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EFFECT OF DURATION OF FERMENTATION AND DIFFERENT METHODS OF DRYING (SOLAR AND SUN) ON SOME QUALITY TRAITS OF COCOA BEANS (*Theobroma Cacao* L.)

BY

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DECLARATION

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

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DEDICATION

I dedicate the thesis to my late father, Francis Asante, my mom Rose Kusi, my wife Patience Nyadudzi and my children, Nana kwasi Asante, Marfowaa Asante, Nyhiraba Akua Asante and Adom Kusi Oboadum Asante.

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ABSTRACT

Ghana earns a premium on each ton of cocoa exported to the world market based on the quality of the cocoa beans coming from the country. This is used as a benchmark in determining quality standards for cocoa coming from other parts of the world into the world market. However, the persistent improper drying resulting from farmrs spending lesser time for drying has resulted in poor quality beans. This study was, therefore, conducted to develop a solar technology for drying cocoa beans with good quality standard comparable to sun dried cocoa beans. Structured and semi structured questionnaires as well as interpersonal discussions were used to collect data. Parameters studied included cut test, pH, Total Titratable Acidity (TTA), moisture content, ash content, temperature and relative humidity.Information generated covered harvesting methods, fermentation days, drying methods and their effect on quality of cocoa beans. Heap fermentation was mostly used by farmers during this experiment and a good percentage (26%) of them fermented their cocoa beans for only five days which led to poor quality cocoa beans. The study revealedthat cocoa beans fermented for seven days with both solar and sun drying produced good quality cocoa beans. However, cocoa beansalso fermented for five, six and eight days in only the solar dryer, similarly, produced good quality traits as per the International Market Standards. Purple beans incidence was also observed to be lower in solar dried beans than sun dried beans while whilst the reverse was true for acidity levels and pH. There was not much difference in their drying rate and time as the recommended moisture level was attained after four days. Overall, cocoa beans dried in solar were of better quality than those dried in the sun as the constructed solar dryer was able to dry the cocoa beans to the recommended premium quality cocoa grade. Therefore, the solar drying technology could be adopted for use in Ghana to address farmer concerns about how to maintain quality of cocoa beans.

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CHAPTER ONE

1.0 INTRODUCTION

Cocoa (*Theobroma cacao* L) is a cash crop grown throughout the humid tropics with about 6.5 million hectares planted with the crop in 57 countries. According to Olmont (2001), more than 20 million people worldwide depend directly on cocoa for their livelihood, and almost 90% of production come from smallholdings of under 5 hectares, where cultivation is generally extensive.

In Ghana, cocoa is ranked number one Agriculture income earner and a source of employment, with 29% percent of the population living of cocoa (van Grinsven, 2009). Cocoa, provided an income earning of US$ 945 million, being 30% of foreign exchange earnings of Ghana in the year 2005 (van Grinsven, 2009).

Currently, Ghana earns a premium on each ton of cocoa exported to the world market based on the quality of the cocoa beans coming from the country. This is used as a benchmark in determining quality standards for cocoa coming from other parts of the world into the world market.

The sustainability of the industry is therefore very important. However, the persistent improper drying resulting from farmers spending lesser time for drying has resulted in poor quality beans. This situation has been exacerbated by competition among license buying companies for dried beans resulting in selling of poorly dried beans (Adu and Appiah, 2011). This situation has the potential to rundown the industry. Development of modified and improved drying methods that has the capacity to reduce the drying period while ensuring quality beans would help the industry to address this threat. This study is therefore essential and cannot have come at a better time.

The main objective of this research therefore was to develop a solar technology for drying cocoa beans with good quality standard comparable to sun dried cocoa beans.

Specifically the objectives were to

1. Identify major problems associated with drying of cocoa
2. Develop and test solar driers for drying fermented cocoa beans
3. Determine appropriate fermentation and drying period suitable for use in solar drying of cocoa beans
4. Determine effect of duration of fermentation and method of drying (sun and solar) on quality of dried cocoa beans

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Fermentation of Cocoa Beans

Fresh cocoa beans are usually fermented using the heap or box methods for 5-7 days depending on the condition of the beans (Lagunes-Gálvez *et al.*, 2007; Hii *et al.*, 2009). The details of cocoa fermentation have been well-reviewed (Roelofsen, 1958; Lehrian and Patterson, 1983; Lopez and Dimick, 1995; Schwan *et al.*, 1995; Thompson *et al.*, 2001). Fermented cocoa beans present generally moisture content between 55 and 60%. After fermentation, the beans are dried immediately to avoid over fermentation, which could lead to product deterioration. During this deterioration, a degradation of polyphenol compounds led to a high production of Nitrogen Ammonium and produced undesirable flavours.

2.1.1 Fermentation temperature

The best results are obtained in fermentations where the maximum temperature reached is between 45^{o}C to 50^{o}C. Generally, the closer to 50^{o}C, that fermentations reach, the better the quality of the dried cocoa is. Turning means that the beans should be mixed around with a shovel or hands to help get air into the fermenting cocoa and to help make the fermentation even throughout the cocoa. When more air gets into the cocoa, because of turning, the rate of fermentation will increase and temperatures will go up a few hours later. Generally, beans need to be turned only on day two of the fermentation. However, if the rise in temperature is slow, the farmer can increase the number of turns given e.g. days three or four, and this will cause the temperature to rise.

Beans placed into the basket straight after pod breaking reach a temperature of 45.3^{o}C and this would be considered to be high enough to produce a good quality cocoa whilst beans spread out on a plastic sheet for two hours prior to fermentation resulted in a much more rapid rise in temperature and this would be better for bean quality.

One of the important parameters in the cocoa fermentation is the fermenting mass temperature. The fermentation process may get a better result at the temperature range between 45 and 47^0 C (Said, *et al.*, 1994). In addition, the temperature of the fermenting mass should be evenly distributed in the entire positions within the heap. The temperature profile of the fermenting mass at all points of measurements i.e. in the left and right side nearby the sidewalls and the center should be relatively uniform. Due to heat losses by conduction, the mass temperature nearby the sidewalls was about 2 - 3^0 C lower than that in the center. During turning, the position of the fermenting mass inside the heap was rotated. Thus, the temperature distribution of the fermenting mass in the entire points equalized. As the fermentation process continued, the temperature of the fermenting mass in the entire positions reached the maximum of 49 ^{0} C. There was also an indication that the temperature of the fermenting mass nearby the walls dropped below 45^0 C after 72 hours fermentation due to heat loss, particularly during nighttime when the ambient temperature is below 25 ^{0} C(Mulato and Mühlbauer, 2000). Fermented beans have registered higher pH values (4.7) than unfermented beans whatever the drying method.

Unfermented beans have a slaty appearance; purple beans are poorly fermented, while increased browning and the reduction of purple coloration in the dried beans indicate increased degree of fermentation (Wood and Lass 1985). Flavour potential of cocoa is measured by the degree of fermentation

2.2 DRYING OF COCOA BEANS

Cocoa beans must be dried to reduce its moisture content to a safe level for storage. The drying process is also a continuation of the oxidative stage of fermentation of the beans, thus, further reducing the constringency and bitterness of the product. Properly dried beans, usually at about 6-8% moisture content (wet basis) have reduced acidity and are characterized by the familiar 'chocolate' brown colour.

Methods of drying the beans are usually by sun-drying and artificial or, forced air drying, depending on some socio-economic considerations and prevailing climatic conditions. Sun drying is simple and cheap, not requiring the expensive mechanical devices used in the artificial dryers, but it is also labour-intensive and there is much concern for a stable weather condition.

Fundamental works on the thin-layer drying characteristics of cocoa beans are limited and are not related to the bean quality (Bravo and McGraw, 1974; McDonald *et al.*, 1981). Although, experimentation on slow drying using the ambient air had produced beans of acceptable quality, there was over-fermentation of the beans with inadequate heat and air movement (Thien and Yap, 1994). In the humid tropics, slow drying with ambient air is not sufficiently attractive because the prevailing environmental conditions of about 29-32o C and 80% relative humidity result in low drying potential.

The drying process involves both heat and mass transfer. The moisture to be removed may exist both on the surface and within the product, and drying is normally examined in terms of moisture removal at these two levels (Garg and Bhargava 1989; Menon and Mujumdar 1987; Sukha 2009).

Lower moisture levels at the surface in the force drawing moisture from within the product. The extent to which internal moisture sources feed surface moisture extraction depends on the nature of the product being dried (Keey 1978; Sodha *et al.*, 1987). Outward moisture migration is retarded by the product's attraction for water molecules.

A product's resistance to internal moisture loss depends on the hygroscopic and colloidal properties and the size of the pores, which govern the capillary movement of fluid (Karel *et al.,* 1975; Garg and Bhargava 1989).

The more moisture that has been removed, the stronger is the attraction to that remaining. Thus drying is itself influenced by the amount of drying that has already taken place (Keey 1978).

Moisture transfer to the surface of the drying solid occurs through various mechanisms including diffusion, capillarity, and internal pressures set up by shrinkage during drying - these factors possibly act in combination (Menon and Mujumdar 1987).

Moisture loss from the product surface depends on drying air conditions while surface moisture conditions influence the mass transfer from the inside to the surface. The removal of moisture at the product-air interface depends on the temperatures of the product and drying medium, air humidity, airflow rates and volume pressure conditions, and the amount of product surface exposed to the drying medium (Menon and Mujumdar 1987; Jayas 1987).

The effects of temperature and humidity of drying air on moisture removal are interrelated. Increases in air temperature effectively lowers the relative humidity of a given volume of air, and thereby increases its capacity to hold moisture. Higher air temperature adds the possibility of heat transfer to the product. When the latter occurs, the vapour pressure within the product increases and the evaporation of moisture from the surface is facilitated (Menon and Mujumdar, 1987; Brooker *et al.*, 1992).

As moisture, evaporation continues and the moisture content of a fixed volume of air increases, its capacity to accommodate more moisture decreases. The continued extraction of surface moisture under the above-mentioned conditions is driven by the maintenance of a water vapour deficit between the product surface and the drying air (Keey 1978). This dictates the removal of saturated air in the immediate vicinity of the product, replacing it with drier air of higher moisture carrying capacity.

Thus under a given set of temperature and humidity conditions the amount of moisture removed depends on the volume of air brought into contact with the product. Once evaporation of moisture is not limiting, maintaining or increasing airflow rates ensures continuation of the drying process.

2.2.1Drying Rates and Patterns

The rate at which a product dries is an important criterion in selecting a drying method. For high moisture products, when moisture content at successive time intervals is plotted against time, the pattern revealed is a period of constant drying and one of decreasing drying rate (Booker *et al.*, 1992).

Drying rate was found to decrease with an increase in relative humidity. Conversely, an increase in temperature at approximately constant humidity increases the drying rate.

2.2.2Air Flow Rates

Removal of moisture from the drying product environment is effected by air change. Mitchell and Potts (1958) found a proportionate increase in moisture loss with increased airflow. Ede (1958) noted that at low moisture contents, airflow and air velocity had no influence on the rate of drying. Shakya and Flink (1986) reported increased drying rates of potato when airflow rates were increased but this effect declined as the product moisture ratio decreased. In the initial stages of drying when the surfaces of cocoa beans are saturated, the rate of moisture loss increases with increased airflow (Bravo and Mc Gaw 1974). There is a limit to which an increase in airflow rate will increase drying rate. This varies with the product moisture content and the airflow rate itself.

2.3Drying methods

Methods of drying cocoa beans are usually by sun-drying and artificial or, forced air drying, depending on some socio-economic considerations and prevailing climatic conditions

2.3.1Sun drying

Sun drying, i.e. exposing the product directly to sunshine, is the most widely used form of solar energy in the post-harvest processing of crops and a number of factors hampers it. These include slow drying rates, low efficiency in the use of space and poor quality (Minka 1986; Arime 1986). Sun drying is simple and cheap, not requiring the expensive mechanical devices used in the artificial dryers, but it is also labour-intensive and there is much concern for a stable weather condition.

It thus appears that the traditional sun drying, though with some limitations, is the most appropriate method for producing cocoa beans with the best quality attributes. The beans are heaped up at sunset, stored away from dews and covered with thick tarpaulin over-night. It is, therefore, a rest period type of drying. It is necessary to keep the beans at higher temperature than the ambient, to eliminate the occurrence of moisture re-absorption. The intermittent process, occasioned by nightfall, aids the full realization of bio-chemical degradation, and browning reactions.

2.3.2SOLAR DRYING

Solar drying is the method in which the sun's heat is managed and utilized for drying while protecting for the product. Many authors have reported the potential for solar drying in the tropics (Arinze 1986; Sodha *et al.,* 1987).

2.3.2.1TYPES OF SOLAR DRIERS

Solar driers may be classified primarily according to the mode of heat collection employed and secondarily on the mode of heat transfer (Sodha *et al.,* 1987).

Solar thermal technologies have been used in various applications either, as natural convective type dryers, or with forced ventilation, in the drying of coffee, paddy, cassava, bananas, mango, medicinal plant and herbs (Sampaio *et al*., 2007; Lutz *et al*., 1987; Müller *et al*., 1989; Madhlopa and Ngwalo, 2007; Bhandari and Gaese, 2008). Materials, which have been used as absorbers and thermal energy storage, include granite, rock bed, pebble bed, sand, water, and thermic oil (Khattab and Bdawy, 1996; Helwa and Abdel Rehim, 1997; El Sebaii *et al*., 2002). Primarily the product of the material density and its specific heat guides the choice of material. The higher the product, the better the material, provided the operating temperature could be sustained.

A direct-mode solar drier is a closed chamber that contains the product, covered by a transparent sheet of either glass or plastic and ventilated by a series of holes. Thus heating is by direct absorption of radiation by the crop (Bhatnagar and Ali 1989). In an indirect-mode drier, the air is heated in a collector and is directed to a dehydration chamber containing a batch or batches of the product (Maulbauher 1986). Where an air-heating collector is coupled with a drying chamber that exposes the product to solar radiation the drier is termed "mixed-mode".

A two-stage process reported by Duncan *et al.*(1989) in which the beans were first ventilated at ambient conditions to about 20% moisture content (w.b) followed by drying at 60^0 C until 7.5% moisture content (w.b) gave quality attributes which were close to those of naturally sun-dried

Fundamental works on the thin-layer drying characteristics of cocoa beans are limited and are not related to the bean quality (Bravo and McGraw, 1974; McDonald *et al.*, 1981). Although, experimentation on slow drying using the ambient air had produced beans of acceptable quality, there was over-fermentation of the beans with inadequate heat and air movement (Thien and Yap, 1994). In the humid tropics, slow drying with ambient air is not sufficiently attractive because the prevailing environmental conditions of about 29-32o C and 80% relative humidity result in low drying potential. Low-cost solar drying has the potential of enhancing drying rate without causing problems associated with drying at high temperatures Jinap *et al.* (1994).

2.4 DRYING AND PRODUCT QUALITY

High temperatures increase drying rates but the temperature, which can be employed, is limited by potential heat damage to product quality.

High temperatures tend to damage the surface of the product thereby impeding further moisture loss, a phenomenon known as case hardening (Van Arsdel 1973).

Harvey *et al.* (1985) observed improved quality of sorrel when dried at slow rates using low temperatures. Mc Gaw (1979) found drying at temperatures above 40^0 c detrimental to nutmeg quality. In general, high temperatures during drying May be detrimental to the quality of primary agricultural products and drying temperature must be chosen with care. On the other hand, low temperature is synonymous with low drying capacity and higher cost under given humidity ratio conditions.

2.4.1 Drying and Cocoa Bean Quality.

Drying practices influence market quality, the development of flavour, final bean acidity, mouldiness and the presence of off-flavour in the beans. Under adverse weather conditions, the slow rate of sun drying results in mouldiness and the development of off-flavour (Ghosh and Cunha 1975). The beans are also more likely to be adulterated by dust and other debris during sun drying.

Artificially dried beans are inferior to sun dried beans in chocolate flavour development (Quesnel and Jugmohunsingh 1970; Shelton 1967).

Artificial drying increases brittleness and produces a high proportion of cracked and broken beans (Urquhart 1961; Ghosh 1972; 1973) and beans with a wrinkled appearance (Bravo and Mc Gaw, 1974). Many authors, with an emphasis on reducing acidity (DeVos, l956), have investigated the causes of the inferior quality of artificially dried beans. Quesnel and Jugmohunsingh (1970) found that under certain conditions temperatures from 60^0 C to 90^0 C gave unacceptable product. Chocolate flavour development, which begins during fermentation, continues during drying and the mediating enzymes are destroyed by temperature over 60^0 C (Quesnel and Jugmohunhsingh, 1970). The drying process is also a continuation of the oxidative stage of fermentation of the beans, thus, further reducing the constringency and bitterness of the product. Properly dried beans, usually at about 6-8% moisture content (wet basis) have reduce acidity and are characterized by the familiar 'chocolate' brown colour.

The high temperatures used in artificial driers, cause rapid drying of the testa and case hardening preventing outward migration of acetic acid from the beans, (Jinap *et al.,* 1994).

Literature points to the physical loss of acidity through outward migration (Jinap *et al.,* 1994), but this may not be the most important process. Laiu (1978) provided much evidence that the reduction of acidity during drying is mainly an oxidation process brought about the enzymes. Consequently, factors, which inhibit enzyme activity, e.g. high temperature and reduced moisture, contribute to acid retention. Thus, the rate of moisture removal and the temperature employed should be balanced so that adequate acid removal and flavour development are both assured.

Jinap *et al*. (1994) found the pH of sun-dried beans not significantly higher than that of beans that were air-blown for 72 hours and subsequently heated at 60^0C. The pH of mould-affected, shade-dried beans was higher than that of sun-dried beans. Despite the higher pH, the mouldy beans had higher total volatile acidity than sun-dried or air-blown beans in addition to an objectionable flavour. Beans, which were oven dried at

600C, had a significantly higher total volatile acidity. The practical consensus is that temperatures beyond 60 ^{0}c generally impair cocoa quality

Thus, drying practice may influence the development of flavour, bean acidity, mouldiness and the presence of off-flavours (Jinap and Dimick, 1994). Acidity of cocoa liquor as measured by pH was found to be positively related ta acidity scores obtained from taste tests (Baigrie and Rumbelow 1987). Several studies have found that the main factor in acidity of cocoa is volatile acidity of which acetic acid forms 95%. Rapid drying at high temperature is known to lower the pH of the dried beans (Shelton 1967). However, artificial drying method reduces the dry matter and causes increase in energy cost (Arinze *et al*., 1996) while quick drying prevents the chemical processes started during fermentation to be completed. Also the rate drying is critical to final quality of raw cocoa.

The removal of moisture from cocoa beans is slower in natural method, and faster in the artificial and mixed drying methods. The differences may be explained by several factors such as exposure time and temperature of drying air, nature of drying airflow and the speed with which moisture migrated from the inner cocoa beans structures to their surface. These observations are in accordance with the studies obtained by Franke *et al*. (2008). The natural drying process was slower due to the limitations the method imposes,

2.5 QUALITY OF COCOA BEANS

The grading criteria and quality categories of commercial cocoa beans are specified in the International Cocoa Ordinance (Wood and Lass 1985). International cocoa trading bodies define quality in terms ofdegree of fermentation and the extent of defects present. Criteria at fermentation, proportion of broken beans, and the degree of moulding and insect infestation and other adulteration (Wood and Lass 1985; Crespo 1985).

2.5.1 Mould Beans

Prolonged drying during the rainy season in the humid tropics is also a very important factor and Wardsworth (1958) has attributed most mould growth affecting quality to this problem.

Beans dried in the solar driers had few signs of external moulding. Bonaparte et al., 1998 surface moulding is a function of very high humidity and low air movement. Sun-dried beans, especially those dried on the wooden surface, recorded some levels of mould growth.

2.5.2 Acidity

Drying practice have been reported to influence the development of flavour, bean acidity, mouldiness and the presence of off·flavours (Jinap and Dimick 1994). Acidity of cocoa liquor as measured by pH was found to be positively related ta acidity scores obtained from taste tests (Baigrie and Rumbelow 1987). Several studies have found that the main factor in acidity of cocoa is volatile acidity of which acetic acid forms 95%. Rapid drying at high temperature is known to lower the pH of the dried beans (Shelton 1967). However, artificial drying method reduces the dry matter and causes increase in energy cost (Arinze *et al*., 1996) while quick drying prevents the chemical processes started during fermentation to be completed. Also the rate drying is critical to final quality of raw cocoa, A large number of reports have referred to the high acidity and poor flavour development of artificially dried beans compared to sun-dried beans with similar levels of fermentation (Shelton 1967; Jinap *et al*., 1994).

Quesnel and Jugmohunsingh (1970) examined the effect of high temperature on browning reactions during cocoa processing. They concluded that these flavour development reactions are enzymatic and are inhibited at drying temperatures beyond 60^0 C. Furthermore, it appears that rapid moisture loss inhibits the enzymatic breakdown of acids (Liau 1978). Acidity of cocoa liquor, as measured by pH, has been correlated to acidity scores obtained from parallel taste tests (Baigrie and Rumbelow 1987). The pH of mould-affected, shade-dried beans was higher than that of sun-dried beans. Despite the higher pH, the mouldy beans had higher total volatile acidity than sun-dried or air-blown beans in addition to an objectionable flavour. Beans, which were oven dried at 600C, had a significantly higher total volatile acidity (Fagunwa *et al*., 2009). According to Barel (1998), too rapid a drying rate results in excessively acid beans with case hardening. A high production of acidity in cocoa beans produces unsuitable raw cocoa for chocolate manufacture and leads to the reject of cocoa at the market.

Zahouli *et al.* (2010) reported pH values of fermented cocoa beans comprised roughly between 3.8 and 4.5, while natural drying processes and mixed drying methods produce less acidic cocoa beans with pH up to 4, artificial method gives high acidic cocoa beans with pH around 3.7

Volatile acidity content of fermented cocoa beans was largely dependent on drying methods (Zahouli, 2010)

Most studies have shown that removal of moisture from beans induce the increase of their acidities. Sun dried beans showed pH 4.6the pH of sun dried beans is usually higher (less acidic) than artificially and mixed dried beans due to the slow and gentle drying process that enable the evaporation of more acetic acid during solar drying (Hii *et al*., 2009). According to Hii *et al*. (2009), low pHs are always associated with high acidic beans. Analyses of fermented beans showed that sun drying method, artificial method and mixed drying processes produce the same higher volatile acidity cocoa beans than other methods. This might be because the loss of these volatile acidities during fermentation was induced by exudation of acidic liquid and not by chemical degradation.

Most studies have shown that generally acetic acid is removed as volatile acidity from fermented beans during a slow and gentle drying process as natural process. However, artificial drying process would dry faster and break the diffusion path of the acetic acid with moisture (Jinap *et al.*, 1994). Hence, artificial drying method cannotavoid retention of excessive acids and most of the acids remain inside the beans and cause excessive sourness note to the beans. For this reason, Jinap *et al*. (1994) have recommended that drying of cocoa should be performed at temperature not exceeding 60ºC.

The practical consensus is that temperatures beyond 60 ^{0}c generally impair cocoa quality

Artificially dried beans are described as brittle and are said to lack lustre (Urquhart 1961) due to the high drying temperatures. The broken beans, which result present problems during roasting (Urquhart 1961) and in storage, are more liable.

The pH of the sun-dried beans is different from the pH of the best flavoured beans sourced generally from West Africa, which is around 5.5 (Franke *et al.*, 2008).

2.5.3Moisture Content

Fagunwa *et al.* (2009) reported that intermittent solar dryer is appropriate for drying cocoa beans to safe moisture level (3.6%, w.b) within 72 hours. The essential quality attributes of the beans are comparable with the product from the traditional sun drying

2.5.4 Microbial Diversity and Population

The cocoa fermentation is a spontaneous process. The pulp is sterile, but as soon as the beans are removed from the pod, the pulp is inoculated with yeasts and bacteria from the surroundings (Jespersen *et al.*, 2004; Nielsen *et al.*, 2006; Takrama & Adomako 1996). As fermentation of the pulp starts, ethanol and acetic acid are produced and penetrate the beans (Doyle *et al.*, 2001).

Yeasts and LAB dominate the first 24 – 36 hours (Nielsen *et al.*, 2006). Yeasts mainly convert sugars in the pulp into alcohol and CO_2. Enzyme activities and maceration of the pulp makes the acidy juices run off as sweating, which result in a rise of pH (Takrama & Adomako, 1996). The yeast cell counts decrease after 24 – 36 hours while LAB remain high throughout the fermentation (Nielsen *et al.*, 2007) Both homo- and hetero fermentative LAB species are observed, metabolizing glucose to respectively lactic acid and lactic acid, alcohol, acetic acid, and carbon dioxide (Takrama & Adomako, 1996). Turning the heap, makes conditions more aerobic, and increases the population of AA. These bacteria species oxidize ethanol to acetic acid, which is an exothermic process that rises the temperature to nearly 50°C (Camu *et al.*, 2008; Takrama & Adomako, 1996)

Spore forming *Bacillus* species are dominant at the end of the fermenting period and while drying (Nielsen *et al.*, 2006; Ardhana, 2003). These bacteria form some undesirable short fatty acids, giving an off-flavor to the final chocolate (Doyle *et al.*, 2001)

CHAPTER THREE

3.0 MATERIALS AND METHODOLOGY

3.1 FIELD STUDY/SURVEY

3.1.2 The Study Area, Population and Sampling Method

The study was conducted at Lineso, a cocoa village in the Bibiani Anwiaso District of the Western Region of Ghana. The population for the study consisted of all farmers in the study area. A sample size of 100 farmers was used for the study. The sample was purposively selected. Purposive sampling was used in the study since the ideal respondents were known.

3.1.4 Instrument for Data Collection

Structured and semi structured questionnaires as well as interpersonal discussions were used to collect data. Information generated covered harvesting, fermentation, drying and quality of cocoa beans.

3.1.5 Method of Data Analysis

Statistical Package for Social Scientists (SPSS) was used to analyse data using descriptive statistics such as frequencies, percentages and means.

3.2 LABORATORY STUDY

3.2.1 LOCATION OF EXPERIMENT

The experiment was conducted at the Department of Horticulture of the Faculty of Agriculture at the Kwame Nkrumah University of Science and Technology, Kumasi. The site falls within the semi-deciduous rain forest with bimodal rainfall pattern suitable for the cultivation of cocoa.

3.2.2 SOURCE OF EXPERIMENTAL MATERIAL

Freshly harvested hybrid pods (Forastero) of cocoa were obtained from a farm at Lineso, a village in the Bibiani Anwiaso District of the Western Region.

3.3 FERMENTATION

Heap fermentation was used during this experiment. Banana leaves were neatly laid on the ground. Fermentation was carried out on a gentle sloping floor for easy draining of cocoa sweating. Cocoa pods were broken and beans were gathered into a large heap and thoroughly mixed before dividing them into 6 smaller heaps. Each heap weighed 8kgSix (6) heaps of 8kg each were fermented every 24 hours. This was to ensure that there were batches that had been fermented for 5,6,7,8,9 or 10 days. Harvesting of the heaps were on some day. The batches were dried simultaneously. A batch of 6 heaps from each of the fermentation days were divided into 2; 3 heaps (replicates) for sun drying and the other 3 replicates days for solar drying. Each heap of beans was then put on the banana/plantain leaves. The beans were covered tightly with banana leaves, and other plant material was added to prevent the top leaves from being blowing off.

3.4 DRYING

3.4.1Traditional Sun drying

Bamboo mats were placed on a raised platform (2m high) to protect the cocoa beans against animals and foreign matters. Fermented beans, whose placenta had been removed (1.374 kg) were weighed and then spread on equally demarcated area of loading capacity of 12.5kg with a thickness of 3cm (Plate 1). Black polythene sheet was used to cover the beans at night to prevent the condensation of dew on the beans. Drying was stopped at moisture content of below 8%.

Plate 1 : sun drying of cocoa on bamboo mate plateform

3.4.2 Solar dryer

3.4.2.1 Philosophy of design

The dryer was conceived as a low cost, easy to fabricate and easy to operate equipment using locally available materials in order to make it suitable for most peasant farmers with little or no formal education (Fagunwa *et al.*, 2009)and financial strength to adopt and contruct.

The solar dryer was made of wood planks and transparent polythene sheets. It had the drying drawer of several compartments with each compartment having a loading capacity of 12.5kg/m^3 and dimension of 5cm x 115cm x 197cm (ie. 0.005m x 0.115m x 0.197m).

Plate 2: Solar Dry

Plate 3: Solar Dryer

3.5 PARAMETERS STUDIED

3.5.1 Cut Test

Cut test was used in this study with a slight modification. In the cut-test-score method, 100 beans were cut lengthwise to expose maximum cotyledon surface. During the cut test, which was done in normal daylight, the beans were checked for internal moulding and insect infestation. The beans were mixed and divided into four piles. Two piles opposite each other were chosen and mixed in an opaque bag. This ensured randomness of picking of every bean that was used for the cut test. After cutting the beans lengthwise, the beans were placed on a white board, divided into 100 squares. One bean was laid on each square. Slaty beans, purple beans and defective beans were grouped and counted.

3.5.2 pH

The nib pH was determined according to the AOAC (1990) Ground nibs (5 g) were homogenized in 45mL boiled distilled water. The homogenate was filtered with Whatman No. 4 filter paper and cooled to 25 ^{o}C. pH was determined using a pH meter (Mettler Toledo, Columbus, OH, USA).

3.5.3 Total Titratable Acidity (TTA)

The nib of beans were used in determining total titratable acidity according to the AOAC (1990) method. Twenty five milliliters (25mL) of the aliquot collected for pH determination was titrated drop by drop with 0.1 M NaOH and recorded titer volume used to estimate TTA.

3.5.4 Moisture Content

Moisture content of beans after fermentation was determined by the AOAC (1990) method. The weight of a dry empty crucible was determined using electronic scale. Five grams (5 g) of sample was placed on to the crucible and allowed to dry overnight in an air oven at 105^{o}C for 24 hours. The crucible containing the sample was then placed in a desiccator and re-weighed after drying.

The moisture content was then calculated from the formula

(A + B) – A = B

(A + B) – (A + C) = B - C = D

% Moisture = D/B x 100

Where A = crucible weight, B = sample weight, C = dry sample weight, D = moisture weight.

3.5.5 Determination of Ash Content

Ash content of cocoa beans was determined by the AOAC (1990) method. An analytical balance was used to weigh 5g of ground sample into porcelain crucible in triplicate. The crucible and sample was then put into furnace for 4 hours at 550^{o}C. The furnace was allowed to cool below 200^{o}C and maintain at this temperature for 20 minutes. The ash crucible was remove from the furnace and placed in a desiccator to cool and then weighed.

The ash content was then calculated from the formula

(A + B) – A = B

(A + C) - A = C

% Ash = C/B x 100

Where A = crucible weight, B = sample weight, C = ash weight.

3.5.6 Temperature and Relative Humidity

Temperature and relative humidity was monitored with a normal laboratory thermometer and a hygrometer which was permanently placed in the dryers.

3.6 STATISTICAL ANALYSIS

Analysis of variance (ANOVA) was conducted using Statistix 8 statistical software and the means separated using Least significant difference (LSD) at 5% level (p<0.05). All treatments and measurements were conducted in triplicates and the mean values reported.

CHAPTER FOUR

4.0. RESULTS

4.1 FIELD SURVEY

4.1.1 BACKGROUND OF RESPONDENTS

Table 4.1 shows the background information of the respondents who responded in the survey. Majority (83%) of the respondents were male while 17% were female.

Table 4.1 Biodata of respondents

Description		Frequency	Percentage
Gender	Male	83	83
	Female	17	17
Age Distribution	21-30	9	9
	31-40	13	13
	41-50	42	42
	51-60	26	26
	>60	10	10
Marital Status	Single	4	4
	Married	91	91
	Divorced	4	4
	Widowed	1	1
Educational Background	Primary	16	16
	MSLC/JHS	56	56
	SHS/VOC/TECH	5	5
	Tertiary	2	2
	No formal education	21	21

As far as age was concerned, 9% were within 21-30 years. Thirteen percent (13%), 42 %, 26% and 10 % were within 21-30, 31-40, 41-50, 51-60 and more than 60 years respectively. Most (91%) were married while 56 % had no formal eduation up to middle school leaving certificate or junior high school.

4.1.2 *Sources of livelihood and farm size*

Most (66%) of the respondents had farm size ranging from 1 to 10 acres cultivated to cocoa (Table 4.2).

Table 4.2 Source of income and farm size

Description		Frequency	Percentage
Size of farm (acres)	1-5	20	20
	6-10	46	46
	11-15	12.7	12.7
	16-20	3.6	3.6
	21-30	5.5	5.5
	31-40	9	9
	>40	3.6	3.6

4.1.3 Fermentation of Cocoa Beans

All the farmers practiced heap fermentation technology as this was the method they were familiar with (Table 4.3)

Table 4.3: Fermentation of beans

Description		Frequency	Percentage
Fermentation Method	Heap	100	100
	Others	0	0
Reason for using for method used	Only method known	100	100
Materials used for floor and wrapping	Banana/plantain leaves	98	98
	Cocoa/fertilizer sacs	2	2
Duration of fermentation	5 days	26	26
	6 days	28	28
	7 days	46	46
Frequency of turning of heaps	Daily	2	2
	Every 2 days	18	18
	Every 3 days	80	80

Almost all (98 %) of the respondents used banana/plantain leaves for covering the cocoa bean heaps during fermentation. According to them, these were readily available and free. As high as 26 % of the farmers fermented their cocoa beans for only 5 days whereas 28 % and 46 % fermented for 6 and 7 days respectively.

As regards reasons given by the 26% (Table 4.4) who fermented for only 5 days the reasons given were either not convenient (30.77%), taking too long (19.23%), need to sell quickly for money (38.46 %) and need to attend to competing alternative farm duties (11.54 %) .

Table 4.4: Reason for fermenting for five days

Description	Frequency	Percentage
Not convenient	8	30.77
Takes too long to prepare	5	19.23
Need for quick sales due to competition from LBCs	10	38.46
Competing assignments/alternative farm jobs	3	11.54

4.1.4 DRYING OF COCOA BEANS

4.1.4.1 Platform for Drying Cocoa Beans

Thirty percent (30 %) of the farmers indicated that the platform reduces contaminants whereas 50 %, 2 %, 15 % and 3 % (Table 4.6) indicated easy air circulation, easy to turn respectively. Most (60 %) of the farmers turned their cocoa beans thrice daily. Majority (98 %) of them dried their beans for more than 5 days.

Table 4.6 Drying of beans

Description		Frequency	Percentage
Type of floor/paleo	Raised raffia mat		100
	Others		0
Reason for using method	Reduction of contamination		30
	Improved air circulation		50
	Ease of polishing beans		2
	Reduction of mouldiness		15
	Ease of turning during drying		3
Frequency of daily stirring	Once		30
	Twice		10
	Thrice		60
Drying period	5 days		2
	6 days		20
	7 days		60
	8 days		18

4.2 LABORATORY STUDIES

4.2.1. CHANGES IN HEAP TEMPERATURE DURING FERMENTATION

Temperature in the heaps of cocoa beans during fermentation varied ($P < 0.05$) during the fermentation periods.

A temperature change during fermentation has been presented in figure 4.1. There was initial temperature of 33°C. A sharp rise of temperature to 45°C was observed from day 2 to 3. Temperature remained relatively constant at up to day 4 and thereafter a sharp decline up today 6. Temperature changes were not significant and were similar to ambient

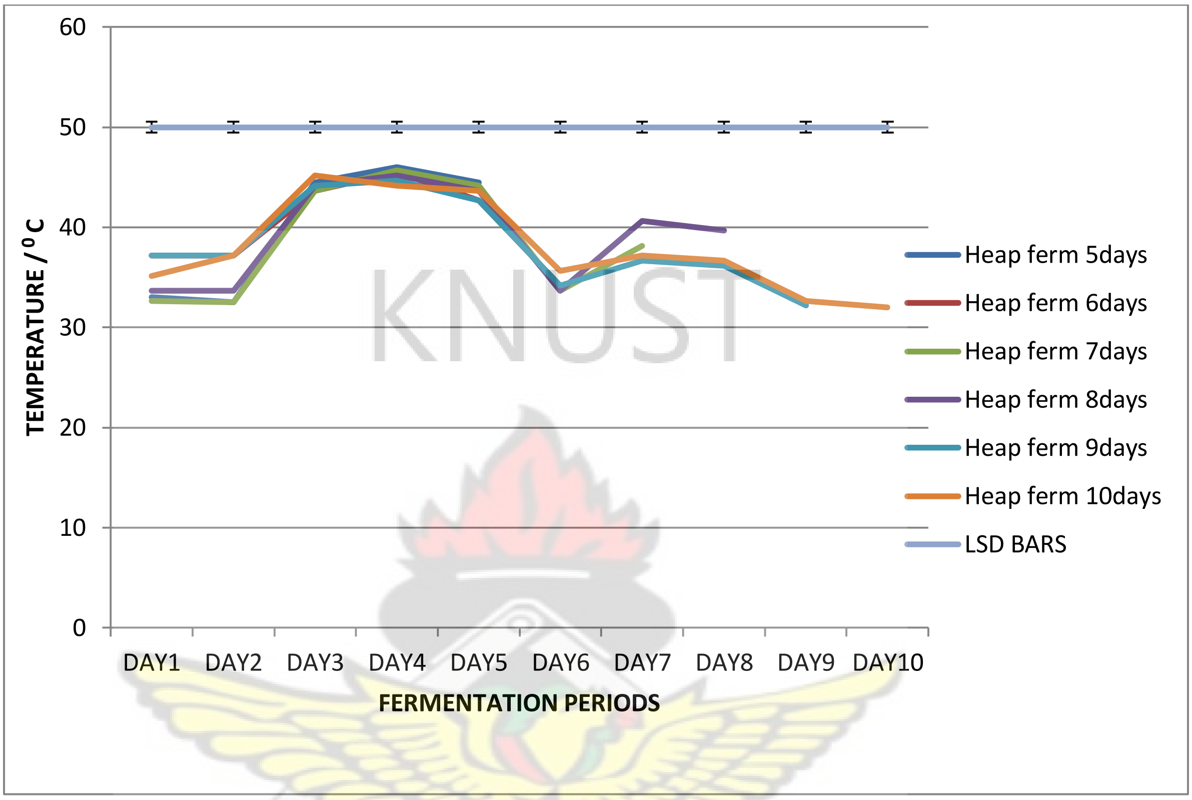

Figure 1: Graph of temperature in fermentation heap over days of fermentation

4.2.2 CHANGES IN MICROBIOLOGICAL POPULATION DURING FERMENTATION

Table 1 presents the results for mean yeast population after fermentation. From the results, beans fermented for 7 days recorded the highest yeast population which was significantly different ($p<0.05$) from beans fermented for 5, 6, 8, 9 and 10 days. Beans fermented for 8 and 9 days were not significantly different ($p>0.05$) from each other. Yeast population showed an increase from 5 days fermentation till it reached a maximum on day 7 then decreased up to day 10 of fermentation.

Table 1: MOULD / YEAST POPULATION

Heap	**Mould**
Heap ferm. For 5 days	77.333 D
Heap ferm. For 6 days	214333 BC
Heap ferm. For 7 days	392133 A
Heap ferm .for 8 days	270567 B
Heap ferm for 9 days	238967 B
Heap ferm for 10 days	164800 C
Lsd	70397
Cv	18.54

4.3 TOTAL COLIFORM POPULATION DURING FERMENTATION

Table 2 presents the results for total coliform population of cocoa beans during fermentation. From the results, heaps of cocoa fermented for 7 days recorded the highest total coliform population which is significantly different ($p<0.05$) from heaps fermented for 5, 6, 8, 9 and 10 days. Beans fermented for 8 and 9 days were not significantly different from each other ($p>0.05$). From the results total coliform populate showed an increase from 5 days fermentation till it reached a maximum on 7days of fermentation and subsequently dropped till the 10 days fermentation.

Table 2: TOTAL COLIFORM POPULATION

Heap	**Total cfu**
Heap ferm. For 5 days	1300.0 E
Heap ferm. For 6 days	261667 C
Heap ferm. For 7 days	426500 A
Heap ferm .for 8 days	338300 B
Heap ferm for 9 days	348233 B
Heap ferm for 10 days	142467 D
Lsd	17303
Cv	3.84

4.4. MOISTURE CONTENT OF BEANS AFTER FERMENTATION

Beans fermented for five days of fermentation resulted in the lowest moisture content of 49.23% (Table 3) significantly different ($p < 0.05$) from beans fermented for nine days which recorded 58.3% moisture content. Beans fermented for five days though significantly different from nine days fermented beans were however not different from the six, seven, eight and ten days of fermentation.

Table 3: Moisture content of beans after fermentation

TREATMENTS	MOISTURE CONTENT
Heap ferm. For 5 days	49.233 B
Heap ferm. For 6 days	55.100 AB
Heap ferm. For 7 days	53.233 AB
Heap ferm .for 8 days	50.767 AB
Heap ferm for 9 days	58.300 A
Heap ferm for 10 days	52.300 AB
Lsd	8.4253

4.5 RELATIVE HUMIDITY OF DRYING ENVIRONMENT OVER DRYING PERIOD

Humidity in the solar dryer and the sun drying environment showed significant differences ($p<0.05$) from day one to day five of drying. The solar drying chamber recorded 94%RH whilst sun drying environment recorded 50% RH on the first day of drying. 83.6% RH was recorded for solar drying against 63.6% RH for sun drying on day two. Day three recorded 51.6% RH for sun whilst solar recorded 82.6%RH.72.6 % RH and 62.6 % RH were recorded on the fourth and fifth days for the solar dryer whilst 67.6% RH and 66.6% RH were recorded on the fourth and fifth days for sun drying respectfully. Day six and seven did not show significant differences ($p>0.05$) between the two drying environments. Solar dryer recorded 62.6 and 66.6 whilst sun drying recorded 60.6 and 65.6 %RH on these days. There were differences between the 72.6 recorded for solar and 67.6 recorded for sun drying on the eight day of drying.

Whilst the solar dryer showed a linear trend (reduction in the relative humidity) from day one to day five the sun drying showed a rise and fall pattern within these periods. Values recorded from the fifth day showed an increment for both drying environments as can be seen from fig. 2.

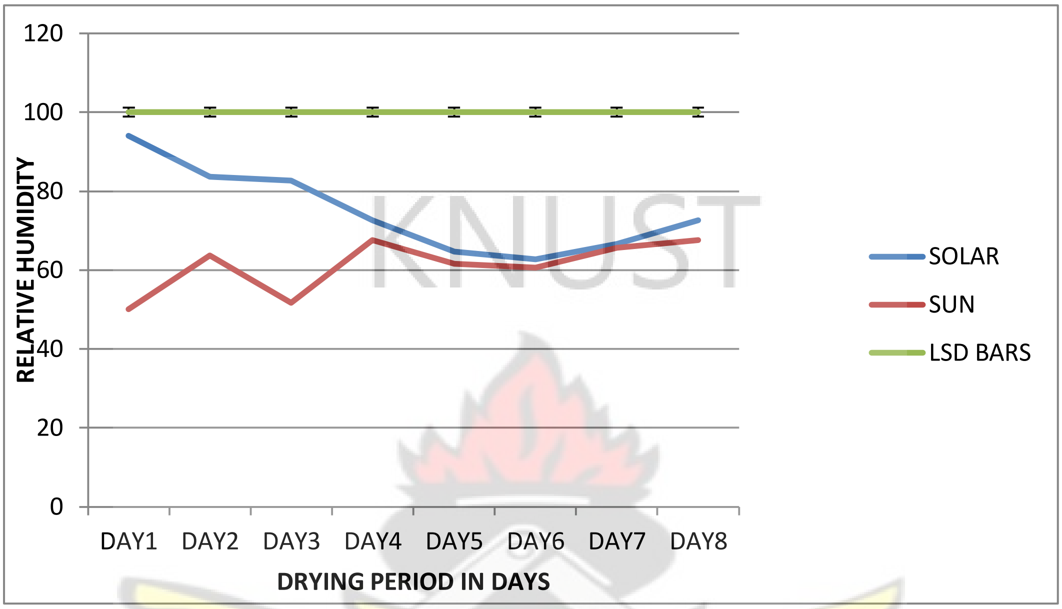

Figure 2: Relative humidity of drying environment over drying period.

4.6. TEMPERATURE OF DRYERS OVER DRYING PERIOD

From figure 3, there were significant differences ($p<0.05$) between the solar dryer and the sun drying over the drying periods with the solar dryer recording significantly higher temperatures throughout the drying period.

Whilst the sun drying environment maintained almost a stable temperature hovering around 39^0C throughout the drying period, values recorded for the solar dryer showed a gradual increase from day 1 to day 4 with a sharp increase from 52^0C to 69^0C on day 5 and then it dropped up to 43^0C on day 7 then rose again to 62^0C on day 8 of drying.

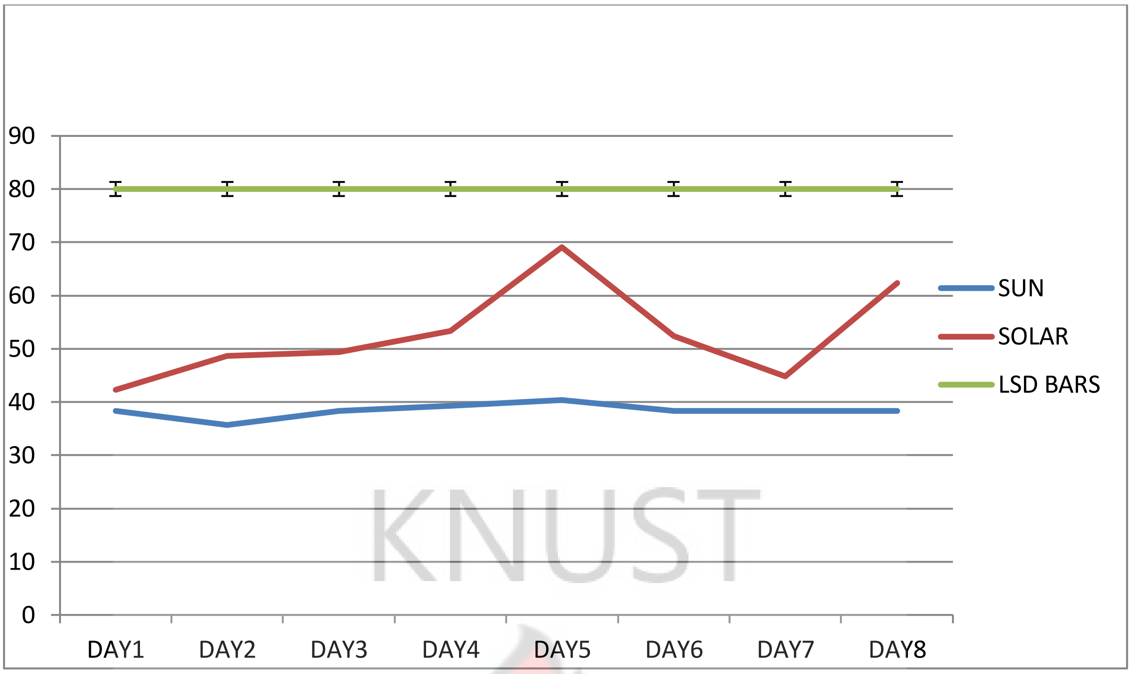

Figure 3: Temperature of dryers over drying period

4.7 EFFECT OF DRYING METHODS AND DURATION OF FERMENTATION ON MOISTURE CONTENT

There were significant differences among the drying methods with the solar dryer having significantly ($p<0.05$) lower moisture content than sun dried beans. Solar dried beans recorded significantly lower moisture content of 4.8 % as compared to sundried beans of 5.5%.

The different fermentation periods showed significant differences with beans fermented for 9 days resulting in lower moisture content than the rest. Beans fermented for 7days had the highest moisture content after drying which was significantly ($p< 0.05$) higher than the rest. Five days fermented beans were not significantly different from those fermented for eight and nine days whilst six days fermented beans were also not different from beans fermented for ten days as seen from table 4.

Table.4: Effect of drying methods and duration of fermentation on moisture content after drying

%Moisture content after drying			
TREATMENTS	**Solar**	**sun**	**mean**
Heap ferm 5days	3.5 G	4.6DEF	4.10 DC
Heap ferm 6days	5.1 DE	6.2 BC	5.60 B
Heap ferm. 7 days	6.5 B	7.5 A	7.0 A
Heap ferm 8 days	4.8DE	4.5 EF	4.60 C
Heap ferm 9 days	3.3 G	3.9 FG	3.60 D
Heap ferm 10 days	5.4CD	6.0 BC	5.70 B
Mean	4.8B	5.5 A	
Lsd	f*D=0.8641	F=0.6110	D=0.3527

4.8 Effect of drying methods and fermentation period on bean germination

There were no significant ($p>0.05$) differences between the fermentation period, dryers and the interaction in terms of germinated beans after drying. Mean values for germinated beans ranged between 1.67% and 1% for all the treatment combinations.

Table 5: Effect of drying methods and fermentation period on bean germination

Germinated beans			
TREATMENTS	Solar	Sun	Mean
Heap ferm 5days	1.00a	1.00a	1.0a
Heap ferm 6days	1.67a	1.67a	1.67a
Heap ferm. 7 days	1.33a	1.00a	1.17a
Heap ferm 8 days	1.00a	1.00a	1.0a
Heap ferm 9 days	1.00a	1.00a	1.0 a
Heap ferm 10 days	1.00a	1.00a	1.0 a
Mean	1.17a	1.11a	
LSD			

4.9 Effect of drying methods and fermentation period on Purple beans development

Purple bean development was significantly ($P < 0.05$) affected by both drying method and the duration of fermentation. Sun drying recorded significantly higher purple beans than solar drying.

Purple bean development was significantly ($p<0.05$) reduced with increasing fermentation duration from5days to 10 days (Table 6)

Five days fermented beans recorded the highest purple bean incidence of 25.5 % significantly different from the other fermentation period. Purple incidents reduced significantly with increasing duration of fermentation.

Solar dried beans recorded the least levels of purple beans (9.67%) incidents significantly different ($p<0.05$) from sun dried beans which recorded 13.94% purple beans after drying.

Sun dried beans fermented for five days recorded the highest purple colouration significantly different from all other treatment combination. Six days fermented sun dried beans recorded the second highest purple beans incidents significantly different from the other treatments. Ten days fermented beans for both sun dried and solar dried beans recorded the least purple incidents (3%).

Table 6.Effect of drying methods and fermentation period on Purple beans development

Purple beans			
TREATMENTS	Solar	sun	Mean
Heap ferm 5days	17.00c	34.00a	25.50a
Heap ferm 6days	16.00e	22.00b	19.00b
Heap ferm. 7 days	11.00f	13.00e	12.00c
Heap ferm 8 days	7.00h	8.00g	7.50d
Heap ferm 9 days	4.00i	3.67j	3.83e
Heap ferm 10 days	3.00k	3.00k	3.00f
Mean	9.67b	13.94a	
Lsd	F=0.1996 d= 0.1152 f*d= 0.2822		

4.10: Effect of drying methods and fermentation period on mould development in dried beans

Beans fermented for eight days recorded the significantly higher mouldy growth of 1% compared to the other durations of fermentation which recorded 0%.

Solar dried beans recorded mean value of 0.33% mould development after drying whilst sun dried beans recorded 0% mould development.

Table 7: Effect of drying methods and fermentation period on mould development.

	Mouldy beans		
TREATMENTS	Solar	sun	Mean
Heap ferm 5days	0.00b	0.00b	0.00b
Heap ferm 6days	0.00b	0.00b	0.00b
Heap ferm. 7 days	0.00b	0.00b	0.00b
Heap ferm 8 days	2.00a	0.00b	1.00a
Heap ferm 9 days	0.00b	0.00b	0.00b
Heap ferm 10 days	0.00b	0.00b	0.00b
Mean	0.33a	0.00b	
Lsd	F=0.3456 d=0.1996 f*d=0.4888		

4.11. EFFECT OF DRYING METHODS AND FERMENTATION PERIOD ON SLATY BEAN DEVELOPMENTS

The duration of fermentation, drying method and the interactive effect showed significant differences (P<0.05) with respect to slaty beans.

Most slaty beans were produced by beans for seven (2.3%) and ten days fermentation (2.2%) durations resulted in insignificant differences (P>0.05). Six days (1.3%) was not significant from eight days (1.3%) fermentation whilst five days was also not significantly different from nine days fermentations. Five and nine day fermented beans recorded significantly lesser percentages of slaty beans compared to the six, seven eight and ten days fermented beans as seen from table 7.

Sun dried beans recorded 1.72% of slaty beans which was significantly higher ($p<0.05$) than solar dried beans which recorded 1.22% of slaty beans.

The synergy effect of duration of fermentation and drying method resulted in six days fermentation solar dried and nine days fermented sun dried beans both recording lower slaty beans percentage of 0.33%, they were significantly different from the other treatment combination except for five days fermented sun dried beans. Seven days fermented beans that were sun dried recorded the highest percentage of slaty beans (3.3%) significantly different from the rest of the treatments combinations.

4.12. Total Titratable Acidity

There were significant differences ($p<0.05$) between the duration of fermentation method of drying and their interactive effects.

From Table 8, five days fermented beans recorded the lowest acidity level of 4.32 meq NaoH 100^{-1} significantly lower than seven, eight, nine and ten days of fermentation but similar to six days fermentation (4.32 meq NaoH 100^{-1}). Ten days fermentation resulted in the highest acidity level of 5.75 meq NaoH 100^{-1} but not significantly different from5.35 meq NaoH 100^{-1} recorded by nine days, and 5.05 meq NaoH 100^{-1} recorded by eight days fermentation.

Solar dried beans recorded significantly higher acid levels of (5.2 meq NaoH 100^{-1}) compared to sun dried beans which recorded acidity of 4.72 meq NaoH 100^{-1}.

The interactive effect showed significant differences in that acidity level was observed to be reducing with increasing duration of fermentation. Ten days fermented solar dried beans recorded the highest acid level of 6.13 meq NaoH 100 $^{-1}$ significantly higher from the other treatment combinations but similar to solar dried to 9 and 10 day fermented beans. From the Table, 5 days fermented sun dried beans recorded the least acid level of 4.00 meq NaoH 100 $^{-1}$ it was however not significantly different from five days sun dried.

Table.8: Effect of interaction of fermentation period and drying method on the Total Titratable acidity of cocoa beans.

Total Titratable Acidity(meq NaoH 100 $^{-1}$)			
TREATMENTS	Solar	Sun	Mean
Heap ferm 5days	4.63 CDEF	4.00 F	4.32 A
Heap ferm 6days	4.70 CDEF	4.33 EF	4.52 AB
Heap ferm. 7 days	4.97 BCDE	4.53 DEF	4.75 BC
Heap ferm 8 days	4.83 BCDE	5.27 BCD	5.05 CD
Heap ferm 9 days	5.50 AB	5.27 BCD	5.38 CD
Heap ferm 10 days	6.13 A	5.37 ABC	5.75 D
Mean	5.20A	4.72B	
Lsd	F=0.5479 D=0.3163 f*D=0.7748		

4.13. Effect of fermentation period and drying methods on pH value of cocoa beans.

The fermentation durations significantly ($p<0.05$) influenced the pH of the dried beans. pH increased with longer periods of fermentation. Ten days of fermentation resulted in the highest pH value of 7.04. This was significantly different from pH of beans fermented for nine, eight, seven, six and five days with respective pH values of 7.01, 6.77, 6.84, 6.67 and 6.27. Five days of fermentation resulted in the least pH value of 6.27 which was significantly different from the rest.

The drying method also had a significant impact on the pH of the dried beans. Solar drying recorded a significantly higher pH value (6.86) compared to the 6.67 recorded by the sun dried beans.

As regards the interaction between days of fermentation and method of drying, apart from solar dried bean fermented for both seven and eight days and sun dried beans fermented for eight and ten days which showed no differences among each other, there were significant differences between the remaining treatments combinations. Solar dried beans fermented for five days recorded the least pH value of 6.23 whilst solar dried beans fermented for ten days recorded the highest pH value of 7.39 significantly different from all treatment combinations.

Table 10.Effect of fermentation period and drying methods on pH value of cocoa beans.

Ph	Solar	Sun	Means
Heap ferm 5days	6.23 J	6.31 I	6.27 F
Heap ferm 6days	6.75 F	6.58 H	6.67 E
Heap ferm. 7 days	6.86 D	6.83 E	6.84 C
Heap ferm 8 days	6.87 D	6.68 G	6.77 D
Heap ferm 9 days	7.05 B	6.97 C	7.01 B
Heap ferm 10 days	7.39 A	6.68 G	7.04 A
Mean	6.86 A	6.67 B	
Lsd	F*D=0.0138	D=0.0056	F=0.0097

4.14. Effect of fermentation period and drying methods on Ash content of cocoa beans.

There were no significant difference (p>0.05) between sun dried cocoa and solar dried cocoa with respect to the ash content.

Six days fermented solar dried beans recorded significantly here ash content of 4.3 whilst sundried beans of the same fermentation duration recorded the lowest ash content of 2.037% significantly different from each other. Seven days fermented solar dried beans recorded the second least ash content of 2.06%. Ash content of beans did not follow any particular pattern.

Table 10: Effect of fermentation period and drying methods on percentage Ash content of cocoa beans.

Ash	Solar	Sun	Means
Heap ferm 5days	4.17 ABC	3.99 DE	4.08 A
Heap ferm 6days	4.31 A	2.04 F	3.17 C
Heap ferm. 7 days	2.06 F	4.19 ABC	3.13 C
Heap ferm 8 days	3.99 DE	3.92 E	3.95 B
Heap ferm 9 days	4.10 BCD	4.24 AB	4.17 A
Heap ferm 10 days	4.06 CDE	4.17 ABC	4.12 A
Mean	3.78 A	3.76 A	
Lsd	F*D=0.1714	D=0.0700	F=0.1212

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 FERMENTATION TEMPERATURE

One of the important parameters in the cocoa fermentation is the fermenting mass temperature. Fermentation temperature is very important in cocoa processing as it influences the type of microorganisms that could proliferate during the fermentation period. Lower temperature results in putrefaction of bacteria which start to proliferate. According to Lambert (2009) length of fermentation is usually 5-7day.

Heap temperature reaches a maximum of around 50 on the third day through to the fourth day then drops to 40 on the fifth day onwards. Temperature decreases with increasing duration of fermentation. Lambert (2009) reported that longer fermentation periods has been associated with hammy-flavour (off-flavour).

Biehl *et al*. (1990), reported that variations in the condition during fermentation such as duration affects the temperature during fermentation. Optimum temperature for polyphenol oxidase activity is around 42–45^{0}C according to Misnawi *et al.* (2002) which corresponds with cocoa bean fermentation conditions .According to Said, *et al.* (1994), fermentation process may get a better result at the temperature range between 45 to 47^{0}C.

5.2 MICROBIAL POPULATION

There are different groups of organisms responsible for cocoa fermentation. Cocoa fermentation is mostly an anaerobic active that requires organisms that can work within this range of environment.

Schwan *et al.*, (1986) reported that fermentation of cocoa is accomplished by a succession of Microorganisms in four phases involving over 50 species. Phase I dominated by yeasts, phase 11 by lactic acid bacteria, phase 111, by acetic acid bacteria and phase IV, by *Bacillus* species Whilst some produces lactic acid others are known to produce alcohol. Camu *et al.* (2008), identified that differences in microbial activities between different heap fermentations can result in dried fermented cocoa beans and chocolates with different flavour characteristics.

According to Camu *et. al.* (2008), the amount, nature and distribution of the micro-organisms present will determine the speed and intensity of fermentation as well as the quality of the fermented beans and the chocolate made thereof.

Jespersen *et al.* (2004) reported that fermentation is a very inhomogeneous process with high variation in both yeast counts and species composition.

The microbial diversity of cocoa bean fermentations has been shown to vary with location and process parameters, such as nutrient availability, temperature, pH, and oxygen tension, and with metabolic activities (Baker *et al.*, 1994; Camu *et al.*, 2007).

The study revealed that both mould and coliform population were highest at 7 days of fermentation. This probably corroborates the position of COCOBOD advocating fermentation for seven days. It is expected that the finest state of fermentation would therefore be achieved on day 7 of fermentation producing the premium quality beans.

In the present study it was observed that microbial population increased from five days of fermentation till it reached a peak on the seventh day then dropped from the eighth to tenth day.

Bonaparte, (1995) reported a reduction in yeasts population during spontaneous fermentation, after 48 hours and the anaerobic conditions created favourable environment suitable for lactic acid bacteria.

Microbial population decline upon prolonged fermentation may be due to exhaustion of appropriate energy sources, production of ethanol and its conversion to acetic acid, and a temperature increase of up to 50 ^{0}C due to aerobic oxidation reactions (Schwan & Wheals, 2004; Camu *et al.*, 2007).

Todar (2009) reported that reduction in nutrient supply with buildup of metabolic by-product leads to reduction in microbial population as organisms get to the death phase of their life cycle.

5.3 MOISTURE CONTENT AFTER FERMENTATION

Moisture content of beans after fermentation is very important as it influences the drying time. The more moisture there is in the beans the longer it will take to remove them resulting in a longer drying period.

According to Zahouli *et al.*, *(*2010), fermented cocoa beans generally contains between 55 and 60% moisture. The results obtained for the present study were within range as differences were generally marginal.

Moisture loss from the beans surface depends on drying air conditions while surface moisture conditions influence the mass transfer from the inside to the surface.

According to Jayas, (1987), the removal of moisture at the product-air interface depends on the temperatures of the product, air humidity, air flow rates and the amount of product surface exposed to the drying medium. Since air flow was impeded as a result of the covering it is expected that the amount of moisture loss will be low though the temperature recorded was sufficient enough to cause drying of the beans.

After fermentation, the water content 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 & Adomako, 1996), the present study suggest.

5.4 TEMPERATURE AND HUMIDITY OF DRYING ENVIRONMENT

The effects of temperature and humidity of drying are interrelated. Increase in air temperature effectively lowers the relative humidity (Menon and Mujumdar 1987).

Although solar dryer experienced higher temperature throughout the period reflecting in higher rate of drying.

Low humidity recorded in sun drying could be due to the increasing air flow. Moisture absorbed by air was easily carried out of the drying environment since the sun drying environment was open air movement was more pronounced as compared to the solar dryer which was enclosed. Bravo and McGraw According to 1974In the initial stages of drying when the surfaces of cocoa beans are saturated, the rate of moisture loss increases with increased air flow.

Drying rate has been found to decrease with an increase in relative humidity (Bonaparte, 1995). Conversely an increase in temperature at approximately constant humidity increases the drying rate.

Solar dryers are designed to trap absorbed heats which gradually build up in the drying compartment resulting in higher temperatures. Whilst heat energy absorbed by sun drying are quickly lost as there are absorbed because of the lack of enclosure to keep the inside hence a lower temperature reading compared to the solar dryer.

According to Thien and Yap, (1994), 80% relative humidity results in low drying potential. The drying process involves both heat and mass transfer.

5.5 DRYING RATE AND WEIGHT LOSS

Drying of the fermented cocoa beans reduces moisture content from 45% to 7%. (Wood and Lass, 1985) Until there is enough moisture, flavour-forming reactions in the beans continue. During drying, strong browning reactions occur that include oxidation of polyphenols with reduction of astringent and bitter taste

Drying temperatures should neither get too high nor too low. At low temperatures, the drying is too slow which allows moulds to grow whilst drying too rapidly will inhibit the activation of enzymes that are necessary to ensure good chocolate flavor (Are & Gwynne-Jones, 1974).

Rate of drying depends on: heat transfer into the bean, water transfer from within the bean to the air, humidity of the air, and surface area of the bean, exposed to the air (Bharath & Bowen-O'Connor, 2007; Sukha, 2009).

With higher temperature values recorded in the solar dryer one will expect that beans in this dryer will have a higher drying rate than that of the sun drying but that was not the case as air movement was not well facilitated hence buildup of humidly in the dryer slowing down the drying rate.

Low humidity in the sun drying environment compensated the comparatively lower temperature in the resulting in almost the same drying rate as the solar drying.

The beans were dried after three to four days for for the treatment combination, this period is too short, according to several authors (Takrama and Adomako, 1996; Are and Gwynne-Jones, 1974), who stated that drying takes 7 – 21 days

Jacquet *et al.* (1980), reported that increase in drying temperature increased astringency

and acidity and recommended that drying temperature should not exceed 65-70°C.

5.6 MOISTURE CONTENT AFTER DRYING

Moisture content of cocoa beans must be reduce to about 7.5- 8% because high moisture in a bean means it has not dried properly and is subject to faster spoilage.

Moisture content for all the treatment combinations ranged between 3.5- 7.55 which fell between the recommended moisture content for the international market, however too much moisture loss means reduction in weight leading to reduction in revenue. Very low moisture content has been reported to cause brittleness leading to breakages causing a high proportion of waste (ICCO, 2009).

The drying process involves both heat and mass transfer. The moisture to be removed may exist both on the surface and within the product, and drying is normally examined in terms of moisture removal at these two levels (Garg and Bhargava, 1989; Menon and Mujumdar, 1987; Sukha, 2009). Moisture loss from the product surface depends on drying air conditions while surface moisture conditions influence the mass transfer from the inside to the surface. The removal of moisture at the product-air interface depends on the temperatures of the product and drying medium, air humidity, air flow rates and volume pressure conditions, and the amount of product surface exposed to the drying medium (Menon and Mujumdar, 1987; Jayas, 1987).

To avoid spontaneous mould and bacterial growth under storage and transport, water content must be reduced to less than 7.5 % during drying (Takrama and Adomako, 1996).

5.7 TITRATABLE ACIDITY

Acidity of cocoa beans is important in terms of fermentation as well as the astringency of the beans.

Acidity was observed to be increasing with increasing duration of fermentation whilst solar drying recorded higher acid levels compared to the sun dried beans.

Acid produced is very volatile during rapid drying (Bonaparte, 1995)

According to Biehl *et al*. (1990), variation in the condition during fermentation such as duration affects the titratable acidity of beans. For instance, pod storage and duration of fermentation will affect pH and temperature during fermentation, thus influencing enzyme activities and flavour development and hence acidity, bitterness and astringency of the processed cocoa beans (Hansen *et al.*, 1998, Biehl, *et al.*, 1990)

The high temperatures in solar dryers, cause rapid drying of the testa and case hardening preventing outward migration of acetic acid from the beans hence higher acidity and pH value , (Jinap *et al.*, 1994) as recorded in the present study. Laiu (1978) provided much evidence that the reduction of acidity during drying is mainly an oxidation process brought about by enzymatic activities hence factors which inhibit enzyme activity, eg. high temperature and reduced moisture, contribute to acid retention.

Thus drying practice may influence the development of flavour, bean acidity, mouldiness and the presence of off·flavours (Jinap and Dimick 1994).

5.8 pH OF COCOA BEANS

On the average pH was observed to be increasing with increasing duration of fermentation.

Values obtain was quite higher as compared to those reported by other authors being 3.8 - 4.5 (Zahouli et al, 2010)

Duration of fermentation have been reported to affect the pH of beans by influencing enzyme activities and flavour development (Hansen *et al.*, 1998, Biehl, *et al.*, 1990)

pH plays an important role in determining the flavor of chocolate produced from cocoa beans if the pH becomes too acid too soon (pH <4.5) there will be both a final reduction in flavour precursors and an over-acid final product.

Optimal activity of the endogenous enzymes will be influenced by fermentation temperature and pH that increase and decrease in the beans, respectively, over fermentation time, as well as by diffusion of ethanol, acetic acid, and to a lesser extent lactic acid inside the beans and polyphenols and alkaloids outside the beans.(Hansen *et al*. 1998, Wollgast and Anklam, 2000) Thus, with respect to the organic acids that diffuse slowly into the cotyledons, timing of initial entry, duration of the period of optimum pH, and final pH are crucial for optimum flavour development.

pH was found to be positively related to acidity scores obtained from taste tests (Baigrie and Rumbelow 1987).

Rapid drying at high temperature is known to lower pH of dried beans (Shelton 1967).

The study indicates that most of the fermentation duration and method of drying produced acceptable pH suitable for good flavor development.

5.9 GERMINATED BEANS

Germination of beans normally occurs before or during fermentation when optimum conditions are created (Niemenak *et al.*, 2006).

The incidence of germination occurred because of the prolonged storage of pods resulting in rotten of pods and subsequent penetration of oxygen to create optimum conditions for growth of the beans (Wood and Lass, 1985).

Afoakwa *et al*. (2011) reported that the lack of generation of enough acids to kill cotyledon results in germination of beans.

From the result obtained percentage of germinated beans did not vary among all the treatments. The recorded values were below critical allowable percentage of 3% according to the international cocoa standards (Wood and Lass, 1985)

The result is indicative that the duration of fermentation and the method of drying did not result in unacceptable levels of fermentation. Therefore be adopted if other quality parameters remain unaffected

5.10 MOULDY BEANS

According to Wood and Lass (1985), internal moulds are the major causes of off-flavours during cocoa processing, and samples of beans with as little as 4% of internal moulds can produce off- flavours in their finished products. Moulds inside the beans can also increase the free fatty acid (FFA) content of the cocoa butter (Wood and Lass, 1985)

Under adverse weather conditions, slow drying rate results in mouldiness and the development of off-flavour (Ghosh and Cunha 1975).

Mouldy beans were found to be generally low with only one treatment recording signs of mould growth. The percentage of beans which recorded mould growth was not significant to cause reduction in total bean quality as the international allowable limit set by the international cocoa standards is 4% (Wood and Lass, 1985).

According to Bonaparte, (1995), surface moulding is a function of very high humidity and low air movement. It is there for not surprising that the mould incident was recorded in the solar dryer.

5.11 PURPLE BEANS

Purple bean incidence has been of a major concern to the Ghana COCOBOD over the past few years as it poses a great threat to the nations well known premium cocoa beans at the international level (Appiah ,(2005).

The increasing changes in brown beans with fermentation is suspected to be resulting from changes in anthocyanin and oxidation products of the polyphenol oxidase activities might have contributed to the brown pigments formation in the cocoa beans during the fermentation period. The brown pigments might also be produced from complexation of condensed tannin, a high molecular weight product of flavonoid polymerization, with protein, via hydrogen bonding (Shamsuddin and Dimmick, 1986).

Ethanol oxidation into acetic acid and oxidation of polyphenol compounds lead to the reduction of purple beans and the increase of brown beans percentages (Biehl *et al*., 1990). Oxidation of polyphenol during the aerobic phase of cocoa fermentation is largely responsible for the characteristic brown colour of fermented cocoa beans (Thompson *et al*., 2001), the percentage purple beans decrease with aeration.

From the results obtain, purple colouration decreased drastically with increasing duration of fermentation. This is so because purple colouration and loss of the characteristic chocolate brown colour is a function of fermentation. Wood and Lass (1985), reported that purple bean is as a result of poor fermentation.

The results corroborates the report of Biehl *et al.*(1990) who indicated that high percentage of purple beans in cocoa fermented might be due to the short length of fermentation.

Unfermented beans have a slaty appearance; purple beans are poorly fermented, while increased browning and the reduction of purple coloration in the dried beans indicate increased degree of fermentation (Wood and Lass 1985).

According to Biehl *et al.* (1990), indicators of well-fermented and dried quality beans are a good brown colour, low astringency and bitterness, and an absence of off-flavours such as smoky beans and excessive acidity

He explained that the observance of the traditional fermentation period ensured much decrease of the antihotyanins or polyphenols (purple) compound content in the cocoa beans to as low as between 9 to 15 per cent but the three to four-day fermentation could keep the compound to as high as between 40 to 80 per cent in the bean Appiah (2005). Glycosides have not yet broken down (Asare 2010).

According to Adzaho (2007), fermentation of cocoa beans for six or seven days did not guarantee the complete removal of anthocyanins and purpleness from the cocoa beans.

5.12 SLATY BEANS

Unfermented beans have a slaty appearance; purple beans are poorly fermented, while increased browning and the reduction of purple coloration in the dried beans indicate increased degree of fermentation (Wood and Lass 1985).

According to Asare, (2010), a dark color indicates that the bean has not been fermented. Slaty beans do not develop the characteristic chocolate aromas and brown color.

According to the Ghanaian quality standards slaty bean for grade one cocoa should not exceed 3% (COCOBOD, 2012). From the results 7 days fermented beans sun dried fell below this grade as it recorded 3.33&% higher than the recommended 3% level. It however qualified for grade 2 classifications which are equally exportable.

slaty beans have not been fermented at all and are normally as a result of immature pods (Barclays Bank 1970).

5.13 Ash Content

The ash contents of the samples were in the range of 2.0 –3.8%, reported by Olaofe *et al.* (1987) reported that the allowable maximum ash content in cocoa is 10%

Ash is the inorganic residue obtained by burning a sample at 500 ^{o}C -600^{o}C. Ashing of samples burns off all organic constituents, leaving behind the non-volatile mineral elements.

Ash content gives indication of mineral content of beans. The study suggests that any of the fermentation periods as well as the drying method would produce beans ash levels that are internationally accepted.

CHAPTER SIX

6.0 CONCLUSION

1. Identify major problems associated with drying of cocoa
2. Develop and test solar driers for drying fermented cocoa beans
3. Determine appropriate fermentation and drying period suitable for use in solar drying of cocoa beans
4. Determine effect of duration of fermentation and method of drying (sun and solar) on quality of dried cocoa beans

The study revealed that a good percentage (26 %) of cocoa farmers were fermenting their beans for only 5 days and many were not drying their beans sufficiently leading to poor quality beans. It was therefore important to develop an efficient drying system suitale for the existing fermentation practices while taking into consideration farmer concerns such as using more time for other farm assignments.

The solar drier that was constructed and used for the study was able to dry the cocoa beans in the premium quality cocoa grade. The study revealed that fermenting of cocoa beans for seven days with both the solar and sun-drying produced cocoa beans with good quality dried beans. On the other hand, 5,6 and 8 days of fermentation and drying in the solar drier similarly, produced good quality traits as per the International Market Standards. Incidence of purpleness was lower in solar dried beans than sun dried beans whilst the reverse was true for acidity levels and pH. Overall solar drying gave good quality beans better than that of sun drying. Drying rate and time was not much different as they all attained recommended moisture level after four days of drying. This study has shown that solar drying technology could be adopted for use in Ghana to address farmer concerns while maintain quality.

6.1 RECOMMENDATION

This solar drying technology could be piloted further data generated for fine-tuning and promotion.

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APPENDIX

Appendix A: results for cumulative drying rate.

Cumulative drying rate for Day 2

Day2			
TREATMENTS	Solar	Sun	means
Heap ferm 5days	37.467 A	37.467 A	37.467 A
Heap ferm 6days	30.433 BC	33.467 B	31.950 B
Heap ferm. 7 days	31.800 BC	32.100 B	31.950 B
Heap ferm 8 days	28.700 C	38.700 A	33.700 B
Heap ferm 9 days	28.833 C	37.333 A	33.083 B
Heap ferm 10 days	30.733 BC	37.633 A	34.183 B
Mean	31.328 B	36.117 A	
LSD	F*D=3.2296	D=1.3185	F=2.2837
Cv	5.66		

Cumulative drying rate for Day2

Day 2			
TREATMENTS	Solar	Sun	means
Heap ferm 5days	51.433 AB	50.067 ABCD	50.750 A
Heap ferm 6days	47.533 CDEF	46.267 EF	46.900 B
Heap ferm. 7 days	48.567 BCDE	50.600 ABC	49.583 A
Heap ferm 8 days	44.433 F	49.800 ABCD	47.117 B
Heap ferm 9 days	49.167 BCDE	52.767 A	50.967 A
Heap ferm 10 days	45.067 F	47.267 DEF	46.167 B

Mean	47.700 B	49.461 A	
LSD	F*D=3.1942	D=1.3040	F=2.2586
Cv	3.88		

Cumulative drying rate for Day 4

	Day3		
TREATMENTS	Solar	Sun	means
Heap ferm 5days	57.233BCDE	58.600 BCD	57.917 BC
Heap ferm 6days	57.200BCDE	55.933 DE	56.567 C
Heap ferm. 7 days	58.233 BCD	60.267 AB	59.250 AB
Heap ferm 8 days	54.100 E	59.467 ABC	56.783 C
Heap ferm 9 days	58.833 BCD	62.433 A	60.633 A
Heap ferm 10 days	54.733 E	56.933 CDE	55.833 C
Mean	56.722 B	58.939 A	
LSD	D*D=3.3153	D=1.3535	F=2.3443
Cv	3.39		

Appendix B: Anova Tables

Analysis of Variance Table for slaty

Source	DF	SS	MS	F	P
Rep	2	5.0556	2.52778		
Fermentat	5	12.4722	2.49444	34.06	0.0000
Dryer	1	2.2500	2.25000	30.72	0.0000
fermentat*dryer	5	11.5833	2.31667	31.63	0.0000
Error	22	1.6111	0.07323		
Total	35	32.9722			

Grand Mean 1.4722 CV 18.38

Analysis of Variance Table for purple

Source	DF	SS	MS	F	P
Rep	2	8.00000	4.00000		
Fermentat	5	2378.00	475.600	2.7E+32	0.0000
Dryer	1	169.000	169.000	9.6E+31	0.0000
fermentat*dryer	5	326.000	65.2000	3.7E+31	0.0000
Error	22	3.854E-29	1.752E-30		
Total	35	2881.00			

Grand Mean 11.500

Analysis of Variance Table for mouldybeans

Source	DF	SS	MS	F	P
Rep	2	0.1667	0.08333		
Fermentat	5	5.0000	1.00000	12.00	0.0000
Dryer	1	1.0000	1.00000	12.00	0.0022
fermentat*dryer	5	5.0000	1.00000	12.00	0.0000
Error	22	1.8333	0.08333		
Total	35	13.0000			

Grand Mean 0.1667 CV 173.21

Analysis of Variance Table for germinate

Source	DF	SS	MS	F	P
Rep	2	8.7222	4.36111		
Fermentat	5	2.1389	0.42778	1.01	0.4330
Dryer	1	0.0278	0.02778	0.07	0.7998
fermentat*dryer	5	0.1389	0.02778	0.07	0.9966
Error	22	9.2778	0.42172		
Total	35	20.3056			

Grand Mean 1.1389 CV 57.02

Analysis of Variance Table for ash

Source	DF	SS	MS	F	P
Rep	2	0.5921	0.29606		
Ferm	5	7.1028	1.42056	138.72	0.0000
Drying	1	0.0042	0.00422	0.41	0.5273
ferm*drying	5	14.6345	2.92689	285.83	0.0000
Error	22	0.2253	0.01024		
Total	35	22.5589			

Grand Mean 3.7692 CV 2.68

Analysis of Variance Table for day1

Source	DF	SS	MS	F	P
Rep	2	37.524	18.762		
Fermentat	5	125.542	25.108	6.90	0.0005
Dryer	1	206.401	206.401	56.74	0.0000
fermentat*dryer	5	137.326	27.465	7.55	0.0003
Error	22	80.029	3.638		
Total	35	586.822			

Grand Mean 33.722 CV 5.66

Analysis of Variance Table for day2

Source	DF	SS	MS	F	P
Rep	2	40.602	20.3011		
Fermentat	5	133.198	26.6396	7.49	0.0003
Dryer	1	27.914	27.9136	7.84	0.0104
fermentat*dryer	5	53.398	10.6796	3.00	0.0326
Error	22	78.284	3.5584		
Total	35	333.396			

Grand Mean 48.581 CV 3.88

Analysis of Variance Table for day3

Source	DF	SS	MS	F	P
Rep	2	19.487	9.7436		
Fermentat	5	99.365	19.8729	5.18	0.0027
Dryer	1	44.222	44.2225	11.54	0.0026
fermentat*dryer	5	37.089	7.4178	1.94	0.1291
Error	22	84.333	3.8333		
Total	35	284.496			

Grand Mean 57.831 CV 3.39

Completely Randomized AOV for mould/yeast

Source	DF	SS	MS	F	P
heap	5	2.512E+11	5.024E+10	32.09	0.0000
Error	12	1.879E+10	1.566E+09		
Total	17	2.700E+11			

Grand Mean 213480 CV 18.54

Completely Randomized AOV for total coliform

Source	DF	SS	MS	F	P
heap	5	3.663E+11	7.326E+10	774.38	0.0000
Error	12	1.135E+09	9.460E+07		
Total	17	3.674E+11			

Grand Mean 253078 CV 3.84

Analysis of Variance Table for pH

Source	DF	SS	MS	F	P
Rep	2	0.02667	0.01334		
Ferm	5	2.35972	0.47194	7106.08	0.0000
Drying	1	0.30618	0.30618	4610.13	0.0000
ferm*drying	5	0.57549	0.11510	1733.03	0.0000
Error	22	0.00146	0.00007		
Total	35	3.26952			

Grand Mean 6.7672 CV 0.12

Completely Randomized AOV for fermentation temperature DAY1

Source	DF	SS	MS	F	P
fermentat	6	65.2917	10.8819	31.23	0.0000
Error	11	3.8333	0.3485		
Total	17	69.1250			

Grand Mean 34.750 CV 1.70

Completely Randomized AOV for fermentation temperature DAY2

Source	DF	SS	MS	F	P
fermentat	6	4.66667	0.77778	2.23	0.1179
Error	11	3.83333	0.34848		
Total	17	8.50000			

Grand Mean 44.167 CV 1.34

Completely Randomized AOV for fermentation temperature DAY3

Source	DF	SS	MS	F	P
fermentat	6	5.29167	0.88194	2.53	0.0865
Error	11	3.83333	0.34848		
Total	17	9.12500			

Grand Mean 45.083 CV 1.31

Completely Randomized AOV for fermentation temperature DAY4

Source	DF	SS	MS	F	P
fermentat	6	7.1667	1.19444	3.43	0.0369
Error	11	3.8333	0.34848		
Total	17	11.0000			

Grand Mean 43.500 CV 1.36

Completely Randomized AOV for fermentation temperature DAY5

Source	DF	SS	MS	F	P
fermentat	6	2943.61	490.602	1618.99	0.0000
Error	11	3.33	0.303		
Total	17	2946.94			

Grand Mean 28.556 CV 1.93

Completely Randomized AOV for fermentation temperature DAY6

Source	DF	SS	MS	F	P
fermentat	6	5855.28	975.880	4025.50	0.0000
Error	11	2.67	0.242		
Total	17	5857.94			

Grand Mean 25.444 CV 1.94

Completely Randomized AOV for fermentation temperature DAY7

Source	DF	SS	MS	F	P
fermentat	6	6349.62	1058.27	5820.49	0.0000
Error	11	2.00	0.18		
Total	17	6351.63			

Grand Mean 18.750   CV 2.27

Completely Randomized AOV for fermentation temperature DAY8

Source	DF	SS	MS	F	P
fermentat	6	4203.74	700.623	5780.14	0.0000
Error	11	1.33	0.121		
Total	17	4205.07			

Grand Mean 10.806   CV 3.22

Completely Randomized AOV for fermentation temperature DAY9

Source	DF	SS	MS	F	P
fermentat	6	2918.40	486.400	8025.61	0.0000
Error	11	0.67	0.061		
Total	17	2919.07			

Grand Mean 5.6944   CV 4.32

Completely Randomized AOV for relative humidity in dryers day1

Source	DF	SS MS	F	P
DRYING	1	2904.00 2904.00	2904.00	0.0000
Error	4	4.00 1.00		
Total	5	2908.00		

Grand Mean 72.000 CV 1.39

Completely Randomized AOV for relative humidity in dryers day2

Source	DF	SS	MS	F	P
DRYING	1	600.000	600.000	450.00	0.0000
Error	4	5.333	1.333		
Total	5	605.333			

Grand Mean 73.667 CV 1.57

Completely Randomized AOV for relative humidity in dryers day3

Source	DF	SS	MS	F	P
DRYING	1	1441.50	1441.50	1081.13	0.0000
Error	4	5.33	1.33		
Total	5	1446.83			

Grand Mean 67.167 CV 1.72

Completely Randomized AOV for relative humidity in dryers day4

Source	DF	SS	MS	F	P
DRYING	1	37.5000	37.5000	28.13	0.0061
Error	4	5.3333	1.3333		
Total	5	42.8333			

Grand Mean 70.167 CV 1.65

Completely Randomized AOV for relative humidity in dryers day5

Source	DF	SS	MS	F	P
DRYING	1	937.500	937.500	703.12	0.0000
Error	4	5.333	1.333		
Total	5	942.833			

Grand Mean 29.167 CV 3.96

Completely Randomized AOV for relative humidity in dryers day6

Source	DF	SS	MS	F	P
DRYING	1	6.0000	6.00000	4.50	0.1012
Error	4	5.3333	1.33333		
Total	5	11.3333			

Grand Mean 61.667 CV 1.87

Completely Randomized AOV for relative humidity in dryers day7

Source	DF	SS	MS	F	P
DRYING	1	1.50000	1.50000	1.13	0.3486
Error	4	5.33333	1.33333		
Total	5	6.83333			

Grand Mean 66.167 CV 1.75

Completely Randomized AOV for relative humidity in dryers day8

Source	DF	SS	MS	F	P
DRYING	1	37.5000	37.5000	28.13	0.0061
Error	4	5.3333	1.3333		
Total	5	42.8333			

Grand Mean 70.167 CV 1.65

Appendix C: Microbial Diversity

IDENTIFICATION OF BACTERIA

1. Heap1 Day 3

Cream Colony Gram tve *Bacillus*

White Dot " +ve *Staphylococcus aureus*

White spread " +ve *Staphylococcus aureus*

Yellow colony " -ve bacterium *Escherichra*

Saccharomyces rosei,

Hansenula anomala

Trichosporon cutaneum

Torulopsis Candida

Pichia fermentans

Pichia membranaefaciens,

Saccharomyces chevalieri,

2. Heap 2 Day 3

White Dot Grm +ve *Staphylococcus aureus*

White spread +ve *Staphylococcus aureus*

Cream Colony +ve *Bacillus*

Trichosporon cutaneum

Torulopsis Candida

Pichia fermentans

Pichia membranaefaciens

Saccharomyces rosei,

3. Heap 3 Day 3

Yellow -ve bacterium *Escharichia coli*

White Dot +ve *Staphylococcus aureus*

White spread *Staphylococcus aureus*

Saccharomyces rosei,

Hansenula anomala

Trichosporon cutaneum

Pichia membranaefaciens,

Saccharomyces chevalieri

4. Heap 4 Day 3

Yellow colours -ve *Staphylococcus aureus*

White Dot +ve *Staphylococcus aureus*

White spread +ve *Staphylococcus aureus*

Trichosporon cutaneum

Torulopsis Candida

Saccharomyces rosei,

Pichia membranaefaciens,

Hansenula anomala

Pichia fermentans

Saccharomyces chevalieri

5. Heap 5 Day 3

Yellow Colour-ve *Escherichia coli*

White Dot +ve *Staphylococcus aureus*

White spread +ve *Staphylococcus aureus*

star colours +ve *Bacillus*

cream colours +ve *Bacillus*

Torulopsis Candida

Hansenula anomala

Trichosporon cutaneum

Pichia fermentans

Saccharomyces chevalieri

Saccharomyces rosei,

6. Heap 6 Day 3

Star colours +ve *Basillus*

Cream Colony +ve *Bacillus*

White Dot +ve *Staphylococcus aureus*

White spread +ve *Staphylococcus aureus*

Trichosporon cutaneum

Torulopsis Candida

Pichia fermentans

Pichia membranaefaciens,

Saccharomyces chevalieri

Saccharomyces rosei,

Hansenula anomala

7. Heap 1 Day 5

White Dot +ve *Staphylococcus aureus*

White spread +ve *Staphylococcus aureus*

Cream Colony +ve *Basillus*

Torulopsis Candida

Pichia fermentans

Pichia membranaefaciens,

Saccharomyces chevalieri

Saccharomyces rosei,

Hansenula anomala

Trichosporon cutaneum

8. Heap 2 Day 5

White Dot +ve *Staphylococcus aureus*

White spread +ve *Staphylococcus aureus*

Saccharomyces rosei,

Hansenula anomala

Trichosporon cutaneum

Torulopsis Candida

Pichia fermentans

Pichia membranaefaciens,

Saccharomyces chevalieri

9. Heap 3 Day 5

White Dot +ve *Staphylococcus aureus*

White spread +ve *Staphylococcus aureus*

Cream Colony +ve *Basillus*

Saccharomyces rosei,

Trichosporon cutaneum

Pichia fermentans

Pichia membranaefaciens,

Saccharomyces chevalieri

10. Heap 4 Day 3

Star colours +ve *Basillus*

White Dot +ve *Staphylococcus aureus*

White spread +ve *Staphylococcus*

Yellow Colour-ve *Escherichia coli*

Hansenula anomala

Trichosporon cutaneum

Torulopsis Candida

Pichia fermentans

Saccharomyces rosei,

Pichia membranaefaciens,

Saccharomyces chevalieri

11. Heap 5 Day 5

White Dot Gram+ve *Staphylococcus aureus*

White spread +ve *Staphylococcus aureus*

Yellow Colour-ve *Escherichia coli*

Saccharomyces chevalieri

Saccharomyces rosei,

Hansenula anomala

Trichosporon cutaneum

Pichia fermentans

Pichia membranaefaciens

Torulopsis Candida

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12. Heap 6 Day 5

White spread +ve *Staphylococcus aureus*

White Dot +ve *Staphylococcus aureus*

Yellow Colour-ve *E. coli*

Saccharomyces rosei,

Hansenula anomala

Trichosporon cutaneum

Torulopsis Candida

Pichia fermentans

Pichia membranaefaciens,

Saccharomyces chevalieri

13. Heap 1 Day4

Star colours +ve *Basillus*

White Dot +ve *Staphylococcus aureus*

White spread +ve *Staphylococcus*

Yellow Colour-ve *E.coli*

Saccharomyces rosei,

Hansenula anomala

Trichosporon cutaneum

Torulopsis Candida

Pichia fermentans

Pichia membranaefaciens,

Saccharomyces chevalieri

14. Heap 2 Day4

Star colours +ve *Basillus*

White Dot +ve *Staphylococcus aureus*

Cream Colony +ve*Basillus*

Yellow Colour-ve *E.coli*

Saccharomyces rosei,

Hansenula anomala

Trichosporon cutaneum

Torulopsis Candida

Pichia fermentans

Pichia membranaefaciens,

Saccharomyces chevalieri

15. Heap 3 Day4

White Dot +ve *Staphylococcus aureus*

White spread +ve *Staphylococcus*

Yellow Colour-ve *E.coli*

Saccharomyces rosei,

Hansenula anomala

Trichosporon cutaneum

Torulopsis Candida

Pichia fermentans

Pichia membranaefaciens,

Saccharomyces chevalieri

16. Heap 4 Day4

Yellow Colour-vei

White Dot +ve *Staphylococcus aureus*

White spread +ve *Staphylococcus*

Cream Colony +ve *Basillus*

Saccharomyces rosei,

Hansenula anomala

Trichosporon cutaneum

Torulopsis Candida

Pichia fermentans

Pichia membranaefaciens,

Saccharomyces chevalieri

17. Heap5 Day4

White Dot +ve *Staphylococcus aureus*

White spread +ve *Staphylococcus*

Yellow Colour-ve *E.coli*

Saccharomyces rosei,

Hansenula anomala

Trichosporon cutaneum

Torulopsis Candida

Pichia fermentans

Pichia membranaefaciens,

Saccharomyces chevalieri

18. Heap3 Day4

White Dot +ve *Staphylococcus aureus*

White spread +ve *Staphylococcus*

Star colours *Basillus*

Saccharomyces rosei,

Hansenula anomala

Trichosporon cutaneum

Torulopsis Candida

Pichia fermentans

Pichia membranaefaciens,

Saccharomyces chevalieri

19. Heap5 Day 9

White Dot +ve *Staphylocouus aureus*

White spread +ve *Staphylococcus aureus*

Yellow +ve *E.coli*

Cream Colony +ve Bacillus

Saccharomyces rosei,

Hansenula anomala

Trichosporon cutaneum

Torulopsis Candida

Pichia fermentans

Pichia membranaefaciens,

Saccharomyces chevalieri

20. Heap 6 Day 9

Yellow Colour-ve.*E.coli*

White Dot +ve *Staphylococcus aureus*

White spread +ve *Staphylococcus aureus*

Cream Colony +ve *Bacillus*

Saccharomyces rosei,

Hansenula anomala

Trichosporon cutaneum

Torulopsis Candida

Pichia fermentans

Pichia membranaefaciens,

Saccharomyces chevalieri

21. Heap 6 Day10

Yellow Colour-ve *E.coli*

White Dot +ve *Staphylococcus aureus*

White spread +ve *Staphylococcus aureus*

Cream Colony +ve *Bacillus*

Saccharomyces rosei,

Hansenula anomala

Trichosporon cutaneum

Torulopsis Candida

Pichia fermentans

Pichia membranaefaciens,

Saccharomyces chevalieri

22. Heap 4 Day7

White Dot +ve *Staphylococcus aureus*

White spread +ve *Staphylococcus aureus*

Cream Colony +ve *Bacillus*

Yellow -ve *E.coli*

Saccharomyces rosei,

Hansenula anomala

Trichosporon cutaneum

Torulopsis Candida

Pichia fermentans

Pichia membranaefaciens,

Saccharomyces chevalieri

23. Heap5 Day 7

White Dot +ve *Staphylococcus aureus*

White spread +ve *Staphylococcus aureus*

Cream Colony +ve *Bacillus*

Yellow -ve *E.coli*

Saccharomyces rosei,

Hansenula anomala

Trichosporon cutaneum

Torulopsis Candida

Pichia fermentans

Pichia membranaefaciens,

Saccharomyces chevalieri

24. Heap P6 Day 7

White Dot +ve *Staphylococcus aureus*

White spread +ve *Staphylococcus aureus*

Yellow -ve *E.coli*

Cream Colony +ve *Bacillus*

star colour +ve *Bacillus*

Saccharomyces chevalieri

Saccharomyces rosei,

Hansenula anomala

Trichosporon cutaneum

Torulopsis Candida

Pichia fermentans

Pichia membranaefaciens,