VOL. 2, NO. 3, April 2012 ISSN 2225-7217

ARPN Journal of Science and Technology

http://www.ejournalofscience.org

A Comparative Study of Some Physical Properties of Large and Medium Size Cocoa Beans from Ghana

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ABSTRACT

The physical properties of Cocoa are necessary for the design of equipment to handle, transport, process and store the commodity. Cocoa beans can be categorised into several groups based on their sizes. A comparative study of the physical properties of the large group (category B) and the medium group (category D) Cocoa beans were evaluated as a function of moisture content within the moisture content range of 5.67 - 25.04% wet basis. The bulk density decreased linearly from 559.60 - 505.05 kg/m^3 between a moisture content range of 8.6 - 23.78% for category B and from 699.9 - 630.18 kg/m^3 between a moisture content of 9.19 - 25.05% for category D. The 1000-bean mass increased linearly from 984.75 – 1112 g and 1125 – 1247 g when moisture increased from 9.19 - 25.04% and 8.6 - 23.78% for categories D and B respectively. The emptying angle of repose for cat D at m.c. range of 9.19 - 25.04% increased from 27.98 – 46.52. Cat B. with m.c. range of 7.56 – 18.8% also increased from 27.26 – 37.47^0. The filling angle of repose for category D increased with values ranging from 30.33 - 42.98^0 between m.c. of 9.19 - 25.04%, whiles for category B at mc of 5.67- 22.0% the filling angle of repose increased non-linearly from 23.74 – 33.81^0. The static coefficient of friction increased linearly from 0.56 - 0.69, 0.48 - 0.60 and 0.21 - 0.28 for plywood, mild steel and rubber respectively for category B and for category D, a linear increment in static co-efficient of friction from 0.53 - 0.62 and 0.56 - 0.63 was observed for mild steel and plywood while in the case of the rubber, static co-efficient of friction increased non linearly from 0.12 - 0.32.

Keywords: *Cocoa, physical properties, 1000-bean mass, bulk density, angle of repose, co-efficient of static friction.*

1. INTRODUCTION

Coupling the ever increasing commercial value of food materials with the high standard being set by importing countries as well as the complexity of modern technology, a good understanding of the significant physical properties of food materials are needed.

It is essential to understand the physical laws governing the responds of these biological materials so that machines, process and handling operations can be designed for maximum efficiency in order that the highest quality of the end product can be assured. Such basic information should be valuable to engineers, food scientists and processors who might need them. Several researchers have determined the physical and mechanical properties of different agricultural products as a function of moisture content in order to provide essential data for the design of equipment for the handling, conveying, separation, drying, aeration, storing and processing of seeds. These include researchers such as [1] for bambara groundnuts; [2]) for maize; [3] for rice and [4] for spinach seed. Amelonado Cocoa is one such food material that has very high commercial value worldwide and the cultivation and processing is of great interest not only to producers like Brazil, Cote D'Ivoire, Nigeria, Ghana, Malaysia among others but importers and chocolate manufactures alike. Cocoa is an international commodity with an estimate of five (5 US dollars) billion dollars in world trade[5].

The genus Theobroma, of which the Cocoa tree belongs, occur wild in the Amazon Basin and other tropical areas of South and Central America [6]. Today, Cocoa can be divided into three main types namely; Criollo, Forastero and Trinitario. The Amelonado variety, which comes from the Forastero, is currently widely grown in Brazil, West Africa and South-East Asia. Approximately 60% of the world's supply of Cocoa originates from West Africa [6]. Postharvest operations for cocoa generally consist of manual seeds extraction by breaking the pod and removing the seeds, drying, cleaning, sorting and grading. In Ghana these post harvest handling operations are often done excellently by the farmer on small-scale and manually leading to superior quality specifications which explains why cocoa beans from Ghana have established a worldwide reputation as the ingredient of preference by quality oriented cocoa products manufacturers.

According to the Quality Control Division (QCD) of the Ghana Cocoa Board, Cocoa beans are sorted by size based on number of beans weighing 100 g into various

Categories. Table 1 shows five categories that are declared for the main harvesting season.

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Table 1. Categories of cocoa in Ghana

Classification	Beans count/100g
Large (Category B)	0 – 100
Medium (Category D)	101–120
Small (Category G)	121– 130
Very small (Category F)	131 – 150
Remnants (Category SR)	151 – 250

However, the sizes depend on environmental factors and the hybrids grown. In Ghana quality control measures are strictly enforced to ensure the marketing of high-quality Cocoa, this explains why Ghana is still the leading producer of good-quality Cocoa world-wide [6]. Plate 1 shows samples of Ghana's cocoa beans prepared for export.

Plate1. Cocoa beans prepared for export

Uniformity in size of Cocoa bean is of paramount interest as it helps to achieve effective bean cleaning. Not all seeds from the pod are useful in processing as some fall short in quality and size. Water is one of the most important components affecting all the physical properties of food materials. Cocoa beans, like all food materials, are hygroscopic and absorb moisture under humid condition until they reach equilibrium with the surrounding. A range of moisture content exists within which optimum performance is achieved. Therefore, the effect of moisture content on the physical properties of the two top categories (B & D) of Ghana's Cocoa beans is of importance in the design of the handling, processing and storage equipment. The objective of this study was to measure and compare the variations that exist in the physical properties of two categories (B & D) of Ghana's Cocoa beans as moisture content varies.

2.0 MATERIALS AND METHODS

The Cocoa used for the experiment had all the quality checks performed and ready for export to the international market. The data available were those obtained from a study of the effect of moisture on the physical properties of categories B and D, representing the large and medium sizes respectively, of Ghana's Cocoa beans. The data used were on the following physical properties:

2.1 1000 bean mass

The mass of 1000-beans was obtained by counting 1000 beans for the desired moisture content and replicated five times. The weight was then taken using an electronic balance with 0.01 g accuracy. Other researchers have used this method including; [7] [8] [9]. [10] [11].

2.2 Bulk density

The bulk density is the ratio of the mass sample of the seeds to its total volume. Bulk density, true density, and porosity play an important role in many applications such as design of silos and storage bins, separation from undesirable materials, sorting and grading, and maturity evaluation [10]. The bulk density of the Cocoa beans at the desired moisture content was determined by filling a 1000 ml container with the beans from a height of about 15 cm, striking the top level and then weighing the contents on an electronic balance [12] [13] [9].

2.3 Filling and emptying angles of repose

The filling angle of repose was determined by the method described by [14] and used by other researchers ([15] [8] [16]. The beans at the desired moisture content were allowed to fall onto a wooden circular plate of 20 mm diameter mounted on a laboratory stand from a height of 150 mm to form a natural heap. The height of the heap was measured and the angle of repose was calculated as:

$$\theta_f = \tan^{-1}\left(\frac{h}{100}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

The emptying angle of repose was obtained using a plywood box of dimensions 300 mm x 300 mm x 300 mm which had front sliding panel. The box was filled with the beans at the moisture content being investigated, and the front sliding panel was quickly slid upward allowing the beans to flow out and form a natural heap. The angle of repose was determined from measured height of beans at two points in the sloping bean heap and the horizontal distance between the two points using the relation:

$$\theta_e = \tan^{-1}\left(\frac{h_2 - h_1}{X_2 - X_1}\right) \ldots\ldots\ldots\ldots 2$$

This procedure has been used by other researchers for grains and seeds [17] [15].

2.4 Co-efficient of static friction

The co-efficient of static friction was determined with respect to three surfaces: plywood, mild steel and rubber. These are common materials used for the transportation, storage and handling operations. A hollow PVC cylinder

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of 100 mm diameter and 50 mm height with an opened ends was filled with the beans at the desired moisture content and placed on an adjustable tilting table such that the cylinder does not touch the table surface. The tilting surface was gradually raised by means of a screw device until the cylinder with the beans just starts to slide down. The angle of the surface was read from a scale and the static co-efficient of friction was taken as the tangent of this angle. This method was used by others: [17] [18].

3.0 RESULTS AND DISCUSSION

The data were processed and suitable graphical representations were made of the various physical properties as they vary with moisture content so as to make a comparative study possible. Two graphs were produced on the same chart for both categories B and D for each property. Attempts were then made to explain the possible cause(s) of the difference that exist between the behaviour of the two categories as moisture content changes.

3.1 Bulk Density

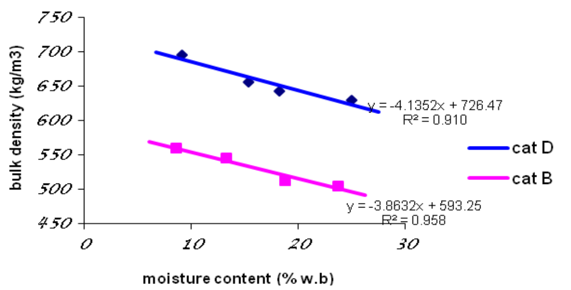

Fig. 1. Effect of Moisture Content Variations On Bulk Density

Fig. 1 depicts the variation of bulk density with moisture content, for categories B and D Cocoa beans. The bulk densities range from 559.60 kg/m^3 at 8.6% moisture content to 505.05 kg/m^3 at 23.78% moisture content for category B and 699.9 kg/m^3 at 9.19% moisture content to 630.18kg/m^3 at 25.05% moisture content for cat. D. The bulk density decreases linearly with increasing moisture content for both categories, the relation being,

$$\rho_b = -3.863M + 593.2 \qquad \text{(cat. B, } r^2 = 0.958\text{)}.........3$$

$$\rho_b = -4.135M + 726.4 \qquad \text{(cat. D, } r^2 = 0.910\text{)}.........4$$

The decrease in bulk density is an indication of a general lower bean weight in comparison to volume increment as moisture content increases. The bulk density of category D is higher than that of category B for the same moisture content. The smaller sizes as well as extent of variation in the shape of category D may have accounted for their higher values. The bulk densities of coffee (arabica and robusta), neem nuts and sunflower showed a similar decreasing variation with moisture content as found by, [19] [20][21].

3.2 Emptying Angle of Repose

The variation in the emptying angle of repose, θ_e, with moisture content is displayed in fig. 2. The emptying angle of repose increased linearly with increasing moisture content for category B, with the relation:

$$\theta_e = 0.915M + 21.32 \qquad \text{(cat B, } r^2 = 0.923\text{)}, ...5$$

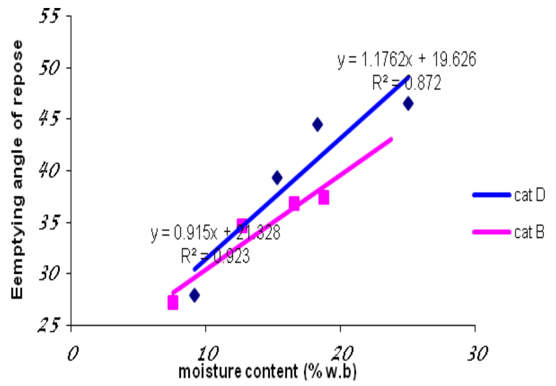

Fig. 2. Effects of Moisture Content Variations on Emptying Angles of Repose Hypotheses

While for category D it increased non–linearly with increasing moisture content, the relation being given as,

$$\theta_e = 1.176M + 19.62 \qquad \text{(cat D, } r^2 = 0.872\text{)}......................6$$

Category D displayed higher emptying angles of repose (from 27.98^0 to 46.52^0 within a moisture content range of 9.19 to 25.08%) than those of cat B which increased from 27.26^0 to 37.47^0 within a moisture content range of 7.56 to 18.8%. This may be due to variations in the surface texture of the both categories as well as the relatively smaller sizes of the cat. D beans. The variation exhibited in Cat. D is somewhat similar to that of bambara groundnut [1]. The emptying angle of repose of Coffee [21], neem nuts [19] and sunflower [22] were reported to have increased linearly with moisture content which is similar to that of Category B.

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3.3 Filling Angle of Repose

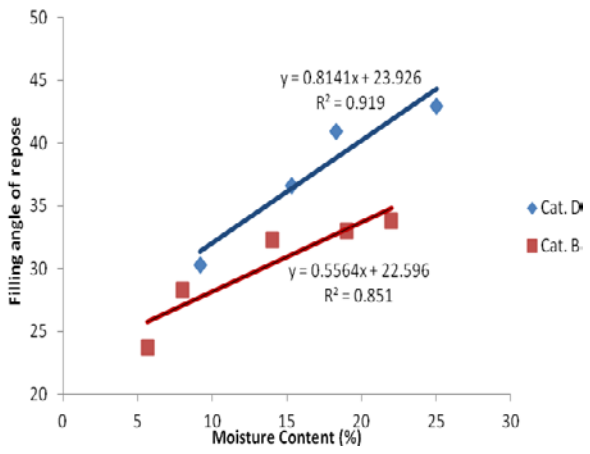

Fig. 3. Effect of Moisture Content Variations on the Filling Angles of Repose

Fig. 3 shows graphically how the filling angle of repose varies with moisture content.

Between moisture content of 5.67 to 22%, the filling angle of repose increases for category D with values ranging from 30.33 ^{0} to 42.98 ^{0}. As moisture content increases from 9.19 to 25.04% for category B a non-linear increment is observed in its values from 23.74^0 to 33.81^0. At about 14% moisture content the filling angle of repose shows slight changes.

The graph for category D exhibits higher values than that of cat. B, which may be due to the differences in the sizes since smaller sizes can interlock more to cause a higher heap formation than relatively bigger sizes. It may also be due to the ability of moisture to adhere more on the surface of the smaller beans.

The relationship between the moisture content and the filling angle of repose may be expressed as,

θ_f = 0.814M + 23.92 (cat. D, r^2= 0.919)………….7

θ_f = -0.0556M + 22.59 (cat. B, r^2 = 0.0.851)….8

The results obtained were slightly lower than those obtained for both arabica and robusta coffee [21], even though there exist an increasing linear relation. A similar relation was observed for neem nuts [19].

3.4 1000 Bean Mass

The 1000bean mass, M_{1000}, of category B and D Cocoa beans is graphically depicted in figure 4. The mass of a 1000 bean mass increased with increasing moisture content for both categories. Between the moisture content of 9.19 to 25.01%, category D recorded a mass of range 948.75 to 1112 g, while category B ranged from 1125 to 1300 g within the moisture content range of 8.6 to 23.08%. The relation is given by,

M_{1000} = 8.831M + 1100.6 (cat. B, r^2=0.984) 9

M_{1000} = 6.538M + 935.1 (cat . D, r^2=0.998) 10

The bigger dimensions of category B as compared to those of category D confirms the categorisation made by the Ghana Cocoa Board. The higher amount of moisture absorbing constituents present in category B might be the cause why category D beans showed lower masses. Both categories exhibited linear relationship with increasing moisture variation. It has also been found that there exist linear relations for bambara groundnuts, coffee, sunflower, flaxseeds, barley grain and black-cumin-respectively [1][21][20][23][10][11].

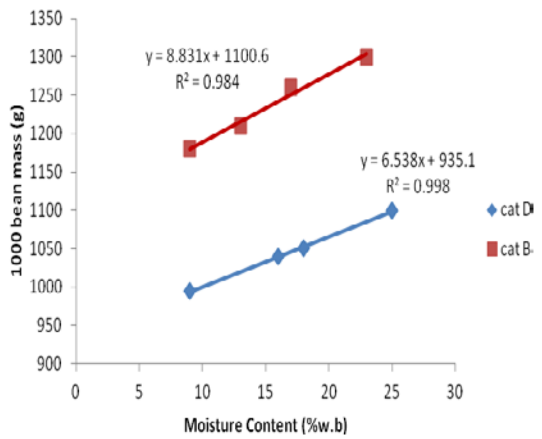

Fig.4. Effect of Moisture Content Variations on the 1000 Bean Mass

3.5 Co-Efficient Of Static Friction

3.5.1 Mild Steel

The values of the co-efficient of static friction observed for mild steel between a moisture content of 9.19 to 25.04% w.b. for category D was 0.53 to 0.615 while that of category B was 0.48 to 0.60 between a range of 8.6 to 18.8%. This is depicted graphically in figure 5 where both categories show an increase in their frictional co-efficient, linearly, on mild steel with increasing moisture content. However, category B possesses higher frictional co-efficient of static frictions than category D for moisture content above 14.73%. Below this moisture content the reverse occurs. The co-efficient of static friction of Cocoa beans (categories B and D) bears the following relationship with the corresponding moisture content:

μ_s = 0.011M + 0.398 (cat. D, r^2= 0.830) 10

μ_s = 0.005M + 0.489 (cat. B, r^2 = 0.945) 11

The reason for the increasing friction co-efficient at higher moisture content may be due to the water present in the bean offering a cohesive force on the surface of

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contact in both cases. The difference in sizes (weight) and differences in surface characteristics could also account for the reason why category B shows higher frictional values of category D.

[21] found a linear relation between moisture content and the co-efficient of static friction for coffee (arabica and robusta) on mild steel. The friction was less for the robusta parchment than for arabica at all moisture contents.

[21] found a linear relation between moisture content and the co-efficient of static friction for coffee (arabica and robusta) on mild steel. The friction was less for the robusta parchment than for arabica at all moisture contents. [21] also reported a similar positive correlation. Also, [10] [11] found an increasing linear relationship for barley and black cumin grains respectively on mild steel, glass and plywood.

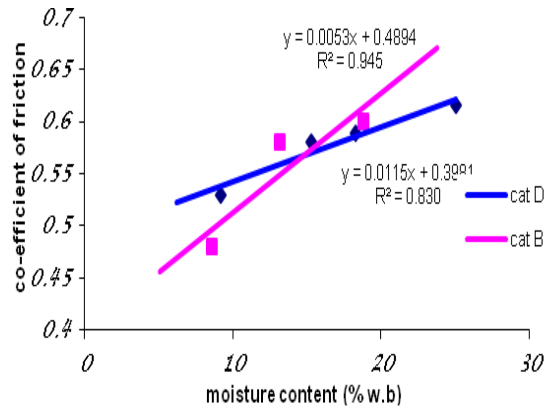

Fig.5. Effect of Moisture Content Variations On Co-efficient of Friction on Mild steel

3.5.2 Plywood

The effect of moisture content of Cocoa beans on frictional co-efficient against a plywood surface is given in fig 6 for both category B and D. The co-efficient of static friction showed a positive linearly correlation with moisture content for both categories with the relation,

μ_p **= 0.012M + 0.451 (cat. B, r^2=0.999) 12**

μ_p **= 0.004M + 0.523 (cat. D, r^2= 0.993) 13**

It was observed that the friction offered was less for category D beans than for category B at all moisture content above 8.28%. The reason for the increases in friction co-efficient on a plywood surface at higher moisture content may be due to the water present in the bean that causes the beans to become rougher offering a cohesive force on the surface of contact in both cases. The difference in sizes as well as rougher surface development could also account for the reason why category B shows higher frictional values than category D. This was similar to the co-efficient of friction on plywood which also increased linearly for neem nuts, sunflower, coffee and black cumin grains as moisture content increased as reported by [19][20][21][11] while it showed a non-linear relationship with bambara groundnuts [1].

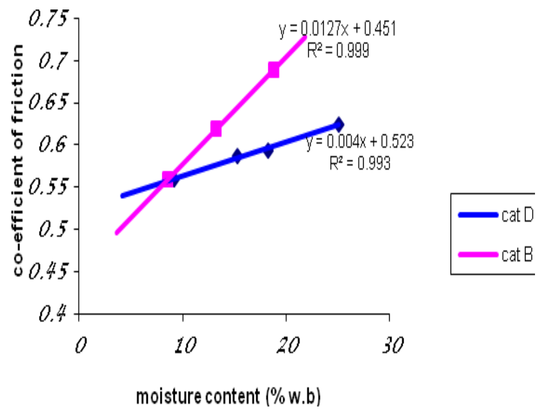

Fig.6. Effect of Moisture Content Variations On co-efficient of Friction on Plywood

3.5.3 Rubber

The co-efficient of static friction on a surface of rubber as displayed in fig. 7

Increased linearly with increasing moisture content for category B, with the relation:

μ_R **= 0.004M + 0.184 (cat** B, **r^2 = 0.945) 14**

The co-efficient of static friction for category B increased non– linearly with increasing moisture content, the relation being given as

μ_R **= 0.001M^2 + 0.62M – 0.327 (cat B, r^2= 0.987).......15**

Category D displayed higher co-efficient of static friction than those of cat B. This may be due to variations in the surface texture of the both categories as well as the relatively smaller sizes of the cat. D beans. The co-efficient of static friction on rubber surface increased with increasing moisture content for coffee and lentil seeds as reported by [21][23].

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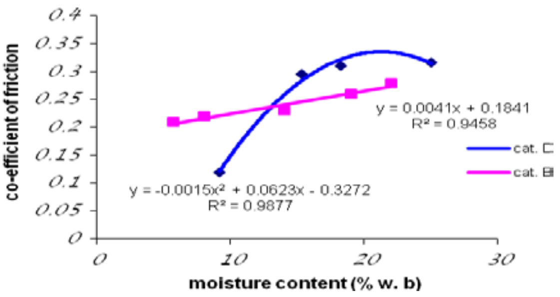

Fig.7. Effect of Moisture Content Variations On Co-efficient of Friction on Rubber

4.0 CONCLUSION

The investigation into the comparative study of the categories B and D Cocoa beans revealed the following;

- A decrease was observed in the bulk density of both categories with category D observing higher values than category B.
- The emptying and filling angles of repose increased for both categories, category D exhibiting greater angles than category B in each property.
- The 1000 bean mass of category B was higher than those of category D even though both categories showed an increase in mass as moisture content rises.
- The co-efficient of static friction increased for both categories on all the surfaces used; for plywood category B displayed higher values than category B; for mild steel category D displayed static frictional co-efficient than category B; for rubber category D had lower co-efficient of static frictions than category B until a moisture content of about 13% when the opposite is observed.

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