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Physical and Engineering Properties of Indigenous Parchment Coffee

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ABSTRACT

Proper understanding and application of physical and engineering properties of coffee seed are necessary for the design of equipment for processing, handling, drying and storage, which will lead to improved and easier operations. Some of these properties of indigenous Robusta parchment coffee at a moisture content of 10.7% w.b. which is within the range of not more than 11% w.b. recommended for safe storage were studied. The seeds were found to be uniformly distributed with average length, width and thickness of 10.15 mm, 7.46 mm and 5.46 mm, respectively. Average values obtained for geometric mean diameter, sphericity, coefficient of static friction and dynamic angle of repose respectively were 7.32 mm, 0.72 and 22.7^{o}. Highest average value of coefficient of friction of 0.47 was obtained for plywood while fiberglass had the least value of 0.27 among other engineering materials tested. Average bulk and true densities were 575.2Kg/m^{3}and 737.9Kg/m^3 while individual seed weight and 1000-seed weight were 0.17g and 167g respectively.

Keywords: *Parchment coffee, Physical properties, Engineering materials, Processing Equipment*

1. INTRODUCTION

Coffee is the most important agricultural commodity traded on the world market [1] and regarded to follow closely after oil in value terms and commercial dealings, contributing greatly to the economy of many countries in Africa, Asia, South and Latin America. It is one of the most widely consumed beverages in the World [2]. In terms of commerce, the main coffee in Nigeria is Robusta which accounts for about 98% of total coffee exported [3] and it is popular for instant coffee and high caffeine content. Coffee production in Nigeria dated back to early 1920 but was cultivated on a less significant commercial level, although export figures show that the crop has been cultivated for a much longer period. Nigeria was regarded to be producing below her potential [4], implying that it had a better prospect in the production of the crop.

High standards being set by importing countries of food and biological materials coupled with the complexity of modern technology necessitates a good understanding of the significant physical properties of these materials [5]. They added, it is essential to understand the physical laws governing the response 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.

Coffee is an evergreen perennial shrub with glossy, ruffled-edged leaves belonging to *Rubiacea* family which is one of 90 genus *coffea* [6]. It grows in tropical climate between latitudes 25^0 N and 25^0 S [7] and can be up to 15 feet tall or more in its native tropical habitat under 21^{0}C or higher temperatures during daylight [6]. Coffee which was used as a beverage by the Arabs as long as 600 A. D. was first discovered in Eastern Africa, in current day Ethiopia before it was introduced to the Mediterranean countries about 1500 A. D. The two main species popularly grown worldwide are *Coffea arabica* (arabica) and *Coffea canephora* (robusta) with robusta more commonly cultivated (Fig. 1).

Fig. 1: Ripe Robusta berries and dry parchment coffee

Others less extensively cultivated species are *Coffea liberica, Coffea abeokutae, Coffea excelsa and Coffea cogenesis.* A major difference between the two main varieties is their organoleptic quality which determines their acceptability and popularity in different places. Though, the size may differ depending on the species, varieties, cropping practices and environmental conditions; coffee berries are similar: being ovoid in shape and glossy red in colour when they are ripe [7]. He stated average sizes of berries as 16 - 18 mm long and 10 - 15 mm wide for arabica while Robusta is 8-16 mm long. The berry consists of the skin (exocarp), pulp (mesocarp), parchment (endocarp) and corneous dicotyledonous bean (endosperm) surrounded by thin silver skin adhering to it [7].

Harvesting varies according to species and location and takes place when berries are ripe (bright red, glossy and firm to touch). Primary processing operations of coffee berries after harvesting involve: sorting (removal of unripe and overripe berries), cleaning (removal of dirt) and conversion of coffee cherries into green coffee beans which may involve pulping, drying to 10.5 – 12% w.b and hulling, depending on either wet or dry method is used. Primary processing to produce green coffee is normally done not later than 24 – 48 hours of harvesting; a step taken to prevent mould growth and development of Ochratoxin A (OTA), one of mycotoxins which may affect final coffee drinks [8]. However, green coffee beans are not affected by external spoilage agents but biochemical changes. In the dry process the ripe cherries are dried in their entirety after which they are mechanically decorticated to produce the green beans. In the washed or wet process which is believed to maintains the natural quality better, the ripe berries are soaked in water, pulped, fermented and washed to remove the sticky sugary coating called mucilage that adheres to the beans (done manually or mechanically), and the beans are then washed and dried. The third unpopular process in which the ripe berry is pulped and dried with the mucilage still adhering to the parchment, originally called semi-washed in Africa, is gaining considerable importance in Brazil where it occupies a place in-between the dry and wet processes. The method chosen to prepare green coffee depends on the species grown, the conditions and resources in each production region. The primary processing is followed by roasting of beans, at about 185^0C – 230^0C for 12 – 15 minutes [7] and grinding, but conventional roasting temperature range is 200 - 230^0C for 12 - 20 minutes [2]. Bean size means everything in coffee production as it is very vital in cleaning, grading and roasting.

One of the major factors identified for high post-harvest losses and decline in production is inadequate processing machines leading to low quality beans and high processing costs [1]. However, the price of agricultural products is based on qualitative parameters and varies significantly depending on the quality presented.

The stimulating effect of coffee is responsible for its popular consumption as beverages and snacks in various forms such as instant coffee. Various brands of coffee drinks and blends are produced from grounded beans depending on varieties and locality. It has low nutritional value as its main constituents are organic acids, tannins, caffeine and minerals with small quantities of partially caramelized carbohydrates, traces of protein and practically no fats (7, Coste, 1992). Coffee is more popularly consumed in Europe and North America with many public places in USA serving varieties of coffee [8]. Potentials of coffee by-products for industrial uses and livestock feeds, bio-fuels and fertilizers in Nigeria are reported by [9] make it a promising instrument for economic development. In the diets of ruminants, waste and by-products of coffee have successfully used 10 – 30% [10]. Research has also indicated that it has some health benefits as it has been reported to have some properties that can prevent some ailments such as type 2 diabetes, heart attack, Parkinson's disease and liver cancer [8 and 11]: it can be source of antioxidants and healthful in low quantities depending on biochemical traits of individuals [12]. But several reports pointed out that excessive consumption above 4 cups daily is dangerous. Coffee plants produce not only the all important coffee bean, but they can make terrific houseplants too [6]. According to [1], if necessary approaches were taken, coffee would be regarded as a valuable source of income for African countries and households; playing an important role in poverty reduction. Improved production and marketing of coffee will ultimately help in the economic development and poverty alleviation in Nigeria [3] while production and processing alone can create millions of jobs for both male and female [8].

Although, a few publications describe the uses, quality, processing, marketing and other related issues on processed (green) coffee, not much information was available on its, especially Nigeria coffee, physical and engineering properties. Knowledge of physical and engineering properties are necessary in the design of machines for harvesting, handling, processing and storage [13]. Some of the important properties that are valuable to engineers, scientists and processors are: sizes, shape, mass, densities, hardness, angles of repose and coefficients of friction. Angle of repose, coefficient of friction and bulk density are essential for processing, handling and storage systems; size, shape, volume and weight are useful for operations such as threshing, cleaning, conveying, heating and cooling while coefficient of internal friction is necessary for determining methods of compressing and packaging materials. Bulk density and porosity are major considerations in designing near-ambient drying and aeration systems as they affect resistance to airflow of the stored mass. Particle density is important in the theories of drag coefficient and porosity determination while porosity is useful for designing aeration systems in storage facilities.

Several researchers have worked on the determination of some of these properties, including those that are moisture dependent, for a number of crops. They include locust bean [14], cocoa beans [15 and 5], pine nut [16], *Prosopis africana* seed [17], pea seed [18], coriander seeds [1 and 20], wild sunflower seeds [21], jathropha seed [22 and 13], corn seed [23], black chickpea [24] and flaxseed [25]. Detailed information on the physical and engineering properties of wet-processed indigenous coffee seed, which may be of interest to the engineers and processors, is not available in the literature. This work was carried out to determine some important physical properties of dried Robusta coffee seed (parchment coffee) to provide relevant information for the promotion of production of necessary equipment and system for effective processing, handling, storage and transportation.

2. MATERIALS AND METHODS

2.1. Seed preparation

Fresh ripe berries were harvested from the plantations of Cocoa Research Institute of Nigeria, Ibadan. They were soaked in water within 24 hours of harvesting after sorting and cleaning to remove unripe and overripe fruits and dirt. The berries were later pulped with pestle and mortar after 3 days of soaking and washed. The resulting wet parchment coffee (seed) was sun dried and stored in polythene bags under room temperature. Immature seeds and broken seeds were carefully sorted out from the required quantity by handpicking. The moisture content of sample used for this work was determined to be 10.7% wet basis using electronic digital moisture meter (Huzhi H. Z. 022 90025).

2.2. Physical properties determination

2.2.1 Axial dimensions

Ten seeds each were selected at random from ten sub-samples of seeds resulting in a total of 100 seeds. The major diameter (length, L), intermediate diameter (width, W) and minor diameter (thickness, T), as described in Fig. 2, were measured with a digital vernier caliper (Raider RDDC 706) of 0.01 mm least count. The averages of replicates were taken as the values for each principal dimension. Similar methods have been reported for measuring these dimensions by several investigators including [15], [23] and [24]. The ratios of other dimensions to the length were also determined using their average values.

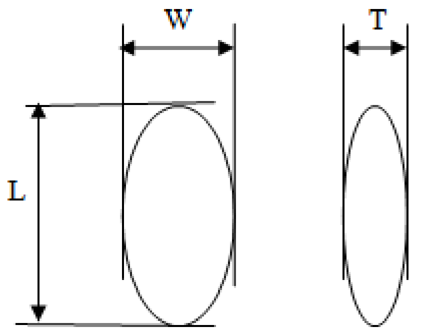

Fig. 2: Axis and three perpendicular dimensions of coffee seed.

The geometric mean diameter (D_g) and sphericity (Φ) were calculated from average values of these dimensions, using equations 1 and 2 respectively as earlier used by [16, 17 and 18]

$$D_g = (abc)^{1/3} \quad 1$$
$$\Phi = \{(abc)^{1/3}\}/a \quad 2$$

Where *a*,*b* and *c* are length, width and thickness respectively.

2.2.2 Mass of individual seed and 1000-seed

Ten seeds each were randomly selected from each of ten sub-samples that were also picked at random from samples to ensure fair selection of material, thus making 100 seeds. Similar method had been used by [15]. The seeds were weighed on an electronic balance (KERRO BL5002) of 0.01g accuracy. The process was repeated 15 times and the average value was taken as the mass of 100-seeds while the seed mass was obtained by dividing the value by 100. Mass of 1000-seeds was determined by randomly selecting 25 seeds from each sub-sample in a like manner as explained earlier resulting in 250 seeds. The weight of the 250 seeds which was multiplied by 4 to obtain weight of 1000-seeds [25 and 26] was determined by electronic balance mentioned earlier. The average of 15 replications was used as mass of 1000-seeds.

2.2.3 Angle of repose and Coefficient of friction

A plywood box of 0.1m x 0.1m x 0.1m having a removable front panel was used to determine the dynamic or emptying angle of repose. The box was filled with samples of clean seeds and the front panel was rapidly removed allowing the materials to flow to their natural slope [13]. This experiment was replicated 20 times. The angle of repose, α was calculated from measurement of grain free surface depths at the end of the box and midway along the slope surface and horizontal distance between the end of the box and the midpoint.

$$\propto = tan^{-1}(h/b) \quad 3$$

where$h$ = difference in depths between the end of the box and midpoint while b = horizontal distance between the end of the box and midpoint of the slope. Similar procedure has been used by [14], [15] and [5].

The coefficients of static friction on five surfaces commonly used engineering materials using the method reported by several investigators including [15], [16], [17] and [18]. A hollow plastic cylinder which opens at both ends was placed on an adjustable tilting table with the surface. The PVC cylinder of 50 mm x 50 mm was filled with pure seeds using 20 replicates. The cylinder was slightly raised such that there is contact between the seeds and the surface only. The table with the cylinder was lifted gently until the cylinder just started to slide down the table surface. The angle of tilt was then read from a graduated scale on the table. The coefficient of static friction was calculated from the equation:

$$\mu = tan\theta \quad 4$$

Where μ and θ are the coefficient of static friction and angle of tilt respectively.

2.2.4 Bulk density, True density and Porosity

The bulk density was determined using AOAC method reported by [14]. This process involves filling a graduated 500 ml measuring cylinder with a predetermined seed mass. The seeds were poured from a height of 150mm from the cylinder and the top level of the seeds was tapped 10 times [15] to ensure they settled properly. The volume occupied was noted and the process was replicated 20 times. Bulk density was determined as the average of the mass-volume ratio.

The true or particle density was found by using water displacement method as earlier used by [14, 16 and 17]. Prior to this experiment, some seeds were soaked in water for 30 minutes. Having been satisfied that the increase in seed mass was insignificant and negligible as earlier used by [14] and [16], the seeds were directly immersed in water. This experience is probably due to the hardness of seed coats and polished surface of the beans. A known mass and number of the seeds was immersed with a metal sponge into a 1 litre measuring cylinder which had been filled with water to a certain level such that the seeds did not float in water. The increase in water level was determined for each of the 20 replications. The true density was determined in a similar way to bulk density. The porosity ε was calculated from average values of bulk and true densities using the equation reported by [14] and [16]:

$$\varepsilon = (1 - \rho_b/\rho_t)x100 \quad 5$$

where ε is porosity, ρ_b and ρ_t are true densities respectively.

2.3 Statistical analysis

Means of all measurements, including standard deviation and coefficient of variation, were obtained using Microsoft Excel software (2007) while graphs were plotted through Microsoft Excel 2010 unless stated otherwise.

3. RESULTS AND DISCUSSION

The summary of the results of various parameters determined is shown in Table 1. Detailed explanation is given in subsequent sections and respective charts below.

Table 1: Summary of physical and engineering properties of parchment coffee at moisture content of 10.7% wet basis

Properties	$\bar{x}$	Max	Min	SD
Length (mm)	10.15	11.85	5.15	1.03
Width (mm)	7.14	8.76	3.11	0.76
Thickness (mm)	5.46	7.78	3.22	0.77
Geometric mean diameter (mm)	7.32	8.50	4.28	0.65
Sphericity	0.72	0.83	0.64	0.04
Individual seed weight (g)	0.167	0.179	0.153	0.01
1000-seed weight (g)	161.0	173.9	153.8	6.65
Bulk density (kg/m^3)	575.2	587.5	552.9	12.75
True density (kg/m^3)	737.9	1000	666.7	84.88
Porosity (%)	22.05	-	-	-
Angle of repose (degree)	22.71	26.75	18.22	2.52
Coefficient of friction on:				
Plywood	0.47	0.55	0.36	0.05
Mild steel	0.45	0.50	0.37	0.04
Galvanized steel	0.42	0.49	0.36	0.04
Stainless steel	0.39	0.45	0.36	0.03
Fibre glass	0.27	0.33	0.22	0.03

Note: $\bar{x}$ is Mean, Max is Maximum, Min is Minimum, and SD is Standard deviation

3.1 Seed dimensions and size

The sizes of coffee seed and their distribution are presented in Fig. 3. The result reveals that there is difference in the axial dimensions of the seed which has been reported for most other crops. The length, width and thickness of the dimensions ranged between 5.15 - 1 1.85, 3.11 – 8.76 and 3.22 – 7.78 while the modes were 10.22, 7.01 and 5.36 respectively. The dimensional ratios are described by the relationship:

$$L = 1.42W = 1.86T \qquad 6$$

The same ratios for locust beans had been reported [14], which imply that the two seeds will behave similarly in separation and handling equipment. The thickness was found to be 0.77 times the width: [17] reported that the closer this ratio to 1.0, the higher the tendency of the seed to rotate about the major axis. The graphs in Fig. 4 indicate normal distribution of all the principal dimensions, except length, which is in agreement with earlier results of [17] for *Prosopis africana* seed, [16] for pine nuts, [15] for category B cocoa beans and [14] for locust beans.

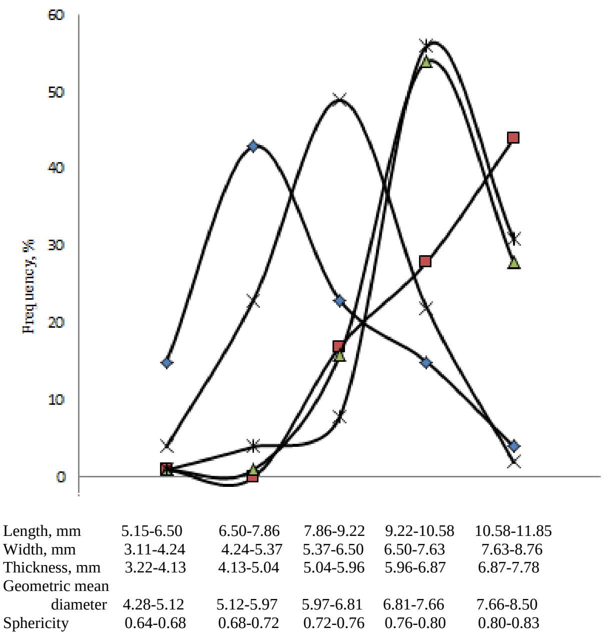

Fig. 3: Frequency distribution for the axial dimensions of coffee seed: ■, *length;* ▲, *width;*x, *thickness;*∗, *geometric mean diameter;* ♦, *sphericity*

This is an indication that the dimensions are relatively uniform, information which is useful in the selection and design of separation and size reduction equipment. It also suggests that grading and separation operations of the seeds could be performed appropriately by sieving.

The average values for sphericity and geometric mean diameter are 0.72 and 7.32 respectively. The sphericity is within what was reported for most agricultural particles by [17]. They also added that the closer the sphericity to 1.0, the higher the tendency to roll about any of the principal axes which was also reported by [16]. The implication is that coffee seed will roll during handling and processing which could be done by machines with circular holes, despite the difference in the axial dimensions.

Skewness and Kurtosis analysis for the frequency distribution of the dimensions is presented in Table 2. Skewness describes the degree of symmetry of a distribution around its mean while kurtosis characterizes the relative flatness of a distribution compared to normal distribution [17]. Positive value of skewness means that the distribution is asymmetric with the tail extending to the right (positive values) and *vice versa* for negative values. The negative values obtained for skewness for all the principal dimensions of parchment coffee indicate that majority of the seeds are relatively large in sizes.

Table 2: Skewness and kurtosis for the axial dimensions and sphericity of the parchment coffee

Dimensions	Length	Width	Thickness	GMD	Sphericity
Skewness	-1.54	-1.45	-0.08	-1.79	0.43
Kurtosis	4.43	6.85	0.89	5.02	0.18
CV (%)	0.10	0.11	0.14	0.09	0.05

Note: CV- coefficient of variation, GMD is Geometric mean diameter

3.2 Weight of individual seed and 1000 seeds

The individual seed weight ranges from 0.153g to 0.179g with average value of 0.167g and CV of 0.04% while the average volume was 0.251 cm^3. The weight of 1000-seed ranges from153.8g to 173.9g with average of 161.0g and CV of 0.04%. This indicates that that the seed are uniformly distributed with respect to weights. This information can be useful in selecting suitable storage and handling containers and for appropriately determining the effective diameter for estimation of theoretical volume.

3.3 Bulk and True densities and Porosity

The average bulk density was 0.58 with minimum and maximum values of 0.55 to 0.59 g/cm^3. The true density ranges between 0.67 and 1.00 g/cm^3 with mean of 0.74 g/cm^3 (737.9 kg/m^3). The result shows that an average coffee seed is lighter than water which has density of 1000 kg/m^3 indicating that coffee seed will float in water. It is also useful information for designing separation and cleaning machines. Bulk density falls within the range for most seeds reported by [17] which include shelled maize (756kg/m^3), vetch seed (785kg/m^3), soya bean (785kg/m^3) and cocoa bean (1124kg/m^3). This implies that the standard materials used for packing these products could be suitable for coffee seeds. Porosity which was determined from means of true and bulk densities was 0.22 per cent.

3.4 Angle of repose and Coefficient of static friction

The mean angle of repose of 22.4^0 obtained was below maximum of 45^0 for agricultural materials as reported by [17] and within the range of values for some crops reported by other researchers. The values for *Prosopis africana,* locust bean, cocoa bean, wild sunflower seed and corn seed are respectively 22.4^0 [17], 20.3^0 [14], 27.3^0 at 7.56% w.b [15], 28.6^0 [21] and 42^0 [23]. The closeness in the values for most of these crops suggests similarity in their shapes and possibility of using the same handling equipment for them.

The average coefficient of friction on plywood, mild steel, stainless steel, galvanized steel and fiberglass were 0.474, 0.455, 0.392, 0.424 and 0.267 respectively. These figures indicate that the coffee seed is a non-rasive agricultural material having 0.4 - 0.5 values obtained by [27] as reported by [17]. It also shows that plywood has the roughest surface while fiberglass is the smoothest. However, plywood, mild steel and galvanized steel will perform similarly when used in handling systems because of the much closeness in the values of their friction coefficients. The slope of the side wall inclination for hoppers and handling equipment for coffee seed will be less steep compared to those of abrasive agricultural materials or those with close values of coefficient on smoother friction surfaces.

4. CONCLUSION

The result of this work has indicated that the physical and engineering properties of Robusta coffee seed (parchment) are comparable with most of similar agricultural products. The implication is that design principles of machines and systems for processing, handling, drying and storing these products appropriately applied to Robusta coffee seed, using similar relevant engineering materials. This work will, therefore, serves as baseline information for engineers, processors, coffee merchants and other relevant bodies to carry out their work more accurately with better results. More importantly, it will help in the production of machinery for processing coffee in Nigeria and other places with good potential but less developed technology for coffee production which will promote better quality coffee production.

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