KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF SCIENCE

ASSESSING THE IMPACT OF A MIXED SOLAR DRYER ON THE QUALITY OF HEAP FERMENTED COCOA BEANS.

A THESIS SUBMITTED TO THE DEPARTMENT OF FOOD SCIENCE AND TECHNOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF

MASTER OF SCIENCE IN FOOD QUALITY MANAGEMENT

BY

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DECLARATION

I, Bisiw Annobil Gabriel, do hereby declare that except for references to other researchers duly cited, this is my original research conducted at Dunkwa in the Western Region while the laboratory work was carried out at the KNUST Food Science Laboratory, Kumasi and that no part of this thesis has been in whole or part presented for a degree elsewhere.

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DEDICATION

This work is dedicated to Almighty God, my lovely wife, Grace Aduambah Appiah, my Son, Reginald E. Bisiw and entire family for their support, prayers and care shown to me throughout my academic pursuit.

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ABSTRACT

Ghana has a high reputation in the world market for producing cocoa beans of premium quality. However, the drying of the cocoa beans comes with intense labour and high losses due to the deterioration of beans during processing. Solar drying technology has the potential to reduce postharvest loses. The use of this technology in Ghana is very limited among cocoa producers and the need to explore its comprehensive value has become imperative. This research study aimed to primarily assess whether solar drying technology enhances the organoleptic properties of cocoa beans using heap fermentation.

Proximate, Free Fatty Acid (FFA), Titratable Acidity, Vitamin C and pH, according to the recommendations of AOAC were determined. Air temperature and relative humidity readings were taken after the cocoa sample had undergone complete heap fermentation for six days. An initial moisture content of 51% was recorded for the freshly fermented samples and put through two treatments: solar and open sun drying systems. The moisture content reduced to 6.0 % for the solar dried sample after the third day and 7.0% for the open sun dried sample after the sixth day. Data collected were subjected to statistical analysis. The findings reveal that solar dried cocoa beans generally had higher crude protein, crude fibre, total carbohydrate, and lower raw fat, ash content as compared to that of the open sun dried sample. There were no defects recorded for the cut test, however percentage purple was lower for solar dried compared to the open sun dried.

The percentage proportions of each of the sensory descriptors assessed by the panelist scored higher in favor of open sun dried cocoa beans. In conclusion, the open sun drying system was better to process cocoa products of good quality in terms of the sensory test but the solar dryer had a shorter drying time.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Cocoa is mainly produced in West Africa representing about 72% of the world cocoa production. The four major West African countries that are main producers of cocoa are Côte D'Ivoire, Ghana, Nigeria, and Cameroon. Pacific Asia area accounts for about 15% and America is 13% of the 3.5 million tons cocoa beans produced world over (Knight, 1999). Cocoa is one of the precious cash crops countries depend on for foreign exchange. Ghana is reported to be one of the major producers of cocoa among other countries with production estimated at 700,000 tons annually followed after Cote D'Ivoire. Ghana is known to be the world's leader in the aspect of quality cocoa beans due to the proper methods used during the processing of cocoa beans after harvest.

The cocoa industry forms a greater share of the nation's labour force, by employing over 60 percent of all the farmers in the country (Appiah, 2004). Farmers enjoy about 70-100% of their annual household income from cocoa cultivation; improving the standard of living of these farmers is a major concern of the government aimed at increasing the country's production and processing of quality cocoa beans into semi-finished and finished cocoa products for local consumption and exports (Awua, 2002).

There are various post-harvest processes undertaken to maintain cocoa bean quality, these include harvesting, breaking of the pods, fermentation, drying, and packaging. The cocoa beans start fermenting immediately it is broken and removed from the pod. The bean is exposed to several microbial activities from lactic acid, yeast, bacteria and acetic bacteria which advance to forming different range of metabolic end

products, which are mostly precursors for the formation of cocoa flavor. Cocoa bean is the main raw material for manufacturing chocolate; therefore good and quality cocoa is required to produce the needed cocoa ingredients like cocoa butter, powder and liquor (Ardhana and Fleet, 2003).

Drying is initiated when fermentation of cocoa is complete; it is part of the continuous process which ensures the complete fermentation of the cocoa beans and this process usually includes oxidation. It usually enable most of the chemical transformation to take place to ensure continuation of the formation process in order to limit the bitterness and enhance the flavor. Drying is supposed to decrease the water content which is usually about 55% to 7.5% (wb) necessary for reduced transportation and shipment cost, prevent microbial contamination and thus extend the shelf life of the beans and make it safe for storage, shipment and further processing into the chocolate (Afoakwa *et al*., 2008).

Drying of cocoa beans can be done in two ways; either by artificial or sun drying. Sun drying is the traditional method which is widely used and believed to be the most effective way of producing quality cocoa beans, although this method comes with its own shortfalls. Cocoa beans are mostly dried on bamboo mats in Ghana, these mats are usually supported by shorter wood frames which raise the platforms above lower grounds. These mats have been designed such that, they can be rolled up to cover the beans after sunset to protect it from bad weather conditions over the night. A comparison by Manoj *et al*. (2013) on both open Sun and Solar drying revealed that solar drying technology has more advantage over the former, such that beans are able to dry in a shorter time and also produce more quality and hygienic beans with less foreign material such as stones, broken sticks, dead insect remains and insect pest droppings.

Also a study by Nguyen (2007) showed that solar driers are suitable for all weather in the whole year round especially in the rainy season, the drying time of cocoa, which is usually longer than 10 days was reduced to about 6-7 days using solar drying. Therefore, over fermentation (rotten stage) was avoided as well as mould contamination and development of smoky off-flavours as fermented produce are in enclosed structures where the temperature of air surrounding the produce is usually higher than the temperature in the dryer.

1.2 Problem Statement

The irregular drying process, which is usually dependent of weather conditions coupled with nightfall, affects the bio-chemical reaction and colorization of the beans. Though this is a very simple method by which cocoa beans are dried in open sun, the drying time is dependent on climatic conditions and temperature. During the rainy seasons, there are prolonged drying times for about two to three weeks and re-wetting of cocoa beans causing the moisture contents to be over 8%. Incomplete drying due to inadequate or very low temperatures disrupt the drying process and fails to reduce moisture level to the accepted standard. This could result in the development of moulds, high concentration of flavor carbonyls which can lead to mouldy/musty beans, unpleasant flavors and the potential Ochratoxin A (OTA) production among the beans which has to be further stored and later dispatched (CAOBISCO, 2015).

1.3 Justification

With increase demand by clients and processing companies all over world for improved quality of cocoa beans and being productive by using cocoa beans that are free from smoky off-flavours especially PAH, free from external and internal moulds, free from adulteration and debris. As a result, a solar dryer with thermal energy was

contemplated, the storage is set to give the thermal inertia that will be able to aid the solar collector throughout the seasons of unfavorable weather conditions as well as sunset; and in addition make available the required impedance against moisture re-absorption during the rest period (Fagunwa, 2009).

1.4 Main Objective

This study is aimed primarily at assessing whether solar drying technology enhances the quality of cocoa beans over the open sun drying under ambient conditions, using heap fermented cocoa beans.

1.5 Specific Objectives

The specific objectives of the study are to:

1. To use the cut test analysis to determine the effect of the drying methods on the physical appearance of cocoa beans.
2. To compare the drying times of both solar and open sun drying systems.
3. To compare the effect of the drying methods on the sensory attributes of the beans.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Cocoa Composting

Cocoa beans are obtained from a plant in the tropics bearing fruit pods, which is usually called *Theobroma cacao* in the field of botany, (Family Sterculiaceae). A typical cocoa pod contains about 40 beans stacked together by the pulp in each fruit. The pulp of each fruit supply in abundance various type sugars (sucrose, fructose and glucose) that is easy to ferment with a pH level lower enough. The pH level is usually in a range of 3.0 to 3.5, which may probably be due to the existence of citric acids. Cocoa beans are the main materials used in the manufacturing of chocolate products (Ardhana and Fleet, 2003).

The Cocoa beans essentially comprises fragmented cotyledons called "nib" protected by the shell. The shell which is usually known as the "pod" is considered to be of no value to the harvester and is often discarded or at times used as fuel and composite material for farming. However, the importance of the pod is becoming broader and is now treated and produced into powder. The powdered pods are usually sold as cocoa fiber products and used as cocoa powder substitute or an additional fiber supplement for chocolate manufacturing. The nib is an important part of the cocoa bean which is used in the manufacturing of chocolate, especially when roasted and grounded. It is also used to produce cocoa butter and other cocoa foods like desserts and beverages (Becket, 2009).

2.2 Post Harvest Processing of Cocoa

There are various postharvest processes involved in cocoa production; these processes include harvesting, fermentation, drying, packaging, transportation and storage. The immediate post-harvest processes that directly affect cocoa beans quality are fermentation and drying.

These steps are very important in all aspects of quality of cocoa beans and also have bearing on the final cocoa product. Fermentation and drying helps in the formation of flavour precursors and produces stability as well as preservation of cocoa beans. Cocoa beans quality is usually determined based physical parameters such as moisture content, flavour, bean colouration, mouldiness. The drying time of the beans has a bearing on the internal and external colouration as well as the external and internal mouldiness of cocoa beans (Amoa-Awua *et al*., 2007).

2.2.1 Fermentation

Pulp of ripe cocoa pods are removed after harvesting and subject to fermentation during the initial preparatory stages of making chocolate.

Methods used in fermentation process vary across different traditional settings. The methods range from using banana leaves alone or placing the beans on banana leaves on container and baskets in the words of (Jinap *et al*., 2003).

All the conditions surrounding the quality formation processes are regarded as convenient. The completion of the process is expected to last between four to five days using the tray and banana leaves heap respectively. (Kirchhoff *et al*., 1989; Lagunes-Galvez, 2007 and Lopez, 1995).There has been wide range of studies into the benefits of good formation process on the quality beans and how it affects the final chocolate for over a century now in several jurisdictions to identify the microbial species influencing this process according to Schwan *et al*. (1995). A micro bacterial

process end up causing the release of certain metabolic end-product like organic acid and alcohols into the beans to cause their deaths during the fermentation which solubilizes the pulp surrounding the beans. This action triggers a biochemical reaction on the cocoa beans and develops a chemical precursor for aroma, color and the chocolate flavor (Lehrian and Patterson, 1983; Jones and Jones, 1984; Hansen *et al*., 1998; Hashim *et al*., 1998; Thompson *et al*., 2001) (Voigt *et al*., 1994 and Schwan *et al*., 2004).The temperature of the beans rises between ranges of 50-55 degrees during the fermentation process due to the presence of exothermic oxidation reaction (Wood and Lass, 1985).The unpleasant taste, bitterness, acidic and the sour taste of the cocoa beans resulting from high quantity of anthocynidines and flavonoids are greatly minimized through a good fermentation process accepted in the manufacturing industry. Microflora infection in the fermentation process causes a great quantity of beans to get mouldy as a result causing bean germination. The bean germination undergoes some physical and physiological developments rendering the beans defective.

2.2.2 Drying of Cocoa Beans

Cocoa beans are dried mostly using sunlight, especially in areas of abundant sunlight during harvesting. After the fermentation of the beans, it is spread on trays, bamboo mats, or a specially prepared platform on the ground to dry. Drying the beans using sunlight is believed to be one of the low cost, effective ways of producing quality beans in a friendly environment. In most part of the West African countries, the beans are dried on any appropriate surface either on the bare concrete floor, polythene sheet. For instance, cocoa beans are preferably dried on bamboo mats and platforms supported above ground level with wooden frames in Ghana. The mats are easy to rolled up against bad weather during the drying process and also makes sorting of

defective beans and other foreign materials from the bulk with fewer contamination. In each of the situations, the beans are turned periodically and at sunset they are heaped and protected from bad weather condition or when it rains. Drying the beans using sun usually takes approximately seven sunny days weather to reduce the moisture content to the accepted 8% required to prevents the beans from becoming mouldy when stored. In an environment where there is limited sunny days during harvest season, other artificial methods are like solar drying are employed to salvage the situation. Several low cost technologies have been introduced as time evolved to dry cocoa beans artificially and this includes the use of translucent plastic tent or roof erected over the cocoa and in addition solar energy collectors (Beckett, 2009).

2.3 Drying Methods

2.3.1 Sun Drying

Getting off moisture from a product by drying it with sunlight is an old age practice throughout civilization. This method is usually referred to as sun drying. An item or product's temperature rises during this process due to its direct contact with the solar radiation. Sun drying is noted to be the most widely used traditional way of drying products, even with its varied downsides. Among the common downsides one may experience for adopting this method include; lack of protection of crops from harsh weather conditions, contamination by insects and other vectors; prolong drying durations which could lead to poor quality of final product. This could occur from a possible cause of enzyme or non-enzyme decolourization arising from mould formation (Fuller, 2002).

2.3.2 Artificial Drying

Artificial method of drying crops is the commonest method used among countries with limited or relatively no drying weathers during their planting and harvesting seasons. Countries in South Eastern Asia, Southern America, and sometimes West Africa depend heavily on this method to dry their cocoa beans after harvest and fermentation. However, the quality of the bean is sometimes compromised, contamination from smoke of fire and even at times excessive drying of the beans. The Samoan or convection driers are the simplest type of artificial drying system which consists of a simple flue in a plenum chamber and a permeable drying platform. Air inlets must be provided in order to allow the convection current to flow without allowing smoke to taint the beans. These dryers are widely used due to their easy nature to build in Western Samoan and Samoan Islands, Brazil (secador drier) and Cameroun. There are other non-conventional methods of drying the beans using platforms with heat exchangers. The products of combustion are separated from the hot air into the atmosphere. In another form, the product of combustion is mixed with the warm air, which is then spread to the beans through the use of a direct fire heater. These driers may derive their power sources from either oil or other solid fuel. The inclusion of a fan pushes the warm air through the beans creating a forced draught dryer. There are other drying procedures which are done through conduction, where a concrete or slate platform is built with a heating source which warms the platform from beneath to keep the beans or crops dry. In Cameroun there are similar types of this drier which is built from metal oil drums or similar containers connected with flues embedded in cement. This type of drier is popularly known as the Cameroun dryers has it downsides as heat is not distributed uniformly. Other innovative technologies have techniques have been developed in addition to these drying

methods to solve the problems of turning or raking the beans on the drier. That is either stirring the cocoa beans in a circular bed or turning it in a drum designed purposefully to rotate (ICCO, 2012).

2.3.3 Solar Drying

Solar drying is another mechanism through which crops can be dried which also comes in different forms. Through this mechanism, the surrounding air temperature of the crop is elevated above ambient temperature. However, in certain situations the crop's temperature may also be raised by direct absorption of solar radiation depending on the type of dryer in use. Solar dryers are mostly known to have a faster drying time than sun dryer because the former is able to produce higher temperature compared to the latter which usually leads to an improvement in the final product quality. Losses encounter as a result of insects and vector attacks and spoilage from rain drops are prevented when a solar dryer is used.

2.3.3.1 Direct Mode

With this mechanism, crops are placed directly under sunlight exposed to the solar radiation directly. A transparent material is used to cover the container (structure) which containing the crops to enable the radiation to pass through to the crops and its surrounding. This radiation is transformed into heat which raises the temperature surrounding the crops. The direct transfer of solar radiation to crops is one of the most efficient ways of generating useful energy for drying through conversion of solar radiation. Quality of crops is always increasing through its direct contact to radiation from solar. For instance, first grade apricots achieve a more concentrated orange color when all its green pigments are destroyed from the effects from ultraviolent solar radiation during the direct drying process. The downside of this method is that, the temperatures are difficult to control because the crops itself absorbs solar radiation

directly. Meanwhile, temperatures from the crops are the major determinants of the drying rate and final quality. Despite its disadvantages, its relative lower cost and simple mode of operation enables all producers to adopt this mode irrespective of their capacity. Direct mode solar dryer can be built to handle several capacities ranging from few kilograms to several metric tons (Fuller, 1991).

2.3.3.2 Indirect Mode

In the indirect dryer, exposure of solar radiation is not directly on the crop but the incident solar radiation is absorbed by some other surface usually a solar collector which is then transformed into heat energy. The air that passes through these absorbers is then warmed, and further transferred to the crops which are housed in non-transparent shed to be dried. The final quality of certain crops types and spices are compromised when they are allowed to come into contact with direct sun radiation for a longer period. A classic example of such plant is cardamom. When they are exposed to sunlight directly, it is likely their pods will burst open which may like to destroy the chlorophyll. Cardamom becomes almost valueless when the pods are no longer the greenish look as the prices to sell it is reduced drastically. Therefore, when drying this type of crop is preferable to use indirect solar drying system in order to maintain the crop quality.

Desirably and accurate temperature can be achieved with this mode of drying, when a fan is used push the air through the solar collector. Despite its numerous benefits, it has its own shortcomings which include its construction difficulty and complexity, high cost of construction and maintaining it. High and controllable temperatures can be achieved in this type of dryer if a fan is used to move the air through the solar collector. Like direct mode dryers, the capacity can range from a few kilograms to several metric tons (Fuller, 1991)

2.3.3.3 Mixed Mode

This is the situation where both direct and indirect modes of drying the seeds are put together as one mode of drying. . With this drying system, temperature surrounding the crop is increase through both direct solar radiation absorption and heat transformation from another solar absorber. This mode of drying is reported to be effective and demonstrate stronger advantage over the others, however, using such mode of drying comes with huge cash burden. Because its complexity makes it quite expensive to adopted for commercial use and as a result is one of the unpopular methods used in practice apart from the two other drying modes. (Fuller, 1991)

2.4 Factors Affecting Quality of Dried Cocoa Beans

2.4.1 Flavour

Flavor is one of the attributes that defines the quality of beans for which manufacturers of cocoa products always look out for. These criteria comprise of both the concentration of the cocoa and chocolate flavors, coupled with other supplementary flavors devoid of any defects. These defects normally occur as a result of excessive or inadequate fermentation and other contaminations.

The cut-test is mostly used to assess the quality of beans as it is able to identify most flavor defects like astringent and excessive bitterness which usually result from high percentage of mouldy and infested beans. The cut-test however cannot solely be regarded as a dependable check for flavour quality. Testing and assessing of quality of cocoa flavour, has to be carried out on liquid form, otherwise known as liquor or full chocolate and subject to tasting. An experienced panel of about five to ten tasters are used. Though, detection of off-flavours can be done effectively by single professional tasters as long as more tasting repetitions are carried out for better statistical rigor, also for all-inclusive flavour description. Liquor tasting is the more demanding but

benefits from the fact that liquors can be tasted directly without adding any sugar, cocoa butter or any form of milk and impart flavour notes unrelated to the cocoa beans being tested. Chocolates also require time for the flavour to stabilize after preparation, do not keep liquors that are not kept either deep frozen or at ambient temperature are often difficult to prepare to normal standards on the farms and estates where the beans are produced due to the need for processing equipment (CAOBISCO, 2015).

2.4.2 Off- Flavours

2.4.2.1 Mouldy Beans

The presence of moulds mainly in the beans, and samples with not less than 3% of internal mould can impart a mouldy/musty flavour into the liquor, and the chocolate produced. During processing mouldy off-flavour cannot be removed by the manufacturer however prolonged fermentation, inadequate or too slow drying as a result of bad weather conditions and excessive moisture re-adsorption due to poor storage system are the primary causes of flavour defects. Through cut test analysis a mould defective bean can easily be identified. High mould growth in cocoa results in high levels of free fatty acids (FFA) in cocoa butter and some specific moulds could cause the formation of Mycotoxins, including Ochratoxin A (OTA) (CAOBISCO, 2015).

2.4.2.2 Smoky Beans

Smoke from wood fires or other sources causes contamination in the drying process and even at storage could lead to objectionable flavor from smoke in the liquor and chocolate. This off-flavour can also not be removed during chocolate production. The presence of Smoky beans in a sample may be detected by crushing some beans in the

hand, or preferably in a mortar, and sniffing them though not as reliable as liquor tasting in the making chocolate on a small scale. A smoky off-flavour is sometimes described as “hammy” because of it is reminiscent of smoke-cured bacon. The off-flavour arises through smoke contamination and over fermentation and can be eliminated when an effective fermentation process devoid of contacts with possible contamination from smoke source in the drying and storing process. Avoiding contact with smoke decreases the chances of the bean contamination with hydrocarbon mineral oil and polycyclic aromatic hydrocarbons (PAH) (CAOBISCO, 2015).

2.5 Quality Control

The price of cocoa beans is hugely influenced by its quality as buyers are only to pay the agreed prices to the famers based on the beans offered for sales. This makes the role of quality control an essential element in processing industry.

The Quality Control Co. Ltd of the Ghana Cocoa Board was therefore established in 1968 to achieve this aim by ensuring that farmers produce and process quality cocoa for both local and international markets. In the course of that, the following standards were set as a benchmark for farmers to follow during the harvest and processing the beans. Proper fermentation and thorough drying of the beans; packaged beans must be devoid of foreign matter, insect infestation, flat, cluster, germinated beans; conformance to the content limits of slate and mould as well as meeting the required moisture level (7.5%) and accepted number of beans per unit (100grams) when weighed.

In all cocoa-growing regions in Ghana, quality control is handled by professionals from Quality Control Company Limited (COCOBOD. Implementation of quality control measures are necessary for farmers to understand the quality parameters and standards as they get involved in the marketing of the produce, in order to achieve the

global desire for quality beans and sustainable cocoa production. This will help as a guide for cocoa farmers to have a broader responsibility in ensuring conformance to quality standards so as to address any inadequacies at an optimum moment. Accordingly with the support from farmers, they are able to meet better marketing opportunities. Encouraging farmers 'participation in cocoa production and marketing will enable several issues including traceability to be handled easily (CAOBISCO, 2015).

2.6 Sensory Evaluation

Flavour is the most essential attribute for chocolate producers. Directly tasting roasted ground nib or cocoa mass (cocoa liquor) can help to readily detect off-flavours such as smoke or putrid over fermentation. On the other hand, mixing the mass with finely ground sugar and/or water or preparing a small-scale dark chocolate can make it more palatable. These tests are vital for beans from origins that are inconsistent in quality or prone to off-flavours. Assessing the level of cocoa flavour and other flavours (such as acidity, bitterness, astringency and any ancillary flavours) for fine cocoa are more difficult but with appropriate test designs and statistical analysis by a well-trained sensory assessment panel results required can be achieved (Fowler, 1994).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Material Source

The study was conducted at Dunkwa, a cocoa growing district in the Western region of Ghana. Ripe cocoa pods harvested from some selected cocoa farms located in Dunkwa in the Western region were transported to the Food Science Department premises (KNUST).

3.2Location of Experiment

The experiment was conducted at the laboratory of Food Science Department of the Nkrumah University of Science and Technology; while sensory evaluation was done at Cocoa Processing Company, Tema in the Greater Accra Region. The experiment was performed within a temperature range of (25-60) °C and a relative humidity range of (10-84) %.

3.3 Fermentation

Heap fermentation was used for this experiment. Banana leaves were neatly laid on the ground in a circular form overlapping each other on a gentle sloping ground for easy draining of cocoa sweating. Ripe cocoa pods harvested were then broken and beans scooped out were gathered to a heap. The freshly heaped beans were tightly covered with banana leaves and held on firmly with other planting materials laid on top the covering. Fermentation was done simultaneously for 120 hours with turning after every 48 hours.

3.4. Traditional Sun drying

Bamboo mats were placed on a raised platform (1m high) to protect the cocoa beans against animals and foreign matters. Fermented beans, whose placenta had been

removed (32 kg) were weighed and then spread on equally demarcated area (Fig 3.1).The beans were covered with a tarpaulin to prevent the condensation of dew on the beans at night. Drying was stopped at moisture content of below 7.5%.

Fig 3.1: Fermented beans on Raffia mat

3.4.2 Solar Drying

3.4.2.1 Philosophy of design

The solar drying chamber was constructed with local materials available and accessible to most of the peasant farmers with little or no formal education (Fagunwa *et al*., 2009) and which is relatively cheaper to afford.

The mixed solar dryer was made of wood with dimensions: 265cm x 175cm x 195cm, and comprising of translucent planks polythene sheets. It had drying trays of several compartments with each having a loading capacity of 2kg (Fig 3.2a).

The fermented cocoa beans were transported in air tight containers to be dried in an mixed solar drying chamber situated at the department of food science, KNUST until the accepted moisture level was achieved (7.5% and below). The cocoa beans were spread thinly on drying trays inside the drying chamber at a capacity of 2 kg per tray as shown (Fig 3.2b). Temperature and relative humidity (RH) of the drying environment and inside the solar chamber were monitored using a hygrometer (model: 7MZ5WU8WV4VQ9,Philipines) and temperature readings were also taken by a data logger setup.

Moisture content and drying time were monitored during the drying period. A part of the heap fermented sample of cocoa beans was used as control.

Fig 3.2a: Mixed Solar Chamber

Fig 3.2b: Arrangement of cocoa beans inside solar dryer

3.5 Parameters Studied

3.5.1 Moisture Content

Moisture content of cocoa beans was measured by an instrument called the Aqua Boy moisture meter(model: KPM, Nr.007248, Germany).A sample of beans fairly bulked cocoa beans was collected in a cap electrode and tightened to lock up. The cap electrode was then fixed to the moisture meter and the moisture content was measured and recorded. This was done for five different samples points and the moisture contents were recorded at two hours interval from 8am-6pm throughout the drying period.

An average was then calculated using the formula:

Average of moisture reading

$$= \frac{Sum\ total\ of\ recorded\ moisture\ readings}{\text{Total number recorded}} \times 100$$

3.5.2 Cocoa Bean Count Analysis

Cocoa bean count per 100g was weighed using an instrument called Cocoscale (model: T6538, United Kingdom). This was done for both the solar dried and open sun dried samples, 300g of cocoa beans for each treatment were sub grouped into three as shown in Fig 3.3aand Fig3.3b. A visual inspection was then employed to identified unusual cocoa beans out of each sub grouped sample; this was done separately for both treatments and recorded (Fig 3.4).

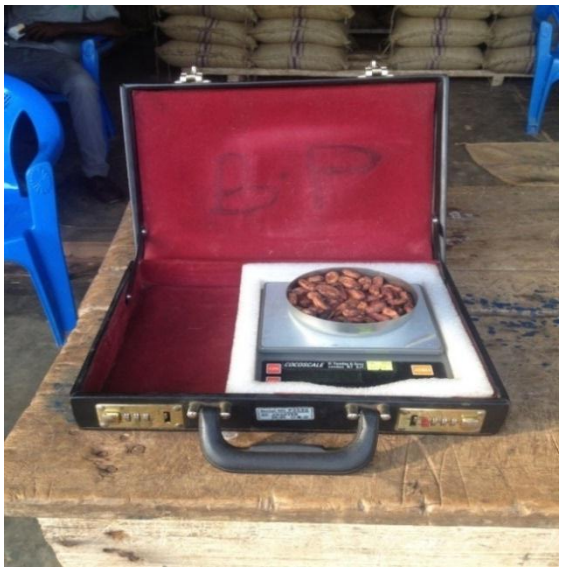

Fig 3.3a: Weighing Cocoa beans

Fig 3.3b: Cocoa bean count

Fig 3.4:Picking Unusual beans

3.5.3 Cut Test

The cut test was done in line with the Quality Control standards of the COCOBOD, where approximately three hundred dried beans were slice open lengthwise with a small pocket knife and the various defects were handpicked under direct observation under well-lit environment by a specialist. Beans were picked and grouped for the various defects, internal mould, slate, germinated, weevil infestation and other defects as shown in Fig 3.5 and Fig 3.6. Each grouping were counted separately and the numbers for each defect was recorded as a percentage of the sampled beans (300) for each treatment.

Fig 3.5: Cross longitudinal section of cut cocoa beans before picking of defect

Fig 3.6: Defective beans picked from the cutting in Plate

Below is the set of data which was collected during the cut test.

3.5.3.1 Average mouldy beans

From the Solar and open dried methods, beans that showed signs of mould from the sample of 100 beans after sorting and counting the beans are considered to be defective. The quantity was then expressed as percentages based on the accepted formula (QCC, 2011).

$$\textbf{Percentage of Mouldy beans (TM)} = \frac{number\ of\ mouldy\ beans}{\text{Number of beans cut}} \times 100$$

3.5.3.2 Average slaty beans

Sorting for Slaty bean was carried out from the sampled 100 beans under observation and numbers were reported as percentages based on the g the formula below (QCC, 2011).

$$\textbf{Percentage of Slaty beans (TS)} = \frac{number\ of\ slaty\ beans}{\text{Number of beans cut}} \times 100$$

3.5.3.3 All other defects

Other defects like germinated beans, weevily, foreign matter, and flat beans were also looked out for from the100 sampled cut beans. The beans with these characteristics were collected and counted and expressed as percentages (QCC, 2011).

$$\%\ \textbf{All other defects} = \frac{number\ of\ AOD\ beans}{\text{Number of beans cut}} \times 100$$

3.5.3.4 Purple beans

Beans with purple colour were also looked out for as part of the defect among 100 beans Quantity was then expressed as a percentage. Using this formula (QCC, 2011).

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

3.5.3.5 Percentage Purity

Purity of the beans was also calculated using the various defective checks (parameters) observed for the quality of the beans. This was also expressed as a percentage using this formula (QCC, 2011).

Percentage of Purity (P) = 100 – [TM + TS + AOD]

Where,

TM = Percentage mouldy beans found

TS = Percentage slaty beans found

G = Percentage germinated beans found

AOD = Percentage (Germinated, Weevily, Flat, Foreign Matter etc.)

3.5.4 Temperature and Relative Humidity

Temperature and relative humidity inside the chamber and ambient were monitored every 30 minutes from 8:30am-6pm daily with a data lodger setup and a hygrometer respectively. Fig 3.7a and Fig 3.7b shows the system setup.

Fig 3.7a: Data Logger Setup

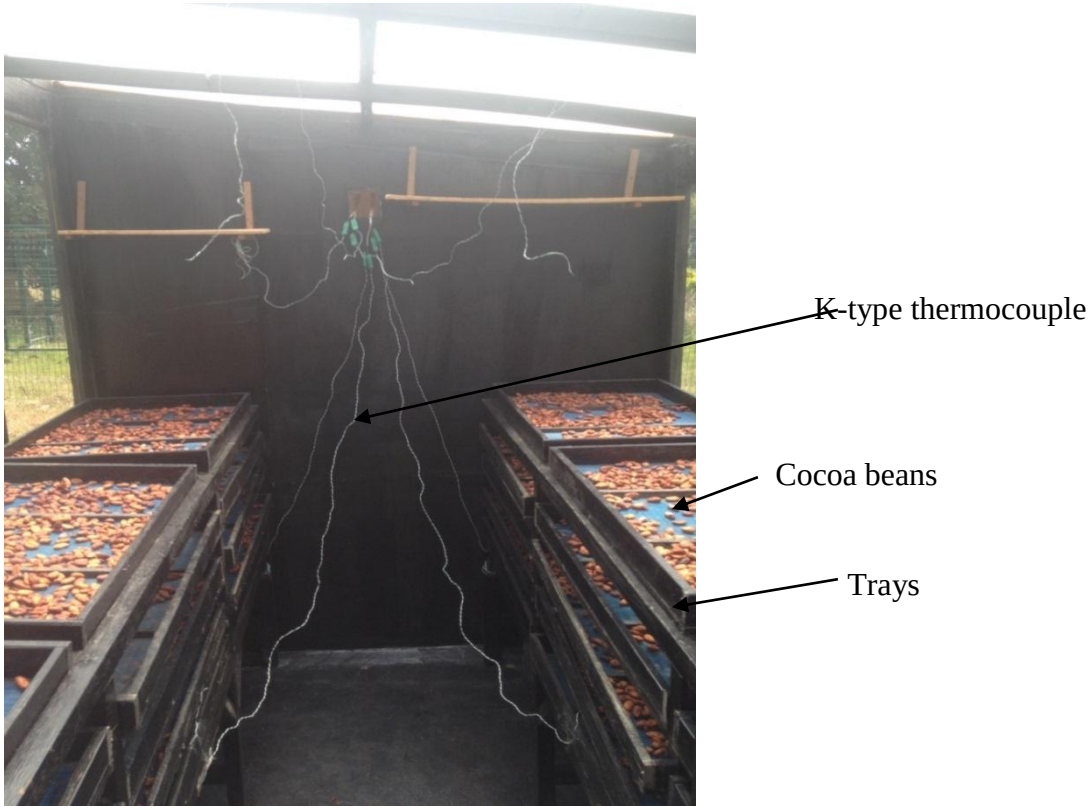

Fig 3.7b: Display of temperature measuring connectors

3.6 Sensory Evaluation

Samples of dried cocoa collected for namely heap solar dried and heap open sun dried cocoa beans were prepared and stored at optimal laboratory conditions at the experimental laboratory of the Research and Development Department of Cocoa Processing Company Ltd.

About 300g of each sample was appropriately labeled and roasted at 130°C for 30 minutes, then the samples were allowed to then cool for 30 minutes and after which 100g of the cooled samples were randomly sampled from each treatment and manually deshelled immediately to separate the nibs from the shells.

Milling of cocoa samples was started using a Stepan Mixer (model: UM-24 E, Germany) and the labeled samples were then sieved to a particular size range of 14-25 microns using an Attrition Ball Refiner (WIS) (model: CAO 1000, Netherlands).

Cocoa liquors rightly labeled as X (Solar dried) and Y (Open sun dried) were then molded into cubes awaiting sensory test.

A multiple comparisons test was used for the sensory analysis; the samples labeled were presented to 20 panelist to be compared to a known reference sample labeled F (Cocoa processing standard). The panelist were to assess based on the following descriptors: Appearance, Flavour, Taste, Mouthfeel and Aftertaste in a questionnaire. Proportions per each descriptor, and score their preference in percentage terms. The preference score for each descriptor scored by the panelist was estimated by dividing it by the total number of panelist and expressed as percentage. The estimated percentage was classified as follows: Weak= (0-49%); Neutral=50%; Excellent= (51-100%).

3.7 Laboratory Work

Samples were taken in triplicates and assessed for the following;

Proximate analysis, Free Fatty acid (FFA), Titratable Acidity, Vitamin C and pH, according to the recommendations of AOAC, (2012).

3.7.1Moisture Content

Moisture content was determined using the oven drying method. Five grams (5g) of sample was placed on to a weighed petri dish and placed in an oven thermostatically controlled at 105 degrees for 8 hours until a constant weight was achieved. The dish was removed and put in a desiccator to cool to room temperature and weighed.

The moisture content was calculated from the formula;

$$\%\mathbf{moisture}\ \left(\frac{\mathbf{wt}}{\mathbf{wt}}\right) = \frac{\text{Wt of wet sample} - \text{wt of dry sample} \quad \times 100}{\text{Wt of wet sample}}$$

3.7.2 Determination of Ash content

About 5g sample was weighed into a tarred crucible and placed in a cool muffle furnace and ignited for 2 hours at about 600 degrees. It was turned off and allowed to cool until the temperature had dropped to at least 250 degrees or preferably lower. The door was opened carefully to avoid losing ash that may be fluffy. Using safety tongs, the crucibles were quickly transferred to a desiccator with a porcelain plate and desiccant. The desiccator was then closed to allow the crucibles to cool prior to weighing.

The ash content was calculated using the formula;

$$\%\mathbf{Ash} = \frac{(\text{weight of crucible} + \text{ash}) - (\text{weight of empty crucible x } 100}{(\text{Wt of crucible} + \text{sample}) - \text{wt of empty crucible}}$$

3.7.3 Determination of Fat Content

Fat content was determined by soxhlet extraction. A previously dried (air oven at 100°C) 250 ml round bottom flask was weighed accurately. About 5.0g of dried sample to 22 ×80mm paper thimble or a folded filter paper was also weighed. A small glass wool was placed into the thimble to prevent loss of the sample. About 150ml of petroleum spirit B.P 40-60°C was added to the round bottom flask and the apparatus was assembled. A condenser was connected to the soxhlet extractor and refluxed for 4 - 6 hours on the heating mantle. After extraction, the thimble was removed and the solvent recovered by distillation. The flask and fat/oil was heated in oven at about 103°C to evaporate the solvent and cooled down to room temperature in a desiccator. The flask was then weighed and determined weight of fat/oil collected.

$$\%\mathbf{Fat}\ (\mathbf{dry\ basis}) = \frac{(\text{wt of flask} + \text{oil}) - \text{wt of flask x } 100}{\text{Weight of sample}}$$

3.7.4Fibre Determination

About 2g sample from crude fat determination was weighed into a 750ml Erlenmeyer flask and 200ml of 1.25% H_2SO_{4was} added. The flask was immediately set on a hot plate and connected to a condenser. The contents were allowed to boil within 1 minute of contact with solution. At the end of 30 minutes, the flask was removed and immediately filtered through linen cloth in funnel and washed with a large volume of water. The filtrate containing sample from acid hydrolysis was washed back into flask with 200ml 1.25% NaOH solutions. The flask condenser was then connected and boiled for exactly 30 minutes and filtered through Fischer's crucible and washed thoroughly with water with the addition of 15ml 96% alcohol. Crucible and contents were dried for 2 hours at 105 °C, cooled in desiccator and weighed. The crucible was ignited in a furnace for 30 minutes, cool and reweighed.

$$\% \ \mathbf{Fibre} = \frac{\text{Weight of crucible} \ + \ \text{sample (before} - \text{after) ashing x 100}}{\text{Weight of sample}}$$

3.7.5 Protein Determination

To the digestion flask, 2g of sample and a half of selenium –based catalyst tablets and a few anti-bumping agents were added. Also 25ml of concentrated $H_2SO_4$was added and the flask was shaken until the entire sample was thoroughly wet. The flask was placed on a digestion burner and heated slowly until boiling ceased and the resulting solution was clear and the solution was cooled to room temperature; the digested sample solution was then transferred into a 100ml volumetric flask and made up to the mark.

3.7.5.1Distillation

The apparatus was flushed out before use by boiling the distilled water in a steam generator of the distillation apparatus with the connections arranged to circulate

through the condenser, for at least 10 minutes. The tip of the condenser was lowered to the receiving flask and heated for 30 seconds in order to carry over all liquid in the condenser.

About 25 ml of 2% boric acid was pipetted to 250ml conical flask 2 drops of mixed indicator was added.

The conical flask and its contents were placed under the condenser in such a position that the tip of the condenser was completely immersed in solution. A measure of 10ml of the digested sample solution was placed into the decomposition flask of the Kejdahl unit, fixed and an excess of 40% NaOH (about 15-20ml) was added to it. The ammonia produced into the collection flask was distilled with the condenser tip immersed in the receiving flask till a volume of about 150ml–200ml was collected. The apparatus was flushed before distilling another sample and on completion of all distillations as in step 1 above. Steam needed was passed until only 5ml of distillate was obtained.

3.7.5.2 Titration

The distillate was titrated with 0.1N HCL solution and acid was added until the solution became colorless; additional acid was added until the solution became pink. The nitrogen content was determined, at least in duplicate, and a blank determination was ran using the same amount of all reagents as used for the sample. The blank would correct for traces of nitrogen in the reagents and include digestion as well as distillation.

Calculation:

$$\% \textbf{ Total Nitrogen} = \frac{100 \text{ x } (Va - Vb) \text{x NA x } 0.01401 \text{ x } 100}{W \text{ x } 10}$$

Va- volume in ml of standard acid used in titration

Vb- volume in ml of standard acid used in blank

NA- normality of acid

W- Weight of sample taken

1. Nitrogen free extract (NFE)

   Calculation

   NFE (%) =100 - (% moisture +% fat + % crude +% protein +% ash)

2. Carbohydrate

   Calculation

   Carbohydrate (%) = % crude fibre + % NFE

   OR

   Carbohydrate (%) =100 - (% moisture +% fat +% protein +% ash)

$$\textbf{Calculations for drybasis} = \frac{(100 - \%\ \text{moisture})\ \text{x wet basis}}{100}$$

3.7.6 Determination of Free Fatty Acids (FFA)

The FFA for each treatment was determined by adding Weigh 5 (±0.05) g of sample into a 250 mL glass stoppered Erlenmeyer flask. The weight was recorded to the nearest 0.01 g and then fifty (50 mL) of neutralized alcohol (ethanol or methanol).

The flask was swirled until the sample was completely dissolved until bubbles were seen

Using a dispensing device, 0.5 mL 1.0 % (w/v) phenolphthalein in 1-propanol was added.

The burette was then filled with 0.1 (0.5) N sodium hydroxide solution and titrated until the appearance of first permanent pink colour. The volume of titrant used was accurately recorded to two decimal places.

Calculations;

$$\% \textbf{ of FFa} = \frac{\text{ml of alkali used x N. NaOH x M}}{\text{weight of sample}}$$

M= 20.0 as Lauric Acid for coconut oil, palm kernel oil and 25.6 as Palmitic Acid for palm oil and fraction 28.2 as Oleic Acid for seed oils.

3.7.7 Vitamin C

About 20 mL aliquot of the sample solution was pipetted into a 250 mL conical flask and 50 mL of distilled water and 1 mL of starch indicator solution were added. The sample was then titrated with 0.005 M iodine solution and the endpoint of the titration was identified as the first permanent trace of a dark blue-black colour due to the starch-iodine complex. The titration with further aliquots of sample solution was repeated until concordant results (titre agreeing within 0.1 mL) were obtained.

$$\textbf{Ascorbic acid content } (\textbf{mg/100g}) = \frac{\text{titre x molarity of titrant x 176.12 x 100}}{\text{Weight of sample}}$$

$$\textbf{Ascorbic acid content } (\textbf{mg/100g}) = \frac{\text{titre x molarity of titrant x 176.12 x 100}}{\text{Volume of sample}}$$

3.7.8 Determination of pH

About 20ml of well mixed (homogenized) sample was transferred into a beaker, the electrode from the storage solution was removed and rinse thoroughly with distilled water. A probe was gently wiped with tissue paper and dipped into the test solution and a reading was taken when the value became stable. The electrode was replaced after rinsing with distilled water (AOAC, 2012).

3.7.9 Titratable acidity

About 5g of the sample was weighed into 200ml conical flask and 50ml of distilled water was added. Titration to a pale pink end-point with 0.5N NaOH solution using

phenolphthalein as indicator was done. Total titratable acidity value was calculated using the following formula;

$$\textbf{Titratable acidity}(\%) = \frac{\text{titre x Normality of titrant x 64 x 100}}{\text{Weight of sample x 1000}}$$

The acid factor is 64 for citric acid which is the dominant acid in citrus fruits (OECD, 1990).

3.8 Data Analysis

Data obtained for all parameters on the field both chemical and physical characteristics were subjected to the Independent Sample T- test at 95% confidence interval using Statistical Package for Social Sciences (SPSS version 20) and Stata 14 software. Tables, graphs and pictures were used to present the outcome.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Moisture loss, temperature and relative humidity changes during drying

A graphical representation of the air temperature and relative humidity are shown in Fig 4.1. In this figure it is observed that temperature increases with decreasing relative humidity. The higher the air temperature the lower the relative humidity. The solar system recorded relatively higher temperature than the open sun system. However, the temperature conditions in both drying methods were within the drying temperature range of not exceeding 70° C recommended in the study of Jacquet *et al*. (1980). Drying at temperatures above 70°C was reported to increase astringency and acidity which leads to poor quality of dried cocoa beans.

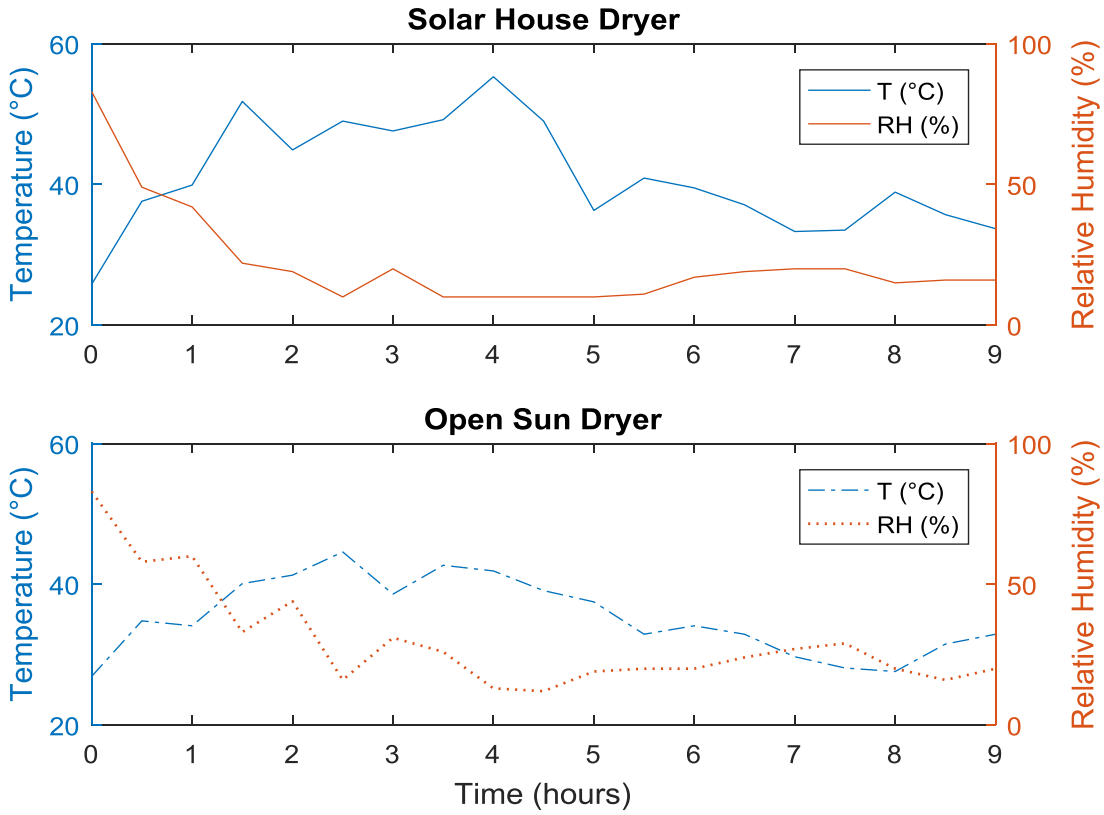

Figure 4.1: Temperature and Relative Humidity changes during drying of the cocoa beans throughout the day.

The relative higher drying rate (shorter drying period) as illustrated in Fig 4.2 for the solar drying technique could be attributed to the higher temperature combined with low relative humidity conditions in the solar drying system. Also as shown in Fig 4.2, there is a noticeable sharp rise in moisture level during the rest periods (6pm-8am) throughout the drying period. After fermentation, the moisture content was about 51% and it must be reduced through drying to less than 7.5% to prevent mould growth. A rewetting problem was envisaged throughout the drying process after the resting period. This was pronounced in the open sun drying process comparatively. The moisture content reduced to 6% and 7% after the third and sixth day for the solar drying and open sun drying systems respectively indicating a shorter drying time for the solar system than the open sun system. Ndukwu *et al*. (2011) reported a range of 5-7% for both solar dried and open sun dried cocoa beans. Readings recorded by the Aqua Boy moisture meter was 6-7% (Table 4.1) which was lower than 8.35-8.82% obtained in the proximate (Table 4.2). The difference might be due storage method and temperature conditions during the rest period for the proximate.

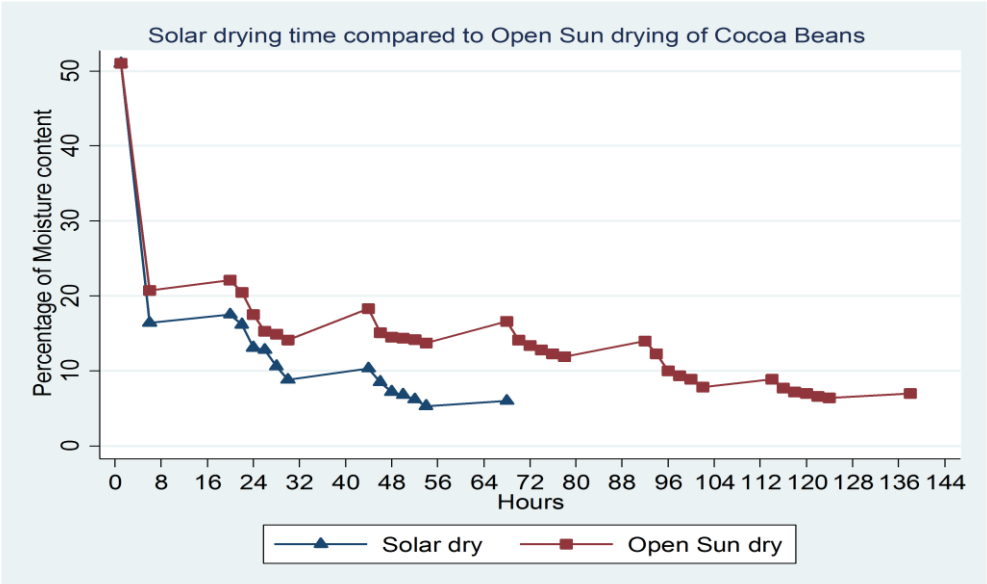

Figure 4.2: Moisture loss during drying of the cocoa beans

Table 4.1: Moisture loss during drying over time

Time (Hrs)	Solar Dried (wb %)	Std. Deviation (±)	Open Sun Dried (wb %)	Std (±)
0	51.0	0.00	51.0	0.00
6	16.4	0.65	20.7	0.45
20	17.5	1.00	22.1	0.42
22	16.1	0.50	20.5	0.46
24	13.1	0.89	17.5	0.50
26	12.8	1.35	15.3	0.67
28	10.6	1.08	14.9	0.89
30	8.7	0.57	14.1	0.55
44	10.3	0.97	18.3	0.67
46	8.5	0.50	15.1	0.89
48	7.2	0.27	14.5	1.00
50	6.8	0.84	14.4	0.89
52	6.2	0.57	14.2	0.45
54	5.3	0.45	13.7	0.45
68	6.0	0.35	16.6	0.55
70			14.1	0.55
72			13.4	0.65
74			12.8	0.57
76			12.3	0.67
78			11.9	0.55
92			14	0.71
94			12.3	0.67
96			10	0.71
98			9.3	0.45
100			8.9	0.74
102			7.8	0.27
114			8.9	0.42
116			7.7	0.67
118			7.2	0.57
120			7	0.71
122			6.6	0.42
124			6.4	0.42
138			7.0	0.35

Triplicate analysis showing the means ± Std of Solar and open Sun drying systems.*Solar dried sample reached 6% after 68hours.

4.2 Proximate Composition of Heap Fermented Dried Cocoa Beans

Table 4.2 indicates that statistically, there was considerable differences in the values obtained for crude fats, crude fibre, and total carbohydrates for both solar and open sun drying methods. Values for crude protein were found to be higher in the solar dried sample than the open sun dried while ash content was comparatively low. These differences could be attributed to temperature variations in the two drying systems with the solar dryer having high temperatures and the open sun system having a lower drying temperature but longer drying duration which is likely to affect the proximate composition of the samples.

4.2.1 Moisture Content

Table 4.2 shows moisture content value obtained in the proximate analysis for open sun dried cocoa beans was 8.82% which was lower than that of the solar dried samples (8.35%). At 95% confidence interval, there was no considerable difference between moisture contents for both samples. High moisture levels of the beans beyond 7.5% shows high water content and the likely development of mould and bacteria growth during storage.

4.2.2 Ash Content

The values obtained for ash content in the study were 3.43% and3.72% for the solar dried and open sun dried samples respectively; the results show that the ash content decrease as the drying temperature increased. There was no significant difference between the ash content for both drying methods. Olaofe *et al*. (1987) reported that the allowable limit for ash content in cocoa beans is 10% and values obtained in this study is far lower. Ash content is the inorganic residue left after burning the sample at

600°C. A study by Ieggli *et al*. (2011) reported that high ash content in dried cocoa beans and its products gives an indication of the high mineral contents.

Table 4.1: Proximate composition of heap fermented dried cocoa beans

Parameter	Solar Dried	Open Sun Dried
Moisture	8.35±0.06[a]	8.82±0.14[a]
Ash	3.43±0.11[a]	3.72±0.15[a]
Fat	39.24±0.31[a]	42.26±0.07[b]
CrudeFibre	22.99±0.13[a]	16.72±0.91[b]
Protein	13.89±0.01[a]	13.01±0.13[a]
Digestible CHO	11.63±0.46[a]	15.94±0.80[b]
Total CHO	34.62±0.32[a]	32.65±0.0.11[b]

Values in the same row with different subscripts are statistically different ($p<0.05$)

4.2.3 Crude Fat

The value obtained for the crude fat for open sun dried cocoa beans (42.26%) was considerably higher than that recorded in the solar dried sample, 39.24% (Table 4.2). High temperatures in the solar dryer accelerates oxidation during drying causing oxidative rancidity associated with the consequentially lower fat content recorded for the solar dried cocoa beans. Afoakwa *et al*. (2014) reported that high temperature drying increased degradation of fat in solar dried cocoa beans. Crude fat provides the main reservoir of energy for the human body providing nine calories of energy per gram when it undergoes catabolism.

4.2.4 Crude Protein

The drying methods showed no considerable effect on the protein content. The solar dried cocoa beans in this study recorded13.89 % crude protein while that of the open sun dried sample gave 13.01 %. Amoah (2013) reported a value of 13.38 % for solar

dried beans. A finding by Afoakwa*et al*. (2015)reported crude protein values decreased with prolonged drying duration. This was marked in open sun drying system with a drying duration of 7 days.

4.2.5. CrudeFibre

The value obtained for the crude fibre content in the solar dried cocoa beans (22.99%) was higher than that of the open sun dried beans which is 16.72%. The difference may be due to the drying duration in both drying methods; According to findings by Afoakwa *et al*. (2015), at high temperatures there is limited enzymatic activity due to case hardening limiting enzymatic reactions retaining more fibre in a shorter drying time. The fibre content in this research (16.70 – 23 %) for dried cocoa beans was lower than 34.8 % reported by Alex (2018). Food products which are rich in fibre prevents constipation, cardiovascular diseases, obesity, and protects the colon. Dietary fibre stimulates the intestines and traps cholesterol by minimizing its absorption from the digestive system into the body (Pereira, 2004).

4.2.6 Digestible Carbohydrates

High carbohydrate content is the body's preferred source of fuel to provide the energy for all its activities. In this study, the digestible carbohydrate content of the solar dried cocoa beans was significantly higher than that of the open sun dried beans (see Table 4.2). A report by Afoakwa *et al*. (2015) showed that carbohydrate content decreases with increasing drying time as there is continuous breakdown and participation of non-reducing and reducing sugars over prolonged drying time.

4.3 Physiochemical properties of heap fermented dried cocoa beans

Table 4.3 shows the effect of the different drying methods on the physicochemical properties of the heap fermented cocoa beans. Statistically, there was significant difference at 5% confidence interval for recorded values of free fatty acid, titratable acidity and ascorbic acid content for both the solar dried and open sun dried samples.

Table 4.2: Physicochemical properties of heap fermented dried cocoa beans

Parameter	Solar Dried	Open Sun Dried
Free Fatty Acid	0.96 ± 0.03^{a}	0.77 ± 0.01^{b}
Titratable Acidity	1.89 ± 0.00^{a}	2.01 ± 0.00^{b}
pH	5.01 ± 0.00^{a}	5.23 ± 0.00^{a}
Ascorbic Acid	470.72 ± 4.70^{a}	524.86 ± 4.31^{b}

Values in the same row with different subscripts are statistically different ($p<0.05$)

4.3.1 Titratable acidity

There is comparatively higher value of titratable acidity in the open sun dried cocoa beans than the solar dried cocoa beans. Bonaparte (1998), predicts that rapid drying easily evaporates acids (volatile acids) produced during fermentation. This confirms the results obtained for the present study as the solar drier employs higher temperatures causing rapid drying of the cocoa beans thereby evaporating more of the volatile acids as compared to sun drying which employs lower drying rate.

4.3.2 pH

The solar dried cocoa beans had a pH value of (5.01 ± 0.00) which is more acidic than that of the open sun dried cocoa beans (5.23 ± 0.00). There is rapid drying and case hardening of the testa, due to high temperatures in solar drying and as a result preventing the outward passage of largely acetic acids from the cocoa beans causing

acid retention whereas open sun drying method allows a slow and moderate drying process that causes the evaporation of more acetic acid (Jinap *et al*., 1994).

pH is very vital in determining the flavor quality of a final product of cocoa beans, if pH is less than 4.5 (more acidic), the final flavour precursors are reduced. According to Zahouli *et al*. (2010), lower pH is an indication of high acidity, hence more sourness may render the final product poor in taste and be rejected on the market.

4.3.3 Free Fatty Acids

The solar dried cocoa beans recorded a higher value for free fatty acids than the values obtained for open sun drying. This is as a result of the higher temperatures used in the solar drier. At higher temperatures, there is more discharge of free fatty acids from triacylglyceride and activation of lipolytic enzymes causing the oxidation of free fatty acids and formation of off-flavours. Guehi *et al*. (2008), reported that the European Economic Community (EEC) directive limits the maximum concentration of free fatty acids to 1.75% oleic acid equivalent in cocoa butter indicating that the solar dried and sun dried cocoa beans in this study produced good percentage FFA and would make quality cocoa butter.

4.3.4 Ascorbic Acid Content

Solar dried cocoa beans recorded lower ascorbic acid content as compared to sun dried cocoa beans. The low value for the solar dried beans is due to the fact that the high air temperature within the solar drier might have destabilized most of the ascorbic acid in the cocoa beans as reported by Liu *et al*. (2002). The ambient temperatures in open sun drying may be suitable for good ascorbic acid content in cocoa beans.

4.4 Cut Test Attributes of cocoa beans

There cut test results revealed interesting observations with respect to mould, slate, germinated and purple percentages of a sample of 300 beans drawn from the various systems: solar dried and open sun dried cocoa beans (see Table 4.4)

These defects criteria put together determined the quality of cocoa in terms of percentage purity. There were no defects observed with respect to mould, slate, germinated, weevily infestation and other defects.

But purple beans defects were found to be high in open sun dried beans (23%) than solar dried cocoa beans (19%) according to this research; this is lower than the purple range (30-50%) graded as substandard according to the standards of Quality Control Company (QCC).

Table 4.3: Cut Test Analysis

Parameter	Solar Dried	Open Sun Dried
% Mouldy beans	0	0
% Slaty beans	0	0
% Germinated	0	0
% Other Defects	0	0
% Weevily	0	0
% Purple beans	19	23

4.5 Sensory evaluation

The sensory evaluation considered sensory attributes such as Appearance; Flavour; Taste; Mouthfeel; and Aftertaste scored by twenty trained panelist. To ensure a high sense of fairness in the comparison of the samples X (Solar dried) and Y (open sun dried) to the F (standard product from Cocoa Processing Company), a series of

distinctive changes to the technological processes was applied to each sample. This included the separate conching of milky chocolate mass and sugar supplements, sugar alcohols and sweeteners. This results in better taste and removal of moisture from the chocolate mass (Kruger *et al*, 2016).

The sensory attribute, appearance, include observations on sensory properties of food products that were registered by the sight sense (eyes) such as the shape, color, surface and the overall similarity of cocoa liquor. The appearance which shows the quality of cocoa beans upon seeing them must have visual attributes: brightness, color, shape, roughness, surface texture, turbidity among others. According to MacDougall (2008), appearance depends on complex interaction of the incident light, its optical properties and visual sensory perception. Sample Y, the open sun dried was identified to be more desirable in appearance compared to Sample X, the solar dried sample.

The sensory attributes flavor and taste characterizes basic sensory information for estimation of quality and intensity of odor. While taste is of the primary importance for determination of aroma (Maruniak, 1988). Sample Y was identified to be more preferable flavor and taste compared to Sample X. Sample Y was identified to be more desirable in appearance compared to Sample X. The likely increased presence of free fatty acids and ascorbic acid in Sample X contributed to the reduced flavor and taste of the cocoa beans.

The sensory attributes of mouthfeel and aftertaste were evaluated by the panelist for sample X and sample Y respectively. The evaluation of mouth feel was done in accordance to the structure and breakage, palpatory firmness and orally chewiness of cocoa beans (Szczesniak, 2002).

Table 4.5 shows the proportions of the descriptors for the sensory evaluation between the samples X and Y as compared to sample F. All the descriptors used in the panelists' assessment of the questionnaire showed a higher preference for Y than sample X with sample F as a reference for each treatment (See Appendix 2). Sample Y had a percentage score of 50 and above for Appearance, Flavour, Taste, Mouthfeel except Aftertaste as against a percentage score of less than 50 for all descriptors of sample X. Therefore in this research, the panelist scored sample Y close to sample F making it the preferred choice. This tends to confirm the previous studies by Afoakwa *et al*. (2011), Anyidoho (2015) and Alex (2018) who reported that open sun dried cocoa beans make better products compared to solar dried heap cocoa beans.

Table 4.4: Proportion of Descriptors for sensory evaluation between Samples X (Solar dried) and Y (Open sun dried)

Discriptors	Samples	Panelist Acceptance	Percentage Acceptance (%)	Evaluation	Remarks
Appearance	X	6	30	< 50%	Weak
	Y	13	65	>50%	Excellent
Flavour	X	5	25	< 50%	weak
	Y	10	50	=50%	Neutral
Taste	X	6	30	< 50%	Weak
	Y	12	60	> 50%	Excellent
Mouthfeel	X	1	5	< 50%	weak
	Y	10	50	=50%	Neutral
Aftertaste	X	3	15	< 50%	Weak
	Y	9	45	< 50%	Weak

*20 Panel descriptors for sensory evaluation. Reference (F) for sensory evaluation
** Weak = (0-49) %; Neutral= 50% and Excellent = (51-100) %

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The effects of the solar drying and open sun drying systems of the heap fermented cocoa beans were assessed.

It can be concluded that, drying of cocoa beans to the acceptable moisture content below 7.5% was achieved in 3 days for the solar drying system and 6 days for the open sun drying system as a result of relatively higher temperature and lower relative humidity in the solar system.

Moreover, there were no defects recorded for physical attributes such as mould, slate and other defects that determine bean quality. Results for moisture content, ash content, and crude protein for both the solar dried and open sun dried heap fermented samples showed no significant effect at 5% significant level.

Furthermore, the solar dried and open sun dried samples showed significant at 95% confidence interval on the crude fat, crude fibre, and total carbohydrate.

Open sun dried heap fermented cocoa beans produced into cocoa liquor had higher score of preference by the sensory panelists. This indicates that open sun dried heap fermented cocoa beans make better products in terms of sensory evaluation, on the other hand the solar dried sample had a shorter (50% less) drying time.

5.2 Recommendations

It is recommended that:

1. Drying with the solar system should be undertaken at the required temperature and relative humidity to maintain and improve the quality of beans in terms of

appearance, flavour, taste, mouth feel and after taste. This is essential for the final quality of cocoa products produce.

2. Further research is required to improve the flavour, taste, appearance, mouthfeel and aftertaste of the solar drying technology as assessed by the sensory panel.

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APPENDICES

Appendix 1.0 Group Statistics for proximate composition of heap fermented dried cocoa beans

	Drying	N	Mean	Std. Deviation	Std. Error Mean
Moisture	Solar	2	8.8219	.14448	.10216
	Open Sun	2	8.3546	.05893	.04167
Ash	Solar	2	3.4303	.11359	.08032
	Open Sun	2	3.7176	.14887	.10527
Fat	Solar	2	39.2398	.30840	.21807
	Open Sun	2	42.2573	.07022	.04965
Crude Fibre	Solar	2	22.9902	.12962	.09166
	Open Sun	2	16.7156	.91195	.64484
Protein	Solar	2	13.8908	.01258	.00889
	Open Sun	2	13.0135	.13052	.09229
DC	Solar	2	48.5081	.33929	.23992
	Open Sun	2	45.6705	.01972	.01394
TC	Solar	2	71.4983	.20967	.14826
	Open Sun	2	62.3861	.89223	.63090

Appendix 1.1: Group Statistics for physicochemical properties of heap fermented dried cocoa beans

	Drying	N	Mean	Std. Deviation	Std. Error Mean
Ascorbic	Solar	2	470.7182	4.70480	3.32679
	Open Sun	2	524.8563	4.31364	3.05020
FFA	Solar	2	.9648	.03237	.02289
	Open Sun	2	.7750	.00967	.00684
TTA	Solar	2	1.8889	.00276	.00195
	Open Sun	2	2.0141	.00154	.00109
pH	Solar	2	5.0100	.00000[a]	.00000
	Open Sun	2	5.2300	.00000[a]	.00000

a. t cannot be computed because the standard deviations of both groups are 0.

Appendix 2.0: Questionnaire for Sensory Evaluation

QUESTIONNAIRE FOR SENSORY TEST

PRODUCT: COCOA LIQUOR

SAMPLES:

1. F (Reference)
2. X (Solar heap fermented)
3. Y (Open sun dried heap fermented)

NUMBER OF PANELISTS: 20

X (SOLAR DRIED HEAP FERMENTED)

Does the sample compare to F?	
Descriptors	**Number of Panellists in favour**
Appearance	6
Flavour	5
Taste	6
Mouthfeel	1
Aftertaste	3

Y (OPEN SUN DRIED HEAP FERMENTED)

Does the sample compare to F?	
Descriptors	**Number of Panellists in favour**
Appearance	13
Flavour	10
Taste	12
Mouthfeel	10
Aftertaste	9

Appendix 3.0: Independent samples t-test for proximate composition of heap fermented dried cocoa beans

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Moisture	Equal variances assumed	3323532112234 4644.000	.000	4.235	2	.051	.46722	.11034	-.00752	.94196
	Equal variances not assumed			4.235	1.324	.100	.46722	.11034	-.33572	1.27016
Ash	Equal variances assumed	1724066261112 417.800	.000	-2.170	2	.162	-.28731	.13241	-.85703	.28241
	Equal variances not assumed			-2.170	1.870	.171	-.28731	.13241	-.89683	.32221
Fat	Equal variances assumed	.	.	-13.492	2	.005	-3.01745	.22365	-3.97976	-2.05514
	Equal variances not assumed			-13.492	1.103	.037	-3.01745	.22365	-5.30109	-.73381
CrudeFibre	Equal variances assumed	1980706649770 6332.000	.000	9.634	2	.011	6.27464	.65132	3.47222	9.07707
	Equal variances not assumed			9.634	1.040	.061	6.27464	.65132	-1.27931	13.82860

Protein	Equal variances assumed	1190077972188 14752.000	.000	9.462	2	.011	.87734	.09272	.47839	1.27629
	Equal variances not assumed			9.462	1.019	.065	.87734	.09272	-.25122	2.00591
DC	Equal variances assumed	2042198011218 4548.000	.000	11.807	2	.007	2.83754	.24032	1.80352	3.87155
	Equal variances not assumed			11.807	1.007	.053	2.83754	.24032	-.16803	5.84311
TC	Equal variances assumed	.	.	14.060	2	.005	9.11218	.64809	6.32369	11.90068
	Equal variances not assumed			14.060	1.110	.035	9.11218	.64809	2.57762	15.64675

Appendix 3.1: Independent samples t-test for physicochemical properties of heap fermented dried cocoa beans

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Ascorbic Acid	Equal variances assumed	32789065883760 3.440	.000	11.995	2	.007	54.13813	4.51346	34.71829	73.55797
	Equal variances not assumed			11.995	1.985	.007	54.13813	4.51346	34.57811	73.69816
FFA	Equal variances assumed	71583831854193 38.000	.000	7.945	2	.015	.18982	.02389	.08702	.29262
	Equal variances not assumed			7.945	1.177	.058	.18982	.02389	-.02452	.40416
TTA	Equal variances assumed	25513396676825 64.500	.000	-56.031	2	.000	-.12521	.00223	-.13482	-.11559
	Equal variances not assumed			-56.031	1.568	.001	-.12521	.00223	-.13786	-.11255