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Physical and Mechanical Properties of Coffee Cherries and Beans in Africa: Review and the State of Arts

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Abstract Coffee is an important source of income for African smallholder farmers. The world is predominated by three coffee varieties, namely Arabica, Robusta, and Liberica originated in the African countries. However, the low coffee quality attributes can affect the coffee beans' price due to the improper post-harvesting processes. Therefore, this work is aimed to review the physical and mechanical properties of the African coffee cherries and beans on the country-wise level, and review the methods used to measure quality parameters and compare the key coffee quality parameters. This work was qualitatively conducted using secondary data on African Arabica and Robusta coffee from journals, conference proceedings, and reports. Methods used for determining the coffee beans' properties were explored country wise. The coffee attributes of the two coffee varieties were compared through statistical analysis using ANOVA. The review found that the coffee quality depends on geographical characteristics, agronomic factors, and post-harvesting processes. The coffee cherries de-pulping process is linked to the coffee quality to avoid the damage of parchment coffee beans based particularly on the size and shape of coffee cherries and beans. The analysed quality parameters showed that the Ethiopian Arabica coffee beans were larger than the Ghanaian Robusta coffee beans. While the size of Robusta coffee in Eastern African countries, particularly Uganda, is bigger than those in Western countries, especially Ghana. Therefore, the information on the coffee quality attributes can help to improve the performance parameters of the coffee de-pulping machine and enhance the price of African coffee.

Keywords Arabica Coffee, Coffee Bean, Coffee Cherry, Coffee Quality, Coffee Processing, De-pulping Process, Robusta Coffee

1. Introduction

Coffee varieties available in approximately 80 countries [1,2] worldwide originated in East and Central African countries. Coffee Arabica originated from Ethiopia and is highly cultivated in tropical countries of Africa, Asia, and Southwest America [3]. The Arabica coffee (Coffee Arabica L.), which is a highland coffee variety originated either from the Great Rift Valley (kaya plateau), or the Kaffa plateau of Southwestern Ethiopia, Mt. Imatong or Boma plateau of Sudan, and Mt. Marabit of Kenya (Berthoud and Cherrier, 1988). It was transmitted from Ethiopia to Yemen by slaves and later spread worldwide. The Robusta coffee (Coffee anaphora L. or also namely coffee Canephora), a lowland coffee that originated either from Central Africa parts such as the Congo River basin, or

East Africa such as Kenya or Uganda (in Bunyoro district, or Buganda Forest). It is primarily cultivated in the West African (Ivory-Coast), Central [3], and Eastern (Uganda) regions [4].

The coffee Arabica and Robusta are also producing about 98 to 99% of total African production from around 34 countries [4,5]. Africa contributes every year up to 10% of global coffee production. The Eastern, Western, and Central African countries produce 69%, 30%, and 1% continent-wide, respectively [6]. Thus, world coffee production increased annually due to the country's agriculture policies.

The other known species are Liberica coffee (Liberian or Liberica coffee) originated either from Western Africa in the tropical forest of the present Liberia country or probably in Ivory-Coast as reported by Prakash et al. 2005 and [7], and coffee Dewvrei (Excelsa) [8]. These all types of coffee produce less than 1% commercially in the world. Therefore, these less productive coffee species account for up to 103 types and are being practised by small-scale farmers in different rural areas of the world [2,7].

According to Avallone (1999), from a morphological perspective view, the ripened coffee cherry has either ellipsoidal, ovoid, glabrous, or an oval shape of about 1 cm x 2 cm for polar and equatorial diameters with two seeds curved on one side and flat on the other one. Coffee fruits also have four main types of bean shapes. These include standard, peaberry, triage, and elephant shapes [3,4]. Their size mainly, length and width and thickness as described by Bikila [4] can vary depending on environmental conditions, planting conditions [9,10], and the geographical and climate factors [3,11–13]. Thus, temperature and altitude are the main criteria for selecting a parcel of land for growing coffee as determined [14].

However, de-pulping coffee cherries and de-hulling of parchment coffee beans can be considered during the investigation of coffee beans' quality attributes that were defined according to ISO (2000). There are two types of cherries harvesting means [9] using either hand-picking which is time-consuming [3], or the stripping method. The last one is most preferred in dry processing [15].

In addition, the post-harvested coffee cherries and beans' profiles can vary in terms of size, shape, and density as well as moisture as defined by Binmahfuth [15]. Thus, information on seeds in terms of physical and mechanical characteristics is also needed for the design and development of agricultural equipment such as coffee pulping machines. In this concern, the ISO 9116 (standard, 2004a) described the quality of green coffee beans and defined their respective measuring methods for each coffee quality parameter at each level [16]. Therefore, the high precision instruments that are mostly used for determining the physical quality characteristics of coffee cherries and beans after harvesting the coffee cherries were described by Saparita et al. [17]. The coffee quality was defined based on bean size, tonnage among other physical characteristics and price [10]. The coffee cherries' de-pulping process is linked with the size, moisture content, sphericity, and coefficient of friction of coffee beans; and the price is linked with tonnage, damaged beans and aroma of green coffee beans [18,19]. Consequently, the improper post-harvesting of coffee cherries such as traditional de-pulping at the farmer level and small-scale de-pulping locally across the continent can affect the quality of parchment coffee beans.

Therefore, the objectives of this present review were to investigate the physical and mechanical properties of both coffee cherries and beans from ten producing countries of Africa, evaluate and describe the methods used in some countries, determine each coffee quality parameter obtained during wet or dry process, and compare the properties of beans in ten African coffee-producing countries.

2. Physical Parameters of Coffee Cherries and Beans

2.1. Weight, Volume, Density, and Shell Content

The mean weight of a coffee bean or cherry [20] can be determined by weighing 1000-beans of a selected sample [21,22] with replications [23,24] using a digital balance with 0.0001g accuracy [7,20,25,26]. The bean screen having specific holes of 14/64-inch [20,25], and sieve number 19 [22] is generally used to determine the percentage weight of each variety [20]. To calculate the corresponding volume of green coffee, Eq. (1) was used [7,20,25,27]. According to the studies [7,17,28–30], water displacement method can be used to validate the Eq. (1). Despite the ISO standard 6669: 115 (en) theory, the bulk density is the mass of coffee beans over their occupied volume of the container [17,29], and it can also be calculated using the Eq. (2) [20,25]. Bulk density is measured using a graduated container of 500 mL [10,20,30]. The bulk density is essential in designing the hopper, storage, and grading equipment [20]. The true density is the ratio of the original volume of coffees to their real weight and it is usually greater than 1g/mL [7]. Then, the true density can be calculated using Eq. (3) [19,20,25,28]. Thereafter, the shell content is the silverskin material covering the parchment coffee and can be determined using Eq. (4) [28]. Hence, weight, volume and shell content help to separate good cherries and floaters before the de-pulping process and determine the coffee pulping machine capacity.

$$\text{Volume (V)}=\pi/6*L*W*T\ (mm^3) \quad (1)$$

$$\text{Bulk-Density } (\rho b)=(\text{weight of washed green coffee beans/bulk volume of green coffee beans) (g/mL)} \quad (2)$$

$$\text{Apparent Density } (\rho t)\ (g/mL)=\text{weight of washed green coffee beans/geometric volume of green coffee bean (g/mL)} \quad (3)$$

$$\text{Chell/Sliverskin Content (Cs)}=((Wus- Ws)/ Wus)*100 \quad (4)$$

2.2. Linear Dimensions, Arithmetic and Geometric Diameters and Aspect Ratio

The sizes of cherries and beans are mainly parameters for defining the quality of coffee. Precision linear measuring instruments are used to measure the size [29] of the coffee seeds. High precision digital caliper with sensitivity or micrometer gauges (0.001 mm) [7,10,20,25,28,29] were used to measure the size of beans [20,23]. However, to find means, and deviations, and minimize errors in measurements; replication of the tests has been performed [31]. Then, diameters and other dimensions can be calculated analytically from the premier dimensions using empirical formulas [7,10,20,25,28,29], as shown in Eqs. (5-8). Thus, these parameters are more important for setting up the coffee pulping machine mechanism and designing the hopper of the machine.

$$\text{Arithmetic Mean Diameter (AMD)}= (L+W+T)/3 \text{ (mm)} \quad (5)$$

$$\text{Geometric Mean Diameter (GMD)}= (L+W+T)^{1/3} \text{ (mm)} \quad (6)$$

$$\text{Aspect Ratio (AR or } R_a)= W/L \text{ (mm)} \quad (7)$$

$$\text{Cross-Sectional Area (CSA)}=\pi/12*(L+W+T)^2 \text{(g/mL)} \quad (8)$$

3. Mechanical Parameters of Coffee Seeds

3.1. Angle of Repose, Coefficient of Static Friction, and Coefficient of Contact

Angle of repose shows how the seeds can sit on the ground or behaviours of how they can slide over themselves during the harvesting and post-harvesting process. It can be identified in two types, emptying and filling angle of repose [7]. The filling angle of repose can be measured as defined by [10,22,28], and can be calculated using Eq. (9). The surface area used is almost made of stainless steel, aluminium, acrylic, and wood sheets [28]. Therefore, the emptying angle of repose can also be measured [7]. The dynamic angle of repose can be measured as described [28,29], and it can be calculated using Eq. (10). The coefficient of static friction of coffee beans or cherries can be measured using different materials like aluminium [22], stainless steel and plywood sheet [17,28,30], fiberglass surfaces [30], and hallowed plastic cylinder [22,28,29]. The coefficient of the static friction measuring method was described [7,32] to define how the seeds slide on coffee processing equipment. The formula used to calculate the coefficient of static friction is shown in Eq. (11) [17,29]. The coefficient of contact of washed coffee beans was calculated using Eq. (12) [20,25]. Thus, the angles of repose can affect the feed rate, whereas the coefficient of friction can affect the separation efficiency of parchment coffee beans with pulps during the pulping process.

$$\text{Filling angle of repose } (\mu)= \tan^{-1}(2H/D) \quad (9)$$

$$\text{Dynamic angle of repose } (\mu d)= \tan^{-1}(H/B) \quad (10)$$

$$\text{Coefficient of friction (Cf)}=\tan\theta \quad (11)$$

$$\text{Coefficient of Contact Surface (CSS)}=(FSA-TSA)/FSA \quad (12)$$

where, Front surface Area (FSA)=$\pi/4*L*W$ (mm^2) and Transverse Surface Area (TSA)= $\pi/4*L*W$ (mm^2).

3.2. Moisture Content, and Porosity

Moisture is an essential factor for the preservation of coffee beans' quality [16]. It can also affect the de-pulping operation which is not performed before 24 hours after cherries are being harvested. Normally, it is recommended to pulp cherries within 8 hours as practicing locally in Rwanda. The moisture content of dried coffee beans which ranges between 10-12.5% is very important for maintaining the quality and flavour of the coffee. The moisture content can be measured using different methods. These include the direct measurement using Moisture Bulk Density Teste AMTAST JV-010S (P 30) with a range of 0-40% (wb) [28], and mass difference of beans dried using an oven (UNB 400, Memmert, Germany [7,22], hot air oven (J.P Selecta, S. A No. Serial #0473987 Barcelona, Spain (Mikru Tesfa 2019) at 105^0C in 24 hours. To identify if there are holes in the seeds or not, porosity can be measured using a porosity meter [22], and calculated using the empirical formula using bulk and true density as shown in Eq. (13) [33]. Thus, Arabica cherries harvested during the heavy rain season can be de-pulped well without water whereas the Robusta cherries sometimes need to be soaked to increase moisture before de-pulping operation [4].

$$\text{Porosity } (\text{€})=(1-\rho b/\rho t)*100 \text{ (g/mm}^3) \quad (13)$$

3.3. Shape Index, Sphericity, and Roundness

The shape index (SI) defines if a coffee bean has an oval or spherical shape for SI >1.5 or SI<1.5, respectively [20,25]. It is an important parameter for designing pulper/huller, coffee screening, and grading machines [17]. Eq. (14 or 15) [17] and Eq. (16) [20,25], are used for calculating the shape index. The sphericity and circularity of the coffee beans are the essential parameters for describing the bean shape [27]. Sphericity is obtained using the Eq. (15) from measured size [22,23,28] or using the revealed formula [34] using Eq. (16). Therefore, the roundness ratio can be determined using Eq. (17). Hence, de-pulping cherries regular in shape can decrease damaging the parchment coffee beans.

$$\text{Shape Index (SI)}= \sqrt{(W+T)} \quad (13)$$

$$\text{or } \quad SI=De/\sqrt{(Dp*T)} \quad (14)$$

$$\text{Sphericity (Sp)}=(L\times W\times T)^{1/3}/L \quad (15)$$

$$\text{Sphericity (Sp)}=(Di-\bar{D})^2/(DN)^2 \quad (16)$$

$$\text{Roundness ratio } (R_r)=r/R \quad (17)$$

3.4. Average Hardness and Fracturability

The hardness is essential for evaluating cherries and beans' feeding amount, their reduction in size; and defining the fracture force that helps in designing a coffee crusher [17]. The fracture force and deformation of cherries were determined using the platform of Instron (Instron, 5566, USA) testing machine [7,17,35]. Thus, the force is also important during pulping processing to reduce the breaking rate of beans.

3.5. Colour and Coefficient of Variation

Referring to [7], the colour was measured by using a colour meter (CR-10, Konica Minolta, Japan). Then, the Coefficient of Variation (CV) was also used to define the quality of the measured parameters regarding their mean of coffee beans, which are naturally irregular in shape and size [20,25]. During selective harvesting, the farmers can only pick either the ripped, overriped or immature cherries based on colour. Therefore, the cherries' colour is the most important parameter [10,20] because pulping immature and avorriped damages the beans and reduces parchment coffee beans' quality. Hence, these affect the efficiency and capacity of coffee pulping machines indirectly.

4. Country-Wise Coffee Beans Quality Parameters and Research Gaps

4.1. Ethiopia

The properties of green coffee beans as shown in Table 1 were investigated on coffee seeds obtained using the drying method [10,20]. The coffee beans investigated were from 25 regions of Ethiopia to select the equipment for sorting, separating, and cleaning.

The experiments started by weighing the 100-beans weight selected randomly from 16 regions using a digital balance with an accuracy of 0.0001 g, ER-120a, Japan; with triplications measurements to find the individual mean weight of a bean. Reviewed data showed that weight is almost the same with a mean of 0.15 g [20], and 0.16 g [10]. However, Tesfa [19] found that, the coffee bean weight depends on moisture content, geographical conditions, and coffee varieties. The linear dimensions were taken for each bean using the electronic digital caliper with 0.01 mm accuracy [10,20]. The other physical and mechanical properties were calculated based on these parameters in both reports. They were analysed using One-Way ANOVA. The properties of the coffee beans were calculated from the work conducted on Ethiopian coffee including bulk density, length, width, thickness, and cross-section area, sphericity and shape index [10,20,25]. Thus, the physical properties of the coffee obtained in the two reports during the drying process cannot be only based on selecting/designing the equipment in wet processing in the country. Besides the drying process can be performed using different methods [3]; however, in the two-research conducted, the drying processes used were not specified and their effect on coffee beans. Therefore, despite the advantages of the dry process [3] and wet processing methods, optimizing the coffee post-harvest processes for both coffee Arabica and Robusta's physical properties at different levels of moisture content can also be based on for selecting, designing, and developing the coffee processing equipment.

Table 1. Ethiopian Arabica Coffee Beans Properties [10, 20]

Parameters	Range	Mean
Weight of bean (g)	0.11 to 0.19 [20]	0.15
	0.127 to 0.2033 [10]	0.16
Bulk density (g/mL)	0.66 to 0.73	0.68*
Apparent density (g/mL)	0.98 to 1.68	1.35
Moisture content (%)	9.77 to 13.0	11.17
Weight over screen 14 (%)	71.94 to 99.09	92.82
Length (mm)	8.28 to 10.4 [20]	9.34*
	9.01 to 11.34 [10]	11.95
Width (mm)	5.59 to 6.82 [20]	5.935*
	6.48 to 7.55 [10]	8.45
Thickness (mm)	3.52 to 4.48 [20]	4*
	2.82 to 4.66 [10]	4.90
Volume (mm^3)	97.17 to 158.30	128.8
Cross-section area (mm^2)	85.55 to 142.10 [20]	103.71
	122.12 [20]	122.12*
Sphericity (%)	63.11 to 72.10	66.45
	65 to 72	70
Shape-index (%)	1.63 to 2.01	1.87
	1.19 to 1.94	1.5
Coefficient of contact (mm^2)	50.49 to 60.78	56.38
Geometric mean diameter (mm)	5.09 to 7.26	6.175*
Arithmetic mean diameter (mm)	5.31 to 7.81	6.17*
Equivalent mean diameter (mm)	5.16 to 7.38	6.27*
Front surface area (mm^2)	32.86 to 65.91	49.385*
Aspheric ratio	0.66 to 0.81	0.735*

4.2. Ivory-Cost

In Ivory-Coast, the chemical quality and sensorial characteristics of the coffee beans were investigated [36]. Those properties were investigated on the Robusta coffee harvested from three regions of the Ivory-Coast. These regions contribute about 41% of coffee production in the country. The properties investigated varied depending on different moisture content (Abengourou: 10.7%, Aboisso: 11.01%, and Divo: 11.2%) with a mean of 10.9%. The moisture content can affect physical parameters and the quality of coffee [3]. The variation of moisture content directly affects the chemical properties, sensorial properties, weight, and density of coffee [25,37]. However, the work was focused only on the chemical properties of coffee Robusta, and it had not been extended to any physical properties of coffee beans. Therefore, moisture content level can also cause the crushing of beans during the pulping process.

4.3. Kenya

Table 2. Kenyan Coffee Arabica Coffee Beans Properties [9,34]

Parameters	Range	Mean
Moisture content	10.17 to 10.84	10.46
Mass (g) for 100 beans	14.67 to 17.33	16
Volume (cm^3)	14.11 to 17.55	15.83
density (kg/cm^3)	895.81 to 1227.0	1061.405*
Weight (g)	0.149 to 0.163	0.154667
Weight-100 dry fruits (g)	17.11 to 20.7	18.448
Length (mm)	10.97 to 11.6	11.34333
	10.46 to 12.18	10.812
Width (mm)	8.26 to 8.78	8.58333
Seed width (mm)	4.56 to 5.02	4.75
Depth (mm)	4.90 to 5.07	4.96
Seed thickness (mm)	2.49 to 2.90	2.791
Sphericity	0.006536 to 0.006899	0.69
Volume (mm^3) for 100 beans	241 to 272	257.2

The comparison of effects of pulping methods (disc, drum, and eco-pulper) on the physico-chemical and sensorial properties of coffee Arabica in Kenya was explored by Koskei et al. [38]. The heavier parchment coffee beans were dried up to 10.46% (wb) to each sample for every pulping method. The analysed physical parameters for the case of Kenya were mass, volume, and density as shown in Table 2. The review showed that the mean moisture content was higher for coffee from disc pulper of 10.75% wb than that of other pulping methods due to immediate drying after pulping operation and, coffee beans mass was lower of 14.5g disc pulper. Density obtained from season 1 using eco-pulping of $1222.62 kg/m^3$ was lower than that of season 2 obtained of $1226.2 kg/m^3$ using also eco-pulping process due to the higher mass of coffee. The difference in density happened because the density of coffee beans depends on the mass variation, not on volume. This means that the de-pulping operation is linked with the coffee beans' size and weight. However, in general, the volume and variations in the size were influenced by climate and agronomic factors rather than both processing methods and the season. Conventionally, there are sun drying and mechanical drying methods [3]. Therefore, the study was conducted on one coffee variety from one region and parameters can show a difference from one region to another, or between different coffee varieties. Thus, besides that, the ratio in mass or weight of cherry mass to parchment coffee beans mass can be evaluated to assess the effect of the coffee pulping machine on parchment coffee mass.

4.4. Ghana

The effect of moisture content of Robusta coffee beans on physical and some aerodynamic or hydrodynamic properties from Ghana has been analysed in Uganda by Niwagaba et al. [37]. The linear dimensions, diameters, mass, densities, sphericity, surface area and porosity, coefficient of static friction, emptying and filling angle of repose were investigated as shown in Table 3. All these parameters increased as moisture content increased from 8 to 12, 24, and 30% except sphericity which had minimal change; and porosity which was decreasing. This was the same for the coffee cherries during the drying process, where moisture content in cherries significantly affects their physical properties by decreasing in superficial area, volume, and diameter as reported by Ghosh et al. [3]. However, the [33], reported that the parchment coffee beans size don't increase with the increase in moisture content, even if mass can be increased. Moreover, most of the measured properties of coffee beans and the calculated ones from the measured linear dimensions were having P-value$\leq$0.05. The investigation was not done on directly harvested and processed coffee beans; this can slightly affect the results. However, using the same approach and the correlation equation as initiated, it can be better to analyse the effect of moisture content on physical and engineering parameters of coffee beans at a controlled moisture content. This is because there is a contradiction in the science as reported by Ghosh et al. [31], that some of the properties of coffee, such as length, width, and thickness were not affected by moisture content as mentioned earlier. Then after, different drying methods can also be used to determine the moisture content of coffee beans and cherries to validate the correlation equations established. The effect of moisture content on coffee attributes and de-pulping machine performance in wet processing can also be investigated using freshly harvested cherries. Hence, the work can be extended to investigate the breakage force of cherries and beans in de-pulping and hulling operations, respectively, considering the level of moisture content [4].

4.5. Nigeria

Olukunle et al. [29], conducted a study to explore the coffee seeds and beans' properties in Nigeria. Those properties are size, sphericity, geometric diameter, emptying angle of repose, co-efficiency of friction, densities (Bulk & true), and porosity as shown in Table 4. The coffee beans at 10.7% moisture content had higher sizes compared to the other types of seeds that were investigated for validation. The research revealed differences in comparisons but the bulk density and true density were lower and higher for coffee seeds and the other seeds, respectively. Therefore, the designed machines for other types of seeds can be used for processing coffee after evaluating that they are fitting with the properties of coffee to provide optimum yield with good quality of coffee beans. The expression of the relation ratio between axial dimensions has been initiated. However, the research did not cover the filling angle of repose, volume surface area, cracking force, and specifying the drying method used as well as the type of coffee investigated. It can also be better to compare coffee parchment beans size from wet to dry process method of cherries from different regions to provide the information needed for improving post-harvest activities at the local level.

Table 3. Ghanaian Robusta Coffee Beans Properties [37]

Parameters	Moisture Content (wb)					Mean
	6%	12%	18%	24%	30%	
Mass (g)	0.1045	0.12	0.134	0.1492	0.1678	0.1351
Bulk density (g/cm^3)	0.7889	0.7512	0.7619	0.7275	0.692	0.7444
Particle density (g/cm^3)	1.187	-	-	-	0.960	1.0735*
Length (mm)	8.49	8.85	9.86	9.46	10.22	9.376
Width (mm)	5.831	6.048	6.582	6.924	7.163	6.509
Thickness (mm)	3.732	4.144	4.33	4.457	4.715	4.2538
Porosity (%)	33.61	-	-	-	21.92	27.765*
Static co-efficient of friction	0.245	0.276	0.293	0.343	0.404	0.3122
Geometric mean diameter (mm)	5.626	6.042	6.547	6.627	7.015	6.3706
Arithmetic mean diameter (mm)	5.982	6.347	6.924	6.949	7.367	6.7138
Angle of repose (degree)	29.80	-	-	-	45.44	37.24*
Sphericity	0.9239	0.9329	0.9249	0.9398	0.9340	0.9311
Surface area (mm^2)	84.049	96.931	113.334	116.814	130.484	108.324
Moisture content (%)	11.6				14.0	13.04

Table 4. Nigerian Properties of Seeds and Beans [29]

Parameters	Range	Mean
Bulk density (g/cm^3)	0.400 to 0.4167	0.4077
True density (g/cm^3)	0.60 to 0.86	0.71
Length (mm)	8.10 to 10.5	9.78
	7.30 to 9.40	8.19
Width (mm)	6.10 to 8.30	7.24
	5.40 to 7.30	6.11
Thickness (mm)	4.50 to 6.00	5.23
	3.60 to 5.30	4.60
Sphericity	-	0.75
Coefficient of friction	0.383 to 0.424	0.40
Geometric mean diameter(mm)	-	7.18
Angle of repose	22.7 to 29.6	25.5
	23.8 to 26.7	24.8
Bulk density (g/cm^3)	0.5882 to 0.6098	0.4974
True density (g/cm^3)	0.9091 to 1.25	1.063
Coefficient of friction	0.2942 to 0.3635	0.3335

4.6. Cameroon

The mass and caracolis properties of Robusta coffee in Cameroon were evaluated from the cherries harvested to the different clones [39] as shown in Table 5. These clones that were cultivated in Cameroon were coming from Central Africa, Ivory Coast, Java, and Madagascar. The average mass of 100-beans evaluated was 19.14 g at 12% of moisture content obtained after 3 weeks of drying and the significant difference was P-value≤0.05. The significant difference between the parameters was calculated using the Newman-Keuls method. The results revealed that mass did not depend on the clone types apart from locations of Robusta coffee. The research conducted in Cameroon focused on mass only and could also be extended to the other parameters as well as for Arabica coffee to provide enough information on the de-pulping process at the local level. This is necessary because setting up the de-pulping machine depends on the cherries' size that differ from varieties and growing area.

Table 5. Cameroonian Robusta Coffee Seeds [39]

Parameters	Range	Mean
Weight (g) -100 seeds	10.99 to 19.14	14.193 near to C6
Moisture content		12

4.7. Uganda

The study of the shape and size of two main coffee species Arabica and Robusta coffee from Rukera Estate (Kenya) and Magigye Estate of Uganda respectively were reported in 1970 [31] at Makerere University. The 52 Arabica coffee samples and 10 Robusta coffee samples with 100-parchment beans in each sample were investigated. The size was measured directly on randomly selected samples, and the surface areas were measured using graph paper with squares. The research revealed four main types of shapes of coffee; triangle, peaberry, elephant, and standard with double cuts. The parameters of two varieties of coffee were compared in terms of size (length, width, depth, and surface areas), and shapes as shown in Table 6. The properties of these shapes were similar to those reported by Ghosh et al. [31]. However, after investigation of size, surface areas, standard deviation, significant difference, the correlation between size parameters, and the empirical formulas were determined and validated with the experimental method. It was revealed that Arabica coffee beans had size and areas greater than that of Robusta coffee beans. The other quality parameters of the coffee beans were investigated like parchment skin, angle of repose, bulk and true density, airflow characteristics, and drying rate. However, the size and shape, as well as the weight are used to define the quality of coffee and based on them during designing the coffee processing equipment. Therefore, it is better to research the two different coffee varieties harvested in the same area to confirm the comparison of their quality parameters.

Table 6. Ugandan Robusta Coffee Beans Properties [31]

Parameters	Range	Mean
Length (in)	0.4050 to 0.4011	0.417
Width (in)	0.2982 to 0.3164	0.311
Depth (in)	0.1931 to 0.2004	0.213
Area of flat surface (sq, in)	0.089 to 0.095	0.093
Area of Transverse Surface (sq, in)	0.047 to 0.053	0.054

4.8. Tanzania

The description of Arabica coffee grain size and shape from Tanzania and Kenya as the key important quality parameters of the coffee was reported by Libor [34]. Samples were ordered using a commercial distribution network from 20 different regions in 13 countries, including Kenya and Tanzania. Apart from the size and mass of 100-beans measured using precision instruments; the other parameters were calculated using empirical formula and their corresponding deviations were also calculated as shown in Table 7. The equations that define the shape contour of coffee beans and sphericity were derived. These equations are useful for coffee processing and handling operations. The comparative analysis of shape variety using elliptical Fourier descriptor showed a relevant difference for all varieties. The description was limited to numeral simulation of coffee grain mechanical behaviour that can be supported by the derived formulas that are also describing the grain contour and sphericity. According to [40], the investigation was conducted using the same data, but with a sample of 20 beans selected randomly (while in previous was 100 beans). The analyses of Arabica coffee roasted experimentally had described the fracture behaviour of the grains and given geometry. However, [40] was confused about the number of beans used to calculate the mean value where 1000-beans were reported in previous work [34]. But the two researchers got the same results on the physical characteristics of coffee selected in 20 regions. Therefore, in a mechanical context, the strength of Arabica coffee beans under static and dynamic loading, and the crushing of coffee beans under quasi-static and dynamic compression were found that are more important for coffee grinding. The relation between crushing stress and grain shape was not significantly different.

Table 7. Tanzanian Arabica Coffee Cherries and Beans [34]

Parameters	Range	Mean
Weight (g)	0.149 ±0.021	0.149
Length (mm)	11.28 ±0.68	11.28
Width (mm)	8.60 ±049	8.60
Depth (mm)	4.78 ±0.30	4.78
Sphericity		0.007269

4.9. Rwanda and Benin

The Rwandan target is to earn $95 million from coffee export by 2024 according to NAEB, (2021) report, and the harvesting target is 700 kg/ha (Introducing National Coffee Investment Agendas for Africa Challenge: Case of Rwanda, 2016). Rwanda produces 99% of Arabica coffee and the remained percentage is for Robusta coffee. However, there is no official document reported on the physical properties of cherries and beans from Rwanda, but some literature described the coffee attributes of Arabica coffee beans [4] in Ethiopia that are almost similar to the ones available in Rwanda. Besides that, the Rwandan coffee cherries have 19.6 mm long and 10 mm in width on average.

Like Rwanda, Benin produces only the Robusta coffee and its annual production is around 42 tons as reported by world Atlas in 2019 [41,42]. Therefore, Benin Robusta coffee and Rwandan Arabica coffee's quality parameters will be investigated in the next work. This will provide the information needed to develop a coffee pulping machine that can help local women farmers and enhance the quality of parchment coffee beans.

5. Statistical Analysis and Comparison of the Recorded Parameters of Coffee Arabica and Robusta

5.1. Analysis of Moisture Content of Arabica and Robusta Coffee Beans

The mean moisture content calculated from the recorded moisture content countrywide during the analysis were 11.17 % wb, and 10.46% wb for Ethiopian [10,20] and Kenyan [38] Arabica coffee respectively, and 13.04% wb for Ghanian Robusta coffee [37] as shown in Tables 1, 2, & 3. It was observed that all moistures are closer, so recorded moisture cannot affect the analysis and comparison of the quality parameters recorded from different African countries. The maximum moisture found is 13.04% wb for Ghanian Robusta coffee, and the average moisture content of 10.84% was obtained in the African countries.

It is useful for storage and to preserve the flavour of the coffee at the buyer but due to this parameter not being controlled by a human being, the comparison was not due to variety or regions. However, moisture content affects the size of beans during the drying process, and separation of pulps to the parchment coffee beans [3].

5.2. Linear Dimensions of Arabica and Robusta Coffee Beans

The coffee cherries' de-pulping plays a big role to the quality parameters of the coffee beans [18]. Then, the reviewed data as compiled in Tables 1-7, in the appendix were used to analyse coffee attributes based on countrywide in the African countries per each parameter. The three main dimensions (length, width and thickness) of the Arabica coffee beans from Ethiopia, Kenya and Tanzania; and Robusta coffee beans from Ghana, Nigeria and Uganda were analysed through statistical analysis. The length of Arabica coffee from the three countries was recorded and the smaller average length of 9.34 mm was from Ethiopian coffee beans as shown in Figure 1. Therefore, the mean average length of Arabica coffee on the African continent was 10.65 mm as shown in Table 8. The Robusta coffee showed a higher value of length, width and thickness of 10.59 mm, 7.90 mm and 5.41 mm, respectively from Uganda as shown in Figure 1 compared to Nigerian and Ghanian grains. Then, the mean average length of Robusta coffee revealed was 9.91 mm. Thereafter, the length of Arabica coffee beans looked bigger than that of Robusta coffee beans. But, the smallest length in the two varieties was found for Arabica coffee too. The width of Arabica coffee was found bigger while its thickness was smaller than Robusta coffee as shown in button distribution in Figures 1 & 2. According to [2] it can be confirmed that the length and width of the coffee Arabica were higher than that of the Robusta coffee as shown in Figure 1. This consideration was found different from other many studies [2,7].

Thus, considering the mean length of 10.65 mm and 9.91 mm and width of 7.705 mm and 7.21mm and thickness of 4.58 and 4.9 mm for Arabica and Robusta, respectively, there small deviation of 1 mm to the length and less than 1 mm to width and thickness as shown in Figure 1 and Table 8. Therefore, it can be suggested to use one coffee pulping machine for de-pulping African Arabica and Robusta coffee cherries by adjusting the de-pulping mechanism at each instant. However, to enhance machine efficiency despite the importance of separating of good cherries to the floaters based on size. The well-designed pulping and dehulling machines were proposed to be used for two coffee varieties [10,20] based on the average size of beans.

Pearson correlation between varieties was also performed to verify the significant difference between linear dimensions of Arabica and Robusta coffee beans. The highest correlation ratio of 0.999 was revealed between the length of Arabica and the width of Robusta beans as shown in Table 8. The lowest correlation ratio of 0.628 was revealed between Robusta length and Arabica thickness. But, the thickness of the beans is smaller compared to their length and width; due to this, thickness cannot affect the performance of the depulping machine as it is like a third of the length, and a half of the width of cherry. This confirms that the dimensions of the two varieties are not much different, therefore pulping operation can be performed by adjusting or setting-up machine parameters according to the coffee varieties and harvesting period curve. Hence, the Principal Component Analysis (PCA) also showed a strong positive correlation of between linear dimensions of the two coffee varieties, as indicated in Figure 9.

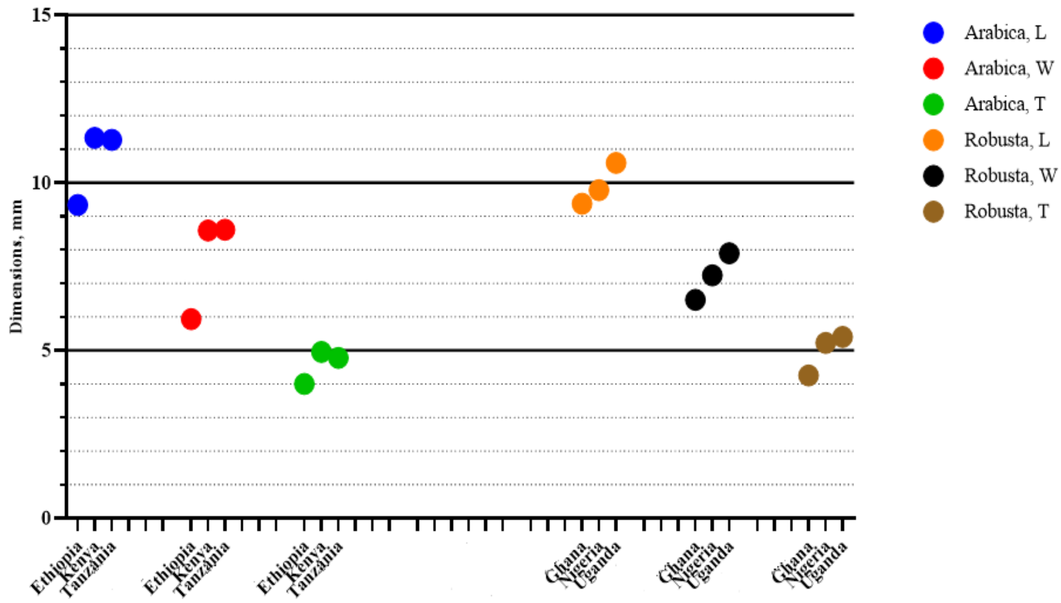


Figure 1. Distribution of Mean linear dimensions of coffee Arabica and Robusta beans for African coffee-producing countries

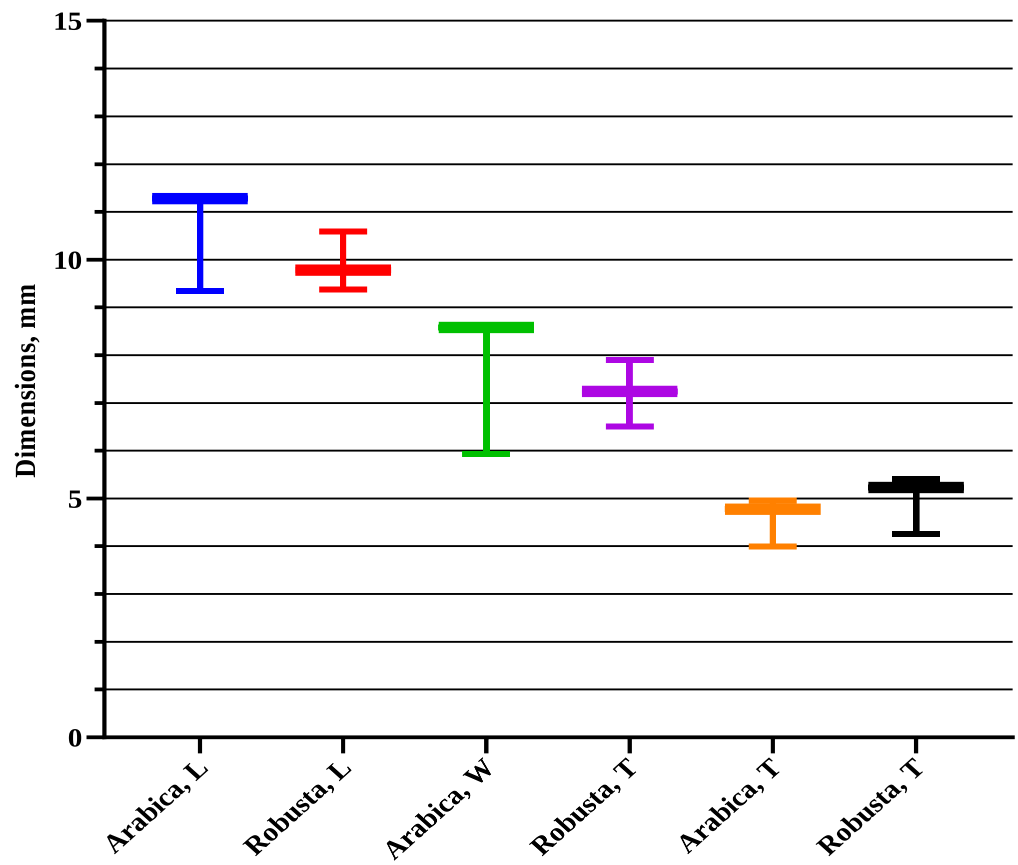


Figure 2. Comparison in length, width and thickness of Arabica and Robusta coffee beans

5.3. Analysis of Weight of Arabica and Robusta Coffee Beans

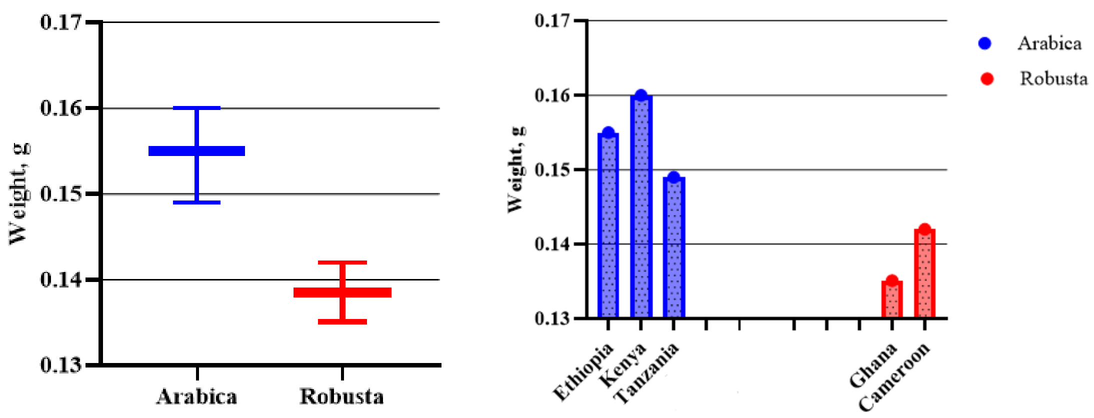
The analysis revealed that the weight of African Arabica coffee 0.155g/bean is greater than that of Robusta coffee 0.138g/bean as shown in Figure 3a. The means weights from three countries (Ethiopia, Kenya, Tanzania and Ghana) showed non-significant differences in countrywide comparison, but with a significant difference between varieties (P-value<0.05), as shown in Figure 3b. Therefore, the Arabica coffee beans from the Eastern regions of Africa had a higher weight than that from the Western region, maybe this happened due to the climate and geographical conditions in the Eastern African countries. However, according to [7], the average mass of coffee Liberica (0.26g) is higher than coffee Robusta and Arabica weight, but Robusta coffee weight was also bigger than of Arabica [7,43]. This property is the most important to fix price of the parchment beans [10] and to determine coffee pulping capacity, beans' breakage rate, mass ratio of pulps, mucilage, and wet parchments to the pulped cherries.

5.4. Analysis of Density of Arabica and Robusta Coffee Beans

Based on Figure 4b, mean bulk density from Ethiopia and Kenya for Arabica coffee and Robusta coffee from Ghana and Nigeria were analysed as recorded in Tables 1, 2 & 3, respectively. The analysis of mean bulk-density revealed that Kenya had a better-quality bulk-density of 1.1g/mL for Arabica coffee beans followed by the bulk-density of 0.8g/mL for Robusta coffee from Ghana as shown Figure 4b. The Arabica beans showed bulk density of 0.8g/mL higher than of Robusta beans of 0.6g/mL as shown in Figure 4a. This can be confirmed by a report conducted by Ismail et al. [7] that Arabica coffee bean had higher bulk density than that of Robusta coffee. The plotted means bulk density showed a significant difference (P-value<0.05) in countrywide comparison as well as between coffee varieties as shown in Figure 4b. Therefore, the bulk-density can vary geographically from one country to another, not depending mainly on coffee variety. In the case of depulping process, the bulk density is an important parameter for defining the quality of cherries in the sorting process and can directly affect the performance of the pulping machine. The parchment beans with less bulk density cannot slide easily by the gravitational force from the hopper to the pulping chamber or from the pulping chamber to the machine outlet et even if it depends mainly on the coefficient of friction but density can also decelerate the friction resistance.

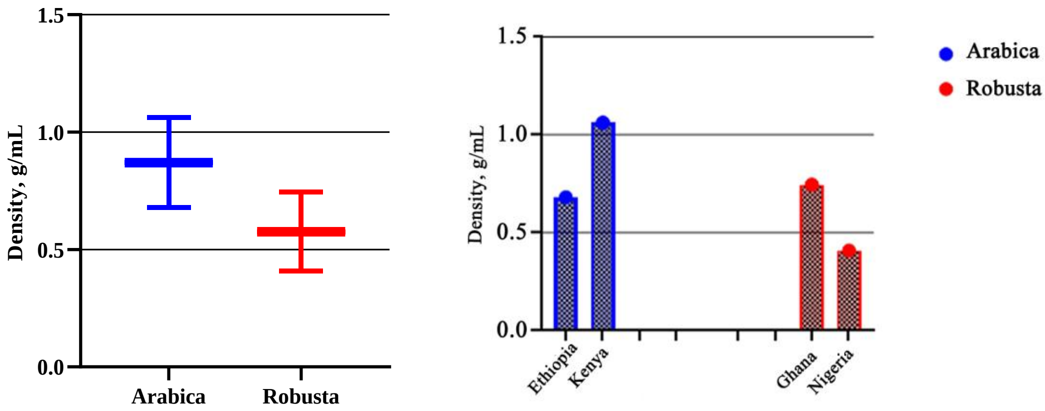
The apparent density is one of the major parameters for identifying the quality of the coffee beans which is relative to the volume and weight as well as the size of beans. Therefore, apparent density from Ethiopia and from Ghana and Nigeria for Arabica and Robusta, respectively were recorded countrywide. Unless the apparent density from Ethiopia Arabica coffee of 1.35g/mL was assumed to represent Arabica coffee at inter country-wise level. It can be assumed that there is a significant difference between Arabica and Robusta coffee beans density as shown in Figure 5a and 5b. Then, it showed that Arabica coffee has a greater density (1.3g/mL) than coffee Robusta (0.9g/mL) between varieties as shown in Figure 5a and between countries as it is also shown in Figure 5b. The apparent density doesn't be affected by pulping process because it is a parameter independent to the performance of the machine. The apparent density is important for defining the capacity of the hopper in relation to the feed rate of the pulping machine. However, the parchment with apparent not proportional to the size due to inappropriate growth or undergrowth beans can results more beans crushing during depulping process.

According to Ismail et al. [7], the Ethiopian Arabica apparent density weighed more than Robusta (Ghana and Nigeria) and Liberica (Malasia). This means that African coffee will cost more at the market level, if all the post-harvesting are performed perfectly.



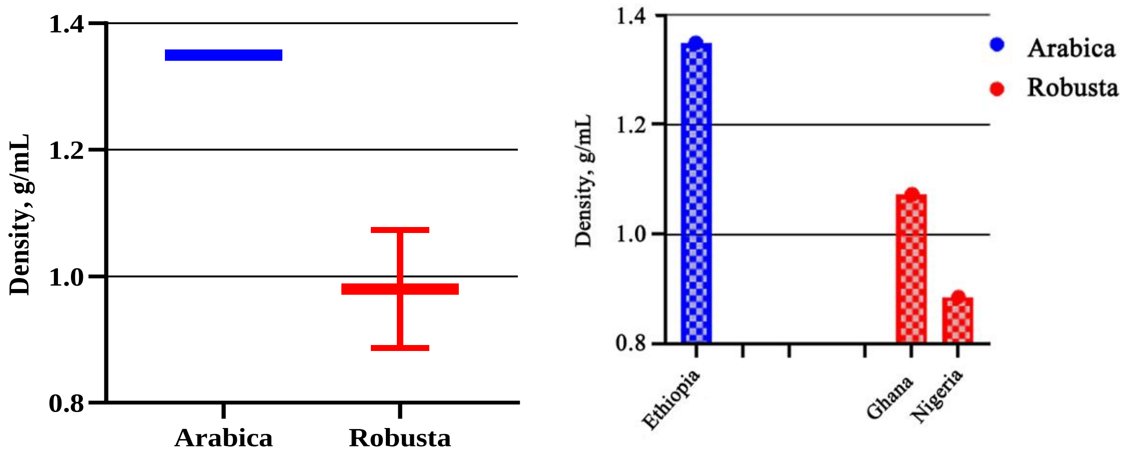
(a) (b)

Figure 3. Weight of Arabica and Robusta coffee beans: (a) Comparison between varieties and (b) Distribution of countrywide weight



(a) (b)

Figure 4. Bulk-density of Arabica and Robusta coffee beans: (a) Comparison between varieties and (b) Distribution of countrywide Bulk-density



(a) (b)

Figure 5. Apparent-Density of Arabica and Robusta coffee beans: (a) Comparison between varieties and (b) Distribution of countrywide apparent density

5.5. Analysis of Coefficient of friction and Angle of repose for Robusta Coffee Beans

The coefficient of friction and angle of repose data were recorded for only Robusta coffee beans for two countries Ghana and Nigeria from the Western region of Africa. However, from experiments conducted in different regions, it had revealed that the coefficient of friction is 0.33 of Ghanian Robusta coffee is lower than of Nigerian Robusta coffee of 0.34 as indicated in Figure 6. Hence, angle of repose defines of how cherries and beans are sitting each other in the hopper which can increase the feeding rate directly and pulping performance indirectly. This is contrary to an angle of repose of 37.24 ℃ and 25.5 ℃ for Ghana and Nigerian respectively, as indicated in Figure 7. Therefore, the coefficient of friction and angle of repose are independent variables at each other for coffee beans of the same variety. Hence, sliding of parchment beans on drum can be a factor of defining the de-pulping and separation rate. The Nigerian Robusta coffee can resist more in sliding on coffee pulping drum surface than Ghanian Robusta coffee according to the coefficient of friction as shown in Figures 6 & 7. However, filling the de-pulping machine hopper for the Ghanian Robusta coffee beans is easier than that of Nigerian Robusta coffee beans. During the pulping process, if the coefficient is not good it can increase the cloggage of beans in pulping chambers that can also increase the breakage of beans. Then if the flowing of beans is not at the standard the beans will not flow from the hopper to the pulping chamber.

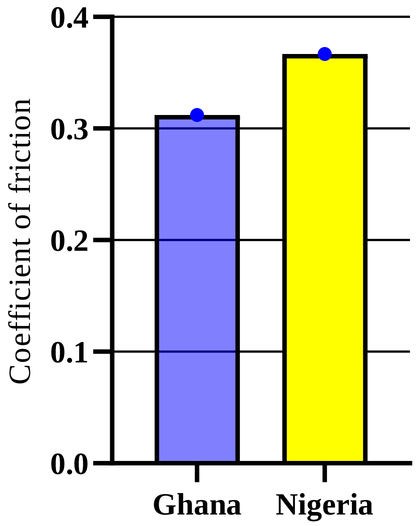


Figure 6. Variation of coefficient of coefficient of Friction of Robusta coffee beans

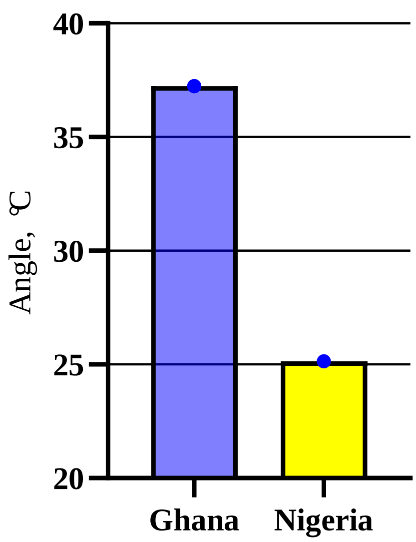


Figure 7. Variation Angle of Repose of Robusta coffee beans

5.6. Analysis of Sphericity of Arabica and Robusta Coffee Varieties

The analysis of sphericity was conducted for the sphericity that were determined using Eq. (16) of 0.695, 0.6531 and 0.7269 recorded for one bean for Ethiopian, Kenyan and Tanzanian coffee, respectively as shown in Figure 8b [34]. The sphericity of coffee beans that is assumed to be ellipsoidal or sphere from four different African countries shows that Ghana is the one with a high sphericity value of coffee. While, the Ethiopian Arabica coffee shows minimum sphericity.

The sphericity of Arabica and Robusta coffee comparison analysis showed a significant difference (P-value<0.05) between the two verities. Unless the results showed that there is no significant difference between sphericity countrywide. The Robusta coffee beans have bigger average sphericity of 0.84 rather than Arabica coffee of 0.693 as shown in Figure 8a.

Therefore, keep in mind that the sphericity depends on length, width, and thickness. This parameter does not affect much geometric properties and weight. Thereafter, geometry properties define the strength of the beans until the first crack [44] in order to perform pulping without crushing the parchment. The grater sleeve of drum pulper, disc pulper contains bulbs that separate pulps and beans and help the beans to slide in pulping clearance toward the outlet of machine. Therefore, according to [40] the analysis showed that the crushing strength of a single bean under static force applied perpendicularly to the flat surface of Arabica coffee beans from Ethiopia, Kenya and Tanzania varies in between 30N and 60N and the correlated dynamic force can rise up 75N. The corresponding displacement is about 0.3mm. Therefore, keeping the correct clearance in the pulping mechanism in relation to the bean's compression strength can avoid the breakage of the parchment. However, the crushing strength of cherries is lower than that of the beans [7], and the crushing strength of Liberica coffee cherries (128.52N) is greater than of the Arabica and Robusta with 30N and 50N, respectively. This means that pulps separated with beans before attaining the fracture force of the parchment; hence, crushing of parchment beans depends on setting up of the machine.

The summary of the means coffee parameter of the two main African coffee varieties from the above analysis is represented in Table 8. The pairwise Pearson correction coefficient and P-value between parameters showed that they are no significant differences for the means of one variety and showed a significant difference between coffee varieties (P-value<0.05). The beans' size and shape differ from one region to another due to different factors [10], but adjustment of the pulping machine should take into consideration based on the correlation between the sizes of the beans among the varieties to reduce the damage of parchments during the pulping process which leads to the low quality of parchment coffee beans. Thus, as much as the beans are more spheric, the pulping operation becomes easier due to proportion in the size and it reduces the breakage rate because the strength increases as the thickness that most defines sphericity increases as also the ratio of geometric diameter to length increases.

Pearson multivariant correlation analysis between the bulk-density to the Apparent density (g/mL), weight of bean (g), length (mm), width (mm), thickness (mm), coefficient of friction and sphericity were 0.562, -0.655, -0.339, -0.651, 0.228, -0.658, and -0.909, respectively. The apparent density was the one showed a positive correlation with bulk density while the length and width showed negative correlation. The highest negative correlation was with sphericity of -0.909 which was significant in the correlation analysis. The density relative was analysed due to its importance on defining the ratio of size and volume as well as the mass of coffee seeds that can fill the pulping machine hopper, design dimensions of hopper, and evaluate the capacity of depulping machines [20].

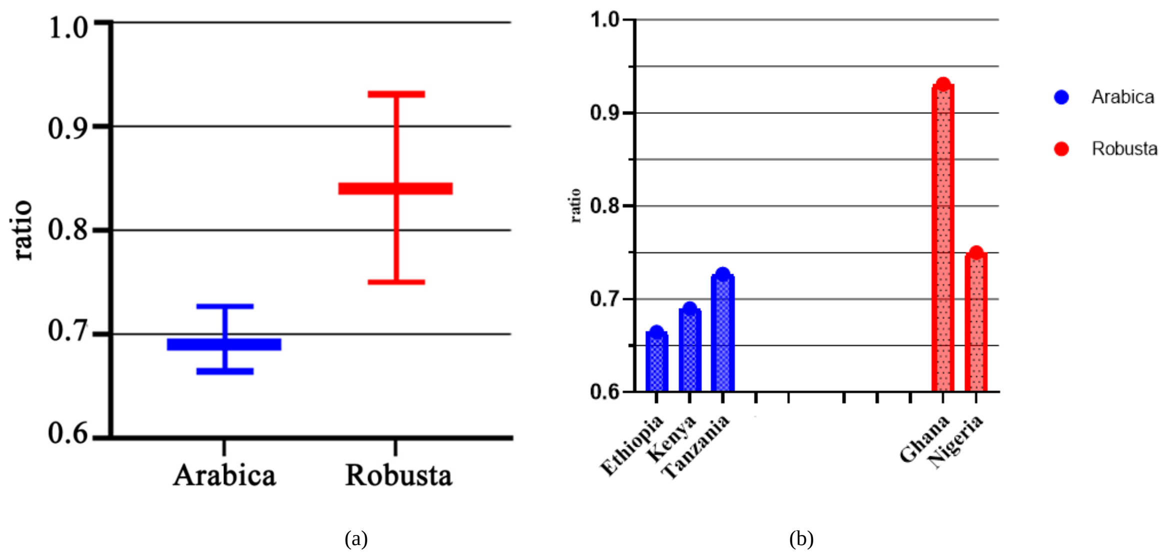


Figure 8. Variation of sphericity of Arabica and Robusta coffee beans: (a) between varieties and (b) distribution in countries

Table 8. Summary of some mean parameters of Arabica and Robusta coffee beans recorded from 8 African coffee producing countries

Parameters	Arabica	Robusta
Weight of bean (g)	0.1546±0.00	0.13855±0.00
Bulk density (g/mL)	0.871±0.27	0.576±0.24
Apparent density (g/mL)	1.350	0.980±0.13
Porosity	-	27.765
Length (mm)	10.653	9.915
Width (mm)	7.705±1.53	7.216±0.70
Thickness (mm)	4.58±0.51	4.965±0.62
Volume (mm^3)	0.0736	-
Coefficient of friction	-	0.339475
Angle of Repose	-	31.195
Sphericity	0.693±0.031	0.84±0.128
Moisture Content	11.085	13.04

5.7. Distribution in Dimensions of African Arabica and Robusta Coffee Beans

The knowledge of the mean size of African Arabica and Robusta coffee cherries and beans as shown Table 9 helps to develop the optimal coffee pulping machine with respect to the homogeneous dimensions of the two coffee varieties at a small-scale level. Therefore, taking into considering the African coffee beans, the means size of the Arabica and Robusta coffee beans, were summarized in Table 8. The variation in dimensions between the two varieties from African coffee producers is illustrated in Figure 2. It shows that the development of coffee pulping machines according to the size of cherries of the two varieties couldn't affect much the quality of coffee beans. The de-pulping mechanism can be adjusted based on the quality of the available cherries.

Table 9. Mean Size of Arabica and Robusta coffee beans harvested in 8 African Countries

L_A	W_A	T_A	L_R	W_R	T_R
8.28	5.09	3.52	8.49	5.83	3.73
10.4	6.82	4.28	10.22	7.16	4.71
9.01	6.48	2.82	8.1	6.1	4.5
11.34	7.55	4.66	10.5	8.3	6
10.97	8.26	4.9	7.5	5.4	3.6
11.6	8.78	5.07	9.4	7.3	5.3
10.46	8.58	4.75	10.29	7.57	4.9
12.8	8.58	4.75	10.19	8.03	5.09
11.28	8.6	4.78	10.23	7.8	4.99

L_A: Length_ Arabica, W_A: Width_ Arabica, T_A: Thickness_ Arabica, L_R: Length_ Robusta, W_R: Width_ Robusta, and T_R: Thickness_ Robusta

The analysis of variance showed that there is a significant difference among the means of three main dimensions of African Arabica and Robusta coffee beans at P-value< 0.05 and R-squared of 0.834. Based on the dimensions of two varieties as shown in Table 9, the design of experiment produced a factorial model with 16 runs of coffee pulping machine efficiency from the range (maximum and minimum) of length, width and thickness of Arabica and Robusta. The model of efficiency of the depulper is represented in Table 10. The three main dimensions of coffee beans are the results from the premier size of cherries that are based on for developing a coffee pulping machine. The model equation produced by Response Surface Methodology (RSM) from the dimensions can be based on for predicting the size of coffee in Africa. The mathematical relationship between the dimensions of Arabica and Robusta coffee to the coffee pulping machine efficiency (see Eq. 18) was a reast-square (R^2) of 0.98 and the adjusted R^2 of 0.92 obtained using fit statics method in One-Way ANOVA. The R^2 showed the variation of size accounts 92-98% to the machine efficiency. In this case, A, AD, AF, and BD are significant model terms at (P-value<0.05) in the regression equation. This means that one dimension of coffee bean or cherry cannot affect the efficiency of the machine, but the combination of three main dimensions of coffee cherries or beans. Therefore, this model equation can be used to navigate the design of de-pulping machines on the African continent based on coffee beans size with an efficiency of at least 97.17%.

$$\text{Efficiency} = +97.19 +0.67A +0.09B -0.62C +0.39E -0.16F +0.81AD -0.65AF -0.96BD +0.40ABF \quad (18)$$

5.8. Principal Composition Analysis (PCA) of Dimensions of African Arabica and Robusta Coffee Varieties

The information about differences and correlation between physical properties of beans is important in developing coffee treatment operation including pulping operation or others [43]. The Arabica and Robusta coffee beans obtained by the coffee pulping machine or by hands de-pulping in African showed a perfect positive correlation between the three main dimensions as indicated in Figure 9.

The grouped dimensions showed a correlation range (r=0.78, 0.84 and 0.94). This confirms the insignificance difference correlation of the terms in the model equation, as shown in Eq. 18. Therefore, the relation in internal variations of the dimension help in decreasing the damage of beans and increase the de-pulping efficiency for a machine [4] adjusted based on the main dimensions of the cherries and their corresponding parchment coffee beans.

Table 10. Analysis of variance for the relationship between dimensions of African Arabica and Robusta coffee for Pulping Machine Efficiency Model Response

Source	Sum of Squares	Df	Mean Square	F-value	p-value
Model	63.62	13	4.89	14.46	0.0665
A-Length_A	7.33	1	7.33	21.66	0.0432
B-Width_A	0.1425	1	0.1425	0.4211	0.5829
C-Thickness_A	6.26	1	6.26	18.51	0.0500
D-Length_R	0.0008	1	0.0008	0.0022	0.9666
E-Width_R	2.49	1	2.49	7.35	0.1133
F-Thickness_R	0.4389	1	0.4389	1.30	0.3728
AC	4.44	1	4.44	13.12	0.0685
AD	10.48	1	10.48	30.97	0.0308
AE	5.28	1	5.28	15.60	0.0585
AF	6.77	1	6.77	20.01	0.0465
BD	14.76	1	14.76	43.63	0.0222
BF	2.60	1	2.60	7.68	0.1092
ABF	2.62	1	2.62	7.73	0.1087
Residual	0.6768	2	0.3384		
Cor Total	64.30	15			

R^2=0.98, adjusted R^2=0.92, df=degree of freedom.

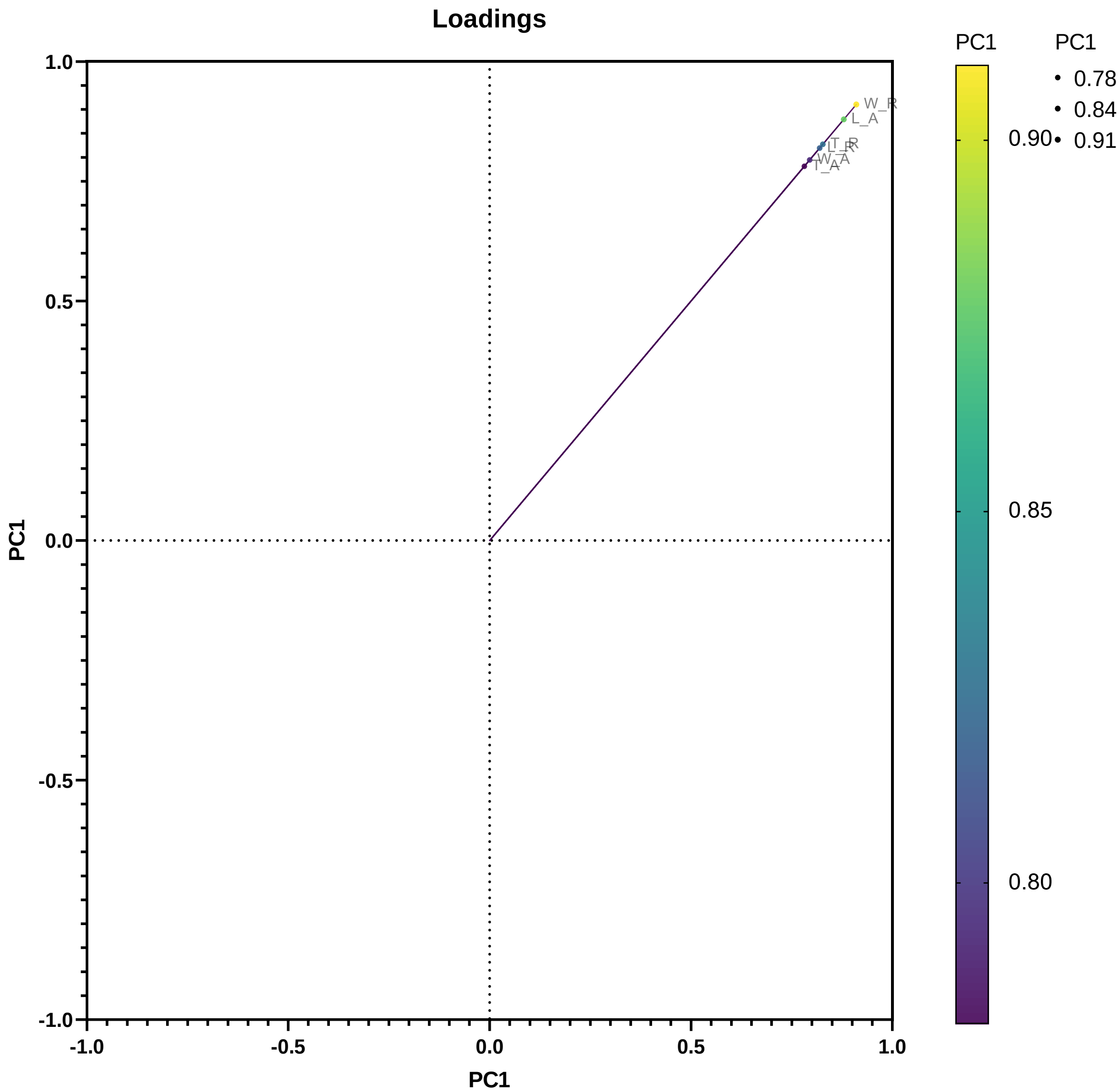


Figure 9. Correlation between Arabica and Robusta coffee dimensions (Length, Width and Thickness) based on Principal Component Analysis

6. The Inter-Zone Coffee Beans Parameters Comparison

The physical and mechanical parameters investigated in different previous review works were not similar in every country. Therefore, inter-zone comparisons in terms of dimensions, moisture content, sphericity maturity of the parchment coffee and maturity of coffee cherries were compared in this section. The Arabica and the Robusta coffee were investigated in ten African countries where the database information of physical properties of coffee cherries and beans were developed in Tables 1-7. The dimensions measured directly and calculated parameters play a key role in designing the coffee processing machines such as pulping and dehulling machines. Besides that, these dimensions are used to identify the quality of coffee in proportional to the bulk density. The dimensions of beans from Easter Africa (Arabica) were bigger than that of the Western Africa (Robusta) due to coffee verities which are favourite to the climate in the two regions while the bulk density of Arabica was greater than of Robusta variety.

Arabica coffee is one of the coffee varieties with higher dimensions but they are less than of the coffee Liberica [7]. Although there are varying from one country to another. The results show small differences that account for less than one millimetre for length, width, and thickness as shown in Figure 1, and Table 8. However, the length of the beans is in the range of more than 11 mm and 9 mm for the Arabica and Robusta coffee, respectively. The highest and smallest lengths are 11.95 mm and 11.28 mm from Ethiopia and Tanzania, respectively. From the above view, the highest and smallest width of 8.60 mm and 8.58 mm are coming from Tanzania and Kenya for Arabica coffee, respectively. The higher and smaller thickness of Arabica coffee of 4.96 mm and 4.9 mm were found from Kenya and

Ethiopia, respectively. For the Robusta coffee among Nigeria, Ghana, and Uganda countries; the higher and smaller average width obtained from the conducted research is 7.89 mm and 6.51 mm for Uganda and Ghana respectively. The thickness of the Robusta coffee showed a bigger size than those of Arabica coffee as shown in Figures 1 & 2. The Ugandan Robusta coffee thickens is greater than that of Ghana with around 1mm. This means that the length and width of coffee beans can vary from one country to another according to different factors including environmental conditions, and soil fertility; where the environmental conditions have a higher effect on the quality of coffee [17]

For standardization of the coffee lot based on size, the coffee beans graded into A, AA, AB, and C retained into the screen size of >18, 18>17, 16>15, and 15>14, respectively and E-Elephant categories (8.3mm) based on Kenyan grading system using weighing screen [45]. However, in Rwanda traditional grading of Arabica based on percentage started using the screen 18 for grade $A1^+$, $A1^-$ $A2^+$, $A2^-$, $A3^+$, $A4^+$ for non-retained percentage of (7%), 6%), (3%), (1.5%), (2%), (21%) respectively, and Ivory-Cost is 0, 1, 2, 3, and 4 for retained screen of >18, 18/16, 16/14, 14/12, and 12/10, respectively. The Arabica coffee beans in a range of 6.75 mm to 7.14 mm and 5.95 mm to 6.35 mm are graded in AA and AB, respectively as by the Kenyan grading while the Robusta coffee beans in a range of in the range of 5.95 mm to 7.10 mm 4.76 mm to 5.55 mm are in grade 1 and 2, respectively as by Ivory-coast grading [46]. The African coffee showed, the average mean size of beans as shown in Table 8, with a length of 10.46 mm and 9.91 mm, width of 7.705 mm and 7.21mm and thickness and 4.58 to 4.9 mm for Arabica and Robusta, respectively. The Arabica coffee is mostly available in East Africa and the Robusta coffee is available in West and East Africa. Therefore, based on size and Kenyan and Ivory-coast grading, the African Arabica coffee is generally ranked in grade AA and African Robusta coffee is ranked in grade 1. Then, the Robusta coffee from Uganda in East Africa with bigger size with the length of 10.56, with of 7.899 and thickness of 5.410 mm can be in grade 1; while the Robusta from Ghana with smaller size with length of 9.37 mm, width of 6.50 mm and thickness of 4.25 mm is also in grade 1. Hence, based on size and shape, Arabica and Robusta are commercially homogenous until the sieve 19 [47].

The bean weight is positively correlated with AA bean size [45], then the A grade cost at New York mark 4.2$/kg of Arabica and 2$/kg of Robusta in 2022 based on statista 2022. The price of the beans depends also on the grade [10], AA is 5$/kg and AB is 4$/kg. Therefore, based on grade and weight as shown in Figures 1 & 3 the Arabica coffee price will be higher than that of Robusta and Easter Africa, coffee price will be better to the western coffee price. Therefore, grading is confusing from one country to another because there is no universal accepted standard of grading. Hence, the size distribution (grade) of coffee beans depends on geographical conditions and processing method and has an influence on density, crushing strength, price and impact on the optimal operational performance of the pulping machine[4].

Therefore, it has been proved in Ghana [37] that moisture content affects the size and the weight of beans increasing linearly as increases moisture. The grading of coffee can also be referred to as moisture content as investigated by Niwagaba et al. [37] in Uganda. However, the moisture content varies from one region to another due to the degree of drying the coffee or post-harvesting process in general and coffee varieties. Moisture content also contributes to the separation of the pulp and coffee beans, the results indicated that as decreasing moisture content, the pulping force increases or vice versa. The standard moisture content is in the range of 10 to 12.5% wb, while that of beyond this range can affect the quality of coffee flavor. The moisture content investigated in Ethiopia, Kenya and Ghana was in this range, the average moisture content of 10.84% wb was investigated to represent African coffee in this review. This value was almost closer to the one determined on Indonesian Robusta coffee which is 12.2% wb on a wet basis [22]. The highest moisture content from the coffee used in this work was 13.04% wb for Robusta from West Africa and the lowest was 10.46% wb Arabica from East Africa in Ghana and Ethiopia, respectively. The moisture content level is an important parameter to define aroma and flavor for the buyer, weight and density, and is a very important parameter in defining the depulping performance of the machine and the quality of both cherries and beans. The cherries take a growing period of 9-11 months to ripen; then after, the harvesting period of Arabica coffee takes 2 to 3.5 months while the Robusta harvesting period is irregular. The Arabica cherries in Ethiopia (East Africa) are harvested when they are about 75% ripened [48]while the Robusta cherries are 60% ripened. The good cherries that provide the good performance of the machine are always in the range of 59% to 65% wb, if not soaking of cherries is needed. Thus, in this range, the efficiency of the machine varies depending on the speed of the machine [49]. The Arabica cherries from highland (East Africa) are higher in size, weight and moisture due to heavy rain compared to the lowland Arabica that is mostly from West Africa, except in Uganda [4]in East Africa where there is little rain seasons and high temperature. Besides that, the Robusta yields more than the production of Arabica coffee for 2300-4000kg/ha and 1500-3000kg/ha of green bean in average respectively [50]. The depulping parchment coffee beans are dried to standard moisture at a market level of 10-12.5% for both Arabica and Robusta. Therefore, the based-on Speciality Coffee Association of America (SCAA) green coffee classification, the green coffee in grades 1 and 2 should attain a drying level of 9-13% per 300g of coffee for both Arabica and Robusta. This moisture content is similar to Banana fruits to maintain sensorial attributes (15.9-13.3g/300g [51]. Hence, size and moisture, and pulping ripened good cherries can be defined as the main determinator factors for market sale and processing of coffee as described by Nesterenko et al. [52], and flavor to enhance the quality and price of coffee needed by the coffee consumer.

Density of the coffee bean depends on the size, and moisture content. Despite that, there are seeds with bulk and apparent density which are less and greater than 1, respectively. The minimum and maximum bulk density revealed is 0.4077 g/mL and 0.7444 g/mL in Nigeria and Ghana, respectively. Similar results on density were reported for Indonesia Arabica coffee [22,28] and in India [33].

The minimum and maximum true or apparent density revealed in Nigeria and Ethiopia are 1.063 and 1.35 g/mL, respectively. The bulk density of Arabica coffee beans in all countries is less than that of Arabica coffee in other countries as conducted in India for both dry and wet processes [53]. Besides, Ghana and Nigeria produce Robusta coffee and this implies that coffee density can vary based on agro-ecological conditions apart from the season, processing, and varietal differences. Hence, according to the size, moisture content, and maturity of the cherries and parchment coffee; the coffee quality is linked to the pulping machine performance parameters such as pulping mechanism setting-up, de-pulping rate of more than 95 percent, and damaging beans rate of less than 3.5 per cent according to different studies [54–56]and standard (PAES 252:2011). The pulps take up to 1m thick of the cherries. The pulp and parchment take 40% [57] and, 20% of the weight of the Robusta and Arabica cherry [50]. Then, if the small-scale coffee producers can follow the process investigated in their respective countries, the quality of African coffee can also be increased. Considering these parameters can increase the coffee price at the market level based on ISO (2004a) or ISO 9116 the standard.

7. Conclusions

Nowadays coffee has been involved in the economy of African countries. The main properties of coffee grains depend on coffee beans variety, location, soil fertility, season, climate, and growing care. The quality of coffee at the market level is affected by inappropriate harvesting and post-harvesting processes such as pulping process. Therefore, the information about the size, shape and engineering properties of coffee grain can play a key role in improving the coffee quality up to the consumer level. The information about coffee beans in different countries could contribute to the modern cultivation of coffee in Africa. On top of these, the significant role of identifying the characteristics of coffee beans is about elaborating the design of the post-harvesting equipment for different regions and fit the requirements of smallholders at the village level. The coffee beans of Arabica were revealed to have a bigger length and width from three countries' reports used during the investigation. Besides, Arabica coffee was found to contribute up to 69% of coffee production in Africa and its size is slightly smaller. However, it is needed to conduct, identify the properties of the coffee cherries and beans in different countries to design their post-harvesting processing machines. The pulping machines can help African coffee farmers to increase their revenue. Comparing to intra-country quality parameters of the Arabica coffee grains are larger than Robusta coffee for the case of Ethiopia and Ghana. While the size of Robusta coffee in Eastern countries is bigger than those of western countries which imply that the high-quality coffee is from Easter Africa producing countries. This confirms that Eastern Africa is producing high-quality coffee worldwide. Further investigation is needed to verify any contrast that the African Arabica coffee geometric size is greater than Robusta coffee. The mean dimensions of Arabica and Robusta coffee have to be explored in each country from where data are not available. Then, the quality parameters for Arabica and Robusta coffee which are the most available in Rwanda and Benin, respectively and variation in size of their cherries during harvesting period will be investigated in the next work.

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Nomenclature

$\bar{D}$	average diameter
N	Number of measurements
AMD	Arithmetic Mean Diameter
AR or Ra	Aspect Ratio
Cf	Coefficient of friction
Cs	Chell/Sliverskin Content
CSA	Cross-Sectional Area
CSS	Coefficient of Contact Surface
D	Diameter of the cone cylinder
Di	Measured diameter
FSA	Front surface Area
GMD	Geometric Mean Diameter
H	Height of the head
L	Length
r	small radius
R	larger radius
Rr	Roundness ratio
SI	Shape Index
Sp	Sphericity
T	Thickness
TSA	Transverse Surface Area

V	Volume
W	Width
Ws	Weight of seed
Wus	Weight of unhulled bean
θ	inclination angle
μ	Filling angle of repose
μd	Dynamic angle of repose
Є	Porosity
ρb	Bulk-Density
ρt	Apparent Density/ true density

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