KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

SCHOOL OF GRADUATE STUDIES

EFFECTS OF TWO DIFFERENT DRYING MATS AT DIFFERENT LOADING DENSITIES ON THE PHYSICAL AND CHEMICAL QUALITIES OF COCOA BEANS

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DECLARATION

It is hereby declared that this thesis is the outcome of research work undertaken by the author, any assistance obtained has been duly acknowledged. It has neither in part nor whole been presented for another degree elsewhere.

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ABSTRACT

Sun drying produces the best quality cocoa beans if it is properly done, but more often than not bad weather conditions make sun drying inefficient and produce beans of inconsistent quality. Various drying methods have been adopted in a bid to arrive at beans that meet the aroma and flavor characteristics required by chocolate manufacturers. This research work was, therefore, set up to compare the drying potentials of the SNSpac drying mat and the raffia drying mat at three different loading densities, ie. 3kg, 6kg, and 9kg, and to assess their impact on the physical and chemical qualities of the dried beans. In terms of drying time, there were significant differences among all the treatments indicating that the type of mat used and the various loading densities all affected the rate of drying of the beans. Fastest drying rates were observed in the 3kg loadings on both mats, but upon chemical analysis it was found that beans from these treatments contained high acidities and free fatty acid levels that were higher than the permissible levels recommended by the Quality Control Company of the Ghana Cocoa Board (QCC). The cut test analysis showed that the treatments on the raffia mat resulted in higher percentage brown beans and lower percentage purple beans, but these were not significantly different from the scores obtained from the SNSpac. Surface moulding was observed in the medium and high (6kg and 9kg) loading on the SNSpac mat, while slight surface moulding occurred only on the high (9kg) loading on the raffia mat. Significant differences in Polyphenol concentrations were due to the different loading densities and not the drying mats. However, the range of total Polyphenol concentration in all the treatments fell within the levels recommended by the QCC. Overall quality assessment showed

that the 9kg treatment on raffia mat produced reasonably good quality beans as compared to the other loadings.

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DEDICATION

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CHAPTER 1

1.0 INTRODUCTION

Cocoa is cultivated in plantations in the tropical regions throughout the world such as Ivory Coast, Ghana, Nigeria, Cameroon, Indonesia, Brazil, Ecuador, Papua New Guinea, Venezuela and Malaysia (Beckett, 1994). The crop is cultivated for its beans which are embedded in a mass of mucilaginous pulp within the pod. Once the pulp bean mass is exposed to the environment by breaking the pod and removal of beans and pulp, a spontaneous fermentation starts during which successive microbial activities of yeasts, lactic acid bacteria and acetic acid bacteria lead to the formation of a range of metabolic end products, such as alcohols, lactic acid, and acetic acid, which are precursors of cocoa flavour formation (Ardhana and Fleet, 2003). The flavour development process continues during drying and the browning process is the most important process occurring at this stage (McDonald *et al*., 1981). Cocoa bean is the principal raw material of chocolate manufacture (Ardhana and Fleet, 2003), and good cocoa beans are needed to produce the cocoa ingredients such as cocoa liquor, butter and powder.

The choice of plant type has effect on flavours and the physical and chemical attributes that are important to the chocolate industry, nevertheless, fermentation and drying are essential steps for the quality of the final product (Bonaparte, 1996). Drying of fermented cocoa beans from 60% to 7.5% moisture content must be realized in good time in order to avoid mouldiness and achieve the formation of chocolate aroma and for safe storage. Sun drying is best for good quality beans and this is because during sun (slow) drying acetic acid, which is volatile, evaporates through the shells, but lactic acid which is non volatile, is partly transported by water from the bean to the shell (Opoku-Ameyaw *et al.,* 2010). More flavour forming reactions occur during sun drying and there is also the oxidation or browning of polyphenols resulting in the reduction of astringency and bitterness (Opoku-Ameyaw *et al.,* 2010). Sun drying is the exposure of cocoa beans to solar radiation in order to reduce the moisture content to storage and transportation level. Traditionally, the fermented beans are spread thinly on a mat made of raffia palm which is supported on a bamboo or wooden platform raised 1 meter above ground level. The mat is rolled up in the evening to protect the beans from possible showers and dew. When it rains during the day the beans are covered to protect them from wetting. The beans are uncovered immediately after the rain or early in the morning so that drying can continue. On the drying mat the beans are frequently stirred to promote aeration and uniform drying. Drying takes 7 to 21 days depending on the weather (Takrama and Adomako, 1996). During this time, germinated beans, flat and black beans, placenta and any foreign materials are picked out to enhance the purity of the beans. Rate of drying depends on heat transfer into the bean, water transfer from within the bean to the air, humidity of the air and the surface area of the bean exposed to the air (Bharath & Bowen-O'Connor, 2007; Sukha, 2009). Rate of drying is also affected by the loading density. The beans are dry when they produce a 'cracking' sound when pressed lightly with the fist (Takrama and Adomako, 1996)

Drying forms a very important part of postharvest processing in the cocoa production chain. But extremes of drying rate must be avoided because of the negative impact they tend to have on the beans. If drying is done too slowly, moulds may develop and can cause serious problems for industry because of the presence of mycotoxins and the off-flavours created if the moulds penetrate the testa. If drying is too rapid, as in oven and solar dryers, however, the oxidation of acetic acid can be prevented and this leads to excess acid trapped within the beans (Bharath & Bowen-O'Connor, 2007). This high acid content will ultimately affect the flavour of the final product. The average Ghanaian cocoa farmer has other livelihood programmes to help him make ends meet, and may not spend all the time attending to cocoa beans on the drying mat. To enable the farmer have time for other jobs, partially dried beans are often sold to cocoa buying agents at a reduced price, who in turn continue the drying process on their premises. This invariably constitutes loss of revenue to the farmer. The Research Department of the Bank of Ghana (2003) reported that in 1997 pressure from the Licensed Buying Companies to obtain cocoa from the farmers was leading to the sale of some cocoa with a high moisture content which encouraged the development of mould, which is one of the most important quality defects of cocoa, and one for which buyers will discount heavily.

Good flavour cocoa beans are needed by industry to produce the ingredients that are used for the manufacture of cocoa products. Fermentation and drying are two important post harvest treatments that affect the browning and flavour of the final product. Many authors have established that sun drying is best for good quality beans. However, sun drying becomes problematic when drying coincides with bad weather, ie. continuous rains.

The hybrid cocoa which is currently cultivated in Ghana bears fruits throughout the year (Opoku Ameyaw *et al*., 2010), which includes the rainy periods. The drying of beans is unfortunately affected by unexpected rains as a result of the effects of climate change even during the dry periods. In the face of such inconsistent weather conditions, sun drying of cocoa beans at the preferred loading density of farmers therefore becomes a challenge to the average cocoa farmer. Consequently, there is the utmost need to explore other appropriate drying methods and loading densities to ensure continued production of good quality beans for which Ghana is noted for.

Recently an innovative synthetic drying mat, called SNSpac, which combines drying with sorting and grading, has been introduced into the cocoa industry. The apertures in this mat allow undersized beans and other foreign matter to fall out from the beans before they are fully dried. Since this synthetic drying platform is a new product in the market its potential needs to be assessed before it can be recommended to farmers for use.

The continuous use of raffia palm for making drying platforms, weaving of baskets, tapping of palm wine, and making of ropes etc. may soon lead to the depletion of vegetation on our wetlands.

The main objective of this research therefore, is to evaluate the use of Raffia mat and SNSpac for drying at three loading densities in terms of the physical and chemical qualities of cocoa beans.

The specific objectives are:

i) To determine the difference between the drying time of cocoa beans sun-dried on Raffia mat and SNSpac at three loading densities.

ii) To assess the difference between the physical and chemical qualities of cocoa beans sun dried on the two drying platforms at three loading densities.

CHAPTER 2

2.0 LITERATURE REVIEW

The physical and chemical parameters used to determine the quality of cocoa beans include the internal colouration, internal and external moulding, the pH and titratable acidity, free fatty acid content, and the polyphenol concentration in the nibs (Amoa-Awua *et al.,* 2007). The drying rate of the beans also has a bearing on the internal and external colouration as well as the external and internal moulding of the beans (Amoa-Awua *et al.,* 2007).

2.1. DRYING TIME OF COCOA BEANS

Hii *et al.* (2008) determined the drying kinetics of cocoa beans with artificial and natural drying methods. The temperature and relative humidity during the drying period fluctuated between 26^{o}C - 33^{o}C and 56% - 82% respectively. Starting with beans with initial moisture content of 51% (wb), they observed that moisture content decreased steadily with drying time. The artificial technique ended drying (ie. 7% mc) in 52 hours due to the faster drying rate while the natural technique ended drying in 73.5 hours. Bharath and Bowen (2008), assessing the drying rate of cocoa beans using small samples, also reported that the smaller the bean masses and the thinner the bean layer, the faster the drying rate. According to Fagunwa *et al.,* (2009) the drying rate of cocoa beans is largely determined by the ambient temperature and the relative humidity. The above assertion appears to reflect the study of Ndukwu (2009) in which the effect of drying temperature and drying air velocity on the drying rate of cocoa beans were determined. The materials and method used were drying air temperatures of 55^{o}C, 70^{o}C and 81^{o}C., drying air velocity of 1.3m.s^{-2}, 2.5m.s^{-2}, and 3.7m.s^{-2}, an initial bean moisture content of 79.6% dry basis, an ambient relative humidity of 80% and a sample mass of 1.38 kg. It was also observed that the calculated average drying rates for the entire drying period at 1.3 m. s^{-2} at 55^{o} C. was 0.149 kg/hr., 0.171 kg/hr. for 70^{o} C. and 0.291 kg/hr. for 81^{o} C. This implies that the equipment could remove an average of 3.576 to 6.984 kg. of water a day with the above drying conditions. There was, however, an increase at 2.5m.s^{-2} giving an average of 3.912kg, 4.464kg, and 7.512kg of water per day respectively at the drying air temperatures of 55^{o}C, 70^{o}C, and 81^{o}C. This shows that the drying rate is a strong function of temperature, air velocity and time. The drying rate was highest at the first one hour of continuous drying for all temperatures and decreased with time. A follow up study by Ndukwu *et al.,* (2010) on cocoa bean drying kinetics, using artificial dryers and thin layer drying of 5cm. deep and a drying air velocity of 2.5 m. s^{-2}, showed that it took 20, 14, and 10 hours to dry fermented cocoa beans to 6% mc. at 55, 70, and 81^{o}C. respectively. In another study, Oke and Omotayo (2011) investigated the effect of forced air, artificial intermittent drying system on quality of fermented cocoa beans. The beans were dried from 08.00 to 17.00 hours and allowed to rest for 15 hours before drying started again. The beans were also exposed to oven temperatures of 35^{o}C, 40^{o}C, 45^{o}C, 50^{o}C, and 55^{o}C. The average relative humidity in the ovens was 38, 29, 21, 14, and 8% respectively. With an initial bean moisture content of 53.4% (wb) their results were as shown in Table 1.

Table 4.1: Bean Moisture Content against drying days in Artificial Drying

No. of Drying days	Temp 35^{o}C	RH 38%	Temp 40^{o}C	RH 29%	Temp 45^{o}C	RH 21%	Temp 50^{o}C	RH 14%	Temp 55^{o}C	RH 8%
1	34%		32%		30%		29%		22%	
2	22%		21%		18%		9%		7%	
3	17%		13%		7%		7%			
4	11%		8%							
5	7%		7%							

Source; Oke and Omotayo (2011)

The moisture loss was high for the first two days in all the samples. The loss was marginal in the third day (between 2 and 11%). After the third day most beans had reached the storage moisture content (7% wet basis) except the sample dried at 35^{o} C and 40^{o}C which reached the storage moisture content on the fifth day of drying. This trend is consistent with what was reported by Ndukwu *et al.,* (2010). In a similar research to determine the drying characteristics of cocoa beans using a solar dryer, Nicholas (2012) confirmed that moisture content decreases as the drying time increases, irrespective of the desired drying air velocities and temperatures. All drying processes resulted in falling rate drying periods, starting from the initial moisture content prior to the final moisture content at the end of drying (ibid)

2.2. EXTERNAL AND INTERNAL COLORATION OF BEANS

The colour of the inside of the cocoa bean tells the quality of post harvest treatment given to the bean. Purple beans have not been sufficiently fermented, while slaty beans (dark grey) have not been fermented at all or that the outside temperature was too low during drying; especially during harmattan weather (Opoku-Ameyaw *et al.*, 2010). The cut test is the standard test used to assess the suitability of cocoa beans for chocolate processing. It is also the standard method of assessing quality as defined in grade standards and can be used to estimate two major off-flavours; mouldy and unfermented beans (Wood and Lass, 1987). On the effect of different drying methods on the internal colour of beans, Bonaparte *et al.*, (1997) compared open air sun-drying and solar drying of cocoa beans at 13kg m^{-2} loading and found no significant difference in the internal coloration of the beans. Hii *et al.*, (2006), using direct solar dryer at different loadings, found that beans from a lower loading (20kg) yielded the lowest percentage of purple beans (7.21%) but the highest percentage of brown colour (77.65%). In a follow up experiment, Hii *et al.*, (2008) determined the physical quality characteristics of fermented cocoa beans which were artificially dried at 60^oC, 70^oC and 80^oC. After subjecting the three samples to the cut test the following results were obtained (Table 2).

Table: 4.2. Cut test Results for Artificially dried beans

COLOUR CATEGORY	60^oC	70^oC	80^oC

Slaty	-	-	-
Purple	-	4.24%	5.56%
Purple brown	31.11%	37.98%	35.55%
Brown	68.89%	57.78%	58.89%

Source: Hii *et al*., (2008)

The authors also observed that the 60^{o}C oven drying treatment showed the highest percentage of brown colour, lowest percentage of purple brown and purple colour beans as compared to beans produced from the 70^{o}C and 80^{o}C treatments. In the 60^{o}C treatment the percentage brown colour was more than 60% which indicates beans with good flavour quality. On the other hand, the beans from the other two treatments showed brown colour slightly below 60%. The authors, therefore, inferred that very high drying temperatures have detrimental effect on bean quality.

2.3. EXTERNAL MOULDING

Surface moulding is usually associated with very high humidity and low air movement during drying. In an experiment by Hii *et al.*, (2006), it was observed that mouldiness on the bean surface was light in the 20kg loading, moderately heavy in the 30 kg loading and extremely heavy in the 60kg loading. The light level of mouldiness in the 20kg loading was expected, as drying was conducted in a shorter period (5 days), as compared to the 30kg (7.5 days), and 60kg (9.5 days) loadings. Mouldiness was highest in the 60kg loading due to high relative humidity, which favoured surface mould growth. For the 60kg loading, it was noted that, water vapour condensed within the bed of the beans in the early morning and hence resulted in a longer drying time.

2.4. EFFECT OF DRYING PROCESS ON pH AND TITRATABLE ACIDITY OF COCOA BEANS

Titratable acidity is the number of protons recovered during a titration with a strong base to a specified endpoint and it can be expressed as a molar quantity (Boulton, 1980). Many researchers use titratable acidity and total acidity as synonymous, but are not. The titratable acidity is always less than total acidity, because not all of the hydrogen ions expected from the acids are found during the determination of titratable acidity. However, titratable acidity is easier to measure (ibid). Titratable acidity measures the amount of acids, especially lactic and acetic acids present in the cocoa beans whilst pH measures the strength of the acids. Titratable acidity is a better measure of total acids in cocoa liquor than pH, but both parameters have been correlated with taste scores or flavour acidity (Guehi *et al*., 2010). Jinap and Dimick (1990) found a -0.91 correlation coefficient relating titratable acidity and pH of samples. All cocoa beans are acid to a certain degree and contain a number of volatile and non-volatile acids, the most important of which are acetic, citric and lactic acids. Citric acid is present in fresh beans at 1 to 2% and about half disappears during fermentation in the sweating or is metabolized, leaving about 0.5% in dried beans (Wood and Lass, 1987). Acetic and lactic acids are formed during fermentation, diffuse into the cotyledon and are present in varying amounts in beans from different countries (ibid) The presence of acetic acid is obvious from the pungent smell of the dried beans but most of the acetic acid is dispelled during full factory processing of chocolate, after which little or no acid flavour remains (Wood and Lass, 1987). On the other hand, lactic acid is non-volatile and is not dispelled during manufacture leaving an acidic flavour in the finished product. The presence of these acids lowers the pH of the dried beans and, as acid beans often lack chocolate flavour, it is possible that the low pH, below 5.0, interferes with the reactions which create chocolate precursors (Wood and Lass, 1987).

Bonaparte *et al.,* (1997), researched into some quality characteristics of solar dried and open air dried cocoa beans at different loading densities. The authors observed that the pH of the dried beans ranged from 4.6 to 5.1 but showed no significant differences with either dryer type or loading density. In general beans dried by the solar and sun drying methods were acidic by commercial standards and had a distinct odour during the cut test. It was also observed that titratable acidity varied from 18.59 to 23.31 meq.NaOH 100^{-1}g. of ground nibs with either dryer type and loading density. At 40.4kg m^{-2} loading rate, titratable acidity was as low as 18.59 meq.NaOH 100^{-1}g. of ground nibs, rising to 23.31 meq.NaOH 100^{-1}g. at 13.5kg m^{-2} loading. Though, statistical analysis revealed no differences in titratable acidity in drying methods, differences due to higher loading rates existed (Bonaparte *et al.,* 1997)

High loading rates have the potential to slow down the initial rate of drying in the bean mass and therefore allow a longer period for the loss of acids either enzymatically or physically (Jinap *et al.,* 1994). Hii *et al.,* (2006), conducted a similar experiment using solar drier at three different loadings, ie. 20kg, 30kg and 60kg. It was found out that the pH of the dried samples ranged from 4.91 to 5.39 with an initial pH of 4.64, showing significant differences among the treatments. pH was significantly higher in the 60kg loading than in the 20kg and 30kg loadings. However, pH was not significantly different between the 20kg and 30kg loadings. A similar trend was observed in the titratable acidity of the dried beans. Titratable acidity of the dried beans ranged from 13.30 to 18.57 meq.NaOH 100^{-1}g, with an initial value of 25.75 meq.NaOH 100^{-1}g The 60kg loading showed significantly lower titratable acidity compared to the other loadings. The authors inferred that higher loading generally causes drying to progress more slowly and enables sufficient evaporation and balanced diffusion of the free liquid, which contained dissolved acids, from the testa and from the nib. The acidity of the beans obtained from the 20kg and 30kg loadings were also slightly better than those reported by Bonaparte *et al.,* (1997) for solar dried beans of pH in the range 4.78 to 4.81, and titratable acidity in the range of 22.38 to 23.03 meq.NaOH 100^{-1}g (Hii *et al.,* 2006). Hii *et al.,* (2008), later reported that high acidic beans are always associated with pH of less than 5.2 while the best flavoured beans from West Africa usually have pH values around 5.5. The authors further submitted that, the pH value of sun dried beans is usually higher (less acidic) than artificially dried beans due to the slow and gentle drying process that enable the evaporation of more acetic acid. High drying rate of the artificial method, according to their research, caused the testa layer of the beans to dry faster and broke the diffusion path of the acetic acid during moisture removal. Hence most of the acids remained inside the beans and caused excessive sourness to the beans. It was therefore recommended that drying should be performed at bean temperature not exceeding 60^{o}C to avoid retention of excessive acids.

Irie *et al*., (2010) compared natural drying with artificial drying and observed that while natural drying process produced less acidic cocoa beans with pH up to 4.0, artificial method gave high acidic cocoa beans with pH around 3.7. The authors also asserted that the typical sour flavour of the artificially dried beans was due to the acetic acid contained in the beans. Guehi *et al.,* (2010) also found similar results of pH levels between 3.8 and 5.2 for oven and mixed dried beans and a range of 4.5 to 5.5 for sun dried beans. Mixed dried beans were sun dried from 9.00am to 6.00 pm until moisture of 25% and consecutively by artificial drying process using an air-ventilated oven until moisture content of 7%. Oke and Omotayo (2011) also reported that beans under forced air artificial intermittent drying were more acidic (pH value of 4.7 to 5.2) against the corresponding attributes of 5.3 for sun dried beans.

2.5. EFFECT OF DRYING ON FREE FATTY ACID CONTENT

The quality of cocoa butter is important as the composition and the crystallization properties of triglycerides determine the texture, hardness and melting properties of chocolate (Murphy and Flood, 2004). The authors indicated that high levels of free fatty acids (FFAs), which are the breakdown products of triglycerides, may cause quality problems in chocolate, and are indication that cocoa beans have not been treated appropriately. The authors further asserted that FFAs are mostly generated by lipolytic enzymes from microorganisms, therefore high levels indicate a high level of beans that are broken, have not been dried properly or have been stored for a long time in inappropriate conditions. Guehi *et al.,* (2008) stated that the quality of raw cocoa beans depends widely on their FFA content. High FFA is a serious quality defect and reduces the economic value of the cocoa beans. Assessing the impact of cocoa processing technologies on FFA formation in stored raw cocoa beans, Guehi *et al.,* (2008) found very low FFA content in whole healthy cocoa beans which generally complied with international standards (1.75% oleic acid equivalent) throughout the storage period while high FFA content was found in poor quality and broken healthy beans. The authors concluded that the formation of FFA did not depend on the genotype or on cocoa post harvest processing technologies. The authors attributed the high FFA content in the defective beans probably to the activity of micro flora which in turn were associated with initial quality and loss of physical integrity of the cocoa beans (Guehi *et al.,* 2008). Earlier Wood and Lass (1987) reported that high FFA content in cocoa beans might result from black beans originating from rotten pods or germinated beans. Likewise, microflora, particularly moulds can cause similar problems during storage (ibid). Further, Wood and Lass (1987) suggested that FFA occurrence in stored cocoa beans might be linked to the action of microbial lipases. Opoku-Ameyaw *et al*., (2010) also stated that high FFA content of cocoa beans is caused by diseases such as black pod and brown rot, pods that have been left on trees for a long time before harvesting, and improper storage or long storage of cocoa beans. According to Johnfiah-Essien and Navarro (2010) FFA content, though not a quality parameter, must be less than 1.0% to meet the acceptable level of 1.75% in cocoa butter extracted from the dry cocoa beans. The authors continued that quality of dry cocoa beans in international trade is assessed on the percentage level of total mould, slaty, purple, insect infested, flat and germinated beans, but more recently the cocoa trade has assumed a more scientific position and a lot of emphasis is placed on the content of FFA which is influenced by many factors, including humidity, moulds and oxygen. Contrary to the earlier assertion that FFA content was attributed mainly to the physical integrity of the cocoa bean, Guehi *et al.*, (2010) in the studies on the effect on drying methods on FFA levels, observed that among three dried samples studied, oven dried cocoa beans showed highest FFA content than both solar and mixed dried beans. The authors further observed that artificial drying process led to the FFA content above 0.70%, while both sun and mixed drying process produced raw cocoa beans with FFA content below 0.70%. Free Fatty Acid content of mixed dried beans is similar to the quality of sun dried beans, demonstrating that beans air blown for seven days and subsequently dried in an oven at 60^oC were of comparable quality to the sun dried beans (Guehi *et al.*, 2010). Both types of beans were of better quality than beans oven-dried at 60^oC. This result was probably because of the breakdown of triglycerides obtained from the liquefaction and the diffusion of cocoa butter during the faster process of oven drying method.

2.6. POLYPHENOL CONCENTRATION IN DRIED COCOA BEANS

Hii *et al.*, (2009) report that polyphenols have gained much interest recently due to its antioxidant capacity and possible benefits to human health such as anti-carcinogenic, anti-atherogenic, anti-ulcer, anti-thrombotic, anti-inflammatory, immune modulating, anti microbial, vasodilatory and analgesic effects. The authors added that polyphenols in cocoa beans contribute to about 12 to 18% of the dry weight of the whole bean and that the main classes of polyphenolic compounds identified are such as simple phenols, benzoquinones, phenolic acids, acetophenones, phenylacetic acids, hydroxycinnamic acids, phenylpropenes, coumarines, chromones, naphtoquinones, xanthones, stilbenes, anthraquinones, flavonoids, lignans and lignins. Hii *et al.*, (2009) identified three main groups of cocoa polyphenols, namely, cathechins also known as flavonols (37%), anthocyanins (4%), and proanthocyanidins (58%). The authors stated that the main cathechin is (-)-epicathechin with up to 35% of polyphenol. According to Kyi *et al.*, (2003), the concentration of total polyphenol declines rapidly during drying because of the enzymatic oxidation of polyphenols. The authors observed that the higher the temperature and the relative humidity of the drying air, the lower the residual amount of polyphenol in the cocoa beans during drying. Hii *et al.*, (2009) confirmed that phenolics or polyphenol concentration in cocoa beans are affected by fermentation and drying mainly due to the enzymatic oxidation reactions. The enzymatic oxidation reaction which begins during fermentation continues during drying provided sufficient moisture still exist in the beans (ibid). The evaporation of the moisture ensures continuous supply of gaseous oxygen to the inner vicinity of the cotyledon. Polyphenols in cocoa beans undergo oxidation to condense high molecular insoluble tannins. The polymeric brown pigments (melanin) formed at the end of the reaction give the typical brown colour of chocolate, (Hii *et al.*, 2009)

Reduction in polyphenol content by post harvest treatments was observed by Kyi *et al.*, (2003), and Hii *et al.*, (2009). In the fermentation and drying studies the authors made the following observations: some polyphenols are lost by diffusion into the fermentation sweating, some undergo oxidation reaction which is both non-enzymatic and enzymatic through the action of polyphenol oxidase, about 24% of total polyphenols diffuse out of the cotyledons after 60 hours of fermentation, reaching 58% after 8 days. During drying polyphenol oxidase is completely inactivated within 24 hours at 65^{o}C (Hii *et al*., 2009). The authors further observed that at 55^{o}C more than 80% loss in activity occurred in 24 hours and over 95% in 48 hours. After drying the level of phenolic compounds decreased by 32% compared to the fermented sample (ibid). The concentration of polyphenols declined rapidly during drying under air conditions of 40 to 60^{o}C and 50 to 80% relative humidity. Freeze drying retained the highest total polyphenol content as compared to hot air and sun drying. The sun dried samples showed the lowest total polyphenol content due to the lower temperature profile and longer drying period (Hii *et al*., 2009). According to Hii *et al.*, (2009), cocoa with too high polyphenol content is undesirable as this will impart high bitterness and astringency to the finished chocolate and mask the characteristic chocolate flavour. However, there still exist niche markets where high polyphenol content chocolate products are sought after by health conscious consumers. Hii *et al*., (2009) assessed the total polyphenol content of different varieties of cocoa from different cocoa producing countries of the world and the results were as shown in Table 3

Table 4.3: Total Polyphenol Content in Cocoa Beans from various regions of the world.

Geographical Origin	Variety	Total Polyphenol Content (mg/g)

Ivory Coast	Forastero	81.5
Columbia	Amazon	81.4
Equitorial Guinea	Amazon Forastero	72.4
Ecuador	Amazon Hybrid	84.2
Venezuela	Trinitario	64.3
Peru	Criollo	50.0
Dominican Republic	Criollo	40.0
Malaysia	Unknown	71.42 to 82.64

Source: Hii *et al*., (2009)

It can be seen that the range of total polyphenols recorded (from 40.0 mg/g to 84.2 mg/g) varies among geographical regions and also the planted varieties. The Criollo variety generally shows lower total polyphenol content since it is lacking in anthocyanins, which is a type of polyphenol, (Hii *et al.*, 2009).

2.7. QUALITY STANDARDS OF THE GHANA COCOA BOARD

The Quality Control Company Limited (QCC) of Ghana Cocoa Board is the agency mandated to enforce quality measures in the cocoa industry in Ghana (Cocobod, 2000). The company is responsible for inspection, grading, and sealing of cocoa for the local and international market. It is also responsible for fumigation and disinfestations of produce. The company has put in place various steps to monitor the quality of cocoa from the farm level to the port. Gorkeh-Sekyim (2011), stated that the guiding principles of controlling the quality of cocoa in Ghana are based on the Code of Practice as approved by the Food and Agricultural Organization (FAO), the Federation of Cocoa Commerce (FCC), the International Cocoa Organization (ICCO), and the Ghana Cocoa Regulations 1968 (NLCD No. 278; LI No. 598). The author emphasizes that the specifications for quality cocoa beans should be thoroughly dry, homogenous in size, free from foreign matter, free from any evidence of adulteration and contamination, free from live insects, rodents and any other form of infestation, and above all fit for human and animal consumption. According to Gorkeh-Sekyim (2011) quality assurance of cocoa beans is at two main centres. These are the Upcountry and Take-Over centres. The upcountry centres/depots are located in seventy-six districts of the six cocoa producing Regions of Ghana and one area office at Hohoe in the Volta region. The take-over centres are located at the two ports of Tema and Takoradi and an inland port at Kaase in Kumasi. At the upcountry centres the Company monitors the activities of the farmer, the Licensed Buying Companies (LBCs), and the transporters. The author further gave details of methodology to be followed by farmers, inspectors and quality control officials all according to guidelines issued by the International Cocoa Organization.

Cocoa quality is obtained on trees through good husbandry and maintained through postharvest practices that include timely harvest, proper fermentation, drying, and sorting of beans. Quality is largely achieved on the farm by the producers themselves. Ghana's quality control program promotes the adoption of quality-enhancing good practices on farms and regulates the quality of beans traded by the Licensed Buying Companies. The Quality Control Company's (QCC's) elaborate procedures begin with assessment at the up-country depots. This is followed by testing of samples for dryness, grade, and category at depots and ports. It is virtually a certification system with traceability, though certification is limited to the physical attributes of beans (Kolavalli *et al.,* 2012)

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1: FIELD LAYOUT

The experiment was set up to find out the influence of two drying mats, raffia and SNSpac and three loading densities on the physical and qualities of sun dried cocoa beans. Field layout and all experimentation were carried out at the Seed Production Unit (SPU) of the Ghana Cocoa Board (COCOBOD), Kwadaso, Kumasi. The study covered only the drying aspect of post harvest management of cocoa, including the drying rate, and the physical characteristics of the dried cocoa beans, which were assessed at the Quality Control Company of COCOBOD at Nkawie near Kumasi. The chemical analysis of the dried beans was carried out at the Biochemistry department of Kwame Nkrumah University of Science and Technology (KNUST) and the Cocoa Research Institute of Ghana, Tafo.

3.1.1: Experimental Design

The design used was a 2 x 3 factorial design with two experimental factors; drying mat (raffia mat and SNSpac) and three levels of loading density (3kg, 6kg and 9kg). All treatments were conducted in triplicates.

3.2. BASIS FOR THREE LOADING DENSITIES

A survey was conducted to identify fifty cocoa farmers in the Nkawie cocoa district from 19th November to 30th November 2012 to find out the loading densities on farmers drying platforms. After one farmer was interviewed he was asked to direct the interviewer to another farmer who was also drying cocoa within the community. This continued until fifty respondents were covered. Based on the findings of the survey the three loading densities were adopted for the study.

3.3: CONSTRUCTION OF DRYING TRAYS

Drying trays were constructed with sawn timber for the raffia mat and the SNSpac. Each tray was divided into three drying cells, each drying cell measuring 60cm. x 60cm. x 5cm. to accommodate the three loadings. (Figure 2)

3.4: PREPARATION OF SAMPLE

Cocoa beans of mixed varieties from a farmer's farm were bought and fermented for six clear days using the three tier box fermentation system which was available at the cocoa station. (Figure 1). The beans were turned over into the next box every two days until the end of the sixth day when they were removed for drying.

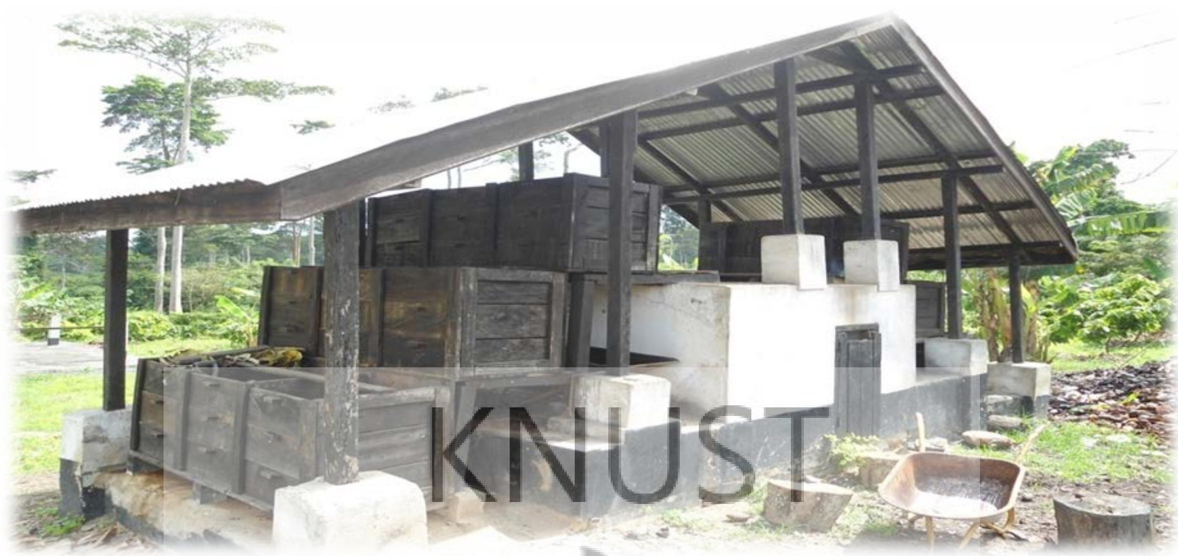


Figure 1: The 3 tier box fermentation system.

3.5: DRYING PROCEDURE

Drying trays were raised one meter above ground and supported below with sawn timber to facilitate the movement of air around the platforms (Figure 2). Nine kilograms (9kg) fermented beans filled the first drying cell to 5cm thick (heavy loading), while 6kg and 3kg filled the second and third drying cells to 3cm thick and 1cm thick (medium and low density loading), respectively. Drying started from sunrise to sunset when the trays were removed and put under a protected shed. Beans were stirred every three hours to ensure uniform drying. During the stirring process flat beans, debris, placenta and all foreign materials were removed from the beans. Drying continued until 7-7.5% moisture content was achieved.

3.6. PARAMETERS FOR ANALYSIS:

3.6.1. Determination of Drying Time

The initial moisture content of the fermented beans was taken with a moisture meter (Aqua-Boy, Type KAM III, Nr. 005772, Germany) and at the end of each drying day, samples from each drying cell were taken for moisture content analysis. The initial weight of the beans was taken with NES Series Table Top Scale (Model NES. 15 – India).

The following data were collected during the drying period;

a) Initial moisture content (mc) of beans

b) Initial weight of beans in each drying tray or cell

c) Moisture content after every drying day

d) Temperature

e) Relative Humidity

f) Rainfall amount

g) Number of days taken to achieve 7- 7.5% mc.

The weather data which were recorded at the Kwadaso Weather Station were taken from the Regional Meteorological Service, Kumasi, and is presented as Appendix 1.

3.6.2. Determination of Internal Coloration:

This was assessed at the Quality Control Company Laboratory at Nkawie near Kumasi, using the Cut-test method based on the International Standards Organization Cut Test Standard ISO 1114:1977 (reviewed and confirmed in 2008) and adopted by the Quality Control Company of the Ghana Cocoa Board. A sample of 100 beans was selected and cut lengthwise through the middle in order to expose the cut surface of the cotyledons. The half which exposes the maximum surface of the cotyledon was selected while the other half was discarded. (Figure 7) The hundred selected cut surfaces were arranged on a white background and examined in full daylight. Upon visual appraisal, the beans were placed in one of the following colour categories:

a) Brown   b) Purple   c) Slaty (Figure 2)

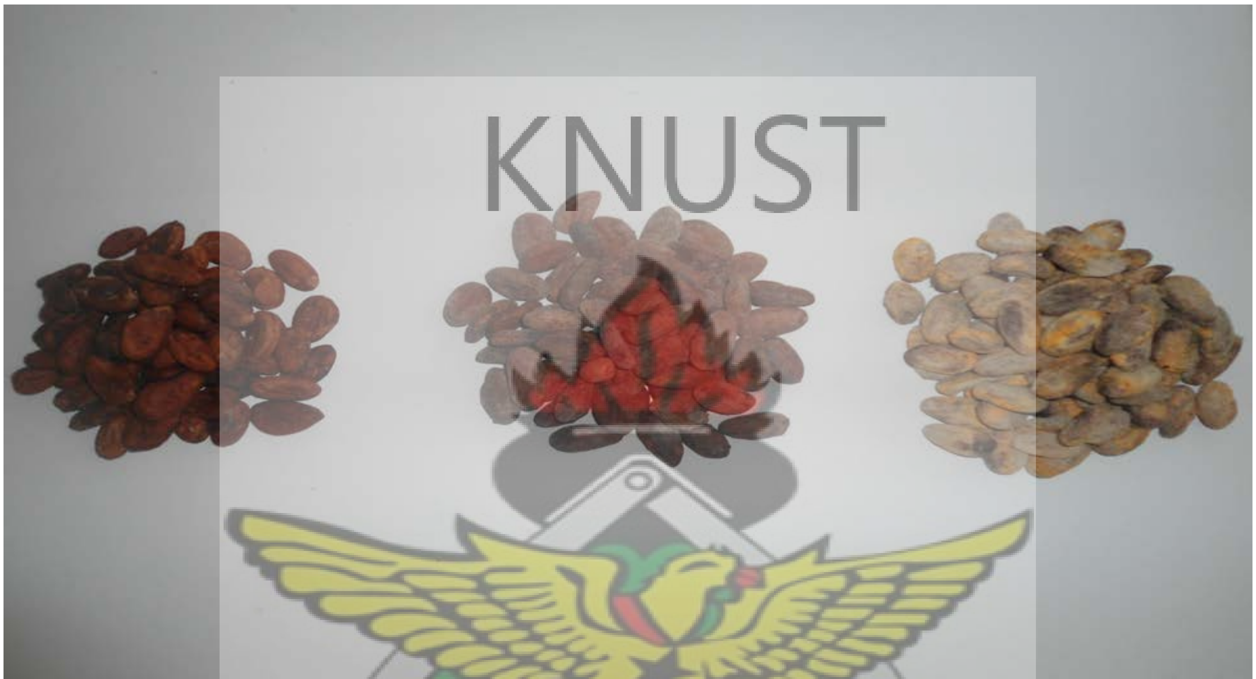
ANOVA was used to determine differences in the internal coloration based on the cut test score.

a) Brown bean   b) Purple bean   c) Slaty bean

Figure 2: The three internal colour categories of dry cocoa beans.

2.6.3: **Determination of External Moulding**:

External moulding was assessed at the Quality Control Company of COCOBOD alongside the cut test process based on the degree of purity. The procedure followed that adopted by Hii et al., 2006 (modified). The sample with the highest surface mould was scored 0, while the sample with no surface mould was scored 100. Midway, a score of 50 was allotted. Three pre-defined bean samples rated at none (100 score), light (50 score), and heavy (0 score), were given as references to the trained staff for comparison during the visual assessment.(Figure 3)



a) None (100 score)   b) Light (50 score)   c) Heavy (0 score)

Figure 3: The three surface mould categories of dried cocoa beans.

3.7: CHEMICAL ANALYSIS

The chemical analysis including pH, Titatable Acidity, Free Fatty Acid content were carried out at the Biochemistry Laboratory of the Kwame Nkrumah University of Science and Technology, using the AOAC protocol. The Polyphenol concentration analysis was done at the Biochemistry Laboratory of the Cocoa Research Institute of Ghana, utilizing the HPLC protocol.

3.7.1: Determination of pH:

Five (5) grams ground nibs were added to 50 mls. distilled water. The mixture was allowed to stand for 30 minutes with intermittent swirling. After 30 minutes the mixture was filtered and the resulting filtrate was measured for pH using the pH meter. The measurements were performed in triplicate.

3.7.2: Determination of Titratable Acidity

Ten (10) grams ground nibs were added to 100 mls distilled water and swirled intermittently for 30 minutes. After 30 minutes the mixture was filtered and 20 mls portion of the filtrate was titrated with 0.1 Molar Sodium Hydroxide (NaOH) solution using phenolphthalein indicator to an end point of faint pink colour which disappeared after few seconds. The titrations were performed in triplicate.

Percentage titratable acidity (%TA) was calculated using the formula:

$$\%TA = \frac{(\text{Vol. of base})(\text{MBase})(\text{Equivalent})(100)}{1000 \times \text{Wt. of Sample}}$$

Equivalent as Oleic acid = 282

Wt. of Sample = 2.00 grams

MBase = Molarity of base

3.7.3: Determination of Free Fatty Acid content

An extraction timble was filled with ground nibs. The fat was extracted using petroleum ether in a Soxlet apparatus. After extraction of the cocoa butter 5grams of the fat was dissolved in a 1:1 mixture of ethanol and diethyl ether (ie. 25mls of ethanol and 25mls of diethyl ether, making up 50mls of solvent.) The solvent was refluxed for some few minutes and titrated with 0.05Molar

Sodium Hydroxide solution using phenolphthalein indicator to a faint pink colour which lasted for few seconds and disappeared. Titrations were done in triplicate. The percentage free fatty acid was calculated as the equivalent of the predominant acid (oleic acid).

The formula used was:

$$\%FFA = \frac{(\text{Vol. Base} - \text{Vol. Blank})(\text{M. Base})(\text{Equivalent})}{\text{Weight of Sample}}$$

Where; Vol. Base = volume of the base

Vol. Blank = blank titre value

M. Base = molarity of base

Equivalent = oleic acid equivalent = $\frac{282 \times 100}{1,000}$

3.7.4: Determination of Polyphenol concentration:

Ground nibs were defatted using petroleum ether. 0.2grams of the defatted sample was put into a 50ml falcon tube. 30mls of Methanol : HCl mixture solution was added to the sample and placed on a shaker to shake for two hours at maximum speed. The filtrate was then decanted into another container. 1ml of the filtrate was taken and placed into a test tube. 5mls of 1:9mls of Folin Ciocalteu's Phenol reagent was added to the content in the test tube. After 8 minutes, 4mls of 0.075g/ml of Na_2CO_3 solution was added unto the mixture in the test tube. The solution turned blue and was left to stand for one hour at 30^oC and another hour at 0^oC, after which the colour of the absorbance was read at 760nm using the UV/VIS Spectrometer. The assays were done in triplicate.

3.8. Analysis of Data:

All experimental data were analyzed by using Analysis of Variance (ANOVA) and means were separated by Least Significant Difference test at 5% level. The statistical software used was GenStat Discovery Edition 3.

3.9: Opportunities and Threats Analysis:

The cost, durability and availability of the two drying mats were assessed against the advantages derived from the use of either mats.

CHAPTER 4

4.0 RESULTS

4.1. RESULTS OF SURVEY

Analysis of the data from the survey revealed that 36% of the respondents were drying at high density (5 cm. thick), 46% were drying at medium density (3 cm. thick), and 18% were drying at low density (1 cm. thick or single layer). The reasons given for the different loading densities were the quantity of beans available at a time, the size of the drying platform and the weather situation. During good weather (adequate sunshine) the farmers dry beans at high density whereas in bad weather they dry at low density.

4.2. DRYING TIME OF COCOA BEANS

The standard storage and transportation moisture content of cocoa beans is between 7.0% and 7.5% and the study sought to determine the treatment that could achieve this moisture content within the shortest possible time without compromising the quality of the cocoa beans.

4.2.1: Time taken to achieve 7 – 7.5% moisture content.

All the treatments on the raffia mat achieved the 7-7.5% moisture content on the fifth day of drying. The 3kg and 6kg loads on the SNSpac also achieved this moisture level on the fifth day of drying, but the 9kg load on the SNSpac achieved this on the sixth day of drying. (Table 4.1)

Table 4.4: Time taken to achieve 7 -7.5% moisture content.

TREATMENTS	TIME (DAYS)	MEAN MC (%)
Raffia at 3kg loading	5	6.93
Raffia at 6kg loading	5	7.0
Raffia at 9kg loading	5	7.3
SNSpac at 3kg loading	5	6.8
SNSpac at 6kg loading	5	7.2
SNSpac at 9kg loading	6	7.5

4.3: PHYSICAL ANALYSIS

4.3.1. Internal Colour of Dried Cocoa Beans (Brown beans)

The minimum and maximum values for brown beans were 76% and 89% respectively. The mean value was 82.33%.

4.3.1.1. Effect of Drying Mats on the Internal Colour (Brown beans) of Cocoa Beans

The percentage of brown beans of the samples dried on raffia was 84.33 while that of the SNSpac was 80.33 (Table 4.2). There were significant differences between the internal colouration of beans on the raffia mat and the SNSpac at 5% significance level.

Table 4.5: Effect of Drying Mat on the Internal Colour (Brown beans) of Cocoa Beans.

Drying Mat	mean (% brown beans)
Raffia	84.33 a
SNSpac	80.33 b
LSD at 5% level	3.48

Mean values assigned with a common letter within the same column are not significantly different

4.3.1.2: Effect of Drying Mats x Load Density on the Internal Colour (Brown beans) of Cocoa Beans: There were no significant interactions between the type of drying mat and loading density for percent brown beans.

4.3.2: Internal Colour of Dried Beans (Purple Beans)

The minimum and maximum values for purple beans were 11% and 24% respectively. The mean value was 17.67%.

4.3.2.1: Effect of Drying Mats on the Internal Colour (Purple beans) of Dried Cocoa Beans. The percentage purple beans of the sample dried on raffia mat was 15.67% while that of the SNSpac was 19.67% (Table 4.3). There was significant difference between the amounts of purple beans from the two drying mats.

Table 4.6: Effect of Drying Mats on the Internal Colour (Purple beans) of Cocoa Beans.

Drying Mat	Mean (% purple beans)
Raffia	15.67 a
SNSpac	19.67 b
LSD at 5% level	3.478

Mean values assigned with a common letter within the same column are not significantly different

4.3.2.2: Effect of Drying Mat x Load Density on the Internal Colour (Purple beans) of Cocoa Beans: There were no significant interactions between the type of drying mat and loading density for percent purple beans.

4.3.3: Effect of Drying Mats x Load Density on Surface Moulding of Cocoa Beans.

The interactions of the drying mats and load densities on the amount of moulding on the dried samples are shown in Table 4.4. The interactions indicated significant differences among the loading densities. 3 kg on raffia and 6 kg on raffia recorded beans without moulds, significantly better than beans on 6 kg on SNSpac and 9 kg on either raffia or SNSpac which had moulds of varied percentages. The mean score of beans from the 3kg, 6kg, and 9kg load densities were 100, 83.34 and 50 respectively.

Table 4.7: Effect of Drying Mats x Load Density on Surface Moulding of Cocoa Beans

LOADING DENSITY (kg)	**RAFFIA**	**SNSpac**	**MEAN SCORE**
3	100	100	100
6	100	66.67	83.34
9	50	50	50
MEAN SCORE	83.33	72.22	

LSD 5%: Drying mat = 12.38 ; Load density = 15.16 ; Drying mat x Load density = 21.44

4.4: CHEMICAL ANALYSIS

4.4.1: pH of Dried Cocoa Beans

The pH of the dried beans ranged from 4.94 to 5.12 with a mean value of 5.02. There were no significant differences in the treatments and their interactions for pH of dried beans.

4.4.2: Effect of Drying Mat x Load Density on Titratable Acidity of Cocoa Beans

The titratable acidity of the dried beans ranged from 5.88% to 8.78% with a mean value of 7.52%. There were significant interactions between the type of drying mat and load densities for titratable acidity (Table 4.5). The interactions resulted in significant differences. 3 kg load on raffia resulted in beans with significantly the least titratable acidity whiles 9 kg loading on raffia resulted in the highest titratable acidity of the beans. The mean titratable acidity of the beans from the 3kg, 6kg, and 9kg loading densities were 6.86%, 7.83% and 7.88% respectively.

Table 4.8: Effect of Drying Mat x Load Density on Titratable Acidity of Cocoa Beans

LOAD DENSITY (kg)	RAFFIA	SNSpac	MEAN (%)
3	5.92	7.79	6.86
6	7.76	7.90	7.83
9	8.84	7.33	7.88
MEAN (%)	7.73	7.67	

LSD 5%: Drying mat = 0.21; Load density = 0.26 ; Drying mat x Load density = 0.36

4.4.3: Free Fatty Acid (FFA) Content of Dried Cocoa Beans

The FFA content of the dried beans ranged from 1.42% to 2.74% with a mean value of 1.90%. There were significant interactions between the type of drying mat and the load densities.

4.4.3.1: Effect of Drying Mats x Load Density on FFA Content of Dried Cocoa Beans

The interactive effects of the drying mat and load density on titratable acidity of beans are shown in Table 4.6. Significant interactions were observed such that the 3kg loading on raffia resulted in the greatest Free Fatty Acid (FFA) content of beans whereas 9 kg loading on raffia had beans with the least FFA. The mean FFA content of the beans loaded at 3kg was 2.03% and that of the beans loaded at 6kg and 9kg were 1.86% and 1.80% respectively.

Table 4.9: Effect of Drying Mat x Load Density on FFA Content of Cocoa Bean

LOAD DENSITY (kg)	RAFFIA	SNSpac	MEAN (%)
3	2.59	1.47	2.03
6	1.56	2.16	1.86
9	1.46	2.14	1.80
MEAN (%)	1.87	1.92	

LSD 5%: Drying mat = 0.08 ; Load density = 0.09; Drying mat x Load density = 0.13

4.4.4: Effect of Drying Mat x Load Density on Polyphenol Concentration in Dried Cocoa Beans

The polyphenol concentration in the dried beans ranged from 70.17mg/g to 83.50mg/g with a mean value of 76.96mg/g. There were significant interactions between the drying mats and loading densities. 9 kg loading on raffia resulted in beans with the highest polyphenol concentration which was similar to that of 3 kg loading on either raffia or SNSpac (Table 4.7). The least polyphenol concentration was produced by beans at a loading density of 6 kg on a raffia mat. The mean polyphenol concentration in the beans dried at 3kg, 6kg, and 9kg loadings were 78.09mg/g, 73.25mg/g and 79.54mg/g respectively.

Table 4.10: Effect of Drying Mat x Load Density on Polyphenol Concentration in Dried Cocoa Beans

LOAD DENSITY (kg)	RAFFIA	SNSpac	MEAN (mg/g)
3	78.12	78.06	78.09 a
6	71.23	75.26	73.25 b
9	81.48	77.60	79.54 a
MEAN (mg/g)	76.95 a	76.97 a	

LSD 5%: Drying mat = 2.07 ; Load density = 2.53 ; Drying mat x Load density = 3.58

CHAPTER 5

5.0 DISCUSSION

5.1: DRYING TIME OF COCOA BEANS:

The results demonstrate large differences in the drying time as shown by moisture loss of beans dried on the raffia mat and the SNSpac. It was also observed that the loading densities accounted for the differences in the drying times. Again the combined effect of the drying mats and the loading densities was also responsible for the variations in the drying timess of the beans. Generally, the moisture content of beans on both the raffia mat and the SNSpac decreased exponentially during the first three days of drying irrespective of the loading density. All the samples lost more than half their initial moisture content during this period. After the third day the rate of moisture loss was generally slowed down until the end of the drying period. Rapid moisture loss was observed in low density (3kg) loadings on both raffia mat and the SNSpac. This indicates that the smaller the bean masses or the thinner the bean layer, the faster the drying time. This phenomenon was also demonstrated by Bharath and Bowen (2008) and Hii *et al*. (2008). Nicholas (2012) also demonstrated that moisture content of cocoa beans decreased as drying time increased.

The weather condition prevailing at the period of drying also accelerated the rapidity of drying. The minimum temperature during the period was 21.9^{o}C and the maximum was 33^{o}C. Even though the relative humidity ranged from 71% to 92%, the incident solar radiation was so high that drying to 7.5% moisture content was achieved in five days except the 9kg load on the SNSpac which was extended to the sixth day. This assertion is supported by Fagunwa *et al*., (2009) who stated that the drying time of cocoa beans is largely determined by the ambient temperature and the relative humidity.

At the initial stages of drying when the moisture content of the bean was very high the interstitial water readily migrated to the cell surface by capillary forces. The water was redistributed into the capillary tubes by diffusion in the bean from its centre with high moisture level to its drier outer surface. Once the water reached the product surface it was evaporated by the diffusion phenomenon. The drying was therefore enhanced by temperature gain of the drying air. As the moisture level in the bean fell, there was higher resistance to the migration of water to the surface, hence reducing the drying rate at the latter stage of drying. The above phenomenon was also demonstrated by Ndukwu (2009) when he assessed the drying time of cocoa beans using small samples. The difficulty with which the interstitial water migrates to the surface as the product becomes dryer was also demonstrated by Fagunwa *et al*., (2009).

Drying time was extended in the 9kg load on SNSpac because it was observed that as the SNSpac took more load the weight of the beans caused the material to sag no matter how much it was stretched and supported below. This situation tended to cluster the beans and prevented the free ventilation of air through the bean mass. Water vapour therefore condensed within the beans and resulted in longer drying time. This finding is supported by Hii *et al.*, (2006) who also observed that at higher loadings there was condensation of water vapour within the bed of the beans in the early mornings and hence resulted in longer drying time. The rigidity of the raffia mat, on the other hand, enabled the beans to spread out and allowed adequate ventilation which accelerated drying on the raffia even at higher loadings.

The apertures in the SNSpac coupled with the low load density explain why the 3kg load on the SNSpac took a lead in moisture loss over the rest of the treatments. As the load on the SNSpac increased it was observed that moisture loss slowed down while beans on the raffia mat continued to lose moisture steadily. This demonstrates that the raffia mat is more effective as far as the drying of cocoa beans is concerned.

5.2: INTERNAL COLOURATION OF DRIED BEANS

5.2.1: Brown Beans

The various loading densities did not account for the variation in the percentage brown beans but rather the type of drying mat used in the drying process. The results of the experiment showed higher percentage of brown beans from the raffia mat than the SNSpac. The highest percentage brown beans was recorded from the 9kg load on raffia mat and this demonstrates that at high loading rates the raffia mat can dry beans with good internal quality. This was due to the fact that drying was gradual and the beans were well aerated and sufficient oxygen ensured better activity of polyphenol oxidase which resulted in the browning of the beans. This finding is supported by Kyi *et al.,* (2003) who stated that the concentration of total polyphenol declines rapidly during drying because of the enzymatic oxidation of polyphenols. At any rate, the very high values (above 80%) of brown beans for all the treatments are an indication of proper fermentation of the beans and adequate oxidation of the polyphenols in the beans. The prevailing ambient temperature during the drying period was also optimal for the activities of the polyphenol oxidase. Hii et al., (2009) observed that polyphenol oxidase is inactivated within 24 hours at 65^{o}C. During the drying period the highest ambient temperature recorded was 33^{o}C. indicating that the temperature during the drying regime was conducive for the oxidation of polyphenols by the enzyme polyphenol oxidase. Very high percentage of brown beans reduces bitterness and astringency of cocoa liquor which is a good quality characteristic. Ghana Export

Grade 1 cocoa beans should contain 80% or more brown beans as recommended by Gorkeh-Sekyim (2011).

5.2.2: Purple beans

The cut test results did not show any significant differences among the various load densities with regards to purple beans. The variations observed in the percentage purple beans could be traced to the type of drying mat used. Where the cocoa beans are well fermented the problem of slaty beans does not arise and therefore there is an inverse relationship between brown beans and purple beans. The low percentage of purple beans was expected because of the very high proportion of brown beans. This is again a reflection of the high degree of fermentation attributed to the long period (6 days) of fermentation. This result confirms the assertion by Opoku-Ameyaw *et al.*, (2010) that purple beans result from insufficient fermentation. Hii *et al.*, (2006), using direct solar drier, recorded lower percentage of purple beans from lower loadings and higher percentage brown beans from higher loadings, but this experiment using traditional sun-drying, gave a contrary result. This result rather showed higher percentage purple beans from lower loadings and vice versa. This result buttresses the view expressed by Crespo (1985) that sun drying is best for good quality cocoa beans. Even though there was significant difference between the beans dried on the raffia mat and the SNSpac the values obtained for both satisfy the requirements for Grade 1 export cocoa. These results suggest that both the SNSpac and the raffia mat can be used as a drying platform to produce beans of good internal quality. According to Opoku-Ameyaw *et al*., (2010), for Grade 1 exportable cocoa beans the Quality Control Company of COCOBOD accepts cocoa beans with less than 20% purple beans, and less than 30% for Grade 11 cocoa, and any parcel with more than 30% purple bean is rejected.

5.3: EXTERNAL OR SURFACE MOULDING:

Surface moulding was caused by the loading density and not the type of drying mat used according to the statistical analysis of the results. The absence of moulding in the low loadings can be explained by the fact that drying was rapid as large surface areas of the beans were exposed to good ventilation and sunlight. In the heavier loadings the thickness of the bean mass impeded free ventilation and this situation favoured surface mould growth. Again the bean cluster which was observed in the high loadings on the SNSpac restricted air movement and accounted for the moulding observed on the SNSpac. Bonaparte *et al.,* (2006) explained that surface moulding is a function of very high humidity and low air movement during drying. In the higher loadings the same phenomena of water vapour condensation within the bean mass, as observed by Hii *et al.*, (2006), accounted for the surface moulding of the beans. Although some mouldiness on the bean surface was observed, especially in the 9kg loadings, this was restricted to the external surface, and the nibs were free from this contamination. This situation arose because drying coincided with good weather (adequate sunshine) which enhanced fast drying thereby preventing internal contamination of the beans.

5.4: CHEMICAL PROPERTIES OR CHARACTERISTICS OF THE DRIED BEANS

5.4.1: pH of Dried Beans:

The statistical analysis indicated that the treatments had no effect on the pH level of the beans. Even though there were little variations in the pH levels of all the treatments, the statistical analysis showed no significant differences. These results indicate that the pH of the nibs did not depend on any of the drying mats used or the loading densities. Bonaparte *et al.,* (1997) researched into some quality characteristics of solar dried and open air dried cocoa beans at different loadings and also did not observe any significant difference with either the dryer type or the loading density. Jinap *et al.*, (1994), earlier on, also did not find any difference in acidity in bean samples that have undergone sun-drying and air blown drying. Low pH values were observed in the 3kg load on raffia, 6kg load on raffia and 3kg load on SNSpac. The high acidity (low pH values) recorded in these treatments could be attributed to the rapid drying rate early in the drying process. This probably caused case hardening which trapped acetic and lactic acid in the beans. This point is substantiated by Jinap *et al.*, (1994) who evaluated the effect of drying on the pH, titratable acidity and volatile acid contents of cocoa beans and the resultant chocolate. These results suggest that at low loadings fast drying rates could lead to poor chemical quality beans due to high acidity. Higher pH values were recorded in the 6kg load on SNSpac, 9kg load on SNSpac, and 9kg load on raffia mat respectively. These results point to the fact that the drying rates in these treatments were comparatively gradual and these enabled sufficient evaporation and balanced diffusion of the free liquid, which contained dissolved acids from the testa and from the nibs. This phenomenon agrees with what Hii *et al.*, (2008) described about the acidity of cocoa beans exposed to fast drying rate by artificial methods. In general, beans dried on the raffia mat at low loadings were more acidic by commercial standards due to the relatively fast drying rate. Beans with pH less than 5.0 are sour to taste and have reduced commercial value because of their high acidity. Gorkeh-Sekyim (2011) recommended that the pH of commercial bean should range between 5.0 and 7.0.

5.4.2: Titratable Acidity:

Titratable acidity is a measure of the amounts of acids present in the cocoa bean. It is a better predictor of acid's impact on flavour than pH (Sadler and Murphy, 2010). Similarly, Jinap and Dimick (1990) found a -0.91 correlation between pH and titratable acidity of cocoa samples. The statistiscal analysis showed that all the treatments had effect on the amount of acids remained in the beans. Titratable acidity was generally high in beans dried on the SNSpac. With the exception of the 9kg load on raffia mat beans dried on the raffia mat generally showed low titratable acidity. This result indicates that, generally, beans dried on the raffia mat have superior chemical quality. Even though the drying rates of the SNSpac and the raffia mat at 3kg loading were simila, their titratable acidity values were significantly different. Further investigations are required to understand the cause of this. Bonaparte *et al.,* (1996), and Hii *et al.,* (2006) have established that low loadings generally enhance fast drying but cause the trapping of acetic acid in the nibs, whereas higher loadings cause drying to progress more slowly and enable sufficient evaporation of dissolved acids from the beans. These researchers recorded higher titratable acidity values for low loadings. The low titratable acidity value for the low loading on raffia mat for the current experiment therefore deviates from the results of Bonaparte et al., (1996) and Hii et al., (2006).

5.4.3: Free Fatty Acid (FFA) Content:

The statistical analysis indicated that the FFA contents were not significantly different whatever the drying mat used, rather the different loading densities accounted for the differences in the FFA content. This indicates that the type of drying mat used had no effect on the hydrolysis of triglycerids which constitute cocoa butter. Irie *et al.*, (2010) also observed that drying methods have no effect on the production of free fatty acids in cocoa beans. According to Johnfiah-Essien and Navarro, (2010) it is expected that the FFA content must be less than1.0% to meet the acceptable level of 1.75% in cocoa butter extracted from the dry cocoa beans. Three treatments, 3kg load on raffia, 6kg and 9kg load on SNSpac produced values which were above 1.75%. The high FFA values recorded from the 6kg and 9kg loadings on the SNSpac may be attributed to moulding which was observed in these treatments. Wood and Lass (1987) stated that microflora, particularly moulds have been associated with FFA occurrence in cocoa beans. The high FFA content from the 3kg load on the raffia mat suggests the breakdown of triglycerids to release FFA into the nibs as a result of high ambient temperature and the very rapid drying rate. Generally, beans dried on the raffia mat at high loadings produced the best quality product in terms of free fatty acids content.

5.4.4: Polyphenol Concentration:

The statistical analysis indicated that the polyphenol concentration was not influenced by the type of drying mat used but rather the different loading densities. The combined effect of the drying mat and the loading densities also had effect on the polyphenol concentrations. Significant difference existed between the 6kg and the 3kg loadings but no significant differences existed between the 3kg and the 9kg loadings. Despite these differences the values obtained all fell within the commercially acceptable polyphenol levels of West African cocoa which range between 70mg/g and 90mg/g (Wood and Lass, 1987). The acceptable polyphenol levels of all the samples indicate that the seven days of fermentation was long enough to allow the diffusion of some of the polyphenols into the fermentation sweating which left the beans before drying started. Again the temperature and relative humidity profile during the drying period was optimal for the further oxidation of polyphenols by the enzyme polyphenol oxidase. Cocoa beans with high polyphenol concentration have final products which are astringent, have bitter taste and low cocoa aroma. However, when nutrition and health promotion are of concern, beans of high polyphenol content are preferred owing to their higher antioxidant properties. The results obtained for polyphenol concentration in the samples fall in line with the results of Hii *et al.* (2009). The general observation is that, with regards to polyphenol concentration in the cocoa bean, the SNSpac just as the raffia mat can be used for drying if the beans are well fermented.

5.5: Opportunities and Threats Analysis:

In terms of cost both drying mats are the same. According to the manufacturer, a 4m x 8m stretch of the SNSpac costs GH¢ 100.00 as at April, 2013. Several farmers contacted during the survey said that a raffia mat of the same size costs about the same amount. The advantage the raffia mat has over the SNSpac is that the raffia mat can be woven by many cocoa farmers at a lesser cost since the bulk of the raw material can be obtained readily from forest for free. On the other hand the SNSpac is an innovation which seeks to reduce the rate of deforestation and protect our wetlands. At the moment there is high pressure on the raffia palm because of the numerous uses to which the raffia is put. The raffia is used for roofing, weaving baskets and mats, construction of cribs, the fibre is used for weaving fetish costume, and the sap is tapped as palm wine for distilling gin. It is therefore obvious that the continuous use of raffia for making drying mats cannot be sustained in the near future. In this regard the SNSpac is an alternative to look at.

In terms of durability the raffia mat has an urge over the SNSpac. Cocoa farmers who were interviewed maintained that the raffia mat can be used season after season for ten years if it is properly stored during the off season. The SNSpac being a plastic material cannot withstand the constant exposure to sunshine for several drying seasons. In fact the manufacturer puts its lifespan at four years. When we consider availability, the regular supply of the SNSpac cannot be guaranteed since it is an imported commodity. For now the raffia mat is readily available. In terms of environmental concerns the SNSpac is more difficult to dispose of since it is not biodegradable, even though recyclable. On the other hand the raffia is biodegradable since it is an organic material. Both drying mats are versatile in their use in that they can be used in the sun drying of many other commodities apart from cocoa. One important benefit that farmers will derive from the use of the SNSpac is its ability to combine drying with sorting and grading of the cocoa beans. The apertures in the SNSpac allow undersized beans and debris to fall out from the bean mass during stirring so that at the end of drying a clean and equal sized beans are obtained which will pass for Grade 1 cocoa. The raffia mat dries superior beans and remnant beans together and this reduces the physical quality of the beans. Being a plastic material the SNSpac is limited to the amount of load it can hold. From observations made during the experiment, the SNSpac tends to sag when the load on it exceeds its tensile strength. The sag in the SNSpac is a mechanical defect that makes the raffia mat superior to it.

CHAPTER 6

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1: CONCLUSIONS

The impact of SNSpac and raffia drying mat at different loading densities on the physical and chemical qualities of sun dried cocoa beans has been investigated, and the following conclusions can be deduced from the outcome of the study.

The percentage of brown and purple beans obtained from both mats at all the loading densities were within the permissible levels recommended by the Quality Control Company of Ghana Cocoa Board. The study revealed that in terms of rapidity of drying the raffia mat was superior to the SNSpac. Low loading densities enhanced the rate of drying on both mats but fast drying rates had deleterious effects on the physical and chemical qualities of the beans. High percentages of purple beans resulted from both mats with low loading densities and fast drying rates. In the same vein low density loadings and fast drying rates produced beans with high acidity and high free fatty acids contents above the recommended levels.

On the other hand high density loading on the SNSpac produced beans with some degree of moulding even during good weather (ie. adequate sunshine).

The study again revealed that the use of either the SNSpac or the raffia mat has no effect on the pH, the Free Fatty acid content as well as the polyphenol concentration of the cocoa beans. Furthermore loading density does not affect pH of the beans.

This study serves as a reference for future studies into the drying kinetics of cocoa beans using natural sunlight. It is envisaged that the results of this study will enlighten cocoa farmers as to the choice of drying mat to use and the loading density to adopt during a good natural sunlight drying regime.

6.2: RECOMMENDATIONS: Based on the results and conclusions of this study, the following recommendations have been made:

- Farmers should continue to use raffia drying platform at high loading in good weather (adequate sunshine)
- During bad weather low or medium loading density on raffia or SNSpac is recommended.
- The SNSpac may be recommended for small holders who harvest small quantities and usually dry at low and medium loading densities.
- The SNSpac may be recommended for sorting and grading of beans but not for high density drying.
- To avoid excessive acid beans and high free fatty acid beans drying at low density in good weather should be avoided.
- This study was conducted during the main crop season (September to March) and the results hold good for main season drying. It is recommended that the same study be replicated during minor or mid crop season (May to August) when natural sunlight is most unreliable to enable cocoa farmers decide how to handle their drying operations during any drying season.

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APPENDICES

Appendix 1: Meteorological Data

Date	Temperature (^oC)		Relative Humidity (%)	Rainfall (mm)
	Minimum	Maximum		
5/12/12	23.0	31.3	74	0.0
6/12/12	23.5	30.8	96	0.0
7/12/12	23.0	33.0	87	0.0
8/12/12	23.4	31.0	92	0.0
9/12/12	21.9	32.7	71	9.0
10/12/12	23.8	31.3	81	8.5

Source: Ghana Meteorological Service, Kumasi

Appendix 2: Raw Data For Statistical Analysis

A. Physical Analysis

1) Results for Internal Colouration

Sample	Brown Beans %			Purple Beans%			Slaty%
	Rep. I	Rep. II	Rep. III	Rep. I	Rep. II	Rep. III	
SL1	82	76	82	18	24	18	NA
SL2	79	84	80	21	16	20	-
SL3	80	82	78	20	18	22	-
RL1	83	86	80	17	14	20	-
RL2	82	81	89	18	19	11	-
RL3	88	84	86	12	16	14	-

2) Results for surface mouldiness

SAMPLE	SURFACE MOULDINESS		
	Rep I	Rep II	Rep III
SL1	100	100	100
SL2	100	50	50
SL3	50	50	50
RL1	100	100	100
RL2	100	100	100
RL3	50	50	50

B. Chemical Analysis

1) Results for pH

Sample	pH		
	Rep. I	Rep.II	Rep.III
SL1	5.02	5.02	4.99
SL2	5.01	5.03	5.11
SL3	5.05	5.02	5.00
RL1	4.97	5.06	4.94
RL2	4.94	4.96	5.01
RL3	5.02	5.10	5.12

2) Results for Titratable Acidity

Sample	Titratable Acidity %		
	Rep. I	Rep. II	Rep. III
SL1	7.847	7.697	7.826
SL2	7.984	7.899	7.808
SL3	7.102	7.291	7.605
RL1	5.883	5.940	5.943
RL2	7.477	7.832	7.956
RL3	7.973	8.518	8.784

3) Results for Free Fatty Acid (FFA) Content

Sample	Free Fatty Acid Content %		
	Rep. I	Rep. II	Rep. III
SL1	1.442	1.501	1.475
SL2	2.201	2.127	2.143
SL3	2.024	2.131	2.277
RL1	2.442	2.588	2.740
RL2	1.545	1.561	1.559
RL3	1.415	1.500	1.472

4) Results for Polyphenol concentration

Sample	Polyphenol Concentration mg/g		
	Rep. I	Rep. II	Rep. III
SL1	74.51	80.92	78.75
SL2	75.00	74.63	76.15
SL3	77.50	76.79	78.50
RL1	77.16	79.74	77.47
RL2	70.17	71.37	72.15
RL3	83.50	82.51	78.44

Appendix 3: Analysis of Variance Tables

***** Analysis of variance *****

Variate: Brown_Beans_%

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.33	0.17	0.02	
Rep.*Units* stratum					
Drying_mat	1	72.00	72.00	6.57	0.028
Load_density	2	7.00	3.50	0.32	0.734
Drying_mat.Load_density	2	9.00	4.50	0.41	0.674
Residual	10	109.67	10.97		
Total	17	198.00			

***** Analysis of variance *****

Variate: FFA_Content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.029883	0.014942	2.69	
Rep.*Units* stratum					
Drying_mat	1	0.013833	0.013833	2.49	0.145
Load_density	2	0.171186	0.085593	15.43	<.001
Drying_mat.Load_density	2	3.099427	1.549714	279.39	<.001
Residual	10	0.055468	0.005547		
Total	17	3.369799			

***** Analysis of variance *****

Variate: PH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.003244	0.001622	0.80	
Rep.*Units* stratum					
Drying_mat	1	0.000939	0.000939	0.46	0.511
Load_density	2	0.009011	0.004506	2.23	0.158
Drying_mat.Load_density	2	0.014078	0.007039	3.48	0.071
Residual	10	0.020222	0.002022		
Total	17	0.047494			

***** Analysis of variance *****

Variate: Polyphenol_concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	5.516	2.758	0.71	
Rep.*Units* stratum					
Drying_mat	1	0.003	0.003	0.00	0.978
Load_density	2	130.430	65.215	16.80	<.001
Drying_mat.Load_density	2	47.023	23.512	6.06	0.019
Residual	10	38.816	3.882		
Total	17	221.788			

**** Analysis of variance *****

Variate: Purple_Beans%

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.33	0.17	0.02	
Rep.*Units* stratum					
Drying_mat	1	72.00	72.00	6.57	0.028
Load_density	2	7.00	3.50	0.32	0.734
Drying_mat.Load_density	2	9.00	4.50	0.41	0.674
Residual	10	109.67	10.97		
Total	17	198.00			

***** Analysis of variance *****

Variate: Titratable_Acidity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.22929	0.11465	2.89	
Rep.*Units* stratum					
Drying_mat	1	0.42106	0.42106	10.63	0.009
Load_density	2	3.97976	1.98988	50.22	<.001
Drying_mat.Load_density	2	6.63311	3.31656	83.70	<.001
Residual	10	0.39624	0.03962		
Total	17	11.65946			

***** Analysis of variance *****

Variate: Brown_Beans_%

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.33	0.17	0.02	
Rep.*Units* stratum					
Drying_mat	1	72.00	72.00	6.57	0.028
Load_density	2	7.00	3.50	0.32	0.734
Drying_mat.Load_density	2	9.00	4.50	0.41	0.674
Residual	10	109.67	10.97		
Total	17	198.00			

***** Analysis of variance *****

Variate: Surface_mouldiness_

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	277.8	138.9	1.00	
Rep.*Units* stratum					
Drying_mat	1	555.6	555.6	4.00	0.073
Load_density	2	7777.8	3888.9	28.00	<.001
Drying_mat.Load_density	2	1111.1	555.6	4.00	0.053
Residual	10	1388.9	138.9		
Total	17	11111.1			

Appendix 4: Exportable Grades of Cocoa Beans

Grade	Mould	Slate	Other Defects	Purple Beans
I	<3%	<3%	<3%	<20%
II	<4%	<8%	<6%	<30%

Source: Gorkeh-Sekyim (2011)

Appendix 5: Drying time of Cocoa Beans

Sample	Moisture Content %																	
	Day 1			Day 2			Day 3			Day 4			Day 5			Day 6		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
SL1	56	56	56	31.4	31.7	31.4	10.5	10.5	10.6	8.5	8.5	8.8	6.6	7.0	6.8	-	-	-
SL2	56	56	56	38.0	38.4	38.2	15.0	15.2	15.1	8.9	9.2	8.6	7.0	7.4	7.2	-	-	-
SL3	56	56	56	47.3	46.9	47.1	24.0	24.2	24.1	13.0	13.1	13.5	8.6	8.2	8.4	7.6	7.6	7.3
RL1	56	56	56	31.2	31.4	31.5	9.0	9.1	9.0	8.2	7.8	8.0	6.8	7.0	7.0	-	-	-
RL2	56	56	56	33.9	33.7	33.8	12.4	12.6	12.5	8.7	8.5	8.3	7.0	7.1	6.9	-	-	-
RL3	56	56	56	40.5	40.7	40.8	18.0	18.2	18.1	10.5	10.1	10.9	7.3	7.3	7.3	-	-	-