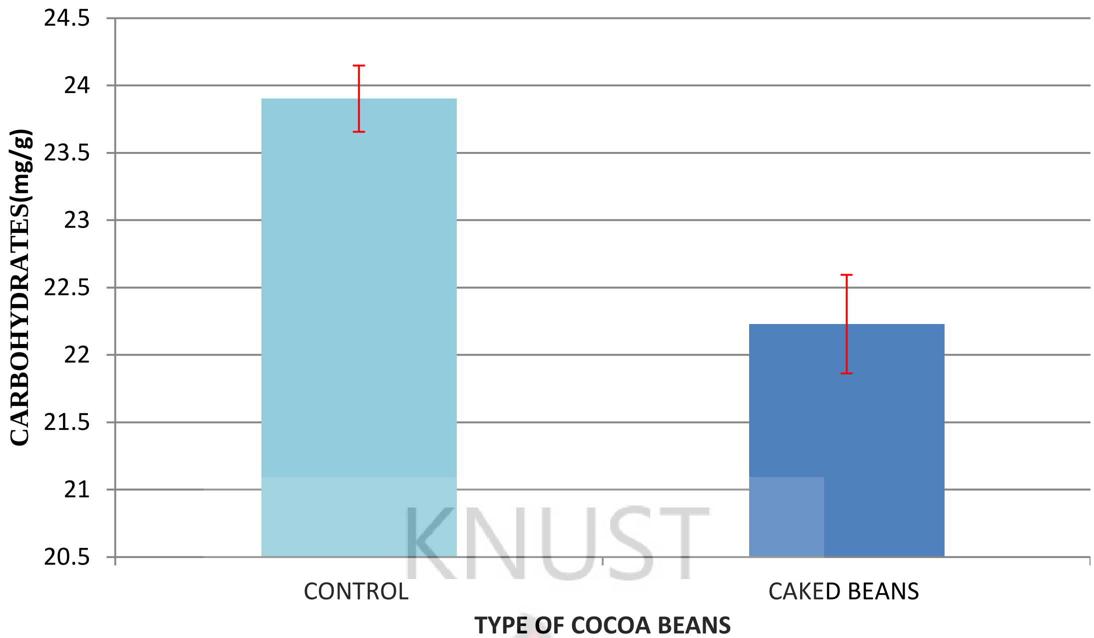

Figure 4.20: Carbohydrate content in caked beans and beans obtained from the control experiment.

Beans from the control experiment had higher levels in carbohydrate (23.9 mg/g) than that of the caked beans (22.2 mg/g). Also there were significant differences in carbohydrate content in beans from both the control and caked beans.

4.10 Determination of pH content in beans.

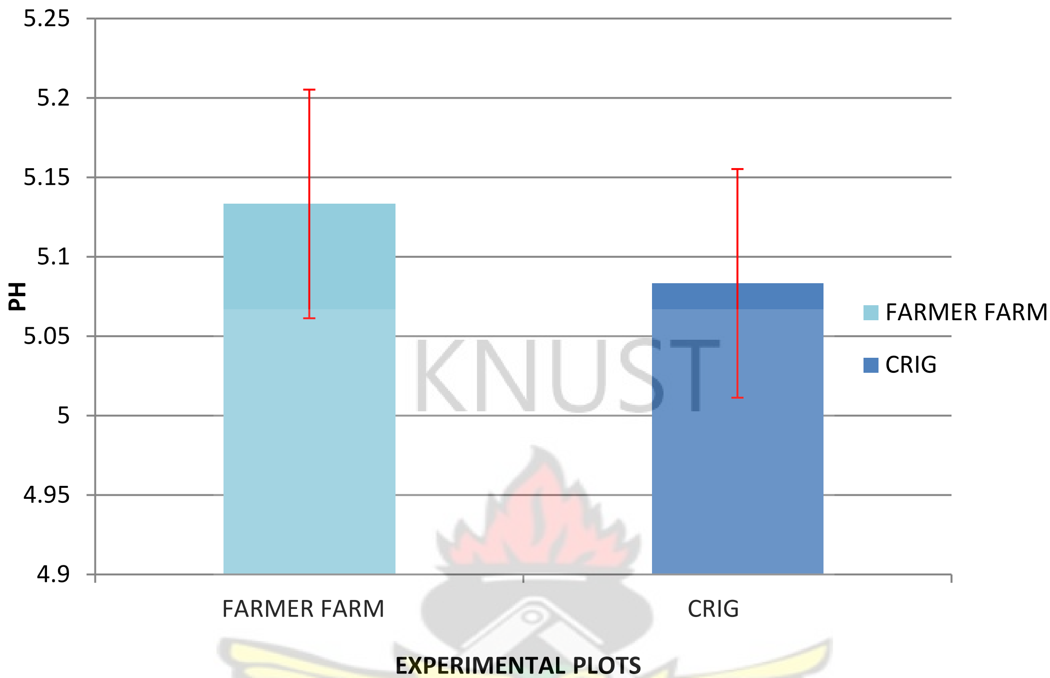

Figure 4.21: pH content in beans from CRIG and Farmers' farms.

There were no significant differences in the pH content of beans obtained from both CRIG and farmers' farms although farmers had higher level of pH in their beans (5.1).

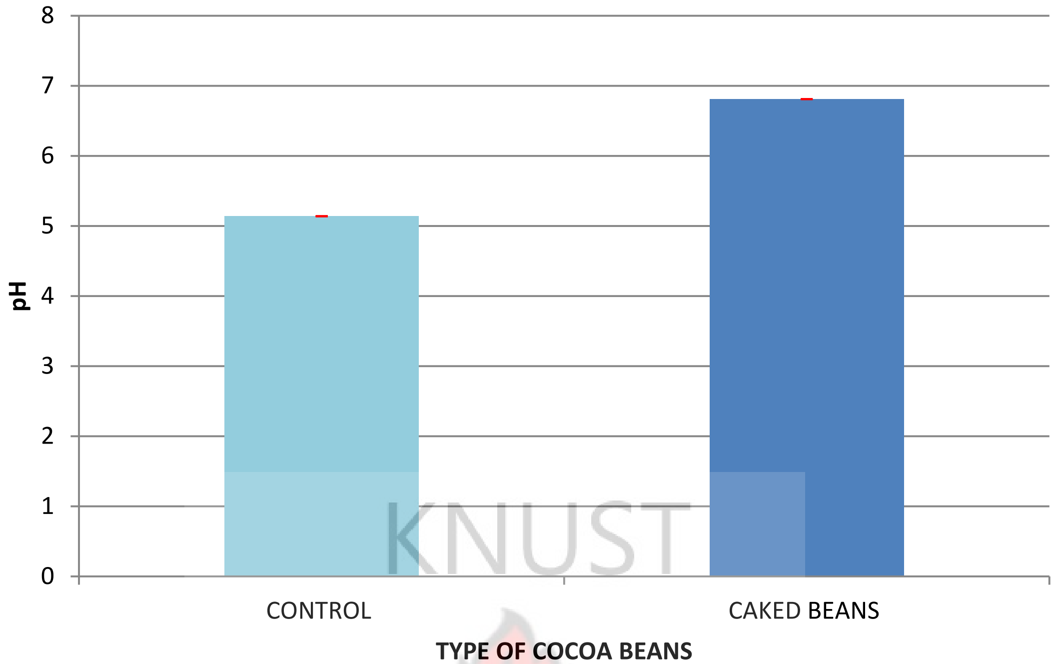

Figure 4.22: pH content in caked beans and beans obtained from the control experiment.

Beans from the control experiment have lower pH (5.1) than that of the caked beans (6.8). Also there were significant differences in pH content in beans from both the control and caked beans.

Table 4.6: Effect of time (days) of fermentation on various quality parameters of cocoa beans.

Time (days)	Protein (%)	FFA (%)	Polyphenol (mg/g)	Carbohydrate (mg/g)	pH
Day 3	15.22 a	0.54 b	35.64 b	53.18 a	4.95 d
Day 4	14.27 b	0.51 b	48.71 a	28.10 b	5.01 c
Day 6	13.40 c	0.50 b	52.97 a	31.41 b	5.15 b
Day 7	13.23 c	0.96 a	31.33 b	28.07 b	5.64 a

From Table 4.6, as the days of fermentation increased, the protein content reduced. Fermenting beans for 7 days produced higher (0.96%) free fatty acids (FFA) and less (28.07mg/g) carbohydrate content. Comparing the days of fermentation, fermenting beans for 6 days had the highest (52.97 mg/g) polyphenol content. There were significant differences in pH between all the days of fermentation.

Table 4.7: Effect of the method of fermentation on various quality parameters of cocoa beans

Fermentation Method	Protein (%)	FFA (%)	Polyphenol (mg/g)	Carbohydrate (mg/g)	pH
Heap	13.38 b	0.60 b	39.18 a	30.10 b	5.28 a
Basket	14.25 a	0.81 a	44.69 a	28.28 b	5.16 b
Tray	14.46 a	0.47 c	42.62 a	47.87 a	5.13 c

From the Table above, fermenting beans using the tray method produced higher proteins and carbohydrates in beans. There were significant differences in pH between all the methods of fermentation. The free fatty acid (FFA) and polyphenol content in beans were also high when the basket fermentation method was used. In using the heap fermentation method, less FFA was produced.

Table 4.8: Effect of method by time (days) of fermentation interaction on various quality parameters of cocoa beans.

Time ; Method	Protein (%)	FFA (%)	Polyphenol (mg/g)	Carbohydrate (mg/g)	pH
Day 3; Heap	14.52 bcd	0.45 de	23.24 de	47.41 b	4.92 i
Day 3; Basket	16.11 a	0.70 c	20.63 e	46.04 b	4.88 j
Day 3; Tray	15.04 b	0.46 de	63.04 ab	66.09 a	5.05 g
Day 4; Heap	13.91 def	0.52 de	23.38 de	25.99 cd	4.93 hi
Day 4; Basket	14.24 cde	0.50 de	74.81 a	7.74 e	4.96 h
Day 4; Tray	14.67 bc	0.49 de	47.92 bc	53.26 b	5.13 f
Day 6; Heap	12.65 hi	0.41 e	61.05 ab	28.15 c	5.25 d
Day 6; Basket	13.22 gh	0.58 cd	61.05 ab	44.12 b	5.19 e
Day 6; Tray	14.33 cde	0.50 de	36.83 cd	21.95cd	5.02 g

Day 7; Heap	12.46 i	1.02 b	49.04 bc	18.83 cd	6.00 a
Day 7; Basket	13.42 fg	1.44 a	22.26 de	15.21 de	5.60 b
Day 7; Tray	13.81 efg	0.43 e	22.69 de	50.17 b	5.30 c
HSD	0.66	0.14	16.02	11.09	0.04
CV (%)	1.59	7.51	12.8	10.55	0.24

From Table 4.8, fermenting beans for 4 days using the basket fermentation method produced the least amount of carbohydrate (the value 7.74 recorded might be an obvious error as it did not fall within the pack). Beans fermented for 4 days using the basket fermentation method also produced the highest level polyphenol content. As the days of fermentation increased, the protein content reduced irrespective of the method of fermentation used. Beans fermented for three days using the basket fermentation method had the highest level protein content (16.11%). Basket fermentation method used in fermenting beans for 3 days produced the lowest pH.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Survey

Results obtained from the farmer survey showed that most (84%) of the respondents (farmers) had formal education. Majority (68%) of the farmers had formal education up to the basic level. This implies that, the literacy level of the farmers was not high; hence their ability to read and understand labels and basic instructions could be limited. Farmers would therefore find it difficult to appreciate technology for adoption.

As far as harvesting, pod gathering, pod breaking, fermentation and head porterage was concerned, hired labour was mostly used. According to most of the farmers (74%), labour used for harvesting was not from the family but dependent on external labour. Hence labour for the activities were highly dependent on external sources. Anytime such labour was unavailable harvesting activities was delayed due to the fact that there was insufficient family labour. Seventy two percent (72%) of the respondents reported that hired labour was also used in pod gathering hence when labour is not available, pod gathering could be a problem and this could lead to postharvest losses. In the process of fermentation and head porterage of the cocoa beans, hired labour was used and this made hired labour an important factor to consider in the cocoa industry. However, lack of resources to hired labour in the cocoa industry would affect production and increase postharvest losses since production is dependent on hired labour. Drying of cocoa beans was usually not labour intensive since this was done mostly by the family members and this was similar to the observations made by Aneani *et al.* (2011). This implies that, beans are therefore protected against theft.

5.2 Farmers' perception on the causes of pre-harvest losses in cocoa

Capsid attack was reported by the farmers to be the major cause of pre-harvest losses. The major cause of the capsid attack was the mirids (capsids) which are major pests that affect cocoa in Ghana. According to Boateng (2011), mirids pierce the surface of cocoa stems, branches and pods using their needle-like mouthpart and also suck the sap of the cocoa tree. In the process of sucking, they inject toxic spit into the plant and this causes the dying of internal cocoa tissues. Also, surrounding farms which are not well maintained and left bushy contribute to these losses since the cocoa farms are unable to attain the suitable environmental condition required to promote proper growth and development. The bushy farms serve as the host of the mirids (capsids) and also reduce aeration required by the cocoa trees.

Black pod rot is another common disease in cocoa production, causing the loss of 30-90 percent of the trees annually. This is the worst of all of the diseases as it is a fungus that can grow on any cacao tree anywhere in the world (*Kostyk, 2010).* In the study, the farmers reported black pod incidence as a major cause of pre-harvest loss in cocoa. The incidence of black pod attack is brought about when there is high humidity (as a result of excessive rainfall) within the farm. High humidity increases fungal activities. Over shading the cocoa trees also facilitate heat accumulation thereby increasing humidity as well as fungal activities.

Farmers also found rodents to be a cause of pre-harvest losses on their farms. The rodents mainly found on their farms were squirrels and this could be as a result of poor maintenance of the farms.

5.3 **Farmers' perception on the stages in the cocoa production chain where major postharvest losses occur**

Pod breaking stage was found to be the stage at which major postharvest losses occurred and these losses were as a result of bad beans found in the pods. Germinated beans, wet beans, caked beans and black beans were considered as bad beans and hence rejected. Germinated beans were as a result of over- ripened pods. Some farmers did late harvesting of their pods and this resulted in germination of their beans. According to Asare (2012), pods are surrounded by germination inhibitors; however, insufficient moisture or rainfall, results in bean germination. The attack of rodents on pods also causes beans germination. This happens when the rodents attack the pods and create holes in them. The holes serve as a point for entry of air into the pods, allowing temperature rise in the pod and hence, promoting germination.

The shield bug has been reported by Boateng (2011) as insects that pierce the pod husk with their mouth parts and suck out the sap of the beans. Cocoa beans that were found caked in pods appeared dried without any sap and this could be as a result of the attack of the shield bug on the pods.

Farmers reported that some losses at harvest may also occur if cocoa pods were located high up on the tree or hiding in canopy and therefore inaccessible. Pods found hiding in canopy could be as result of trees not pruned often. Pruning of cocoa trees is very important since it aids farm aeration and exposure of trees to sunlight. Farmers are unable to gather all pods harvested because they did not weed their farms as recommended. Most of their pods are lost to the bushy farms and remained unpicked due to oversight.

5.4 Determination of postharvest losses in cocoa from harvest to the depot

In the minor season, comparing both farms, the model for the proportion of rodent damaged pods, proportion of pods with black pod disease, and the proportion of pods with germinated beans, caked beans and wet beans was not significantly ($p>0.05$) different . However in the major season there were significant ($p<0.05$) differences in the model for the proportion of pods with germinated beans and caked beans in both farms. Farmer farms had a higher proportion of pods with germinated beans as compared to the CRIG farms and the model for this response could be represented as

Y = - 4.067+7.967x [where x=germinated beans and Y is the total loss].

On the other hand, CRIG farms also had a higher proportion of pods with caked beans as compared to the farmer farms and the model for this response could also be represented as

Y= 30.350 + 48.983a [where a=caked beans].

According to Asare (2012) there was a decrease in rainfall during the major season and this reduced fungal activities but made the insect activity high. The insects (shield bug) therefore depended on the pods for moisture since moisture content in the atmosphere was low. The insects thus sucked the sap in the pod which presumably caused the beans to cake in the pods.

In the estimation of quantitative losses in both farms in the major and minor season, the incidence of caked beans was very high. Black pod attack was also similar in both CRIG and farmer farms in the minor season. This could be as a result of the rainfall pattern. There was lesser rain in the major season and this helped in reducing the incidence of black pod attack. The incidence of rodent attack was higher in the farmer farms in both seasons and this could be attributed to poor maintenance of farms.

5.5 Physical assessment of dried cocoa beans

Cut test results on dried beans obtained from CRIG experimental plots and farmer farms showed that both farms produced Grade 1 cocoa. The results corroborate the report of Boateng (2012).

According to Boateng (2012), Grade 1 cocoa are thoroughly dry, free from foreign matter, smoky beans and any evidence of adulteration, and contain 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. The results are indicative that farmers conformed to the required number of days of fermentation and turning required to obtain Grade 1 cocoa.

Cocoa beans fermented for 3 and 4 days using the heap and basket method of fermentation resulted in substandard grade cocoa. This was because the beans were not fermented for the required number of days (6days). According to the standards of Quality Control Company (QCC), cocoa beans are graded as substandard when the purple range falls between 30.3-50% and this was shown in Table 4.5. Substandard grade of cocoa are usually not purchased by the Ghana Cocoa Board because they are of low quality and do not meet their standard.

5.6 Protein Content

There were no significant differences in the protein content of beans obtained from both CRIG and farmer farms. This indicates that the protein content of the beans from the farmer farms were similar to that from the CRIG farm. The protein content was similar to that reported by Biehl *et al.*, (1982); and Spencer and Hodge (1992), who reported protein content of 15-20% in dried cocoa beans.

Protein content in the caked beans was significantly higher than that of the control. Although caked beans are considered bad beans, farmers tend to adulterate their good cocoa beans with caked beans to increase weight. However, the cocoa quality is affected since this brings about other undesirable characteristics such as an increase in free fatty acids as observed in Fig. 4.16 which corroborates the findings of Dand (1997).

As the days of fermentation increased, the protein content reduced irrespective of the method of fermentation used. Protein content in the dried beans was affected by the fermentation time. As fermentation time increased, protein content reduced. The observed decreases in protein content with fermentation might be due to protein breakdown during the curing process, partly due to hydrolysis into amino acids and peptides and partly by conversion to insoluble forms by the action of polyphenols as well as losses by diffusion (Afoakwa *et al*. (2008); Afoakwa and Paterson (2010)).

This result corroborates with earlier works that as fermentation time increased, total protein concentration decreased (Adeyeye *et al.*,(2010); De Brito *et al*., (2000); Hashim, *et al.*, (1998)).

In this experiment, the protein content in beans ranged between 13.5% - 20%. Even though caked beans are considered bad beans, they fell within this range. However, contrary to the results obtained in this study, Aremu *et al*. (1995) reported a significant increase in bean protein content by the sixth day of fermentation.

5.7 Free Fatty Acid Content.

The free fatty acid (FFA) content in the caked beans was significantly higher than that of the control. Beans obtained from CRIG and farmers' farms also showed significant differences in the free fatty acid content. 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). Free fatty acid content in beans from CRIG and Farmers' farms was lesser than 1.75%. This means that, even though there were significant differences in FFA content of the beans from both farms, both farms produced good beans with respect to the percentage FFA. The significant differences could be as a result of the fermentation process and practices used by the farmers. Caked beans produced higher FFA content (8.4 %) than beans obtained from the control (0.8%). Caked beans are considered bad beans and are not to be included during production. However some farmers tended to mix these beans with their good beans. The higher FFA observed in caked beans samples might be due to the action of lipases naturally present in the beans and those introduced by microbial activity during fermentation. These lipases act to breakdown the triglycerides into separate groups of the fatty acids and glycerol thereby freeing the fatty acids (Dand 1997), resulting in rancidity of the product. The FFA content however was not affected by the method and days of fermentation. Fermenting beans for six days using the heap method was the best since it resulted in the production of the least FFA.

5.8 pH of dried cocoa beans.

The pH of cocoa beans during fermentation is crucial as it dictates the fermentative quality of the beans. There were no significant differences in the pH content of beans obtained from both CRIG and farmers' farms. The reason could be that, there were no differences in the practices used by both farmers. However, the pH content in the caked beans was significantly higher than beans from the control. Beans of higher pH (5.5–5.8) are considered unfermented, with a low fermentation index and cut test score, and those of lower pH (4.75–5.19), well-fermented (Afoakwa *et al.,* 2008). On the average pH was observed to be increasing with increasing duration of fermentation irrespective of the method of fermentation used.

Duration of fermentation have been observed to affect the pH of beans thus influencing enzyme activities and flavour development and hence acidity, bitterness and astringency of the processed cocoa beans (Hensen *et al.,* 1998). Fermenting beans for more than six days increased the pH of the beans (>5.19). Caked beans also had a high pH (6.8) and this confirms the facts that, they were bad beans therefore needed to be rejected.

5.9 Polyphenol Content.

Polyphenols have gained much more attention in recent times, owing to their antioxidant capacity (free radicals scavenging and metal chelating) and their possible beneficial implications in human health, such as in the treatment and prevention of cancer, cardiovascular disease, anti-microbial and other pathologies (Agarwal andMukhtar, 1996). Polyphenol reactions with sugar and amino acids contribute flavour and colour to cocoa bean whereas the alkaloids contribute to the bitterness (Afoakwa and Paterson, 2010).

Polyphenols also have bitter, astringent flavours and their antioxidant properties help protect the seed from damage and disease (Kyi *et al*., 2005).

There were no significant differences in the polyphenol content of beans obtained from both CRIG and farmer farms. Polyphenol content fell between 34-60mg/g and this agreed with work done by Nazaruddin *et al.* (2001) who reported that the total polyphenols ranged from 34 to 60 mg/g in cocoa beans. Total polyphenol content in caked beans was 20.5mg/g and this was far below the specified range. The polyphenol content of the beans from the control as observed in this study were slightly higher than the reported values. It is possible that the levels in polyphenols of the beans obtained from the control increased slightly because of the fermentation process and its reactions and the environmental conditions present at the time of fermentation. Fermenting beans for six days yielded the best results of polyphenol content in dried beans.

5.10 Carbohydrate Content

There were significant differences in carbohydrate content in beans from both the control and caked beans. Also beans from CRIG farms showed significantly higher levels in carbohydrate content than beans from farmers' farms. According to Berbert (1979), the sucrose concentration in the unfermented beans generally comprised about 90% of the total sugars, whereas both fructose and glucose made up about 6%. Bean carbohydrate changes are due to hydrolytic enzymes in the beans that were released during fermentation by decompartmentalization of cells within the bean. This process causes a reduction in the carbohydrate level at the end of the fermentation period and this trend is shown in the beans obtained from the farmers' farm (6.4mg/g). This confirms the findings conducted by Afoakwa *et al.* (2011) which showed a significant decrease in total sugars by the sixth day of fermentation. Previous reports have shown that, pod storage results in decreases in pulp volume per seed due to water evaporation and inversion of sucrose; diminishes total sugar content leading to reduced acid production during fermentation (Biehl *et al*., 1989).

However, the reduction in carbohydrate content in beans was not prominent in CRIG farms. Surprisingly, the control also had a high level of carbohydrate. Afoakwa *et al.* (2011) reported an increase in carbohydrate content after storing pod for a longer period of time before pod breaking. Cocoa fermentation is influenced by many factors such as variety of cocoa, disease, climatic and seasonal differences (Afoakwa 2010), turning, batch size (Lehrian and Patterson 1983), and quantity of beans (Mamot and Samarakhody 1984; Wood and Lass 1985). The factors listed above might have contributed to the increase in carbohydrate content in the beans.Fermenting beans for six days using the tray method, and seven days using the heap and basket fermentation method resulted in the decrease in carbohydrate content.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

According to the farmers the major cause of pre-harvest losses in cocoa was attributable to capsid attack, which was facilitated by dense and closed canopy (too much shade) of cocoa trees as well as adjacent or nearby bushy farms. Other pre-harvest causes of postharvest losses in cocoa as perceived by the farmers were black pod attack and rodent infestation. Generally, the farmers' perception about pre-harvest causes of loss was founded suggesting that they were well informed about the causes being capsid attack, black pod disease and rodent infestation.

As regards postharvest losses the farmers indicated that most postharvest losses occurred at the pod-breaking stage where diseased, caked, wet and germinated beans were removed prior to fermentation. Rodent damage to cocoa pods and beans were identified by the farmers as other causes of loss.

Farmers mostly required hired labour for harvesting, pod gathering, pod breaking, fermentation and head portage. It was found out that labour was a limiting factor in the absence of which most of the cocoa went bad due to non-collection.

At farmer level, the causes of losses were at harvest, pod breaking, fermentation and drying. Losses along the production chain occurred as a result of bad beans during pod breaking, fermentation and drying.

In the major season, the proportion of caked beans and germinated beans caused significant losses in the farmers' farms and CRIG experimental plots. Farmers' farms had a higher proportion of pods with germinated beans, and the CRIG farms also had a higher proportion of pods with caked beans.

Fermenting beans for the required number of days and proper turning of beans resulted in Grade 1 cocoa, which was the required standard (according to Quality Control Company) as far as quality, is concerned. However, cocoa beans fermented for 3 and 4 days using the heap and basket method of fermentation resulted in substandard grade of cocoa. Tray fermentation was the best since by day 3, beans were already well-fermented and fermenting cocoa up to 6 days did not spoil the cocoa by this method as the FFA again remained very low compared to basket and heap method. Generally, the longer the fermentation period the lower the protein content became.

Caked beans produced higher (>1.75) FFA content which when mixed with good beans by the farmers would result in poor quality produce when used as raw material for processing. Farmers therefore should desist from mixing their good beans with caked beans because caked beans are not good beans and also cause an increase in free fatty acid content and pH, and these affect the quality of cocoa.

Fermenting beans for six days using the heap fermentation method produced beans with lower FFA than basket and tray. Fermenting beans for six days yielded the best results of polyphenol content in dried beans.

Postharvest losses in the major season could be predicted by the models**:**

Y = - 4.067+7.967x [x=germinated beans] and **Y= 30.350 + 48.983a** [a=caked beans]; where y is the total loss. This model could be used in estimating losses when the quantities of germinated and caked beans are known. All efforts must be employed to reducing germinated and caked beans.

6.2 Recommendation

Based on the results of this research, its recommend that:

- Further studies on the causes of postharvest losses are conducted in other regions as well.
- Since germinated beans and caked beans contributed significantly to quantitative loss, further studies should be conducted to develop methods by which losses due to these two factors are reduced.

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APPENDICES

APPENDIX I

QUESTIONNAIRE TO SOLICIT FARMER'S PERCEPTIONS ON SOURCES, CAUSES AND EXTENT OF POSTHARVEST LOSSES/ QUALITY IN COCOA PRODUCTION SYSTEM IN THE EAST AKIM DISTRICT OF GHANA

CONFIDENTIALITY: THIS QUESTIONNAIRE IS BEING USED FOR AN ACADEMIC PURPOSE THEREFORE; INFORMATION PROVIDED SHALL BE KEPT CONFIDENTIAL. THANKS FOR YOUR ASSISTANCE.

Location of farmer: …………………………Sex: ………………...Age: ………………..

Farm size (cocoa): ……………………….. No. of cocoa farms: ……………………….

Level of education: ………………………… Household size: ……………………….

Cocoa production (kg): 2009/2010 …………………. 2010/2011 …………………

Type of labour <u>mainly</u> used for these operations:

(A. family B. hired C. abusa D. abunu E. combination of ……….)

Capsid control (spraying): …………………… Black pod control: …………………

Harvesting: ……………………………. Pod gathering: ………………………

Pod Breaking: ……………………………….. Fermentation: ………………………..

Head poterage (to drying mat): ………………. Drying of cocoa beans: ………………..

Perception of where major losses occur: (List& Rank): During Pre-harvesting

Capsid attack: estimated loss (%)…………Cause …………………………………………

Black pod attack: estimated loss (%) ……Cause …………………………………………

Rodents &other insects: estimated loss (%) Cause…………………………………………

Pilfering: estimated (%)…………………………….Cause……………………………

Perception of where major losses occur: (list & Rank): During post harvesting

Harvesting: estimated loss (%) ……………….. cause ………………..

Gathering: estimated loss (%) ………………… cause……………….

Pod breaking: estimated loss (%) …………………. cause …………….

Fermentation: estimated loss (%) …………………. cause ……………

Drying: estimated loss (%)……………………cause……………

Others; specify & explain: …………………. (%) …………………….

Farm management practices: No. of times theses farm activities are carried/year

Weeding: ………………………………..

Fungicide application including CODAPEC: …………………………..

Insecticide application including CODAPEC: ………………………….

Fertilizer application (Yes OR No): ……………………….

Drying of cocoa beans: ………………………………………..

Harvesting /year: ………………………………………

Which method of fermentation do you usually use? 1. Heap 2. Basket 3.Tray 4. Box

How many times do you turn your beans during fermentation? ………………………….

How many days do you ferment your cocoa beans? …………………………………

In which of these areas do you encounter much losses & why?

1. Harvesting 2.Pod breaking 3.Fermentation 4.Drying

Explain

……………………………………………………………………………………………

……………………………………………………………………………………………

Any other questions/observations………………………………………………Date……

APPENDIX II

Models of the dependent variables with farm types as factors for the major cocoa season

Dependent variable	Farm type	coefficient	Std Error	t-value	p-value	
Proportion of germinated beans	Intercept	7.967	0.745	10.698	0.000	$F_{0.05}(1,7)$ =9.940 p-value = 0.016 R^2 = 0.587
	CRIG experimental plot	-4.067	1.290	-3.153	0.016	
	Farmer's cocoa farm	0#				
Proportion of pods with black pod disease	Intercept	26.783	7.194	3.723	0.007	$F_{0.05}(1,7)$ = 1.807 p-value = 0.221 R^2 = 0.205
	CRIG experimental plot	-16.750	12.460	-1.344	0.221	
	Farmer's cocoa farm	0#				
Proportion of pods with wet beans	Intercept	5.833	1.617	3.607	0.009	$F_{0.05}(1,7)$ = 0.906 p-value = 0.373 R^2 = 0.115
	CRIG experimental plot	-2.667	2.801	-0.952	0.373	
	Farmer's cocoa farm	0#				
Proportion of pods with caked beans	Intercept	48.983	6.786	7.218	0.000	$F_{0.05}(1,7)$ = 6.668 p-value = 0.036 R^2 = 0.488
	CRIG experimental plot	30.350	11.753	2.582	0.036	
	Farmer's cocoa farm	0#				
Proportion of rodent damaged pods	Intercept	6.283	2.615	2.402	0.047	$F_{0.05}(1,7)$ = 1.168 p-value = 0.316 R^2 = 0.143
	CRIG experimental plot	-4.897	4.530	-1.081	0.316	
	Farmer's cocoa farm	0#				

The parameter is set zero because it is redundant

Models of the dependent variables with farm types as factors for the minor cocoa season

Dependent variable	Farm type	coefficient	Std Error	t-value	p-value	
Proportion of germinated beans	Intercept	7.957	1.619	4.914	0.001	$F_{0.05}(1,8) = 0.001$ p-value = 0.980 $R^2 = 0.000$
	CRIG experimental plot	0.076	2.956	0.026	0.980	
	Farmer's cocoa farm	0#				
Proportion of pods with black pod disease	Intercept	32.214	8.007	4.023	0.004	$F_{0.05}(1,8) = 0.030$ p-value = 0.868 $R^2 = 0.004$
	CRIG experimental plot	-2.514	14.619	-0.172	0.868	
	Farmer's cocoa farm	0#				
Proportion of pods with wet beans	Intercept	5.957	1.072	5.557	0.001	$F_{0.05}(1,8) = 0.223$ p-value = 0.650 $R^2 = 0.027$
	CRIG experimental plot	-0.924	1.957	-0.472	0.650	
	Farmer's cocoa farm	0#				
Proportion of pods with caked beans	Intercept	50.614	8.232	6.149	0.000	$F_{0.05}(1,8) = 0.122$ p-value = 0.736 $R^2 = 0.015$
	CRIG experimental plot	5.252	15.029	0.349	0.736	
	Farmer's cocoa farm	0#				
Proportion of rodent damaged pods	Intercept	3.286	1.260	2.608	0.031	$F_{0.05}(1,8) = 0.672$ p-value = 0.436 $R^2 = 0.078$
	CRIG experimental plot	-1.886	2.300	-0.820	0.436	
	Farmer's cocoa farm	0#				

The parameter is set to zero because it is redundant.

APPENDIX III

ANOVA TABLES

ANOVA table of free fatty acid content in CRIG and Farmer farms

Source	df	ss	ms	f	p
TRT	1	0.24208	0.24208	5.87	0.0277
Error	16	0.66036	0.04127		
Total	17	0.90243			

ANOVA table of free fatty acid content in caked beans and the control

Source	df	ss	ms	f	p
TRT	1	85.7692	85.7692	504774	0.0000
Error	4	0.0007	0.0002		
Total	5	85.7699			

ANOVA table of free fatty acid content in beans using different days and method of fermentation

Source	df	ss	ms	f	p
Rep	2	0.00035	0.00018		
Days	3	1.38139	0.46046	207.98	0.0000
Method	2	0.67897	0.33949	153.33	0.0000
Days*method	6	1.04209	0.17368	78.45	0.0000
Error	22	0.04871	0.00221		
Total	35	3.15151			

ANOVA table of pH content in CRIG and Farmer farms

Source	df	ss	ms	f	p
TRT	1	0.01286	0.01286	0.53	0.4758
Error	19	0.46167	0.02430		
Total	20	0.47452			

ANOVA table of pH content in caked beans and the control

Source	df	ss	ms	f	p
TRT	1	4.18335	4.18335	91273.1	0.0000
Error	4	0.00018	0.00005		
Total	5	4.18353			

ANOVA table of pH content in beans using different days and method of fermentation

Source	df	ss	ms	f	p
Rep	2	0.00007	0.00004		
Days	3	2.61699	0.87233	5544.82	0.0000
Method	2	0.14762	0.07381	469.17	0.0000
Days*method	6	0.79551	0.13259	842.76	0.0000
Error	22	0.00346	0.00016		
Total	35	3.56366			

ANOVA table of polyphenol content in CRIG and Farmer farms

Source	df	ss	ms	f	p
TRT	1	830.14	830.144	3.14	0.0956
Error	16	4233.78	264.611		
Total	17	5063.92			

ANOVA table of polyphenol content in caked beans and the control

Source	df	ss	ms	f	p
TRT	1	2918.37	2918.37	150.93	0.0003
Error	4	77.35	19.34		
Total	5	2995.71			

ANOVA table of polyphenol content in beans using different days and method of fermentation

Source	df	ss	ms	f	p
Rep	2	142.9	71.45		
Days	3	2877.3	959.11	32.93	0.0000
Method	2	185.8	92.90	3.19	0.0608
Days*method	6	9757.7	1626.28	55.84	0.0000
Error	22	640.7	29.12		
Total	35	13604.4			

ANOVA table of protein content in CRIG and Farmer farms

Source	df	ss	ms	f	p
TRT	1	0.0002	0.00024	0.00	0.9905
Error	16	26.6490	1.66556		
Total	17	26.6492			

ANOVA table of protein content in caked beans and the control

Source	df	ss	ms	f	p
TRT	1	6.03129	6.03129	372.35	0.0000
Error	4	0.06479	0.01620		
Total	5	6.09608			

ANOVA table of protein content in beans using different days and method of fermentation

Source	df	ss	ms	f	p
Rep	2	0.1011	0.05053		
Days	3	22.7004	7.56681	151.22	0.0000
Method	2	7.7965	3.89826	77.90	0.0000
Days*method	6	4.2520	0.70866	14.16	0.0000
Error	22	1.1009	0.05004		
Total	35	35.9508			

ANOVA table of carbohydrate content in CRIG and Farmer farms

Source	df	ss	ms	f	p
TRT	1	2056.83	2056.83	5.18	0.0369
Error	16	6349.72	396.86		
Total	17	8406.55			

ANOVA table of carbohydrate content in caked beans and the control

Source	df	ss	ms	f	p
TRT	1	4.20174	4.20174	10.82	0.0302
Error	4	1.55284	0.38821		
Total	5	5.75458			

ANOVA table of carbohydrate content in beans using different days and method of fermentation

Source	df	ss	ms	f	p
Rep	2	9.0	4.48		
Days	3	3841.2	1280.40	91.78	0.0000
Method	2	2811.6	1405.79	100.77	0.0000
Days*method	6	4092.3	682.05	48.89	0.0000
Error	22	306.9	13.95		
Total	35	11060.9			