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# RESEARCH ARTICLE

# SOME ENGINEERING PHYSICAL PROPERTIES OF BEANS OF SELECTED CULTIVARS OF COFFEE (*COFFEA ARABICA L.*) GROWN IN SOUTH WEST, ETHIOPIA

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## ABSTRACT

Coffee Arabica is an essential commodity to the livelihood of millions of Ethiopians and its quality had critical importance to the coffee industry. A study was conducted to determine engineering physical properties of nine newly released coffee cultivars dried by open sun drying ( direct sun light) .Coffee cultivars were (Gawe , Dessu , 744, 7440, 74148, Gesha , Merdacheriko , Wushwush and CJ 19) prepared using wet (washed) processing method during harvesting of 2017/18 cropping season, which were collected from different altitude of south west, Ethiopia. Physical properties of the green bean such as dimensions (length, width and thickness), geometric mean diameter, arithmetic mean diameter, equivalent mean diameter, frontal surface area, cross sectional area, sphericity, aspect ratio, shape index, hundred bean weight, bulk and true density, bean volume, porosity and angle of repose for each cultivar were studied. Most large values of physical properties such as major dimensions, arithmetic mean, geometric mean and equivalent mean diameters; frontal surface area, hundred bean weight and volume of beans were recorded for cultivar 744 at moisture content of 11.67% (wb) and highest values of bulk density, true density, porosity and angle of repose and the lowest values of 100 bean weight, moisture content and volume were recorded for cultivar74148 at moisture content of 9.60%. In the future study other engineering properties should be studied to provide fairly comprehensive information on design parameters involved in recent coffee post-harvest machineries.

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## INTRODUCTION

The coffee bean is obtained from the fruit of the coffee plant, a small evergreen shrub belonging to the genus *Coffea*, family *Rubiaceae*. Although the genus *Coffea* is diverse and reported to comprise about 103 species (Davis *et al*., 2006), only two species namely Arabica (*Coffea arabica L.*) and Robusta (*Coffea canephora*) are under commercial cultivation (Lashermes *et al*., 1999; Anthony *et al*., 2002; Pearl *et al.,* 2004). Arabica coffee accounts for about 70% of the world coffee production and known for the preparation of high quality beverage (Anthony *et al.,* 2002). Ethiopia is the original home of *Coffea arabica L*, and thus, possesses the largest diversity in coffee genetic resources (Mayne *et al*., 2002; Girma, 2003). The criteria commonly used to evaluate the quality of coffee beans include bean size, color, shape, roast potential, processing method, storage period, flavor or cup quality, and the presence of defects (Franca *et al*., 2005).

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Size and shape of coffee berries and beans (as well as their other properties) depend on many factors such as coffee variety (Ghosh *et al*., 1970), planting conditions (Muschler, 2001) and geographical zone (Freitas *et al*., 1999). Wormer (1996), for first time statistically reviewed Coffee Arabica bean shape. Shape of an object (including agricultural product) can influence its mechanical or thermal properties. Thus, its knowledge is critical, for designing manipulation, handling, and processing devices. The evaluation of the coffee grain shape is relatively difficult owing to its complexity. The exact evaluation of the grain shape must be generally based on the use of 3-D scanning, but, for the solution of many problems, it is sufficient to know the shape of the contour of the grain projection in given directions. A frequent problem, which occurs while manipulating with coffee beans (sieving, sorting, and/or grinding), is also the calculation of the exact volume and surface area. Many researches have been carried out on the physical and engineering properties of the agricultural products (Mohsenin, 1970; El-Raie *et al*., 1996). The information on size, density, and crushing strength are required for the development of the grading system of coffee berries and for the pulpers (Gosh, 1969).

Physical characteristics of agricultural products are the most important parameters for determination of proper standards of design of grading, conveying, processing, and packaging systems (Tabatabaeefar, 2003; Tabatabaeefar and Rajabipour, 2005). Data on physical properties are important in the design of a specific machine or analysis of the behavior of products in order to perform various post-harvest operations (Singh *et al*., 2004). Therefore, to optimize the design of equipment's for advanced post-harvest handling and processing of different released coffee cultivars the physical properties of the bean should be known. This information is also useful for engineers and food scientists who would be studying on different aspect of the coffee bean. Jimma Agricultural Research Center is a national coffee research co-coordinator that has developed improved coffee cultivars based on different aspects for different agro ecology. However, there is a limited research on scientific information on engineering and physical properties of such newly released Coffee Arabica cultivars. Therefore, the objectives of this study were to characterize the major engineering and physical properties of beans of selected new Coffee Arabica cultivars harvested in different growing area.

**The objectives of the present study were:** To determine some engineering physical properties of Coffee Arabica beans of nine released cultivars of different agro- ecological zones dried by open sun or direct sun light.

***Physical Attributes of Coffee Arabica Green Bean***

***Moisture content of green bean:*** Moisture content of the coffee bean is a very critical parameter and very important attribute and indicator of quality. At higher moisture content, the coffee can lose its sensory effects and at lower moisture content (less than 9.0%) may be irreversibly damaged in color, as well as in their cup test, flavor and consistency that means it is not worth reducing the moisture content to such a low level when drying (Sivetz and Desrosier, 1979). If the beans are too wet, for example, more than 12.5% moisture, the beans can easily grow moldy during storage, whiles, if too dry (below 8%) they lose flavor. The moisture content of the coffee beans plays an important part in determining the coffee storage stability against deterioration (Clarke, 1989).

The way coffee roasts are influenced by the amount of moisture in the bean as well as its weight loss. Leroy et al. (2006) indicated that green coffee tends to roast faster when the moisture content is lower than those with higher moisture content are. Internationally, coffee should not be exported when the moisture contents are outside the internationally accepted levels (8.0% = X = 12.5%), (ISO, 2000). Moisture content also has a great influence in threshing, separation, cleaning and grading operations. Aviara et al. (1999) noted that the moisture dependent characteristics of physical properties have effect on the adjustment and performance of agricultural product processing machines. They further noted that the optimum performance of machines could be achieved at a specific range of moisture contents. It has been reported that the knowledge of physical properties and their dependence on the moisture content are useful for the design and development of methods and equipment (Oje, 1993; Visvanathan et al., 1996).

**Geometric properties:** The geometric properties such as size and shape are one of most important physical properties considered during the separation and cleaning of agricultural grains. In theoretical calculations, agricultural seeds are assumed spheres or ellipse because of their irregular shapes (Mohsenin, 1980; Nalbandi et al., 2010). The quality of coffee beans is partly determined by their size and shape (Banks et al., 1999). The engineering properties of big coffee beans resulted from wet process were explored in respect to different colors of coffee cherry origins. The average values of length, width, thickness and frontal area of beans were 11.61 to 12.1 mm, 8.35 to 8.84 mm, 5.04 to 5.45 mm and 76.12 to 83.94 $mm^2$, respectively (Sidebang et al., 2015). Olukunle and Akinali (2012) observed some engineering properties of coffee beans at 10.7 % moisture content and reported that length; width, thickness and sphericity of beans were 8.19 mm, 6.11 mm, 4.60 mm and 0.75, respectively. Bean shape is determined in terms of its sphericity and aspect ratio (divide length of the bean to the width). The average values of sphericity are 0.67, 0.65, 0.64 and 0.66 and the aspect ratio for non- defective coffee bean, full black, immature and full sour are 0.68, 0.67, 0.65 and 0.66, respectively (Ataklti et al., 2014).

**Gravimetric properties:** Determination of gravimetric properties is important because it determines the capacity of the storage and transport systems. The average values of weight of 1000 beans, porosity, bulk density and true density of coffee Robusta beans were 262.93-304.63 g, 0.49-0.54 ,740-788.9 $kg/m^3$ and 1540.6-1614.8 kg $/m^3$, respectively (Sidebang et al., 2015). The average porosity values for non-defective coffee bean, full black, immature and full sour coffee beans are 0.56, 0.49, 0.55 and 0.51, respectively and the bulk density of the beans were 0.582, 0.613, 0.580 and 0.609 $g/cm^3$ for non-defective, full black, immature and full sour, respectively (Ataklti et al., 2014).

The physical properties such as size, angle of repose, crushing strength and bulk density are important in the design of the handling system, grading and hulling (Chandrasekar and Viswanathan, 1999). Olukunle and Akinali (2012) observed some engineering properties of coffee Robusta beans at 10.7 % moisture content reported that the value of angle of repose were 24.8 degree. The repose angle of the different categories of the coffee bean cultivars determined by allowing the beans to flow on a plate to form a pile and to accumulate and form a conical heap on the surface. Then, the angle of repose is calculated from the ratio of the height to the base radius of the heap formed.

## MATERIALS AND METHODS

**Description of Study Area:** The study was conducted at Jimma Agricultural Research Center (JARC) and the coffee samples were obtained from Jimma (Melko), Tepi Agricultural Research Center and Gera sub center of JARC from harvests of 2017/2018 cropping season collected from coffee trees of 8 - 10 years age. Jimma Agricultural Research Center is located in Jimma zone, Oromia National Regional State, 358 km away southwest of the capital, Addis Ababa. The centre (Melko) is found at a distance of 10 km west of Jimma city and located at 7°40'37"N and 36°49'47"E and at an altitude of 1753 m above sea level. The average minimum and maximum temperatures are 11.9 and 26.2 °C, respectively. The area receives an average annual rainfall of 1532 mm (Lemi et al., 2018). Teppi National Spice Research Center (TNSRC) is located in Yeki district, Sheka Zone of Southern Nations, Nationalities and Peoples'

Regional State, which is 600 km away southwest of the capital, Addis Ababa. It is found at 35°08'28"E longitude and 7°08'54"N latitude and at an altitude of 1200 m above sea level. The average minimum and maximum temperatures are 15 and 30 °C, respectively. It receives an average annual rainfall of 1630 mm (Shamil *et al*., 2017). The relative humidity of the site reaches 80 to 90% and the soil type is Nitosoil dominated by a loam texture (Girma *et al*., 2009). Gera agricultural research sub center of the Jimma agricultural research center is located at latitudinal gradient of 7°70"N and longitudinal gradient 36°35"E with an altitude of 1940 m above sea level. The mean annual rainfall of the area is 1878 mm with an average maximum and minimum air temperatures of 24.4 and 10.5 °C, respectively.

**Experimental Materials:** Samples of nine coffees Arabica (*Coffea arabica L.*) cultivars adapted for mid land (1500-1750 meter above sea level), high land (above 1750) and low land (500-1500) altitudes were collected of the 2017/18 harvesting season at Jimma (Melko), Gera and Tepi growing areas. The coffee samples were to represent each agro ecological zone. Harvesting was conducted in the period between mid of October and December 2017. Eight-kilo grams red ripe coffee cherries were harvested by hand picking from each selected coffee cultivars from the indicated areas.

Experimental Design: The experiment was consists nine coffee cultivars selected to represent different growing altitudes. The Coffee cultivars were Gesha, Catimor J-19, Dessu, 744, 7440, 74148, Gawe, Merdacheriko and Wushwush. Each treatment was done in triplicate and the experiment laid out in a Completely Randomized Design (CRD).

**Statistical Data Analysis:** Analysis of variance (ANOVA) was computed for each parameter data using General Linear Model (GLM) of SAS procedure version 9.0. In order to identify the variability among the cultivar in CRD design. For characters having significant mean differences, the difference between treatment means was compared using least significant difference (LSD) at 5% level of significance. For each coffee cultivar dried by open sun (direct sun light) measurement of some engineering physical properties of bean data was repeated three times and taken mean values with their standard deviations.

Data Collection

**Measurement of physical attributes of coffee beans**

**Moisture content***: The moisture content of whole clean coffee bean was determined using five grams of bean samples from each cultivar, dried in hot air oven (J. P. Selecta, S. A. No. Serial #:0473987 Barcelona, Spain) at 105 °C for 24 hours (Reh* et al*., 2006). The weight loss of samples was recorded and the moisture content was determined in percentages. The average moisture content (%wb) was calculated using the following relationship*:

$$MC\ (\%\ wb) = \frac{Mi - Mf}{Mi} * 100 \qquad \text{Eq.1}$$

Where:

MC = Moisture content (%)
Wi = Initial mass of sample (gram)
Wf = Dried mass of sample (gram)

*Size and dimension:* To determine the dimension of the beans, each sample was properly mixed and divided according to the procedure established for using rotary sample divider laborette 27 (Fritsch, Germany). Then from each selected coffee cultivar sample of 100 clean green beans were randomly selected. From selected coffee cultivar for each individual bean, three principal dimensions, namely length (L) was measured along the major axis, width (W) measured along minor axis and thickness (T) was measured elongation at the thickness orientation by using electronic digital Vernier Calliper (with resolution 0.01mm accuracy).

*Geometric mean diameter: Based on measured three dimensions of randomly selected beans for each cultivar geometric mean diameter were calculated using the following mathematical expression (Mohsenin, 1970):*

$$D_g = \sqrt[3]{L * W * T}\ ,\ (mm) \qquad \text{Eq. 2}$$

*Arithmetic mean diameter: After measuring the dimension of randomly selected beans for each cultivar, arithmetic mean diameter was calculated by the following equation (Mohsenin, 1970):*

$$D_a = \frac{L+W+T}{3}\ ,\ (mm) \qquad \text{Eq. 3}$$

*Equivalent mean diameter: After measuring the three dimensions of randomly selected beans for each cultivar, equivalent diameter was calculated by the following equation (Mohsenin, 1970):*

$$D_e = \sqrt[3]{\frac{L\ (W+T)^2}{4}}\ ,\ (mm) \qquad \text{Eq.4}$$

*Frontal surface area* **:** *The area of front surface of beans calculated from measured average dimension (length and width) with bean position placed on vertical to horizontal was obtained by the following formula (Mohsenin, 1970):*

$$\text{Frontal surface area} = \frac{\pi}{4}\ (L * W),\ (mm^2) \qquad \text{Eq.5}$$

*Sphericity: Sphericity (S) is the criteria for describing the shape of the beans of each cultivar and calculated by the following formula (Mohsenin, 1980):*

$$S = \frac{\text{Geometric mean diameter}}{\text{Length}} * 100 \qquad \text{Eq.6}$$

*Aspect ratio***:** *The average length (L) and width (W) of coffee beans of each coffee cultivar were measured then the aspect ratio was calculated by the following formula (Omobuwajoa* et al*., 1999):*

$$R_a = \frac{W}{L} \qquad \text{Eq.7}$$

*Shape index: The average dimensions (length, width and thickness) of coffee beans of each cultivar were measured and the shape index (SI) was calculated by the following equation (Mohsenin, 1970):*

$$SI = \frac{L}{\sqrt{W * T}} \qquad \text{Eq. 8}$$

The coffee bean is considered an oval if the shape index > 1.5 on the other hand it is considered spherical if the shape index ≤ 1.5. Hundreds bean weight: Hundred coffee beans were randomly selected from each cultivar sample and weighed by sensitive digital balance (KERN 440-49N, Max 4000g, =0.1g). The average value of hundred-bean weight (gm) was recorded. Volume: The average volumes of the beans were calculated from measurements of major, minor and intermediate diameters of individual beans and the assumption that each bean could be taken as half a triaxial ellipsoid (Dutra et al., 2001):

$$V=\frac{\pi}{6}(L*W*T), (mm^3) \quad \text{Eq. 9}$$

*Density: True bean density ($\rho_t$): Randomly selected hundred beans from each selected coffee cultivars were weighed and average weight (gm) recorded. Then each bean volume was calculated by equation no. 9.Then true bean density was determined by dividing the weight of 100 beans by the total volume of the 100 beans (Franca* et al.*, 2005):*

$$\rho_t = \frac{\text{Weight of hundred bean}}{\text{total volume of hundred beans}}, (gm/mm^3) \quad \text{Eq. 10}$$

Bulk bean density ($\rho_b$): The bulk density of coffee beans was determined by weighed the beans and filling in a graduated cylinder (Merck, Germany) which had known volume of 500 ml from the height of 30 cm at constant rate. Beans were packed in to a cylinder gently to allow beans to settle in acylinder and were taken average value (Chandrasekar and Viswanathan, 1999):

$$\rho b = \frac{\text{Weight of packed bean}}{\text{Volume of cylinder}}, (gm/mm^3) \quad \text{Eq. 11}$$

Porosity : The porosity ($\epsilon$) of the beans of coffee cultivars at each moisture contents was calculated from the average values of bulk density and true density using the following relationship (Mohsenin, 1986) :

$$\epsilon = \left(1 - \frac{\rho b}{\rho t}\right) * 100 \quad \text{Eq. 12}$$

Angle of repose: The angle of repose is the angle measured in degree between the base and slope of a conical pile of beans formed by a free vertical fall of the mass to a horizontal plane. An inverted cylinder having a diameter of 12 cm was filled with coffee bean at height of 15 cm at constant rate and flows gradually then the mass of coffee bean forms a heap on a circular plate. A ruler measured the height of the conical heap. Then the angle of repose was calculated by the following relationship (Ozguven and Vursavus, 2005):

$$\theta = \tan^{-1}\frac{2H}{D} \quad \text{Eq.13}$$

Where, H and D are the height of heap and diameter of the cone (cm), respectively.

## RESULTS AND DISCUSSION

Physical Properties of Coffee Arabica Cultivars of Green Bean

**Effect of coffee cultivar on dimensions and related parameters of beans:** The recorded average results of the physical properties of coffee beans dried in open sun were shown in Table 3. Average lengths were not significantly (P>0.05) differenent among the coffee cultivars Gawe, Gesha and CJ-19 but significantly different (P< 0.05) for the remaining five cultivars. The highest value 11.34 mm was of cultivar 744 whereas the lowest values 9.01, 9.05 and 9.32 mm were for Gawe, Gesha and CJ-19, respectively. The width data indicated that cultivar 744 showed the largest value 7.55 mm whereas the lowest value (6.48 mm) was cultivar Gawe. Significant differences (P<0.05) existed among different values of the various cultivars but 6.92, 6.97, 6.99 and 7.02 mm of cultivars Wushwush, Merdacheriko, 7440 and CJ-19, respectively, were not different from each other but different from the remaining values. The thickness data also ranged from 2.82 mm (cultivar 74148) to 4.66 mm (cultivar 744). Many of the intermediate values are statistically different from each other except the 4.14, 4.15, and 4.25 mm of cultivars Merdacheriko, Gesha, CJ-19 and Wushwush, respectively, which were statistically the same. The geometric mean diameter data also varied from 5.09 of cultivar 74148 up to the highest 7.26 mm of cultivar 744 with significance difference (P<0.05) among most. Similarly, the arithmetic mean diameter ranged from 5.31 mm of cultivar 74148 to 7.84 mm of cultivar 744, again with significance difference (P<0.05) among them. The trend with equivalent mean diameter data appeared to be the same with the highest value 7.38 and lowest value 5.16 belonging to the same two cultivars. Perez Alegria *et al.* (2001) also reported similar results on statistical differences in the length, width and thickness of parchment of coffee bean. Similar results concerning the mean length, width and thickness of the Arabica parchment at 9.9% (wb) were 11.95, 8.45 and 4.90 mm, respectively, as reported by (Chandrasekar and Viswanathan, 1999).

**Effect of cultivar on derived parameters of coffee beans dried in direct sun light (open sun):** The recorded average results of the above physical properties of the coffee beans are shown in Table 4.The frontal surface area showed significant differences (P< 0.05). The highest (65.91 mm$^2$) and lowest (32.86 mm$^2$) values were recorded for coffee cultivars 744 and 74148, respectively. All values were significantly different from each other. The average values 68.01 to 142.10 mm $^2$ of cross-sectional area of coffee beans of the different cultivars were significantly different (P< 0.05) from each other, except between cultivars Dessu and Wushwush with values of 115.10 and 115.20 mm$^2$, respectively. The highest value was of cultivar 744 and the lowest was of cultivar 74148. Similarly, most of the average results of sphericity were significantly different (P< 0.05) among the coffee cultivars. The highest (0.72) and lowest (0.65) record were of Gesha and 7440, respectively. As per the report of Gamayak *et al.* (2008) and Mishra (1988), the grain is spherical when the sphericity value is also greater than 0.70. The average values of aspect ratio were significantly different (P< 0.05) among most of the cultivars. The highest and lowest values were 0.81 of Gesha and 0.66 of 744 coffee cultivars. Likewise, the shape index values were significantly different (P < 0.05) among all coffee cultivars, with the highest (1.94) and lowest (1.19) values being of 744 and Gawe cultivars. The shape index indicates the shape of coffee beans. According to Abd- Alla (1993) coffee beans shape are spherical if shape index <1.5 but if shape index > 1.5 the shape of coffee bean is considered to be oval. Bean shape is determined in terms of its sphericity and aspect ratio. Olukunle and Akinali (2012) observed some engineering properties of Robusta coffee beans at 10.7 % moisture content and reported that the value of sphericity was 0.75.

**Table 1. Effect of cultivar on dimensions, GMD, AMD, EMD and MC of coffee beans dried in direct sun light (open sun).**

| Cultivars | MC (%wb) | Length (mm) | Width (mm) | Thickness (mm) | GMD (mm) | AMD (mm) | EMD (mm) |
|---|---|---|---|---|---|---|---|
| Gawe | 10.67$^{abc}$±1.15 | 9.01$^{e}$±0.21 | 6.48$^{e}$±0.09 | 3.82$^{e}$±0.15 | 6.06$^{e}$±0.04 | 6.45$^{e}$±0.03 | 6.21$^{d}$±0.1 |
| Dessu | 11.67$^{a}$ ±0.58 | 9.93$^{b}$±0.24 | 7.26$^{b}$±0.09 | 3.97$^{de}$±0.07 | 6.66$^{b}$±0.14 | 7.02$^{b}$±0.17 | 6.80$^{b}$±0.07 |
| 744 | 11.67$^{a}$ ±0.58 | 11.34$^{a}$±0.44 | 7.55$^{a}$±0.06 | 4.66$^{a}$±0.14 | 7.26$^{a}$±0.22 | 7.84$^{a}$±0.08 | 7.38$^{a}$±0.07 |
| 74148 | 9.60$^{c}$ ±0.23 | 7.37$^{f}$±0.36 | 5.20$^{f}$±0.29 | 2.82$^{f}$±0.22 | 5.09$^{f}$±0.19 | 5.31$^{f}$±0.10 | 5.16$^{e}$±0.15 |
| 7440 | 9.87$^{bc}$ ±0.53 | 9.49$^{cd}$±0.03 | 6.99$^{d}$±0.16 | 4.02$^{cde}$±0.05 | 6.40$^{cd}$±0.16 | 6.85$^{cd}$±0.08 | 6.59$^{c}$±0.07 |
| Gesha | 11.33$^{a}$ ±0.58 | 9.05$^{e}$±0.24 | 7.24$^{bc}$±0.04 | 4.15$^{bcd}$±0.17 | 6.25$^{de}$±0.16 | 6.78$^{d}$±0.09 | 6.58$^{c}$±0.09 |
| CJ-19 | 11.00$^{ab}$ ±1.0 | 9.32$^{de}$±0.03 | 7.02$^{cd}$±0.19 | 4.24$^{bc}$±0.11 | 6.45$^{bcd}$±0.08 | 6.88$^{bcd}$±0.10 | 6.70$^{bc}$±0.12 |
| Merdacheriko | 9.93$^{bc}$ ±0.12 | 10.05$^{b}$±0.08 | 6.97$^{d}$±0.04 | 4.14$^{bcd}$±0.10 | 6.64$^{bc}$±0.14 | 7.03$^{b}$±0.04 | 6.81$^{b}$±0.11 |
| Wushwush | 11.33$^{a}$ ±0.58 | 9.90$^{bc}$±0.20 | 6.92$^{d}$±0.08 | 4.25$^{b}$±0.08 | 6.56$^{bc}$±0.07 | 6.95$^{bc}$±0.11 | 6.71$^{bc}$±0.02 |
| CV (%) | 6.19 | 2.56 | 2.01 | 3.26 | 2.26 | 1.4 | 1.43 |
| LSD (0.05) | 1.14 | 0.42 | 0.24 | 0.22 | 0.24 | 0.16 | 0.16 |

Mean values followed by the same letter with in column are not significant difference (P < 0.05); MC=Moisture content at wet basis, GMD= Geometric mean diameter, AMD= Arithmetic mean diameter, EMD =Equivalent mean diameter, Wb = wet basis, CV= coefficient of variance, LSD= least significance difference

**Table 2. Effect of cultivars on FSA, CSA, SP, AR and SI of coffee beans dried in direct sun light (open sun).**

| Cultivars | FSA (mm$^{2}$) | CSA (mm$^{2}$) | AR | SI | SP (%) |
|---|---|---|---|---|---|
| Gawe | 45.81$^{h}$±0.18 | 97.27$^{g}$±0.17 | 0.72$^{c}$±0.0 | 1.19$^{g}$±0.02 | 67.90$^{c}$±0.5 |
| Dessu | 55.55$^{b}$±0.08 | 115.10$^{c}$±0.15 | 0.73$^{bc}$±0.01 | 1.79$^{dc}$±0.03 | 67.10$^{cd}$±0.0 |
| 744 | 65.91$^{a}$±0.30 | 142.10$^{a}$±0.12 | 0.66$^{f}$±0.02 | 1.94$^{a}$±0.05 | 65.10$^{e}$±1.0 |
| 74148 | 32.86$^{i}$±0.08 | 68.10$^{h}$±0.04 | 0.74$^{b}$±0.01 | 1.74$^{d}$±0.03 | 68.20$^{c}$±0.3 |
| 7440 | 52.15$^{e}$±0.14 | 110.50$^{d}$±0.07 | 0.71$^{d}$±0.0 | 1.87$^{b}$±0.05 | 64.97$^{e}$±0.0 |
| Gesha | 50.44$^{g}$±0.08 | 107.00$^{f}$±0.04 | 0.81$^{a}$±0.01 | 1.61$^{f}$±0.02 | 72.43$^{a}$±0.4 |
| CJ-19 | 51.29$^{f}$±0.17 | 110.00$^{e}$±0.19 | 0.71$^{d}$±0.03 | 1.68$^{e}$±0.03 | 70.43$^{b}$±1.9 |
| Merdacheriko | 54.93$^{c}$±0.11 | 117.30$^{b}$±0.15 | 0.69$^{e}$±0.0 | 1.88$^{b}$±0.03 | 66.27$^{de}$±0.4 |
| Wushwush | 53.73$^{d}$±0.12 | 115.20$^{c}$±0.14 | 0.71$^{d}$±0.01 | 1.81$^{cd}$±0.01 | 66.57$^{d}$±0.4 |
| CV (%) | 0.3 | 0.12 | 2.04 | 1.95 | 1.17 |
| LSD (0.05) | 0.26 | 0.22 | 0.02 | 0.06 | 1.3 |

Mean values followed by the same letter with in column are not significant different (P > 0.05); FSA=Frontal surface area, CSA =Cross sectional area, SP= Sphericity, AR=Aspect ratio and SI = shape index, CV = coefficient of variance, mm = millimeter, LSD = least significance difference

**Table 3. Effect of cultivars on gravimetric properties of coffee beans dried in direct sun light (open sun).**

| Cultivars of Coffee | 100 bean weight (gm) | BD (kg/m$^{3}$) | TD (kg/m$^{3}$) | Porosity (%) | Angle of repose (degree) | Volume (mm$^{3}$) |
|---|---|---|---|---|---|---|
| Gawe | 14.40$^{e}$ ±0 .87 | 72.00$^{ab}$ ±0.0 | 120.00$^{c}$ ±0.0 | 40.33$^{de}$±1.53 | 19.10$^{d}$±1.47 | 117.10$^{g}$±1.03 |
| Dessu | 17.43$^{cd}$ ±0.45 | 68.70$^{de}$ ±0.6 | 121.00$^{c}$±1.0 | 41.67$^{cd}$±1.44 | 23.20$^{b}$±0.00 | 146.70$^{d}$±0.35 |
| 744 | 20.33$^{a}$ ±0.78 | 68.00$^{e}$ ±1.00 | 99.30$^{d}$±1.20 | 31.67$^{f}$±1.53 | 17.70$^{e}$±0.96 | 203.90$^{a}$±0.30 |
| 7440 | 17.65$^{c}$ ±0.50 | 70.00$^{cd}$ ±1.00 | 148.00$^{b}$ ±2.0 | 52.07$^{b}$±0.60 | 22.60$^{b}$±0.00 | 141.40$^{e}$±0.60 |
| 74148 | 12.70$^{f}$ ±0.15 | 71.70$^{abc}$ ±0.6 | 191.00$^{a}$ ±1.0 | 62.07$^{a}$±0.06 | 30.10$^{a}$±0.52 | 66.09$^{h}$±0.97 |
| Gesha | 17.20$^{d}$ ±0.87 | 68.00$^{e}$ ±1.00 | 121.00$^{c}$ ±1.0 | 42.93$^{c}$±0.40 | 18.30$^{de}$±0.0 | 137.90$^{f}$±0.32 |
| CJ-19 | 17.00$^{d}$ ±0.50 | 72.70$^{a}$ ±1.20 | 120.70$^{c}$ ±1.2 | 40.00$^{e}$±0.00 | 22.90$^{b}$±0.52 | 141.80$^{e}$±0.47 |
| Merdachriko | 18.83$^{b}$±0.49 | 71.00$^{abc}$±1.0 | 119.70$^{c}$±1.5 | 40.40$^{de}$±0.35 | 23.90$^{b}$±0.00 | 152.20$^{b}$±0.30 |
| Wushwush | 18.43$^{bc}$±0.21 | 70.30$^{bcd}$ ±2.1 | 120.70$^{c}$ ±1.2 | 40.47$^{de}$±0.31 | 20.80$^{c}$±1.39 | 149.80$^{c}$±0.58 |
| CV %) | 3.44 | 1.52 | 0.94 | 2.10 | 3.55 | 0.43 |
| LSD (0.05) | 2.38 | 1.83 | 2.08 | 1.56 | 1.34 | 1.04 |

Mean values followed by the same letter with in column are not significant difference (P $\geq$0.05), BD =bulk density, TD=true density, CV =Coefficient of variation, LSD = least significance difference, gm = gram, KG= kilo gram, mm$^{3}$ = millimeter cube

**Effect of cultivar on gravimetric properties of coffee beans dried in direct sun light (open sun):** Weight data of 100 coffee beans are shown in Table 5 for the nine cultivars considered in the study. The highest value (20.33 gm) was for cultivar 744 and the lowest (12.70 gm) of cultivar 74148 and with most of the values belonging to the different cultivars being statistically different from each other. The weight, size and volume of the Arabica beans varied with the coffee growing regions to regions (Ghosh, 1996). This is corroborated by other authors who reported that Arabica coffee were diverse in average bean weight (Wintegens, 2004; Yigzaw, 2005).

The bulk densities also exhibited significant (P < 0.05) differences because of cultivars with the highest values 71.00, 71.70, 72.00 and 72.70 kg/m$^{3}$ belonging to cultivars Merda cheriko,74148, Gawe, and CJ-19 and the lowest values 68.00 and 68.70 of being of cultivars 744 and Gesha for the former and cultivar Dessu for the latter.

The values of bulk density reported in this research are similar with the results reported by Franca *et al*. (2005) and Ramalakshmi *et al*. (2007) for different coffee origins. Determination of these parameters is important because it helps to estimate the capacity requirement for the storage and transport systems. The true densities varied between the highest value 191.00 kg/m$^{3}$ of cultivar 744 with significant (P< 0.05) differences between the two and from other cultivars. All the remaining cultivars, except for cultivar 7440 with true density value of 148 kg/m$^{3}$, showed no statistical difference (P>0.05) with values ranging from 119.70 to 121.00 kg/m$^{3}$. Porosity data of the coffee beans presented in Table 5 shown significant difference due to cultivar. Statistically the highest porosity value (62.07%) of cultivar 74148 followed by of as cultivar of 7440 (52.07%). Many of the remaining cultivars show intermediate values between the highest as indicated above and the lowest porosity value of 31.67% for cultivar 744.

The data of angle of repose of the coffee beans shown in the Table 5 exhibited significant differences due to cultivar. The largest value ($30.1^0$) was of cultivar 74148. This was followed by values 23.90, 23.20, 22.90 and 22.60 degrees for cultivars of Merdacheriko, Dessu, CJ-19 and 7440, respectively, with no statistical difference (P> 0.05) among them. The lowest values 18.30 and 17.70 degrees belonged to Gesha and 744 cultivars. The angle of repose indicates the flow ability nature of the beans when handled in bulk. All the values indicated in the table fall in the very free flowing category (Sahay and Singh, 2001). In general there is the relationship between angles of repose and bean size. Larger size of bean would have lower angle of repose and vice versa. The angle of repose is of paramount importance in designing hopper openings, sidewall slopes of storage bins and bulk transporting of seeds using chutes (Elaskar *et al*., 2001; Irtwange and Igbeka, 2002). The result of bean volume was shown to have significant difference (P < 0.05) among the above coffee cultivars except 7440 and CJ19. The highest (203.9 $mm^3$) and the lowest (66.09 $mm^3$) average values of bean volume were recorded for 744 and 74148 cultivars of coffee, respectively. These values are in agreement with the dimensions of the beans shown in Table 3. The dimensions, seed mass, bulk density, true density and projected area of agricultural grains change with variety of grain, agronomical conditions that product was grown and moisture content of grain (Konak *et al*., 2002; Aydin, 2002). The bulk density, true density and porosity are useful in storage, transport and separation systems (Kachru *et al*., 1994).

**Conclusions and Recommendation**

This study concludes with information of physical properties of nine released coffee Arabica cultivars those represents different growing areas such as Gawe, Dessu, 744, 74148, Gesha, CJ-19, Wushwush and Merdacheriko, which should be useful for designing much of equipments used for coffee postharvest practices. The considered cultivars, most large values of physical properties such as major dimensions, arithmetic mean, geometric mean and equivalent mean diameters; frontal surface area, hundred bean weight and volume of beans were recorded for cultivar 744 at moisture content of 11.67% (wb). Because of these, the smallest mean values of bulk and true densities, porosity, aspect ratio and angle of repose were recorded for this cultivar. Cultivar of 74148 at moisture content of 9.60% (wb) had highest values of bulk density, true density, porosity and angle of repose and the lowest values of 100 bean weight, moisture content and volume. The current study indicated the need to undertake additional studies in other engineering properties such as mechanical, frictional, optical, etc to generate basic information needed to design any postharvest equipments regarding to coffee. Similar studies are advisable on other coffee Arabica cultivars released by research centers for the same reason.

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