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QUALITY RESPONSE OF ROBUSTA COFFEE (*Coffea robusta var. canephora*) BEANS TO METHODS AND DEPTHS OF DRYING.

BY

FRANCIS ENYAN

SEPTEMBER, 2011

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

BY

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DECLARATION

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

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DEDICATIONS

This work has been dedicated foremost to the Almighty God. Secondly to my beloved wife, Faustina and my daughter Nadia Lillian for their support, love and understanding.

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ABSTRACT

Due to the poor quality of coffee beans arising from poor processing methods, studies were conducted at KwahuBepong, with laboratory support at the Cocoa Research Institute of Ghana (CRIG) and the Horticulture Department of KNUST from November, 2010 to March, 2011. The objectives of the studies were to; (I) determine the combined effect of the method of drying and the depth of drying on the coffee cup quality of Robusta coffee beans, (II) determine the effect of the drying process (method and depth) on the incidence and percentage infestation of fungal mould as a determinant of quality. The experimental design was a 3 x 3 factorial arrangement in randomized complete block with three replications. The first factor was methods of drying at three levels - M_1:- drying on a raised raffia mat at 0.8 m above ground; M_2:- drying on a concrete floor and M_3:- drying on a black polythene sheet on concrete floor. The second factor was the depth of drying at three levels - D_1:- 5 cm; D_2:- 10 cm and D_3:- 15 cm. Data collected included number of days to drying, percent caffeine and crude protein contents, temperature and moisture within bean heap, fungal load and defective beans. The number of days to drying, temperature and moisture within heaps, total fungal load and defective beans differed significantly ($P < 0.05$) with respect to drying methods and depth of drying of the coffee beans. However, the treatments did not have any effect on the caffeine contents. Microbial counts were found in all samples during drying of the coffee beans with *Aspergillus*species being the most prevalent. Generally, beans dried on raised raffia mat dried faster and with less microbial count. There was a significant relationship between percentage crude protein content and temperature within the heap of coffee beans.

The temperature in the heap of coffee beans during drying accounted for 77% of the variation in total crude protein content. The relationship is expressed as Total Crude Protein = 0.891 + 0.098 (Temperature); R^2 = 0.77; P = 0.002. The study concluded that drying coffee beans on black polythene sheet on concrete floor at a depth of 5 cm resulted in desirable effects similar to those obtained using the raised raffia mat. The desirable effects included faster drying time and increased crude protein content of beans coupled with lower fungal load contamination. Consequently, in the absence of a raised raffia mat due to the unavailability of its basic materials, the black polythene sheet on concrete floor could be a worthy substitute without compromising on coffee bean quality with its consequent effect on cup quality.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Plates **Page**

LIST OF ABBREVIATIONS

RCBD	Randomized Complete Block Design
FAO	Food and Agriculture Organization
WHO	World Health Organisation
WTO	World Trade Organisation
GDP	Gross domestic product
ISO	International Standard Organization
ITC	International Trade Centre
MoFA	Ministry of Food and Agriculture
CPC	Crude Protein Content
CRIG	Cocoa Research Institute of Ghana
COCOBOD	Ghana Cocoa Board
JECFA	Joint FAO/WHO Expert Committee on Food Additives
DADU	District Agricultural Development Unit
OICC	Office International du Cacao et du Chocolat
RM & E	Research Monitoring & Evaluation
KNUST	Kwame Nkrumah University of Science and Technology
OTA	Ochratoxin 'A'
ORSTOM	Institute Francais de RechercheScientifique pour le D'evelopementenCoope'ration
ICO	International Coffee Organization
IARC	International Agency for Research on Cancer
ppb	Parts Per Billion
HPLC	High Performance Liquid Chromatography
FOB	Free on Board
GDP	Gross Domestic Product

QCCL	Quality Control Company Ltd.
LI	Legislative Instrument
N L C D	National Liberation Council Decrees

1.0 INTRODUCTION

The coffee bean is obtained from the fruit of the coffee plant, a small evergreen shrub, belonging to the genus *Coffea* and family Rubiaceae. Hicks, (2002) and Davis, (2006), reported that *Coffeaarabica*(Arabic coffee) and *Coffeacanephora* (Robusta coffee) are the two most important varieties under commercial cultivation and account for about 70% of world production.

In Ghana, the Robusta coffee is the variety that is predominantly cultivated.It provides livelihoods for about 3,500 farmers located mostly in parts of the Eastern, Ashanti, Central, BrongAhafo, Western and Volta Regions of Ghana(Amoah, 2000). The total acreage of Robusta coffee is about 70,000 hectares, with a total annual production of 500 – 2000 metric tonnesand between 2005 and 2009 coffee production was little over 5,000 metric tonnes with a free-on-board (FOB) value of US$ 5,626,026.86. Economically it contributes between 0.06% - 0.19% to the national gross domestic product (GDP).Ghana’s coffee is exported mainly to United Kingdom, The Netherlands and Germany (Mutua, 2000).

Coffee which is intended for export should be free from any extraneous matter and consist of clean dry beans free from mustiness and not contains more than twenty percent (20 %) by count of defective beans and which shall be inclusive of not more than four percent (4 %) by count of black beans (COCOBOD, 1970). The ISO standards also do take into consideration defects of one or all of the following: discoloured beans, insect attacked, mouldy or decayed beans, and a measure of some intrinsic qualities like acidity, total crude protein and percentage caffeine content.

In spite of its huge market potential, Ghana's coffee, however, sells at a discount on the world commodity market due largely to it its unsatisfactory quality arising from poor processing methods (Mutua, 2000).ACocoa Research Institute of Ghana (CRIG), (2000), report identified the drying process of the coffee beans as a major postharvest constraint due to its significant effect on the quality of the beans. Even though some attempts have been made by Lowor*et al.*, (2007), to date, no in-depth work has been done to examine the drying process in relation to the quality of the coffee beans produced in Ghana.

Due to the scarcity of information on how drying depth and method of drying affects the quality of Ghanaian Robusta coffee var. *Coffeacanephora*, the present study was undertaken to determine the effect of different drying depths and methods on the quality of Robusta coffee.

Specific objectives of the study were to:

(1) investigate the effect of three (3) drying depths on rate of drying Robusta coffee beans,

(2) investigate the effect of different drying methods on rate of drying and,

(3) determine the interactive effect of the depth and method of drying on the quality of Robusta coffee.

2.0 LITERATURE REVIEW

2.1 COFFEE

2.1.1Botanical Description

Botanists regard the Robusta coffee as an evergreen shrub of variable size that usually grows to a height of 10 - 15 m and 6m wide. The branches are semi-erect when young and spreading when old (Coste, 1992). Growth is by monopodial branching where the branches (primaries) remain subsidiary to the main stem. The root has a stout central root, often multiple and tapering abruptly. The leaves are dark, green, glossy and are borne in opposite pairs on the sides of the branches which are usually about 10 – 15 cm long and 4 – 6 cm wide. The flowers are axillaries and clusters of them blooms simultaneously followed by their oval beans of about 1.5 cm (Clifford and Wilson, 1985). Fruits of the coffee plant are orange-red to red on ripening. It is 15-17 mm long and 10-14 mm wide. The fruits have a colouredexocarp (skin), a fleshy yellow-white mesocarp (pulp) and two beans, which are attached along their flat sides. The size and shape of the beans differ depending upon the variety, environment and agronomical practices (Coste, 1992). The beans are green when immature and they gradually change to yellow as they ripen, then to crimson red after several months. The beans ripen between ten to eleven months for the Robusta *spp* whereas for the Arabica *spp*, it takes between seven to nine months (Amoah, 2000).

The coffee plant takes about 3 years to develop from the seed to first flowering and fruit production. Furthermore a well-managed coffee tree can be productive for more than 80 years, but the economic span is rarely more than 30 years (Wintgens, 2004).

The genus Coffea consists of more than one hundred differentspecies and they vary in their chemical composition (Clifford and Wilson, 1985). The two main species which the international coffee trade is promoting are *Coffeacanephora* (predominantly known as 'Robusta') and *C. arabica* (Arabica coffee). In Ghana the main coffee species produced is the *Coffeacanephora* (Robusta) (Amoah, 2000). *Coffeacanephora*, *C. excelsa* and *C. liberica* are self-incompatible and require out crossing. Cuttings, grafting and budding are the main methods of vegetative propagation into useful forms of hybrids. On the other hand, *Coffeaarabica* is predominantly self-pollinating and as a result, the seedlings are generally uniform and vary little from their parents.On the other hand, *Coffeacanephora*, *C. excelsa* and *C. liberica* are self-incompatible and require out crossing.Cuttings, grafting and budding are the main methods of vegetative propagation (Coste, 1992).

2.1.2 Importance and uses of Coffee

Globally, coffee is one of the most widely traded tropical agricultural commodities with a relatively stable production output of a little over 133 million bags for the 2009/10 crop season. Coffee production in Africaaccounted for about 12.3% of global production and less than 11% of global exports of the product for the 2009/10 season. The collective contribution of production from Africa to the global coffee marketis almost equal to that of Indonesia, the third largest world producer of the commodity. Despite the small contribution of Africa’s production, the commodity constitutes a large proportion of both GDP and exports share in some of the small economies in Africa. Ghana’s annual production for the coffee crop year 2009/10 is 20000 bags but Coffee output is expected to reach 1,260 metric tons during the 2010-11 harvest, making Ghana the third-smallest producer of the beans in Sub-Sahara

Africa. Ghana mainly grows the Robusta variety of coffee which is of lower- quality and used primarily for the production of instant coffee (Mafusire*et al*., 2010).

Coffee is used almost exclusively in the drinks industry, and is offered to consumers as instant coffee, ground, and also as roasted beans. It is one of the most popular beverages of the present times. In most important consumer countries, roasted coffee is almost always sold as a blend of different origins and qualities. People drink coffee to relieve mental and to increase mental alertness. Coffee is also used to prevent Parkinson's disease, gallstones, type 2 diabetes, gastrointestinal, lung and breast cancer. It is also used to treat headache, low blood pressure, obesity and attention deficit-hyperactivity disorders. An important constituent of the coffee bean is caffeine. The free caffeine content in a bean is dependent on the coffee type, variety, the site conditions and other factors. It works by stimulating the central nervous system, heart and muscles (WebMD, 2011).

2.1.3Coffee Bean Quality

According to the International Organization for Standardization (ISO), quality is a set of inherent characteristics of product, system or process which fulfils the requirement of customers and/or interested parties (ISO, 2000). These inherent characteristics are collectively called attributes. Coffee quality is attributable to its botanical variety, weather and topographical conditions, handling and care during growing, harvesting, storage, preparation for export and transport. Presently, as described by Leroy *et al.,* (2006)the quality definitions have variations on its production as well as the consumer chain.

- At the farmer level – coffee quality is seen as a combination of product level, pricing and the easiness of cultivation;
- At the exporter and/or the importer level – The quality of coffee is associated with the bean size, absence of defect and deformities, uniformity and/ or homogeneity of beans, physical characteristics and price;
- At the roaster level - coffee quality depends on moisture content, stability of the characteristics, origin, price, biochemical compounds and organoleptic qualities;
- Each consumer market or country defines its own organoleptic qualities, so at the Consumer level, coffee quality is associated with the price, taste, flavour and aroma, health effect and alertness, and geographical origin. Environmental and sociological aspects for organic coffee, Fair Tradeand sustainable coffee have also become criteria of choice (ISO, 2000).

Lately, many producing countries have expanded their production and export. According to current trends of overproduction and significantly low prices in the coffee trade, improvement in coffee quality can bring into the coffee chain new gains (Leroy *et al.*, 2006). Increasing production and supply of good quality coffee isimportant for coffee exporting countries. Therefore, providing good quality coffee ensures sustained competiveness on the world market (Behailu*et al.,* 2008). ISO, (2003), defines green coffee quality standards (ISO 9116 standard) depending on information like the geographical and botanic origins of the coffee, the harvest year, moisture content, total defects, the proportion of insect-damaged beans, bean size and some chemical compounds.

According to the Fruit Industry (Coffee) Regulation on the Decrees and Legislations on Produce Inspection Division of the Ghana Cocoa Board (COCOBOD), (1970), the quality standards of coffee intended for export shall be free from any extraneous matter and consist of clean dry beans free from mustiness and with the total defects consisting of one or all of the following: black and/or discoloured beans, insect attacked/damaged, bean size and mouldy or decayed beans.

In recent years, environmental and/or green issues, such as organic, fair trade or sustainable coffees have also become criteria of choice for the consumers. These new quality criteria can bring benefits for the planters who receive a guaranteed minimum price, or a bonus for above-standard quality (premium) and are advised on quality control and market needs (Viani, 2002).

2.2PHYSICOCHEMICAL FACTORS AFFECTING COFFEE BEAN QUALITY

The quality of the coffee bean is a complex characteristic. The quality is evaluated by key factors such as the species or variety (genetic factors), environmental conditions (ecological factors), agronomic practices (cultivation factors), processing methods (postharvest factors), and storage conditions, preparation of the beverage and taste of the consumer (Moreno *et al*., 1995 and Behailu*et al*., 2008). Coffee quality is of critical importance to the coffee trade.However, in Ghana the quality of coffee produced is generally not impressive. Viani (2002) reported that inadequate methods of harvesting, postharvest processing, storage are responsible for the wide spread failure to maintain the inherent quality of coffee produced.

2.2.1Effect of Climatic and Soil Factors on Coffee Bean Quality.

The environment has a strong effect on coffee quality. Altitude, daily temperature fluctuations, amount and distribution of rainfall and the physical and chemical characteristics of the soil are important factors. Climate, altitude and shade play an important role in temperature management (maximum-minimum temperature), light and water availability and humidity during the ripening period (Decazy*et al*., 2003). The distribution and intensity of rainfall as well as sunshine strongly influences flowering, sink flow, bean expansion and ripening (Clifford and Wilson, 1985). Higher altitudes (lower air temperatures) slow down the ripening process of coffee beans and under shading, allowing for more time for complete bean filling. On the other hand, yielding beans that are denser at lower altitude (or under full sunlight) usually give better cup characteristics and stronger flavours (Vaast, *et al.*, 2006).

Climate varies according to the elevation and in some cases day length. According to Olympio and Kumah, (2008), the same crop variety which is grown in different locations of the world will not necessarily have the same product characteristics in terms of flavour, texture, skin thickness, handling ability or storage life. The differences are caused by an interaction of climatic factors and are also influenced by day length and altitude. The altitude as a factor is closely related to moisture, relative humidity and temperature. According to Wintgens, (2004), periods of prolonged drought may also result in lower bean quality.

The cup quality is influenced by the rate of the maturation process. The slower maturation process also guarantees for the right biochemical processes needed for the development of a beverage quality, the benefits of which can also be derived from the duration of the bean-filling period as well as the leaf area-to-fruit ratio (better bean-filling capacity) which is also linked to a better cup quality (Vaast*et al*., 2006).It is admitted that the acidity of coffee brews is recognized as an important attribute of coffee quality (Coste, 1992).

2.2.2 Effect of Moisture and Relative Humidity (RH) on Coffee Bean Quality

Coffee is 98.5 to 99% water hence the moisture content of the coffee bean is a very critical parameter of coffee and is an important attribute and indicator of quality. At higher moisture content, the coffee can lose its sensory effects and at lower moisture content (< 9.0% moisture content) may be irreversibly damaged in colour, as well as in their cup test, flavour and consistency which means that it is not worth reducing the moisture content to such a low level when drying (Sivetz and Desrosier, 1979). If the beans are too wet, for example, more than 12.5% moisture, the beans can easily grow mouldy during storage, whiles, if too dry (below 8%) they lose flavour. The way coffee roasts are influenced by the amount of moisture in the bean as well as its weight loss. Leroy *et al*.,(2006) indicated that Green Coffee tends to roast faster when the moisture content is lower than those with higher moisture content. Internationally, coffee should not be exported when the moisture contents are outside the internationally accepted levels (8.0% ≤ X ≤ 12.5%), (ISO, 2000).

Studies have also revealed that at moisture levels 15% - 16%, the corresponding Relative Humidity (RH) level is 75%. According to Ramaiah, (1985), levels like these are seen as critical for fungal development according to the Henderson balance. A RH level of less than 60% is most acceptable to keep down further fungal growth. Reducing the available water down to the safe storage level of water activity, the chemical reactions and microbial developments are slowed down considerably (Christensen and Kaufmann, 2006). One of the most indicative effects of high RH in combination with temperature variations allow for condensation of water which facilitates fungal and insect infestation. However under ideal conditions, the general losses of coffee during storage should not exceed 1% in order to maintain the weight during storage and transportation (Wintgens, 2004).

2.2.3 Effect of Temperature on Coffee Bean Quality

The natural limits to the postharvest life of all types of fresh produce are affected by biological and environmental conditions. Temperature, without a doubt, is the most important factor affecting postharvest life. This is because temperature has a profound effect on the rates of biological reaction, e.g., metabolism and respiration. The Van't Hoff Rule states that the rate of a biological reaction increases 2 to 3 fold for every $10^{o}C$ rise in temperature. An increase in temperature causes an increase in the rate of natural breakdown of all produce as food reserves and water content become depleted (Kitinoja and Kader, 2002). Coffee with moisture content as low as 11.0% is said to loss their quality after six months under a temperature of $35^{0}C$ whereas others with moisture content above 15.0% maintains their quality at temperature as low as $10^{0}C$. Coffee, therefore, needs to be maintained at low storage temperatures in order to reduce its rate of metabolism and respiration. The duration for light exposure (day length) and the intensity of light have both been reported to affect coffee quality (Avellino, *et al.*, 2005). Shelf life is shortened at lower altitudes by approximately three months. However, for those stored above 1400m, the natural shelf life can be as long as eight (8) months. High altitudes as locations for coffee storage however, will be most appreciated by importers, exporters and industrialists (Wintgens, 2004).

2.2.4 The Effect of Pre-harvest and harvest factors on Coffee Bean Quality

An excess of soil nitrogen increases the caffeine content which results in a more bitter taste of the cup. The Caffeine and chlorogenicacid (CGA) contents of the beans are also not affected by the levels of phosphorus, calcium, potassium and magnesium in the soil. High concentration of calcium (>0.11%) and potassium (>1.75%) in the beans is associated with a bitter and "hard" taste. On the other hand, there is no correlation between the phosphorus content and the physical and organoleptic quality of the bean. Good conditions for coffee tree growth (weed control, appropriate planting density and pruning) usually have a positive effect on bean size and flavour (Wintgens, 2004).

Pests and diseases attack can affect the beans directly or cause them to deteriorate by weakening the plants and the production of immature and/or damaged fruits. Disease and insect attack (such as leaf miner and mites) may also result in lower quality beans (Wintgens, 2004). OTA (Ochratoxin A) a form of mycotoxin, produced as a metabolic product of *Aspergillusochraceus*, *A. carbonarius*and strains of *A. niger*isreported to exist on coffee dried on bare ground (Eshetu and Girma, 2008).Thismycotoxin is highly poisonous and therefore, drying processes employed in coffee drying should not be conducive for these moulds that produce OTA to thrive, thereby affecting the quality of the bean. The age of the coffee tree has a direct influence on the cup quality than from agronomic practices (Yigzaw, 2006). Studies by Vaast*et al*., (2006), revealed that there is an interactive effect between tree physiology, plant age and period of picking of the coffee beans on the final characteristics of the product. Further findings showed that location of the beans on the tree and fruits-to-leaves ratio also influenced strongly on the chemical content of the beans.

One of the main factors affecting the natural coffee quality is the method of harvesting(Hicks, 2002). The traditional hand-picking and husbandry labourproduce the best quality green coffee by decreasing the percentage defects. Further observations indicated that when the yellow or green coffee beans are picked at the end of the picking season, they may contain beans with higher maturity levels than the red beans of *Coffeacanephora*picked at the start of the picking season. Low caffeine content were found in beans harvested at immature stage (unripe) and in over-ripe coffee beans as well as those in the bud and yet to develop stage (Vaast*et al*., 2006).

2.2.5 The Effect of Postharvest Factors on Coffee Bean Quality

Processing is a very important activity in coffee production and plays a crucial role in its quality determinationand must begin immediately after harvestingthe beans to prevent the pulp from fermenting and deteriorating. The harvested coffee beans are either processed by the wet or dry method, and these vary in the complexity and expected quality of the coffee. The sun-drying method which is less labour intensive, cheaper, simpler and produces “natural” coffees (Hicks, 2002) is predominantly operated in Ghana (Amoah, 2000). However, studies have shown that dry processed coffee is generally considered to be of lower quality than the wet processed and commands a lower market price (Clarke, 1985; Varnam and Sutherland, 1994).

However, a premature harvest can sometimes be carried out by strip picking for needs of cash, fear of theft and lack of labour. According to Clifford, (1985), dry processed coffee is less aromatic and acidic but has greater body. Washed coffee and its perceived acidity are significantly higher than the acidity found in naturally (dry) processed coffees. This is because the body of the dry processed coffee masks the acidity (Yigzaw, 2006).

The covering period during drying and depth of the spread affect the total time required to dry the parchment coffee to an optimum moisture level ranging from 11% to 12%. Coffee is dried on large patios made of asphalt or cement (concrete) or on raised raffia mats/platforms. Sometimes the cemented floor is covered with a polythene sheet to reduce contamination. Behailu*et al.*, (2008) indicated that coffee dried at a drying depth of 5cm gave a lower cup quality, confirming earlier studies (Mburu, 2006) that drying depths of 2, 3 and 4 cm produced better cup quality.

2.2.6 Effect of Drying Method on Incidence of Fungalload

One of the most common forms of *Mycotoxins, Ochratoxin 'A'* (OTA) is produced as a metabolic product of certain fungi and it is also of concern for human health. These fungi are mainly of the genera Aspergillums and Penicillium. Apart from *Penicilliumverrucosum*which is important for cold damp conditions of Northern Europe, *Aspergillusochraceus*and *Aspergillusniger*serve as the two most important species for warmer climatic regions of the world. Foods, apart from cereals and cereal products, coffee and cocoa beans are very susceptible to Ochratoxin contamination. The*Aniger*, according to reports, is the commonest of the group, fast growing and aggressive, making it virtually the only fungus in commodity samples but rarely produces mycotoxins or strong taints. A greater proportion of *A. carbonarius*isolates produce significant amounts of OTA and, as far as the *niger* group is concerned, *A. carbonarius*attracts lots of attention(Santina, *et al*., 2002).

Studies by Magan, *et al*., (2003); Cairns-Fuller, (2004) and Cairns-Fuller, *et al*., (2005) have shown several relationships between water availability (water activity), temperature and growth of OTA production for *P. verrucosum* and *A. ochraceus.* The growth of mould on coffee beans is possible if the moisture content of the beans exceeds the standard for an extended time. Coffee beans containing OTA cannot be detected directly, in all cases, by visual and organoleptic assessment. According to Bucheli,*et al*., (2002), it is because either not all the mouldy beans, (during and after drying) are infected by OTA, or that some non-mouldy dried beans may still contain the toxin. Several studies have also reported the presence of OTA in raw coffee beans since 1980 and their findings have been able to show that broken and infested coffee beans, together with husks were the most important sources of OTA contamination found in green coffee (Santina*et al*., 2002).

The occurrence of 319 parts per billion (ppb) of OTA in an aggregate husk sample of a public coffee de-huller demonstrated that husks are the richest sources of OTA in green coffee. Other studies suggested in particular, that the level of OTA contamination in green coffee was too high with samples coming from different parts of the world with samples from African countries being more contaminated(Santina*et al*., 2002).

Aspergilluscarbonarius, found to be synonymous with coffee beans contamination, is an invasive fungus and able to colonize and penetrate coffee beans even without skin damage (Belli *et al*., 2007).It has been reported that*Aspergilluscarbonarius*could be an importantOTA producer in coffee and is the main mycotoxin that has been detected with its occurrence been attributed to environmental conditions and/or processing conditions. It is the most studied metabolite due to its occurrence in food and its toxicological significance in human and animal diets(Sua´rez-Quiroz *et al*., 2003). This toxin is known to have immunotoxic, teratogenic, nephrotoxic and carcinogenic (Group 2B) effects on animals (IARC, 1993 and JECFA, 2001).Balkan endemic nephropathy is said to be enhanced by OTA contaminated food (Stefanovic*et al*., 2006). OTA interacts mainly with the kidney which may lead to chronic interstitial nephritis and atrophic changes in the tubule architecture and other organs such as the immune system, liver, or spleen. Because of its strong ability to bind to blood proteins, OTA may also remain in human blood for a long period (Stormer and Lea, 1995).

Some European Commission (EC) member states have statutory legal OTA limits for coffee; Italy, (8 ppb for green coffee and 4 ppb for final product), Finland (10 ppb) and Greece (20 ppb). These notwithstanding, most coffee consuming countries are becoming keen on the quality of green coffee and other produce because, contamination with OTA is a postharvest problem and soon, there is likelihood of a legal OTA limit being set together with other quality standards by the EU and other importing giants (Santina*et al*., 2002). Ghana, unfortunately, has not set acceptable standards for its OTA levels.

2.2.7 Effect of Handling Methods on the Quality of Dried Coffee Beans

Traditionally, coffee beans are selectively picked by hand. As a labour-intensive method,it involves the selection of only the beans at the peak of ripeness. More commonly, the beans are strip-picked where all beans are harvested simultaneously regardless of ripeness by person or machine. The presence of 2.5% or more of unripe coffee in a coffee batch is known to significantly affect the quality of the coffee (Viani, 2002).

The harvest and postharvest processes of coffee production are considered as some of the difficult and sensitive tasks in the coffee production chain. The harvest of mature coffee beans is essential in the postharvest process for the determination of coffee quality. However, specialty Coffee, which is a brand of processed coffee beans, is the synthesis of many things: the combination of the species and variety of the coffee bean, the method of processing, roasting as well as the care, handling and selling of the beans (Wintgens, 2004).

Washed coffee frequently has higher moisture content than unwashed coffee, due to the processing technique used, making it more at risk from sweat. Moisture damage therefore, does not generally become apparent until several days after the beans have come into contact with water given out a musty odour and showing visible changes to the beans. Long exposure to wetness, as a result, turns the beans white which subsequently becomeblack, mouldy and swollen resulting in a rotten odour (Viani, 2002).

Generally, the longer the beans roast, the darker their colour and stronger their flavour. Stored coffee may present flavour damage, and the incidence of the existing damage may become more serious during storage. Potential damages, caused during handling and storage which affects cup flavour are baggy, mouldy, earthy, onion, old crop and contamination. In addition to the impact on green coffee colour, the defect due to poor handling can result in bleached beans (Lingle, 1986). The generally accepted time for green coffee storage under normal conditions, is one calendar year otherwise, the quality becomes blemished. The inherent biochemical activity in the bean is not affected by long storage but, rather some minor components become transformed resulting in the cup tasting woody and harsh after roasting (Wintgens, 2004).Dried coffee beans are usually packaged in new bags of woven natural jute or sisal materials, which allow free air circulation. There is a close connection between fluctuations in the ambient temperature and the formation of condensation water in the hold.If coffee beans have an excessively high moisture content, there is a risk of mustiness, mould growth and post- or over-fermentation (Coste, 1992).

2.3POSTHARVEST HANDLING OF COFFEE BEANS

2.3.1 The Dry Processing Method

Drying is a natural process which is usually simple, done in the sunand is very time consuming. It is the part of the postharvest process that enables the removal of excess moisture to a level that is safe for long time storage without any impact on aroma or taste of the final beverage. Drying is said to be completed when the covering of the bean (husk) can be removed easily by pressing between the fingers. In this process, the fresh beans are dried immediately after harvesting in order to stabilize it and preserve quality. Once they are dried, the pulp, mucilage and parchment forms the husk enveloping the beans (Clarke, 1985). The dry processed coffee is called hard coffee and the premium offered for dry processed Robusta coffee is smaller than that of the Arabica type.

Drying is important and critical for coffee preparation which may affect thequality of the end product. Drying therefore, removes the surface moisture that could potentially initiate a harmful post-fermentation reaction if allowed to remain. This may occur when moist coffee beans are spread out in thick layers and inadequately stirred. The thickness or depth of the layer of beans must not exceed 6cm, when on the drying material to reduce the risk of mould developing, seed germination and black beans forming. Drying begins when the layer of coffee beans are exposed to the sun, stirred every 30 to 40 minutes, protected from rainy weather and takes up to 30 days depending on the seasonal weather pattern to dry. The duration of the drying period depended on the climate, the diurnal temperature, the sun's intensity, relative humidity, ventilation and the nature of the drying material (Coste, 1992). However, the success of this method depended largely on the continuance of clear and warm weather over a period. Inadequate drying to moisture content greater than twelve percent (12 %) will however cause mouldiness making the aroma stale during storage. However, it has also been observed, through studies that, coffee beans take longer periods to dry during cold weather conditions and some re-absorb moisture thereby facilitating the production of mycotoxins (Mburu, 2006).

2.3.2The Wet Processing Method.

Coffee can also be wet processed. It produces the 'washed' or'mild' coffees and this involves more capital outlay, more water and more care than the dry method (Hicks, 2002). In the wet or washed coffee processing, the ripped fruit is squeezed during pulping, allowing the soft pulpy part of the bean with the skin to be separated. The resulting product called washed coffee can have its parchment easily hulled to provide the dry green bean (Sivetz and Desrosier, 1979). According to Clarke, (1985) and Hicks, (2002), the main difference between the wet and the dry methods is that in the wet method the pulp is removed from the beans within 12 – 24 hours after harvesting instead of allowing the berries to air dry. This method helps to preserve some intrinsic qualities of the bean better and also the green coffees produced, as a result, are more homogeneous with few defects. Studies have shown that coffees produced by this method are of better quality and commands higher market price.

2.4 THE METHODS OF ASSESSING COFFEE QUALITY

2.4.1 Physical Qualities

Drying of coffee induces a volumetric contraction of the bean to approximately 12 – 15 percent (%) and that if they are not sufficiently dehydrated, water may move from the internal tissues to the superficial layers. This moisture migration may cause alterations in the physical composition of the bean making the appearance discoloured with spots and other variegations. The drying aspect of coffee is one of the critical stages where the value of the product is said to be affected. Coffee of excellent origin therefore, can lose some of their quality traits if poorly dried (Coste, 1992).

TheICO's (2001) Coffee Quality Improvement Program (CQP) asked members of producing countries not to export Arabica or Robusta coffee of any grade with moisture content between 8% and 12.5% (i.e. 8%≤ X ≤ 12.5%). ISO, (2003), has established a standard (ISO 10470) that described coffee bean defects as; any foreign matter ofnon-coffee origin; of non-bean origin such as pieces of parchment or husks; abnormal or irregular bean shape and other defects by way of visual appearance such asblack beans and for taste of the cup.

Bean sizes are very important for roasters as the uniformity of beans also determines the roasting and cup quality. Beans of the same size are expected to roast uniformly; however, the differences in the shape and sizes of coffee beans are influenced by botanical variability and the environment. There is no universal grading and classification system and for this reason producing countries have their own minimum standards for export (Wintgens, 2004).

Production surpluses between the late 1990s and early 2000 called for coffee qualities in the world market to be eliminated and the International Coffee Organization (ICO) council passed a resolution to this effect. The International Coffee organization (ICO, 2001) therefore implemented a Coffee Quality Improvement Program (CQP) on 1stOctober, 2002 with specified recommendations to exporting countries not to export coffee with the following characteristics; for Arabica Coffee, in excess of 86 defects per 300 grams sample (New York green coffee classification/Brazilian method, or equivalent); and for Robusta Coffee, in excess of 150 defects per 300 grams (Vietnam, Indonesia, or equivalent classification).

In Ghanahowever, the Fruit Industry (Coffee) Regulations, L. I. 644(COCOBOD, 1970), mandates the Produce Inspection Division, now Quality Control Company

Limited (QCCL) of the Ghana Cocoa Board (COCOBOD) to inspect and certify Ghana's coffee before export. COCOBOD has it that the standards forcoffee quality which is intended for export shall be as follows;

1. Superior Quality – Coffee which is free from extraneous matter and consists of clean dry beans free from mustiness and which contains not more than 20% by count of defective beans which shall be inclusive of not more than 4% by count of black beans.
2. Fair Average Quality – Coffee which is free from extraneous matter and consists of clean dry beans free from mustiness and which contains not more than 25% by count of defective beans which shall be inclusive of not more than 8% by count of black beans.
3. Sub-Standard Quality – Coffee which is free from extraneous matter and consists of clean dry beans free from mustiness and which contains more than 25% but less than 50% by count of defective beans which shall be inclusive of not more than 8% by count of black beans.

The International Coffee Organization (ICO, 2001) describes coffee defects in respect of the total defective beans as:

- Foreign material of non coffee bean origin;
- Foreign material of non coffee bean origin, such as pieces of parchment or husk or due to insect attack;
- Abnormal beans with poor shape regularity and/or integrity as well as broken beans;

- Abnormal beans for visual appearance, such as black and/or discoloured beans,
- Abnormal beans for taste of the cup after proper roasting and brewing;
- Mould is seen as a major defect.

2.4.2Organoleptic Qualities

The most important parameter in the appreciation of quality is the organoleptic quality of the cup which is mainly due to the volatile substances present as well as sensory analysis referred to as cup quality. The cup quality is determined on the basis of the level of acidity, body and flavour of the brew (Yigzaw, 2006). Studies show that these volatile substances account for not more than 0.1% of the total aromatic compounds, while the non-volatile compounds can only explain acidity and bitterness (Viani, 2002). However, an important attribute of coffee cup quality is the perceived acidity (Woodman, 1985; Dagenhardt*et al*., 2006 and Lowor, et al., 2007). Recent studies by Lowor*et al*., (2007), showed that aliphatic carboxylic acids are the main acids found in coffee and coffee infusions. Changes in the pH can therefore lead to changes in the character of the flavour as well as the acidity. Clifford, (1985), also indicated that acidity shows the bitter or acidicbalance and therefore, high acidity gives better quality and more intense aroma to the beverage. The pH of coffee has been found to correlate with the perceived acidity of coffee and a pH range of 4.9 to 5.2 is preferred for a good cup of coffee(Yigzaw, 2006).

Beans from different countries or regions can usually be distinguished by differences in their flavour, aroma, body and acidity. Studies have indicated that the chemical baseand organoleptic (taste and testing) qualities of a coffee depend mainly on the coffee's growing region and processing rather than the variety of the coffee(Viani, 2002). Others (Prodolliet, 2004), also say that to assess organoleptic quality; one has to take into account consumers' specific taste preferences according to their nationality which may lead to an unreliable definition. Varieties are generallyknown by the region in which they are grown, such as Colombian, Java and Kona(Coste, 1992).

2.4.3 Health Qualities of Dried Coffee Beans

The level of pesticide residue in coffee is usually low however, one of the major mycotoxinsfound in coffee, is *OchratoxinA* (OTA). Thesemycotoxins are normally classified as being carcinogenic to humans. The genuses of mould that produce OTA in coffee are *Aspelgillusniger. A. carbonarius,* and *A. Ochraceus*(Eshetu and Girma, 2008).

Many studies have however examined the inter-relationship between coffee consumption and certain medical conditions and whether the overall effect of coffee is positive or negative has widely been disputed. Studies at the Cocoa Research Institute of Ghana (CRIG) at Tafo showed the presence of some antioxidant properties due to phenolic and chlorogenic acids (CGA) even after storage before drying on Ghanaian Robusta coffee (Lowor and Amoah, 2008). The presence of antioxidants like caffeine, trigonelline and other related chemicals which give brewed coffee its chemo- protective effect makes it safer to human health when taken in moderation(George *et al*., 2008). Coffee has also been linked to a lot of potential health benefits including protection from Parkinson's disease. Studies suggest that coffee might also protect against liver cancer and type *2Diabetes mellitus.* However, it has also been shown that its harmfulness is associated with people who are sensitive to stimulants. Beyond this, there is no evidence that coffee intake is connected with adverse health effect (Schilter*et al*., 2008).

2.4.4 Quality Assurance of Dried Coffee Beans

The quality of coffee beans is said to be at their highest when they are first produced. Studies have shown that if the quality subsequently declines, it becomes difficult, or impossible to make good the quality loss. The loss of quality in coffee is equal to loss of value.Quality assurance therefore, commences at the time of harvestandcontinues through processing, drying, cleaning, packagingand storage (Walker *et al*., 2006) in order to sustain and maintain quality.

Consumers the world over, experience the quality of a good cup of coffee due to a quality assurance program which is implemented by all the key players involved in the coffee production to consumer chain (Prodolliet, 2004). Dessie, (2008) and ISO, (2000), defines quality as the ability of a product to satisfy consumers' expectation by way of good sensory characteristics (e.g. aroma, flavour, body and acidity), the absence of off-flavours (mouldiness, earthy, fermented and chemical), and its wholesomeness and/or safety (free from contamination like pesticides and mycotoxins). These required quality characteristics do not come by chance but through planned and systematic activities which are adhered to in order to ensure that the quality of coffee is attained or maintained and to some extent, can be predetermined by the genotype, the climatic condition and soil characteristics of the coffee growing region (Prodolliet, 2004).

2.4.5Green coffee

The drupe of the coffee plant contains two beans which when subjected to an appropriate treatment are named as green coffee. After roasting, they are used as beverage and for food preparation. The caffeine content in the Robusta green coffee, which is in the order of 2 to 2.5%, is significantly higher than that of green coffee from arabica (1 to 1.5%) and therefore seen as a drawback (Pochetand Flemal, 2001).

The International Organization for Standardization issued guidelines for the sale and purchase of green coffee. The ISO 9116 standards which describe the quality of the green coffee require that the under listed parameters are adhered-to when dealing with green coffee (ISO, 1992):

- The geographic and country of origin, plantation,
- The botanic origin (species and variety),
- The crop year,
- The moisture content,
- The total defect and presence of any foreign matter,
- The content of insect damaged bean,
- The bulk density,
- Bean uniformity and/or size.

2.4.6Sensory evaluation

The sensory evaluation, as seen in the coffee industry, is required to be used in order to know of the product quality as well as its consistency with time along the various conditions for processing. According to Clifford and Wilson, (1985) as well as Petracco, (2005), the tool used in ascertaining the quality is by using a trained and experienced panel of assessors (professionalcup-testers) with the necessary expertise to describe all the attributes of the beverage which may be desirable and undesirable.The sensory profile, as a quality evaluation tool for the raw green coffee is needed to ensure consistency in the quality reception and after roasting for good cup taste, flavour and aroma. The cup quality is often referred to asdrinking quality or liquor quality and is an important attribute of coffee acting as a yardstick for the coffee trade (Prodolliet, 2004).

3.0 MATERIALS AND METHODS

3.1 Geographical Location and Characteristics of Study Area

The study was conducted at KwahuBepong in the KwahuSouth District of the Eastern Region of Ghana. It is bounded to the North by Kwahu East District, to the West by Asante AkimNorth and South Districts of the Ashanti Region, to the East by KwahuEast and Afram Plains Districts and to the South by the Kwahu West, Fanteakwa and EtiwaDistricts. Out of a total land area of 1,313 sq km, 946 sq km is the cultivable land area with a farming population of 112,500. The soil texture is predominantly clayey loam. The topography is gentle with undulating to steep slopes. The rainfall pattern is bi-modal with an average annual rainfall ranging between 1,580mm to 1,900mm and a relative humidity (RH) of between 65% - 85%. The vegetation type comprises both semi-deciduous forest and derived savannah (Ministry of Food and Agriculture (MoFA), 2010). The experimental site was the courtyard of the 2006 – 2009 Chief Coffee Farmer of KwahuBepong where the various drying methods were mounted and replicated.

3.2 Harvesting, Experimental Design and Data Collection

Harvesting was done between December, 2009 and mid February 2010. The coffee beans were strip - harvested from the trees after which dried and dead coffee beans were removed from the harvested lot. The remaining coffee beans were mixed thoroughly and samples were subsequently taken for the experiment.

The treatments were factorially arranged in a Randomized Complete Block Design (RCBD) and replicated three times. The treatments consisted of two factors. Factor One, comprising of three drying methods (M) viz: - M_1:- drying on a raised raffia mat of 0.8 m above ground; M_2:- drying on a bare concrete floor and M_3:- drying on black polythene sheet on concrete floor and Factor Two, three drying depths (D) (this refers to the height of the heap of coffee beans above the drying floor). Viz: - D_1:- 5 cm; D_2:- 10 cm and D_3:- 15 cm).

The treatments were sun-driedfor 20 days at ambient temperature of 32º/23 ºC, day/night with periodic stirring (every 30 to 40 minutes) during the day. The coffee was covered from the evening to the morning or whenever necessary against rains.Two set of samples were randomly taken for further analysis. In the first set, 300g of beans from each treatment was weighed, labeled and sent to the CRIG laboratory for biochemical and pathological quality analyses. The parameters comprised of total caffeine, pH, total crude protein and fungal load. In the second set, 200 beans were randomly counted from each treatment, weighed, labeled and sent to the Department of Horticulture, Kwame Nkrumah University of Science and Technology (KNUST) for physical quality analysis. At the Department of Horticulture, the dried beans were manually de-hulled for the determination of sound, broken, shriveled and/or black beans, insect damage and the parchment(husk) of the coffee beans.

3.3 DATA COLLECTION

3.3.1 Determination of Temperature and Moisture Content in Heap

Thebeans were dried under ambient day and night temperatures (23^0C and 33^0C respectively). The moisture content of the beans in each treatment heap was measured using a standard moisture tester (Aqua Boy) certified by QCCL. For temperature, readings were taken using a thermo hygrometer. In each heap, readings of both moisture content and temperature were taken from the middle and corners of the heap from which the mean of each was computed. Readings were taken daily at three time periods (9:00 cm; 12:00 noon and 3:00 pm) and until a moisture content of 11% – 12.5% within each heap was attained.

3.3.2 Determination of Total Caffeine

Caffeine content was measured by High Performance Liquid Chromatography (HPLC) using the methods of Anon, (1990) and Sotelo and Alvarez, (1991) with some modifications. In a 250 ml capacity round bottom flask, a defatted sample of 0.200g was weighedto which 95 ml of distilled water was added and refluxed for 25 minutes. After cooling, water was added to adjust the weight to 100g. The mixture was thoroughly shaken and centrifuged for 5 minutes at 5000 rpm to obtain a supernatant. Prior to the analysis, the extracts were filtered through a 0.45 µmMillex filter (SLHV013SL, Millipore, Carrigtwahill, Ireland). The HPLC system comprised a Waters 1525 binary HPLC pumps fitted with a 20µl sample loop and a Waters 2487 dual absorbance detector set at 280 nm. A Hypersil ODS C18 column (25mm x 4.6mm) fitted with a guard column (H5ODS-1521A, HICHROM Ltd) was used to achieve the chromatographic separations. Compounds were eluted with an isocratic mobile phase of methanol: acetic acid: water (20:1:79; HPLC grade) at a flow rate of 1ml/min at 25^{o}C. Data was quantified based on a standard curve drawn from running caffeine standards.

3.3.3 Determination of pH

The pH determination was in accordance with the procedures of the Office International du Cacao et du Chocolat (OICC) (1972). 10 g of ground coffee was extracted with 90 ml boiling de-ionized water. The coffee was extracted for 10 min, cooled to 25°C, and the pH was determined using a Mettle-Toledo pH meter.

3.3.4 Total Crude Protein

For each sample, an approximate analysis for the total nitrogen was determined in according with the standard method of the Association of Analytical Chemist (A.O.A.C.), (1990). The crude protein (% N x 6.25) content was then calculated from the nitrogen free extract and the value obtained corrected by approximation.

3.3.5 Determination of Fungal Load

Ten grams of each sub-sample were homogenized for 3 minutes in 90 ml (10^{-1}suspension) peptone water (Oxide, code CM 9, Basingstoke, England). Ten–fold dilutions were prepared till a 10^{-3}suspension was attained. From each dilution in peptone water 1 ml was spread onto plates of two media: Dichloran Rose Bengal Chlortetracycline Agar (DRBC) and Sabourad's agar with choramphenicol (BD Diagnostic Systems) with 0.25 ml per plate; the plates were incubated at 25ºC in the upright position for 5 days. Taxonomic identification of all colonies considered as different was achieved through macroscopic and microscopic studies. *Aspergillus*species were identified according to Raper and Fennel, (1965) and other fungal genera, according to Domsch and Gams, (1980).

3.3.6 Determination of Sound and Defective Beans

Two hundred dried coffee beans from each treatment were randomly counted, weighed and manually hulled or de-husked. After de-husking, the shape and make for each bean was evaluated visually and designated as sound, cracked and/or broken, shrivelled and/or black in accordance with Ghana Cocoa Board's (COCOBOD) Standard Fruit Industry (Coffee) Regulations, L.I. 644 (COCOBOD, 1970).Each designated sample was weighed using a top-loading sensitive weighing scale of type Coco scale and manufactured by H.Fereday& Sons, London N7 8JT.

3.3.7 Determination of Insect damaged beans

Two hundred dried coffee beans from each treatment were weighed and manually hulled or de-husked. After de-husking, the insect attacked or damaged beans were identified according to Ghana Cocoa Board's (COCOBOD) Standard Fruit Industry (Coffee) Regulations, L.I. 644 (COCOBOD, 1970), countedand weighed with a Coco scale and the percentage insect damaged beans computed.

3.3.8 Identification and determination of other defective beans

3.3.8.1 Broken beans

Broken beans are determined visually and by identification of beans which are less than half of a bean and the result counted and weighed with a Coco scale in accordance with Ghana Cocoa Board's (COCOBOD) Standard Fruit Industry (Coffee) Regulations, L.I. 644 (COCOBOD, 1970) and the percentage defective beans computed.

3.3.8.2 Shrivelled and/or black beans

In accordance with Ghana Cocoa Board's (COCOBOD) Standard Fruit Industry (Coffee) Regulations, L.I. 644 (COCOBOD, 1970), a bean of which more than half is black externally, malformed in shape, mottled and desiccated, shrivelled and often also corrugated or ridged on the surface is said to be defective. The percentage defect was therefore computed.

3.4 STATISTICAL ANALYSIS

Data collected was subjected to statistical analysis using Analysis of Variance (ANOVA). Statistical package used was Statistix version 8. Testing for differences between means was at 5% level (P = 0.05)

4.0 RESULTS

4.1Temperature and Moisture Readings within Coffee Bean Heap

Temperature was highest (32.7^{o}C) in 15 cm depth of coffee beans dried on black polythene sheet on concrete floor and the least (30.4^{o}C) in 5 cm on raised raffia mat. On raised raffia mat, increase in temperature was directly proportional to increase in thickness of the heap or depth. Similar trends occurred for coffee beans dried on the bare concrete floor as well as that on the black polythene sheet on concrete floor, indicating that increase in heap temperature was directly proportional to increase in heap depth irrespective of the drying materials used (Figure1)

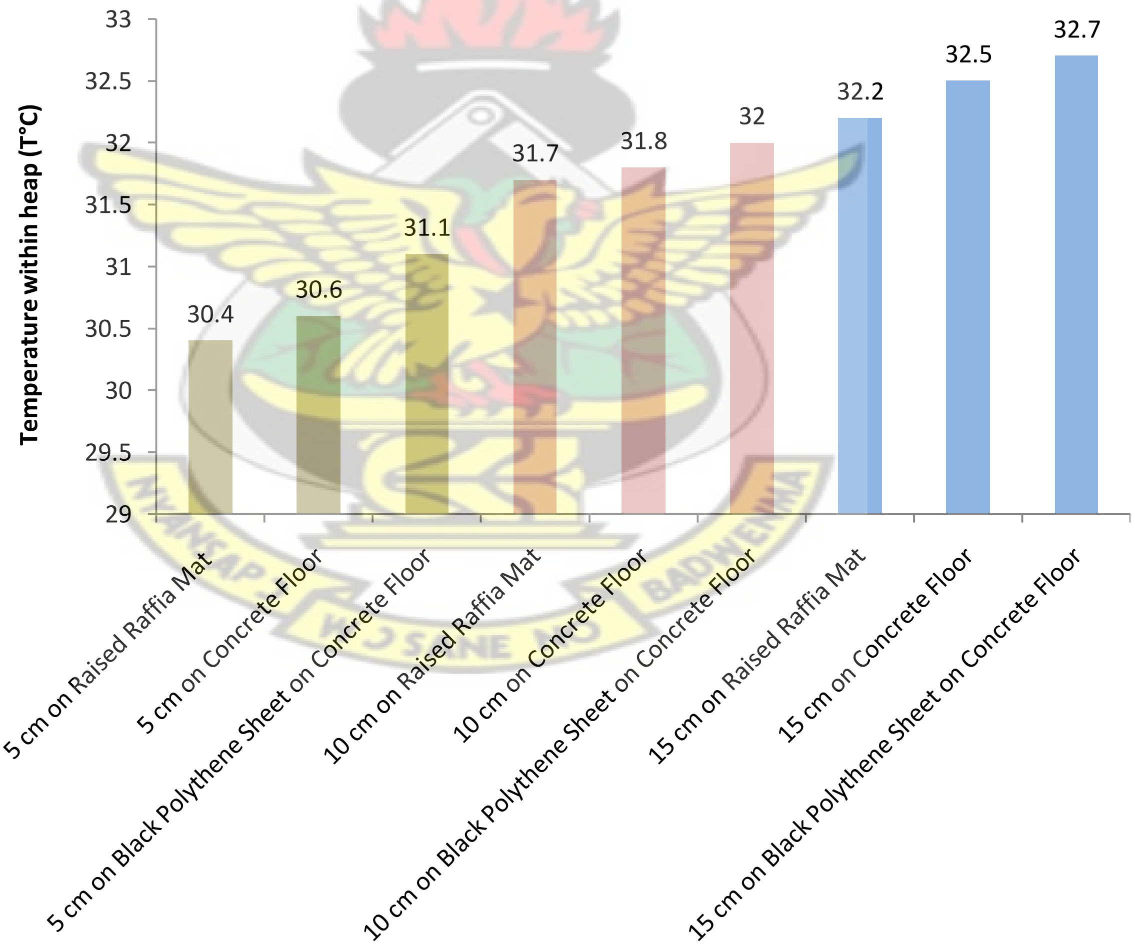

Figure1: Temperature within different depths of coffee on different drying methods

Irrespective of the depth of the heap of beans, coffee beans on raised raffia mat also lost moisturefaster than those on the black polythene sheet on concrete floor. Similarly, there was a fasteer loss of moisture from the beans on the bare concrete flooras compared to that on the black polythene sheet on concrete floor (Figure 2). Moisture is therefore lost in the following order with respect to depth or heap size, 5 cm < 10 cm < 15 cm .

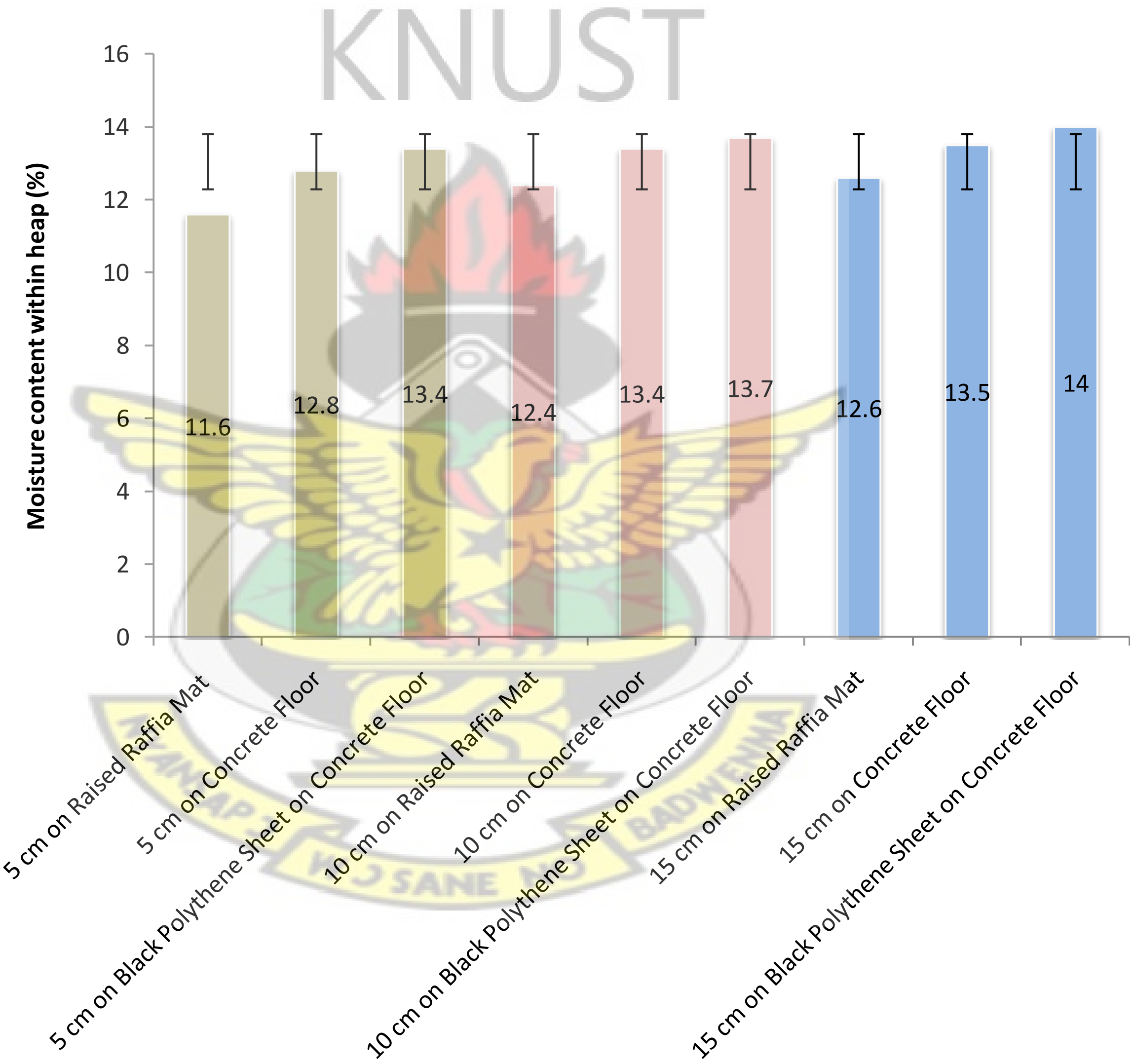

Figure 2: Moisture content within different depths of coffee on different drying materials

4.2 Number of Days to Drying of Coffee Beans

There was significant ($P < 0.05$) interaction between drying method and drying depth for the number of days taken for the coffee beans to dry (Table 1). Coffee beans on raised raffia mat and at depth of 5 cm was the earliest to dry (6 days), significantly faster thancoffee beans dried on the black polythene sheet on concretefloor which also dried significantly faster than those dried on Concrete Floor. Beans on the concrete floor at 15 cm depth took the longest time (17 days) to dry. Depth of drying therefore affected significantly, the time taken for the coffee beans to dry in the following order 5 cm < 10 cm < 15 cm. In comparison to the earliest (5 cm on raised raffia mat), the latest (15 cm on concrete floor) took about 2.8 times more days to dry. The raised raffia mat and black polythene sheet on concrete floor at 5 cm depth similarly took significantly less time to dry than all the other interactions. In general, on both raised raffia mat and black polythene sheet on concrete floor, coffee beans dried significantly ($P < 0.05$) faster compared to those on concrete floor. In general, the following order shows significant differences between the other interactions: Raised Raffia Mat x 10 cm = Black Polythene Sheet on Concrete Floor x 10 cm > Raised Raffia Mat x 15 cm > Concrete Floor x 15 cm = Black Polythene Sheet x 15 cm, which took at least 16 days to dry. In addition, coffee beans at the least depth dried faster than those at greater depths, with the number of days to drying increasing with depth.

Table 1: Effect of method and depth (cm) of drying on number of days to coffee beans drying.

Drying Depth	Method of drying			Mean
	Raised Raffia Mat	Concrete Floor	Black Polythene Sheet on Concrete Floor	
5cm	6.0	7.7	6.3	6.7
10cm	9.7	11.3	10.3	10.4
15cm	14.3	17.0	16.0	15.8
Mean	10.0	12.0	10.9	

HSD (5%) : Drying methods = 0.42; drying depth = 0.42; methods x depth = 1.01

4.3Influence of Drying Methods and Depths on pH

The pH of the coffee beans was significantly higher when dried on concretefloor, and this was significantly different from those dried on raised raffia mat and black polythene sheet on concretefloor (Table 2).

Table 2: Effect of method of drying on pH of coffee beans

Drying method	pH
Raised Raffia Mat	5.8
Cemented Floor	5.9
Black Polythene Sheet on Cemented Floor	5.8

HSD (5%) = 0.06

4.4Influence of Drying Method and Depth on Total Crude Protein Content of Coffee Beans

The Total crude protein content of the coffee beans was significantly (P >0.05) highest when dried on concrete floor or black polythene sheet on concrete floor than on raised raffia mat, the difference being almost 4% (Table 3).

Table 3: Effect of drying method on total crude protein content of coffee beans

Drying method	Total crude protein
Raised Raffia Mat	3.92
Cemented Floor	4.08
Black Polythene Sheet on Concrete Floor	4.07
HSD (5%): Drying Method = 0.14	

4.5Relationship between Quality Parameters and Environmental Conditions

There was a significant relationship between percentage crude protein content and temperature within the heap of coffee beans in that as the drying temperature increases, protein content also increases. The variations observed in the total crude protein content in the treatments is therefore determined by the increased temperature in the heap of beans during drying which accounts for 77% of the variation in the total crude protein content.The relationship is expressed as Total Crude Protein = 0.891 + 0.098 (Temperature); R^2 = 0.77; P = 0.002.

4.6The Interactive Effects of Drying Method and Depth on Fungal Load of Coffee Bean Husk.

Aspergillusniger load was greatest on husks of coffee beans on the concrete floor (68.6 %)as compared to that on the black polythene sheet covering the cemented floor (42.9 %) and the raised raffia platform (38.1%). A similar trend was also observed for *A. carbonarius.* In terms of drying depth, the greatest load of both *A. niger* and *A. carbonarius* was in the 15cmdepth. In general however, *A. niger*was more prevalent (49.8%) on the dried coffee bean husks than *A. carbonarius* (39.1 %)(Table 4).

Table 4: Fungal load on dried coffee husk under various drying methods and depths

Drying Method	Drying Depth (cm)	Percentage (%) of mould genera	
		Aspergillus Niger	*Aspergillus Carbonarius*
Raised raffia mat	5cm	14.3	9.5
	10cm	38.1	33.3
	15cm	61.9	61.9
Concrete Floor	5cm	47.6	28.1
	10cm	67.6	38.1
	15cm	90.5	66.7
Black polythene sheet on concrete floor	5cm	28.6	9.5
	10cm	33.3	38.1
	15cm	66.9	66.7

Mean 49.8 39.1............

4.7The Effects of Drying Method and Depth on Fungal Load on Coffee Bean Kernel

Aspegillusniger was the most predominant fungus with a load of 65.6% in the coffee bean kernels. *Aspegilluscarbonarius,*was completely absent. *A. niger* was less in the bean kernels on the raised raffia mat (53.9%) as compared to the black polythene sheet on concrete floor (68.3%) and the concrete floor (74.6%). Fungal load increased with increasing depth of bean kernels and ranged from 57 % to about 75 % (Table 5).

Table 5: Fungal load (%) on dried coffee kernels under various drying methods and drying depths (cm).

Drying Depth (cm)	Drying Methods			Mean
	Raised Raffia Mat	Concrete Floor	Black PolytheneSheet on concrete Floor	
5	47.6	61.9	61.9	57.1
10	52.4	76.2	66.7	65.1
15	61.9	85.7	76.2	74.6
Mean	53.9	74.6	68.3	

4.8The Effect of Drying Method and Depth on Percentage Defective Coffee Beans

The total percentage defective coffee bean kernels on raised raffia mat was lower (30%) than that on black polythene sheet on concrete floor (45%) and on concrete floor (49%) (Table 6) Irrespective of the depth of drying, the raised raffia mat resulted in the least percentage of defective bean kernels. The combined action of concrete floor and 10cm depth resulted in the highest percentage of defective bean kernels.

Table 6: Percentage of defective coffee beans as influenced by method of drying and depth (cm)

Drying Method	Drying Depth (cm)	Weight of 200 beans (g)	Weight of Sound Beans (g)	Weight of defective Beans (g)			Weight of Parchment (Husk) (g)	Percentage defective Beans (%)
				Broken	Insect Damaged	Shriveled/ Black		
Raised	5	95	42	1.3	4	3.3	33.3	9
raffia mat	10	106	44	0.7	6	3.3	37.3	9
	15	105	50	2	6.7	4	38.7	12
Concrete	5	87	44	1.3	6	4.7	42	14
Floor	10	90	41	2.7	10.7	3.3	43.3	19
	15	88	46	0.7	6	7.3	45.3	16
Black polythene	5	104	49	0.7	10.7	5.3	37.3	16
sheet on concrete	10	99	49	1.3	8	3.3	42	13
floor	15	101	52	7.3	4	4.7	44	16
Total		875	417	16.7	58.1	35.9	363.2	124
Mean		97.2	46.3	1.9	6.5	4.0	40.4	14

5.0 DISCUSSION

5.1 Number of Days to Drying of Coffee Beans

Coffee beans dried on raised raffia mat and at a depth of 5cm dried fastest to the required moisture content (within 6 days), making the combination the best among the treatments. This could be due to the combined effect of the environmental temperature and the air circulating around and within the beans due to the holes in the raffia mat. Green beans need to be dried faster to the required moisture content to avoid quality deterioration; unpleasant tastes caused by moulds or bacterial activity and black beans resulting in hard, sour beverages (ITC, 2002).

The present result is similar to the report of FAO (2004) which indicated that, about 5cm to 6cm thickness of coffee beans during drying can be taken as a near optimum compromise for loading rates. Similarly, the findings of Silva *et al.,* (2000), also showed thatheap of coffee beans at 10 cm dried in the sun on concrete floors took undesirably longer days (15-25 days) to dry with subsequent natural microbial fermentation that could influence the final quality of the product.

5.2 Effect of Temperature and Moisture within Heap of Coffee Bean

The raised raffia mat had many air spaces between the strips and this helped in aerating the heap of beans with a subsequent lowering of the temperature within the heap. On the contrary, both the concrete floor and black polythene sheet on concrete floor resulted in heat build-up and therefore caused an increase in temperature within the heap. Temperature is the most important factor that affects coffee bean quality (Schenker*et al*., 2002; Oosterveld*et al*., 2003). Higher temperature results in increased metabolic activityand therefore, green coffee beans needs to be maintained at low temperature to reduce its metabolism and respiration (Sivetz and Desrosier, 1979). The temperature values obtained in the heap on the raised mats were low butwithin the acceptable range of 29°C or less (Oosterveld*et al*., 2003). The raised mats also resulted in lower moisture content, a fact due mainly to the circulating air which prevented moisture build-up in the heap. It is generally recognized that the ideal coffee moisture content for preservation is 12 % for Arabica and 13 % for Robusta (Sivetz and Desrosier, 1979). At this level, mould growth and enzymatic activity is minimal. In the study, a direct relationship was observed between the heap moisture content and the heap depth, such that as the heap depth decreased so did the moisture content of the heap. The effects of undesirable moisture content of coffee bean does not become apparent until several days after the beans have come into contact with water with a manifestation of a musty odour coupled with visible changes to and on the beans (Ramaiah, 1985).

5.3 Influence of Drying Method on pH

The pH of the beans was affected by the method of drying such that the drying on the concrete floor resulted in significantly higher pH of the beans than the other methods.Changes in the pH can lead to changes in flavour, body, aroma as well as the acidity. This is because pH levels have been identified as major drivers for flavour differences in different coffees (Lowor*et al*., 2007). The pH of coffee in this study, were very close to that reported by Salva*et al*., (2006)for Brazilian and Lowor*et al*., (2007) for Ghanaian Robusta coffees. Acidity is a primary coffee taste sensation which is created as the acids in the coffee combined with the sugar to increase the overall sweetness and sensation of the coffee (Petracco, 2000). High acid coffees have a sharp, pleasing snappy flavour, not biting and give better quality and more intense aroma to the beverage (Clifford, 1985). Coffee with a high acidity (pH range: 4.8-5.1) are typically sold at premium price. Consequently, the coffee beans in the present study need further processing such as roasting to reduce the pH and increase the acidity to levels that would command premium price. The depth of bean heap did not significantly affect the pH of the beans in the study.

5.4Effect of Drying Method on Caffeine and Total Crude Protein Contents of Beans.

The percentage caffeine content of the beans was not affected by either drying method or drying depth. However, the present study showed similarities to the findings of Sivetz, (1963) and Varnam and Sutherland, (1994) who indicated that the quantity of caffeine in green beans was not affected by green coffee processing. The caffeine valueswere however much higher than the 1.6 to 3%range Coste, (1992), reported. The percentage crude protein content of the beans on the concrete floor and black polythene sheet on concrete floor were significantly higher than on the raised raffia mat which, may be due to the high bean heap temperatures recorded for the concrete floor treatments. In the study, a significant relationship was found between temperature and crude protein of beans such that temperature is considered a major factor in the determination of the level of crude protein in the coffee beans. Warmer temperatures are known to promote microbial proliferation resulting in increased bioactivity and therefore fermentation with the resultant increase in crude protein content (Sivetz, 1963). The crude protein values in the study (3.9 – 4.1) are however at variance with reported values from Tanzania (9.3 – 20.8%) (Rodrigues *et al.*, 2010) and Brazil (9.8 – 15.9 %) (Mori *et al.*, 2001).

5.5 Influence of Drying Method on Fungal Load

The drying methods substantially affected the degree of fungal contamination in dried coffee husk and dried coffee beans. Viable mould count in both cases increased as the days to drying increased and as the thickness of the beans on the drying platform increased. *Aspergillusniger* was found in both dried coffee husks (90.5 %), and dried green coffee bean kernels (85.7 %) whereas *A. Carbonarius*was present in only the dried coffee husks (66.7%). Nonetheless, the 85.7% *A. niger* contamination of coffee bean kernels in the present study was lower than the 93% contamination in Vietnam coffee (Ilic*et al*., 2007) and 98% contamination in Thai coffee (Noonim*et al*., 2008). Generally, the total fungi count increased with increasing depth on both the dried husk and the dried kernels. Several reasons could be attributed for the variability and complexity of fungal load in coffee beans. Variation in climatic conditions, harvesting, processing method, and drying could substantially affect the degree of fungal infection in coffee beans (Silva *et al*., 2000). Eshetu and Girma, (2008), reported that *A. carbonarius* and strains of *A. Niger* existed on coffee dried on bare ground and therefore cautioned that drying coffee on bare ground could expose the beans to such quality deteriorating factors. In summary, Taniwaki (2006),stated that no coffee producing country is free from fungal contamination. *Aspergillus, Penicillium, Fusarium*and *Cladosporium*species are referred to as natural coffee contaminants,and are present from the field to the warehouse (Nakajima *et al.*, 1997 and Pereira *et al.*, 2005). The damage caused to coffee by these microbes can be extremely serious both from the financial point of view and that of consumers' health. Pitt and Hocking (1997), indicated that, *Aspergillus*competes for substrate with *Fusarium*and *Penicillium*, and its incidence increases only in environments with high temperature and low water activity, which were the ideal conditions found in the final stages of drying, hence the high incidence of *Aspergillus* in the present study. *Aspergillusniger*and *A. carbonarius*are the two species reported to be capable of producing Ochratoxin A (OTA), the main mycotoxin that has been detected in coffee. The occurrence of Ochratoxin A in coffee beans has been attributed to environmental conditions and processing conditions (Sua´rez-Quiroz, *et al*., 2003). Both *A. niger* and *A. carbonarius* have been implicated in the production of OTA which is reported to have immunotoxic, teratogenic, nephrotoxic and carcinogenic (Group 2B) effects on animals (IARC, 1993; JECFA, 2001; Peronne*et al*., 2007 and Noonim*et al*., 2008).Stefanovic*et al*., (2006), reported that Balkan endemic nephropathy was enhanced by OTA contaminated food. Due to its toxicological consequences in human and animal diets, the occurrence of OTA has become a pre-eminent factor in coffee trading.

5.6Effect of the Drying Method on Defective Beans

ISO (2003), has established a standard (ISO 10470) that describes defects as: foreign material of non coffee origin; foreign materials of non bean origin, such as pieces of parchment or husks; abnormal beans for shape regularity/integrity; abnormal beans for visual appearance, such as black beans; abnormal beans for taste of the cup after proper roasting and brewing. In the present study, drying beans on the concrete floor and black polythene sheet on concrete floor resulted in a higher percentage of defective beans (more than 40 % each) than on the raised raffia mat (30 %). The presence of defects in coffee is indicative of its quality given by the type and number and also determines the price andacceptability of coffee on the commodity market (Mattielo, 1991). Insect damage and shriveled/black beans constituted more than 70 % of the defective beans in the present study which is an indicative of the quality arising from the processing methods. Unroasted coffee beans with more than 25% black, deep blue, or dark brown surface area, may be considered black beans. Black beans have a detrimental effect on coffee taste. The number of black beans in a representative coffee bean sample is a basic measure of coffee grade (ITC, 2002).

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Keeping the influences of other factors constant, the following conclusions were drawn from the present study;

Drying coffee beans on black polythene sheet on concrete floor at a depth of 5 cm resulted in desirable effects similar to those obtained using the raised raffia mat. The desirable effects included faster drying time and increased crude protein content of beans coupled with lower fungal load contamination.

Irrespective of the depth of drying, the percentage of defective beans was however found to be much less on the raised raffia mat. The level of defective beans is a measure of the standard quality of coffee intended for export.

The relationship found in the present study between temperature and total crude protein could be exploited in the industry to improve on coffee cup quality. However, none of the drying methods and depths affected the total caffeine content of the beans.

In the absence of a raised raffia mat due to the unavailability of its basic materials, the black polythene sheet on concrete floor could be a worthy substitute without compromising on coffee bean quality.

6.2 Recommendation

The following recommendations are made;

- Only red-ripped coffee beans should be harvested for further processing, among other things, in order to improve the quality of the product however,
- Further studies should be undertaken in the area of coffee bean storage to maintain the quality of the bean obtained after good drying.
- A farmers' training programme should be instituted by COCOBOD to disseminate the findings of the present study in the coffee growing areas of Ghana.

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Plate 1: Picture showing ripped coffee berries on branches at a farm inBepong, Kwahu

Plate 2: Picture showing unripe coffee berries on branches

Plate 3: Mouldcontaminated coffee beans during drying

Plate 4: A close-up of contaminated coffee beans during drying

Plate 5: Defective coffee beans due to insect attack

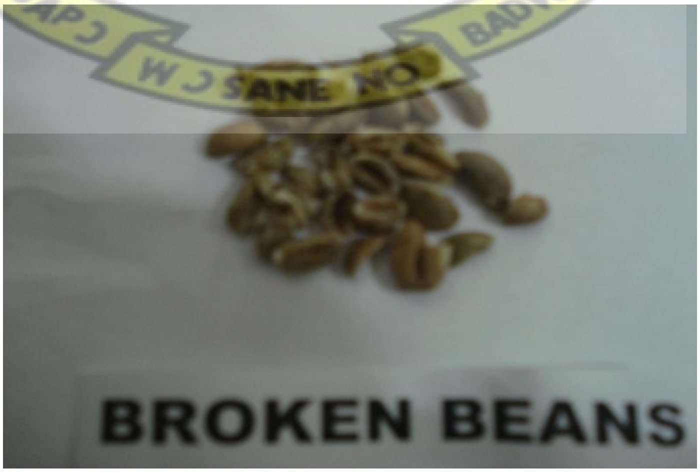
Plate 6: Parchment (husk) of coffee beans

Plate 7: Black and or shriveled as defective coffee beans.

Plate 8: De-hulled coffee beans showing sound kernels (beans).

Plate 9: Broken coffee beans, seen as a defect during

de-hulling orremoval of the husk



APPENDICES

APPENDIX A: ANALYSIS OF VARIANCE (ANOVA) TABLES

Appendix A1: ANOVA Table for Number of Days to Drying

Source	DF	SS	MS	F	P
Treatment	2	2.074	1.037		
Method	2	18.074	9.037	75.08	0.0000
Depth	2	377.185	188.593	1566.77	0.0000
Method*Depth	4	1.704	0.426	3.54	0.0299
Error	16	1.926	0.120		
Total	26	400.963			

Grand Mean 10.963 CV 3.16

Appendix A2: ANOVA table for pH

Source	DF	SS	MS	F	P
Treatment	2	0.00161	0.00080		
Method	2	0.01956	0.00978	4.74	0.0241
Depth	2	0.00216	0.00108	0.52	0.6017
Method*Depth	4	0.01593	0.00398	1.93	0.1543
Error	16	0.03299	0.00206		
Total	26	0.07225			

Grand Mean 5.8359 CV 0.78

Appendix A3: ANOVA Table for Total Crude Protein

Source	DF	SS	MS	F	P
Treatment	2	0.05147	0.02573		
Method	2	0.14762	0.07381	5.50	0.0152
Depth	2	0.01216	0.00608	0.45	0.6438
Method*Depth	4	0.03496	0.00874	0.65	0.6345
Error	16	0.21480	0.01343		
Total	26	0.46100			

Grand Mean 4.0200 CV 2.88

Appendix A4: ANOVA Table for Total Caffeine

Source	DF	SS	MS	F	P
Treatment	2	0.00642	0.00321		
Method	2	0.00809	0.00404	0.41	0.6676
Depth	2	0.00136	0.00068	0.07	0.9332
Method*Depth	4	0.04269	0.01067	1.09	0.3930
Error	16	0.15611	0.00976		
Total	26	0.21467			

Grand Mean 1.4789   CV 6.68

Appendix A5: ANOVA Table for Total *Asparagus niger*

Source	DF	SS	MS	F	P
Treatment	2	0.7002	0.35008		
Method	2	1.5958	0.79792	1.07	0.3669
Depth	2	0.4016	0.20079	0.27	0.7677
Method*Depth	4	3.1681	0.79203	1.06	0.4079
Error	16	11.9507	0.74692		
Total	26	17.8165			

Grand Mean 1.8427   CV 46.90

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

Appendix B1: ANOVA Table for Linear Regression of Crude Protein

Source	DF	SS	MS	F	P
Regression	1	0.04767	0.04767	22.83	0.0020
Residual	7	0.01462	0.00209		
Total	8	0.06229			

Cases Included 9 Missing Cases 0

Appendix B2: ANOVA Table for Total Caffeine

Source	DF	SS	MS	F	P
Regression	1	0.04767	0.04767	22.83	0.0020
Residual	7	0.01462	0.00209		
Total	8	0.06229			

Cases Included 9 Missing Cases 0

APPENDIX C: ANOVATABLE ON PAIR-WISE COMPARISONS

Appendix C1: Pair-wise Comparisons Test of Total Caffeine Content ofDrying Methods

Drying methods	Total Caffeine
Raised Raffia Mat	1.50
Concrete Floor	1.46
Black Polythene sheet on Concrete Floor	1.46
HSD (5%) = 0.12	

Appendix C2: Pair-wise Comparisons Test of Total Caffeine Content for Drying Depths.

Drying methods	Total Caffeine
Raised Raffia Mat	1.48
Concrete Floor	1.46
Black Polythene sheet on Concrete Floor	1.48
HSD (5%) = 0.12	

Appendix C3: Comparisons Test of Total Caffeine Content for the Combined Effect of Drying Depths and Drying Methods.

Drying Depth (cm)	Method of Drying			Mean
	Raised Raffia Mat	Concrete Floor	Black Polythene Sheet on Concrete Floor	
5	1.53	1.48	1.43	1.48
10	1.52	1.46	1.42	1.46
15	1.45	1.45	1.55	1.48
Mean	1.50	1.46	1.46	

HSD (5 %): Drying methods = 0.12; Drying depth = 0.12; Methods x Depth = 0.28

APPENDIX E: CLIMATOLOGICAL DATA DURING PERIOD OF COFFEE DRYING.
SOURCE: METEOROLOGICAL AGENCY - ABETIFI KWAHU, EASTERN REGION, GHANA

PERIOD: OCTOBER 2010 - FEBRUARY 2011

PERIOD	MEAN VALUES FOR PARAMETERS							
	RAINFALL (mm)	TEMPERATURE(°C)		WIND SPEED (kts)	RELATIVE HUMIDITY (%)			SUNSHINE DURATION (Hrs)
		MAX	MIN		9:00 AM	12 NOON	3:00 PM	
Oct-10	359.0	28.0	21.1	3.0	86.0	76.0	77.0	6.2
Nov-10	101.7	28.7	21.3	3.0	80.0	72.0	70.0	7.8
Dec-10	67.6	29.3	21.6	3.0	77.0	66.0	56.0	9.1
Jan-11	0.0	30.0	21.5	3.0	60.0	49.0	44.0	7.3
Feb-11	106.1	30.6	21.7	3.0	70.0	56.0	53.0	7.8
TOTAL				**15.0**	**373.0**	**319.0**	**300.0**	**38.2**
MEAN	***126.9***	***29.3***	***21.4***	***3.0***	***74.6***	***63.8***	***60.0***	***7.6***