SOME ENGINEERING PROPERTIES OF FIVE DIFFERENT GROUNDNUT VARIETIES (KERNELS)

Sathish Kumar N K, Saravanakumar M*, Kamaraj P, Rajarathinam P, Baskar M

Sathish Kumar N K
Doctoral Research Scholar, Department of Farm Machinery and Power Engineering, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur, Trichy.

Saravanakumar M*
Associate Professor and Head, Department of Farm Machinery and Power Engineering, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur, Trichy.

Kamaraj P
Assistant Professor (Farm Machinery), Department of Farm Machinery and Power Engineering, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur, Trichy.

Rajarathinam P
Assistant Professor (Agronomy), Institute of Agriculture, Kumulur, Trichy.

Baskar M
Professor and Head, Department of Soil Science and Agricultural Chemistry, Anbil Dharmalingam Agricultural College and Research Institute, Tamil Nadu Agricultural University, Kumulur, Trichy.

*Corresponding Author. E-mail : msaravana_aptnau@rediffmail.com

Abstract

The study was aimed to determine some engineering properties (Geometric, Gravimetric and Frictional parameters) of five varieties of groundnuts viz., VRI 2, VRI 3, VRI 5, VRI 8 and CO 3. For all the five varieties of groundnut kernels, average values of length, width, thickness, arithmetic mean diameter, geometric mean diameter, square mean diameter, equivalent diameter, sphericity, aspect ratio, shape factor, volume, surface area, moisture content (d.b.), 1000 unit mass, true density, bulk density, porosity, angle of repose and static coefficient of friction were found out by following the standard methods and procedures. The values were ranged between 12.39 – 14.69 mm, 7.70 – 7.77 mm, 8.28 – 8.96 mm, 9.47 – 10.48 mm, 9.23 – 10.05 mm, 6.39 – 6.80 mm, 8.36 – 9.11 mm, 0.69 – 0.75, 0.53 – 0.63, 2.43 – 2.63, 134.05 – 171.70 mm^3, 269.56 – 318.66 mm^2, 5.4 – 6.9 %, 338.36 – 954.18 g, 1428.36 – 1575.36 kg/m^3, 708.06 – 716.89 kg/m^3, 49.87 – 54.23 %, 23.12 – 24.94 °, 0.42 – 0.43 for galvanized iron, 0.24 – 0.30 for stainless steel, 0.48 – 0.52 for mild steel, 0.45 – 0.47 for aluminium, 0.43 – 0.47 for plywood and 0.50 – 0.57 for rubber respectively. Engineering properties of seeds plays a major role while designing agricultural machines for various operations such as harvesting, threshing, decortication, cleaning, grading, drying, storage, transportation and oil extraction.

Keywords: Length, Width, Thickness, Sphericity, Aspect ratio, Shape factor, Volume, Surface area, Moisture content (d.b.), 1000 unit mass, True density, Bulk density, Porosity, Angle of repose and Static coefficient of friction.

1. Introduction

Groundnut (Arachis hypogea) also known as the peanut belonging to family Leguminosae and also called King of oilseeds. Peanuts are rich source of edible oil (43-55%) and protein (25-28 %) (Dilmac & Altuntas, 2012). Food legumes are known to be of high nutritional value because of their high protein content (Asare et al., 2010). Groundnut are made up of approximately 70 % of grains or seeds and 30 % of shells (Araujo et al., 2015). It is a legume crop mainly grown for its edible purposes and classified as both a grain legume and oil crop due to its higher oil content. It is one of the important cash and food crops of our country. Groundnut crop is an important source of protein in human nutrition and livestock feeds (Aydin, 2007). The oilseed production in India has grown by almost 43 % from 2015-16 to 2020-21 i.e., from 25.3 MT to 36.1 MT (Anon., 2022). China ranks first and followed by India in the production of groundnut all over the world. In India, groundnuts were sown under the area of 60.15 lakh ha with a production and productivity of 102.44 lakh tonnes & 1703 kg/ha in the year of 2020-21 and the area of 48.26 lakh ha with a production and productivity of 98.51 lakh tonnes & 2041 kg/ha in the year of 2019-20. Gujarat ranks first and accounts for about 41% followed by Rajasthan (16.4%) and Tamil Nadu (10.5%) of the country's production (Anon., 2020). Groundnut can be grown on all types of soils such as sandy, sandy loam and heavy black soils. Most suitable soils for groundnut production are well-drained, light-textured, loose sandy-loam or sandy clay loam soils with good drainage, having reasonable high calcium, pH 5.5 to 7.0 and a moderate organic matter. The principal axial dimensions of grains are used for calculating the power requirement during milling, and for selecting sieve separators. The volume of kernels and surface area are important during aeration. True density and bulk density can be useful in sizing storage facilities and grain hoppers. The angle of repose gives the flowability of grain which will be useful in hopper design. The friction coefficient is important in the design of conveyors (Dilmac & Altuntas, 2012; ElMasry et al., 2009; Jan et al., 2019; Mpotokwane et al., 2008). Optimum moisture content for storage of grain was 7% (Muhammad et al., 2017). Engineering properties of seeds plays a vital role in designing agricultural machines for various operations such as harvesting, threshing, decortication, cleaning, grading, drying, storage, transportation and oil extraction (Ghosal & Sarangi, 2020; Gupta et al., 2018; Izli, 2014; Olajide & Igbeka, 2003).

This study was therefore carried out to determine the geometric parameters (length, width, thickness, arithmetic mean diameter, geometric mean diameter, square mean diameter, equivalent diameter, Aspect ratio, sphericity, shape factor, volume and surface area), gravimetric parameters (moisture content, 1000 grain mass, true density, bulk density, and porosity) and frictional parameters (angle of repose and static coefficient of friction) of different varieties of groundnut in order to develop appropriate equipment.

2. Materials and methods

2.1. Sampling

The groundnuts were procured from farmer's field and KVK (Krishi Vigyan Kendra) research stations. The sample were selected and cleaned manually. It was ensured that the grains were free of dirt, broken ones and other foreign materials (ElMasry et al., 2009). The measurement of engineering properties was conducted at department of Farm Machinery and Power Engineering and department of Processing and Food Engineering in Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur, Trichy. Five bunch type different groundnut varieties were taken to study their engineering properties viz., VRI 2, VRI 3, VRI 5, VRI 8 and CO 3.

2.2. Moisture Content (MC)

Moisture content was immediately measured on arrival by oven dry method of 105°C till it attains constant weight of the sample. Initial weight of the sample was noted before placing the sample on hot air oven. For every hour, sample weight was measured using electronic digital balance with an accuracy of 0.001g. Experiment continued till it attains same weight for consecutive hours and final weight of the dried sample was noted. The moisture content (dry basis & wet basis) of the different varieties of groundnut kernels were calculated using any of the following equation. Moisture content measurement using hot air oven was shown in Figure 1.

$$\text{Moisture content in dry basis (\%)} = \frac{initial\ wt.of\ the\ sample - final\ wt.of\ the\ dried\ sample}{final\ wt.of\ the\ dried\ sample}$$

$$\text{Moisture content in wet basis (\%)} = \frac{initial\ wt.of\ the\ sample - final\ wt.of\ the\ dried\ sample}{initial\ wt.of\ the\ sample}$$

Figure 1 – Measurement of Moisture Content using Hot Air Oven

2.3. Axial Dimensions

The principal dimensions are the length, width and thickness. The length (L) is the major diameter (D_1), thickness (T) is the minor diameter (D_3) and width (W) is the intermediate diameter (D_2) of the kernels (Ghosal & Sarangi, 2020). For this experiment, 100 groundnut grains were selected randomly. For each kernels, the three principal dimensions, namely length, width and thickness were measured. The length (L), width (W) and thickness (T) and mass of five different varieties of groundnut grains were measured using a digital vernier caliper with least count of 0.02 mm and digital weighing balance with an accuracy of 0.001g (Gupta et al., 2018; Olajide & Igbeka, 2003). Measurement of Length, Width and Thickness using vernier caliper was shown in Figure 2a, 2b, 2c.

2a 2b 2C

Figure 2a, 2b, 2c – Measurement of Length (L), Width (W) and Thickness (T) using vernier caliper

2.4. Arithmetic Mean Diameter (AMD)

Arithmetic mean diameter of the different varieties of groundnut kernels were found out based on length (L), width (W) and thickness (T) data by using the following equation (Balasubramanian et al., 2011; Chukwu et al., 2018; Fashina et al., 2014; Izli, 2014; Jan et al., 2019; Mohsenin, 1986).

$$\text{AMD} = \frac{D_1 + D_2 + D_3}{3}$$

Where,

AMD - Arithmetic mean diameter,
D_1 - Length of each kernel,
D_2 - Width of each kernel and
D_3 - Thickness of each kernel.

2.5. Geometric Mean Diameter (GMD)

Geometric mean diameter of the different varieties of groundnut kernels were found out based on length (L), width (W) and thickness (T) data by using the following equation (Aydin, 2007; Bagheri et al., 2011; Balasubramanian et al., 2011; Chukwu et al., 2018; Fashina et al., 2014; Izli, 2014; Jan et al., 2019; Kaliniewicz et al., 2018; Kaptso et al., 2008; Mohsenin, 1986; Mpotokwane et al., 2008; Olajide & Igbeka, 2003).

$$\text{GMD} = \sqrt[3]{D_1 D_2 D_3}$$

Where,

GMD - Geometric mean diameter,
D_1 - Length of each kernel,
D_2 - Width of each kernel and
D_3 - Thickness of each kernel.

2.6. Square Mean Diameter (SMD)

Square mean diameter of the different varieties of groundnut kernels were found out based on length (L), width (W) and thickness (T) data by using the following equation (Balasubramanian et al., 2011; Chukwu et al., 2018; Fashina et al., 2014; Jan et al., 2019; Mohsenin, 1986).

$$\text{SMD} = \sqrt[3]{D_1 D_2 + D_2 D_3 + D_1 D_3}$$

Where,

SMD - Square mean diameter,
D_1 - Length of each kernel,
D_2 - Width of each kernel and
D_3 - Thickness of each kernel.

2.7. Equivalent diameter (EQD)

Equivalent diameter of the different varieties of groundnut kernels were found out based on length (L), width (W) and thickness (T) data by using the following equation (Balasubramanian et al., 2011; Mohsenin, 1986).

$$\text{EQD} = \frac{AMD + GMD + SMD}{3}$$

Where,

EQD - Equivalent diameter,
AMD - Arithmetic mean diameter,
GMD - Geometric mean diameter and
SMD - Square mean diameter.

2.8. Sphericity (S_p)

Sphericity is an expression of a solid shape relative to that of a sphere of the same volume. A sphericity value of a biomaterial between 50 and 100% is an indication of the ability of that material to slide on the surface in contact with it (Chukwu et al., 2018). Higher sphericity value indicates the groundnut kernels tending to a spherical shape. Sphericity of the different varieties of groundnut kernels were found out based on length (L), width (W) and thickness (T) data by using the following equation. (Araujo et al., 2014; Aydin, 2007; Bagheri et al., 2011; Balasubramanian et al., 2011; Chukwu et al., 2018; Fashina et al., 2014; Izli, 2014; Jan et al., 2019; Kaliniewicz et al., 2018; Kaptso et al., 2008; Mohsenin, 1986; Mpotokwane et al., 2008; Olajide & Igbeka, 2003; Zielinska et al., 2012).

$$S_p = \frac{GMD}{D_1}$$

Where,

S_p - Sphericity,
GMD - Geometric mean diameter and
D_1 - Length of each kernel.

2.9. Aspect Ratio (AR)

The aspect ratio relates the width to the length of the seed which is an indicative of its tendency towards being spherical in shape. The ability of any grains or fruits to either roll or slide depends on the aspect ratio and as well as sphericity (Davies, 2009). Aspect ratio of the different varieties of groundnut kernels were found out based on length (L), width (W) and thickness (T) data by using the following equation (Balasubramanian et al., 2011; Chukwu et al., 2018; Ghosal & Sarangi, 2020; Kaliniewicz et al., 2018; Mohsenin, 1986; Mpotokwane et al., 2008).

$$AR = \frac{D_2}{D_1} x\, 100$$

Where,

AR - Aspect ratio,
D_1 - Length of each kernel and
D_2 - Width of each kernel.

2.10. Volume (V)

Volume of the different varieties of groundnut kernels were found out based on length (L), width (W) and thickness (T) data by using the following equation (Chukwu et al., 2018; Davies, 2009).

$$V = \frac{D_1 D_2 D_3}{6}$$

Where,

V - Volume,
D_1 - Length of each kernel,
D_2 - Width of each kernel and

D_3 - Thickness of each kernel.

2.11. Surface Area (SA)

Surface area of the groundnut kernels is important for quantifying the rate of heat, water and gas transfer during processing such as drying and roasting of groundnut kernels. The larger the surface area of the material, the higher the exposure of groundnut kernels to the heat source and results in greater heat absorption (drying or roasting) and desorption during processing (Ofori et al., 2020). The surface area (SA) of the different varieties of groundnut kernels were found out based on length (L), width (W) and thickness (T) data by using the following equation (Bagheri et al., 2011; Chukwu et al., 2018; Davies, 2009; Dilmac & Altuntas, 2012; Izli, 2014; Jan et al., 2019; Mohsenin, 1986; Muhammad et al., 2017; Olajide & Igbeka, 2003).

$$SA = \pi \text{ x } GMD^2$$

Where,

SA - Surface area and
GMD - Geometric mean diameter.

2.12. Shape Factor (λ)

The shape of groundnut kernels will determine the shape of apertures in the concave and sieves or separators of the shelling machine. If $\lambda > 1.5$, then the groundnut kernel is observed oblong, and $\lambda \leq 1.5$ the groundnut kernel is observed spherical (Choudhary et al., 2020). Shape factor (λ) for the different varieties of groundnut kernels based on volume and surface area of grain was determined using following equation (Balasubramanian et al., 2011).

$$\lambda = \frac{b}{a}$$

$$a = \frac{V}{{D_2}^3},\ b = \frac{SA}{6{D_2}^2}$$

Where,

λ - Shape factor,
V - Volume,
SA - Surface area and
D_2 - Width of each kernel.

2.13. Bulk Density (ρ_b)

The bulk density is determined by using the mass/volume relationship by filling an empty calibrated glass beaker of predetermined volume and tare weight with grains by pouring from a constant height, striking off the top level and weighed. The procedure was repeated 10 times for each variety and the mean value was calculated. Bulk density of the different varieties of groundnut kernels were determined using following equation (Abioye et al., 2016; Balasubramanian et al., 2011; Choudhary et al., 2020; Chukwu et al., 2018; Davies, 2009; Fasina, 2008; Jan et al., 2019; Mpotokwane et al., 2008; Muhammad et al., 2017). Measurement of bulk density was shown in Figure 3.

$$\rho_b = \frac{M}{V}$$

Where,

ρ_b - Bulk density,

M - Mass of material and

V - Volume of container.

Figure 3 – Measurement of Bulk Density

2.14. True Density (ρ_t)

The true density was determined using water displacement method. It is defined as the ratio of the mass of the sample to its true volume. A known volume of water was filled into the beaker and its initial reading was recorded, a known mass of sample was filled into the beaker, change in water level was noted. The procedure was repeated 10 times for each variety and the mean value was calculated. True density of the different varieties of groundnut kernels were determined using following equation (Choudhary et al., 2020; Chukwu et al., 2018; Davies, 2009; Jan et al., 2019; Mpotokwane et al., 2008; Muhammad et al., 2017; Ofori et al., 2020).

$$\rho_b = \frac{M}{V_d}$$

Where,

ρ_t - True density,

M - Mass of material and

V_d - Volume of water displaced.

2.15. Porosity (ε)

Porosity is usually needed in air flow and heat flow situations like winnowing, cleaning, drying, storage, etc. It indicates the amount of pores in the bulk materials. The porosity of the different varieties of groundnut kernels computed from the values of the true density and bulk density of the groundnut kernels. It is defined as the fraction of space in the bulk grain which is not occupied by the grain, is calculated from the following equation (Abioye et al., 2016; Aydin, 2007; Bagheri et al., 2011; Chukwu et al., 2018; Davies, 2009; Dilmac & Altuntas, 2012; Gupta et al., 2018; Izli, 2014; Jan et al., 2019; Kaptso et al., 2008; Mohsenin, 1986; Mpotokwane et al., 2008; Sravani et al., 2020; Xie et al., 2019; Zielinska et al., 2012).

$$\varepsilon\ (\%) = \left(\frac{\rho_t - \rho_b}{\rho_t}\right) x\ 100$$

Where,

ε - Porosity,

ρ_b - Bulk density and

ρ_t - True density.

2.16. Thousand Unit Mass

The 1000 unit mass was determined using digital electronic balance with an accuracy of 0.01 g. To evaluate the 1000 unit mass, 100 randomly selected samples are weighed and multiplied by 10. The procedure was repeated 10 times for each variety and the mean value was calculated (Balasubramanian et al., 2011; Chukwu et al., 2018; Davies, 2009; Falade & Nwajei, 2015; Izli, 2014; Mpotokwane et al., 2008; Ofori et al., 2020; Zielinska et al., 2012).

2.17. Angle of Repose (θ)

Angle of repose is also a very important engineering property of pod/kernel, useful for the design of processing, storage and conveying systems of agricultural materials. When the grains or seeds are smooth and rounded, the angle of repose is low. Very fine and sticky materials have high angle of repose due to high friction among them (Ghosal & Sarangi, 2020). The angle of repose of groundnut kernels was determined by the following method. The groundnut kernels were allowed to fall from a height of 320 mm on circular discs of 150, 200 and 250 mm diameter until maximum height was reached and the height of seed heap was noted. The experiment was replicated 10 times for each kernels variety and the average values were computed. The following equation was used to calculate the angle of repose of the selected groundnut kernels (Chukwu et al., 2018; Davies, 2009; Dilmac & Altuntas, 2012; Izli, 2014; Jan et al., 2019; Mohsenin, 1986; Shukla et al., 2019). Measurement of angle of repose was shown in Figure 4.

$$\theta = \tan^{-1} \frac{2H}{D}$$

Where,

θ - Angle of repose,

H - Height of the heap and

D - Diameter of the discs.

Figure 4 – Measurement of Angle of Repose using measuring apparatus

2.18. Static Coefficient of Friction (μ)

A topless and bottomless cylinder having a diameter of 110 mm and height of 100 mm was used to store the groundnut kernels on six different surfaces *viz.*, Galvanized Iron, Stainless Steel, Mild Steel, Aluminium, Plywood and Rubber respectively. Weighed amount of sample was placed on the surfaces (Normal force) and it was attached to another cylinder by using the thread connected between them. Known weight was added to the second cylinder, which hangs freely on the pulley. The force required to create sliding action (Frictional force) on the first cylinder was noted. Static coefficient of friction (μ) is the ratio of frictional force (F) to the normal force (N). The procedure was repeated 10 times for each variety and the mean value was calculated. The following equation was used to calculate the static coefficient of friction of the selected groundnut kernels (Choudhary et al., 2020; Dilmac & Altuntas, 2012; Ghosal & Sarangi, 2020). Measurement of static coefficient of friction was shown in Figure 5.

$$\mu = \frac{F}{N}$$

Where,

μ - Static coefficient of friction,

N - Normal load and

F - Frictional load.

Figure 5 – Measurement of Static Coefficient of Friction using measuring apparatus

3. Results and Discussions

3.1. Sampling

A random sample of about 100 groundnut kernels was taken from each variety to obtain data about some engineering properties (geometric, gravimetric and frictional parameters) such as, size, shape, arithmetic mean diameter, geometric mean diameter, square mean diameter, equivalent diameter, sphericity, 1000 unit mass, surface area, aspect ratio, true density, bulk density, porosity, angle of repose, static coefficient of friction and moisture content. All the samples taken from different locations to study its engineering properties were studied successfully by following the standard methods and procedures.

3.2. Moisture Content

Moisture content (w.b.) for the groundnut kernels were found out to be 6.5 % for VRI 2, 5.2 % for VRI 3, 6.1 % for VRI 5, 5.2 % for VRI 8 and 5.7 % for CO 3 variety. Moisture content (d.b.) for the groundnut kernels were found out to be 6.9 % for VRI 2, 5.5 % for VRI 3, 6.5 % for VRI 5, 5.4 % for VRI 8 and 6 % for CO 3 variety. Moisture content for different groundnut varieties was shown in Figure 6. At the shown moisture contents, measurement of engineering properties of different groundnut varieties was carried out. Moisture content values were shown in Table 2.

3.3. Axial Dimensions

The geometric parameters of groundnut kernels for the five different groundnut varieties are showed in Table 1. Figures 7 - 11 shows the variations of the groundnut kernels three axial magnitudes (length, width and thickness). Groundnut kernels average maximum length value was found in VRI 8 variety (14.69 mm), followed by VRI 5 (13.67 mm), CO 3 (12.71 mm), VRI 3 (12.62 mm) and the minimum length was recorded in VRI 2 (12.39 mm). Groundnut kernels average maximum width value was found in VRI 8 variety (7.77 mm), followed by VRI 3 (7.75 mm), VRI 5 (7.74 mm), VRI 2 (7.73 mm) and the minimum width was recorded in CO 3 (7.70 mm). Groundnut kernels average maximum thickness value was found in VRI 8 variety (8.96 mm), followed by VRI 5 (8.71 mm), CO 3 (8.48 mm), VRI 3 (8.37 mm) and the minimum thickness was recorded in VRI 2 (8.28 mm). Mean values of the dimensions shows a trend towards normal distribution curves (Aydin, 2007; Bagheri et al., 2011) and as well as skewness in the distribution curves (Fasina, 2008) as shown in Figures 7 - 11.

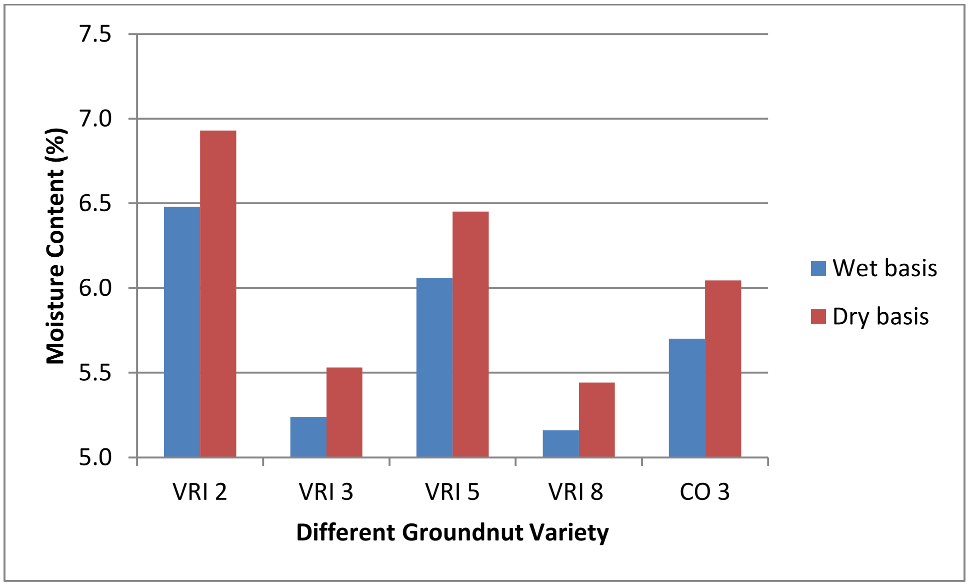

Figure 6 – Moisture Content value for different groundnut varieties

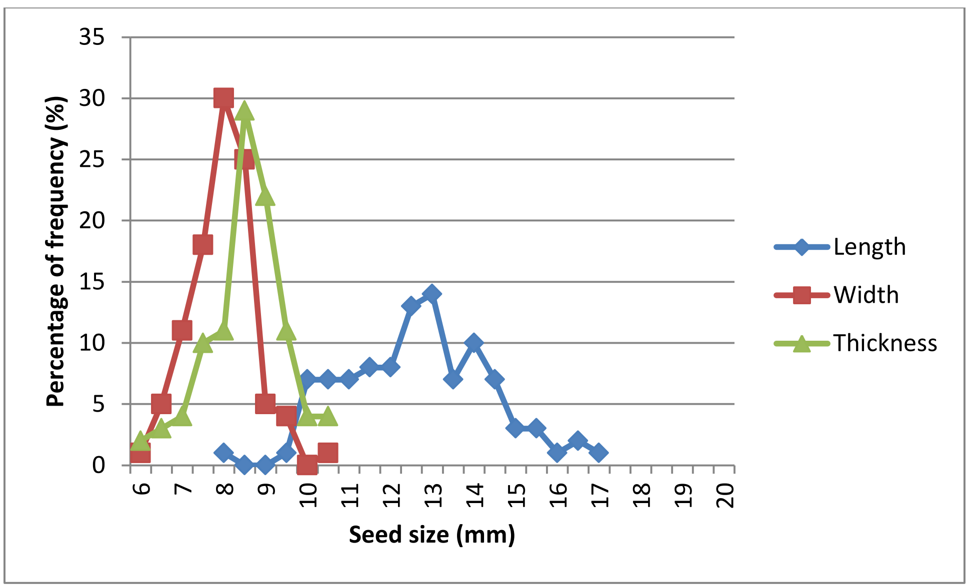

Figure 7 – Frequency distribution curves for VRI 2 Kernels dimensions

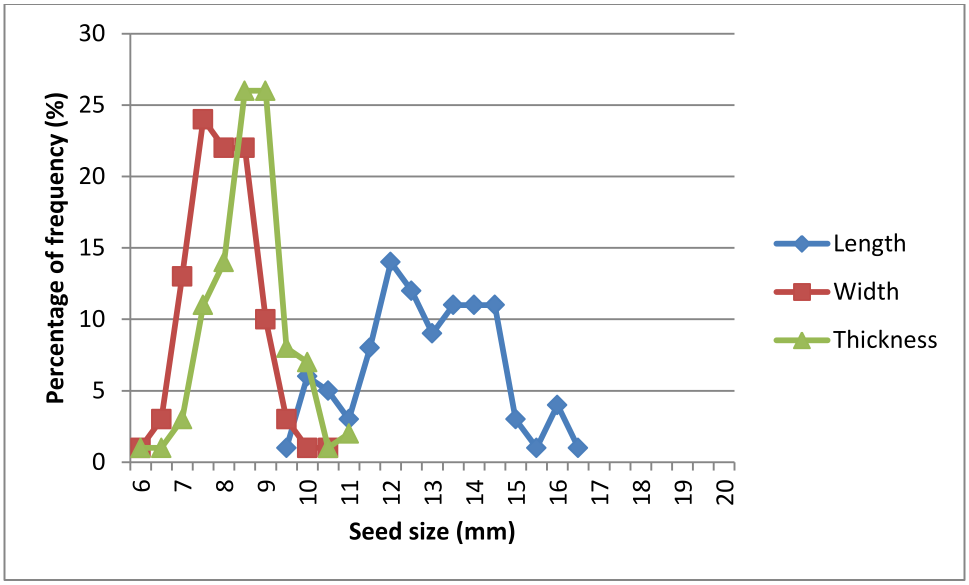

Figure 8 – Frequency distribution curves for VRI 3 Kernels dimensions

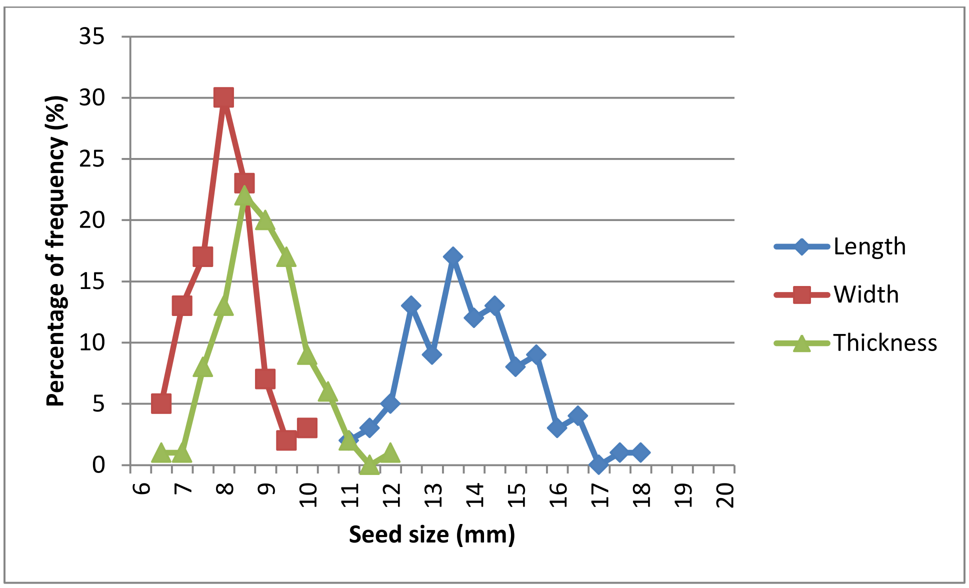

Figure 9 – Frequency distribution curves for VRI 5 Kernels dimensions

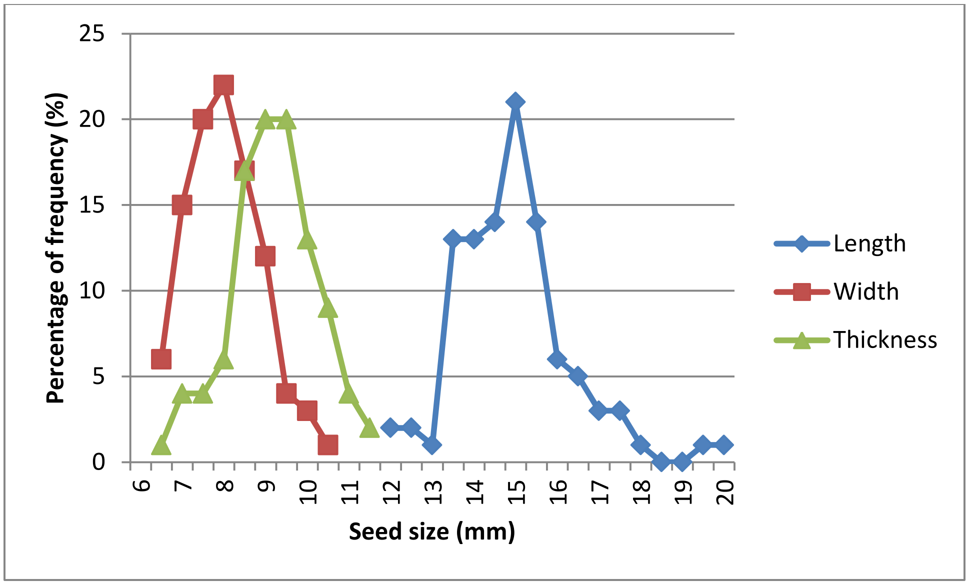

Figure 10 – Frequency distribution curves for VRI 8 Kernels dimensions

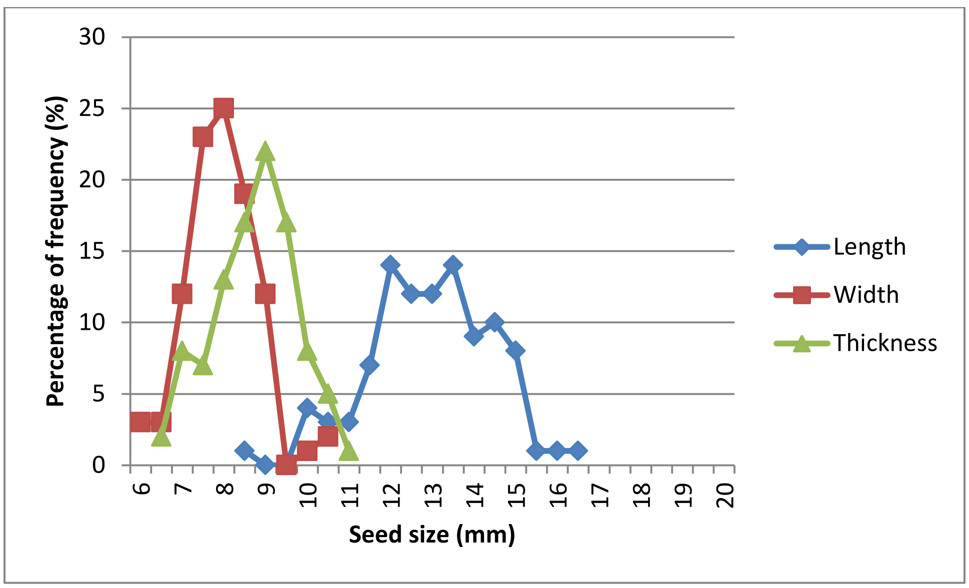

Figure 11 – Frequency distribution curves for CO 3 Kernels dimensions

3.4. Arithmetic Mean Diameter

Groundnut kernels average maximum arithmetic mean diameter value was found in VRI 8 variety (10.48 mm), followed by VRI 5 (10.04 mm), CO 3 (9.63 mm), VRI 3 (9.58 mm) and the minimum arithmetic mean diameter value was recorded in VRI 2 (9.47 mm) as shown in Table 1. Figure 12 shows that VRI 8 records the highest average arithmetic mean diameter and for VRI 2 and VRI 8, most of the values lies in second quartile of the boxplot whereas the mean is not located at center. For VRI 3, VRI 5 and CO 3, mean is not located at the center and most values lies in the third quartile of the boxplot. Circles in VRI 3, VRI 8 and CO 3 indicate the data which are outlined (skewness) from the normal distribution curves. VRI 2 and VRI 5 were properly lies in the normal distribution curves. These values are used to determine the concave openings clearance for groundnut decorticating, separating machines and also important in screening out solids to remove foreign materials from the product (Ofori et al., 2020).

Table 1 - Geometric Parameters of different groundnut varieties (Kernels)

S. No.	Parameters	No. of Observations	VRI 2	VRI 3	VRI 5	VRI 8	CO 3
1	Length, mm	100	12.39 ± 1.70	12.62 ± 1.57	13.67 ± 1.39	14.69 ± 1.34	12.71 ± 1.43
2	Width, mm	100	7.73 ± 0.75	7.75 ± 0.77	7.74 ± 0.76	7.77 ± 0.88	7.70 ± 0.81
3	Thickness, mm	100	8.28 ± 0.95	8.37 ± 0.87	8.71 ± 0.94	8.96 ± 0.98	8.48 ± 0.98
4	AMD, mm	100	9.47 ± 0.85	9.58 ± 0.62	10.04 ± 0.60	10.48 ± 0.70	9.63 ± 0.64
5	GMD, mm	100	9.23 ± 0.81	9.31 ± 0.56	9.70 ± 0.56	10.05 ± 0.72	9.36 ± 0.62
6	SMD, mm	100	6.39 ± 0.38	6.44 ± 0.27	6.63 ± 0.26	6.80 ± 0.31	6.46 ± 0.28
7	EQD, mm	100	8.36 ± 0.68	8.44 ± 0.48	8.79 ± 0.47	9.11 ± 0.57	8.48 ± 0.51
8	Sphericity	100	0.75 ± 0.08	0.75 ± 0.07	0.71 ± 0.06	0.69 ± 0.06	0.74 ± 0.07
9	Volume, mm^3	100	134.05 ± 33.94	136.13 ± 24.78	153.43 ± 26.75	171.70 ± 37.18	138.34 ± 28.01
10	Surface area, mm^2	100	269.56 ± 46.32	273.37 ± 33.06	296.15 ± 34.38	318.66 ± 45.73	276.12 ± 36.78
11	Aspect Ratio	100	0.63 ± 0.11	0.63 ± 0.11	0.57 ± 0.07	0.53 ± 0.07	0.61 ± 0.10
12	Shape factor	100	2.63 ± 0.19	2.62 ± 0.24	2.51 ± 0.19	2.43 ± 0.16	2.58 ± 0.24

*Values represented in table are mean values ±standard deviation values

3.5. Geometric Mean Diameter

Groundnut kernels average maximum geometric mean diameter value was found in VRI 8 variety (10.05 mm), followed by VRI 5 (9.70 mm), CO 3 (9.36 mm), VRI 3 (9.31 mm) and the minimum geometric mean diameter value was recorded in VRI 2 (9.23 mm) as shown in Table 1. Figure 13 shows that VRI 8 records the highest average geometric mean diameter and for VRI 2 and VRI 8, most of the values lies in second quartile of the boxplot whereas the mean is not located at center. For VRI 3, VRI 5 and CO 3, mean is not located at the center and most values lies in the third quartile of the boxplot. Circles in VRI 3, VRI 8 and CO 3 indicate the data which are outlined (skewness) from the normal distribution curves. VRI 2 and VRI 5 were properly lies in the normal distribution curves. These values are used to determine the concave openings clearance for groundnut decorticating, separating machines and also important in screening out solids to remove foreign materials from the product (Ofori et al., 2020).

3.6. Square Mean Diameter

Groundnut kernels average maximum square mean diameter value was found in VRI 8 variety (6.80 mm), followed by VRI 5 (6.63 mm), CO 3 (6.46 mm), VRI 3 (6.44 mm) and the minimum square mean diameter value was recorded in VRI 2 (6.39 mm) as shown in Table 1. Figure 14 shows that VRI 8 records the highest average square mean diameter and for VRI 2 and VRI 8, most of the values lies in second quartile of the boxplot whereas the mean is not located at center. For VRI 3 and VRI 5, mean is not located at the center and most values lies in the third quartile of the boxplot. Mean is exactly located at center for CO 3 variety. Circles in VRI 3, VRI 8 and CO 3 indicate the data which are outlined (skewness) from the normal distribution curves. VRI 2 and VRI 5 were properly lies in the normal distribution curves. These values are used to determine the concave openings clearance for groundnut decorticating, separating machines and also important in screening out solids to remove foreign materials from the product (Ofori et al., 2020).

3.7. Equivalent Diameter

Groundnut kernels average maximum equivalent diameter value was found in VRI 8 variety (9.11 mm), followed by VRI 5 (8.79 mm), CO 3 (8.48 mm), VRI 3 (8.44 mm) and the minimum equivalent diameter value was recorded in VRI 2 (8.36 mm) as shown in Table 1. Figure 15 shows that VRI 8 records the highest average equivalent diameter and for VRI 2 & VRI 8, most of the values lies in second quartile of the boxplot whereas the mean is not located at center. For VRI 3 and VRI 5, mean is not located at the center and most values lies in the third quartile of the boxplot. Mean is exactly located at center for CO 3 variety. Circles in VRI 3, VRI 8 and CO 3 indicate the data which are outlined (skewness) from the normal distribution curves. VRI 2 and VRI 5 were properly lies in the normal distribution curves. These values are used to determine the concave openings clearance for groundnut decorticating, separating machines and also important in screening out solids to remove foreign materials from the product (Ofori et al., 2020).

3.8. Sphericity

Groundnut kernels average maximum sphericity value was found in VRI 2 and VRI 3 varieties (0.75), followed by CO 3 (0.74), VRI 5 (0.71) and the minimum sphericity value was recorded in VRI 8 (0.69) as shown in Table 1. Figure 16 shows that VRI 2 and VRI 3 records the highest average sphericity and for VRI 5, most of the values lies in second quartile of the boxplot whereas the mean is not located at center. For VRI 2, VRI 3, VRI 8 and CO 3, mean is not located at the center and most values lies in the third quartile of the boxplot. Circles in VRI 2, VRI 5 and CO 3 indicate the data which are outlined (skewness) from the normal distribution curves. VRI 3 and VRI 8 were properly lies in the normal distribution curves. Sphericity value for all the varieties indicates the higher values, so groundnut kernels has more ability to roll than slide which is important while designing hopper and conveying equipment (Chukwu et al., 2018). Smaller seeds results in higher sphericity (Mpotokwane et al., 2008).

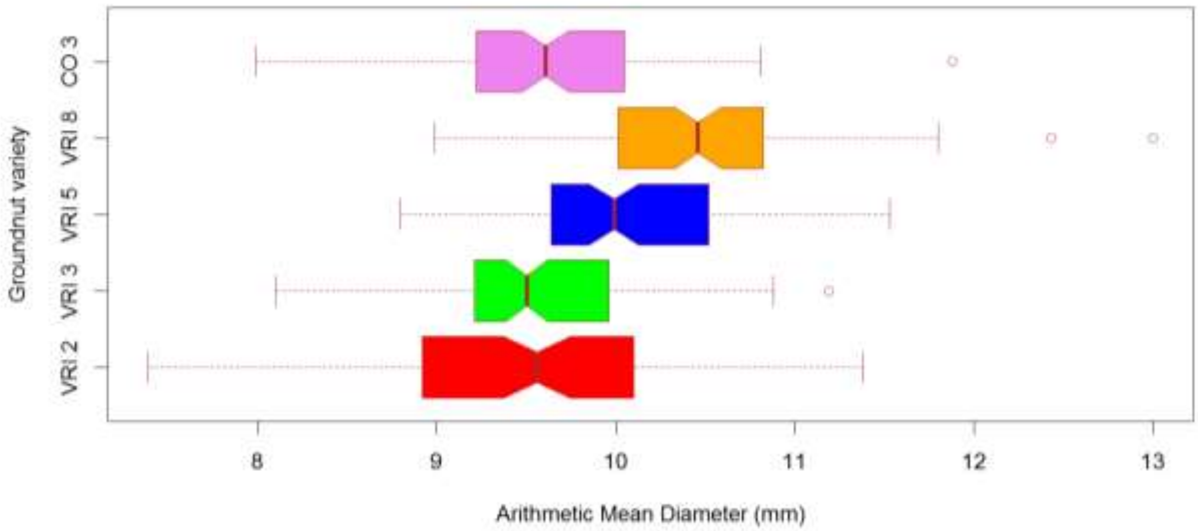

Figure 12 – Frequency distribution of Arithmetic Mean Diameter for different groundnut varieties

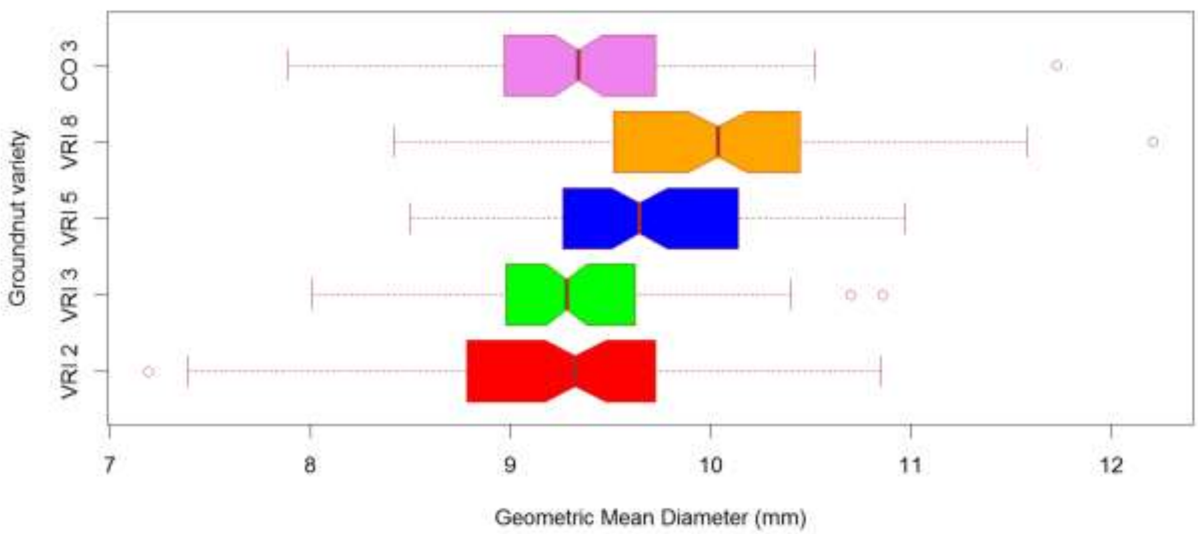

Figure 13 – Frequency distribution of Geometric Mean Diameter for different groundnut varieties

3.9. Aspect Ratio

Groundnut kernels average maximum aspect ratio value was found in VRI 2 and VRI 3 varieties (0.63), followed by CO 3 (0.61), VRI 5 (0.57) and the minimum aspect ratio value was recorded in VRI 8 (0.53) as shown in Table 1. Figure 17 shows that VRI 2 and VRI 3 records the highest average aspect ratio and for VRI 3, VRI 5 and CO 3, mean is not located at the center and most values lies in the third quartile of the boxplot. Mean is exactly located at the center for

VRI 2 and VRI 8 variety. Circles in VRI 2, VRI 5, VRI 8 and CO 3 indicate the data which are outlined (skewness) from the normal distribution curves. VRI 3 was properly lies in the normal distribution curves. Aspect ratio value for all the varieties indicates the higher values, so groundnut kernels has more ability to roll than slide which is important while designing hopper and conveying equipment (Chukwu et al., 2018). Smaller seeds results in higher aspect ratio (Mpotokwane et al., 2008).

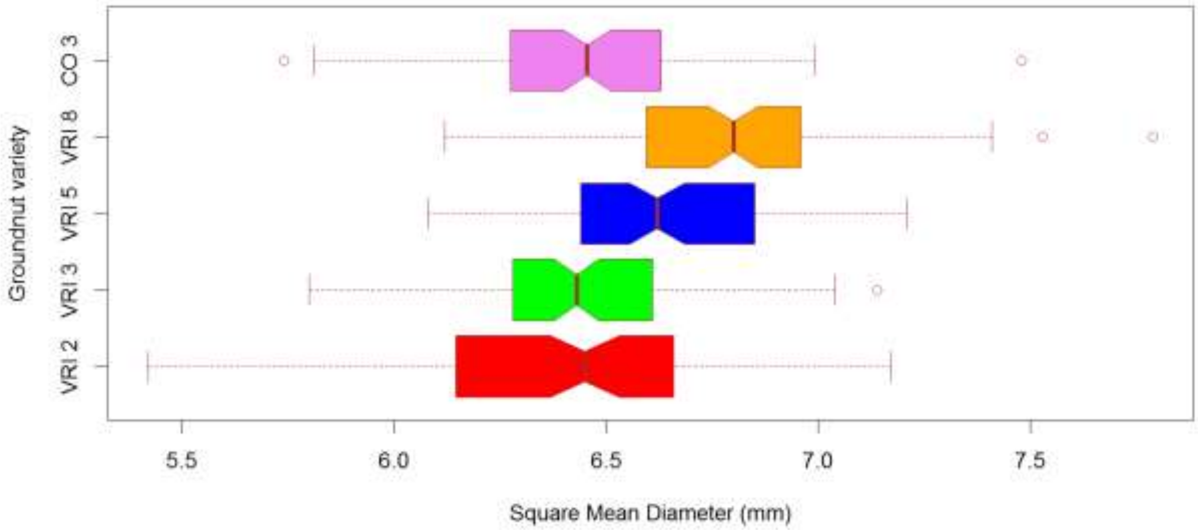

Figure 14 – Frequency distribution of Square Mean Diameter for different groundnut varieties

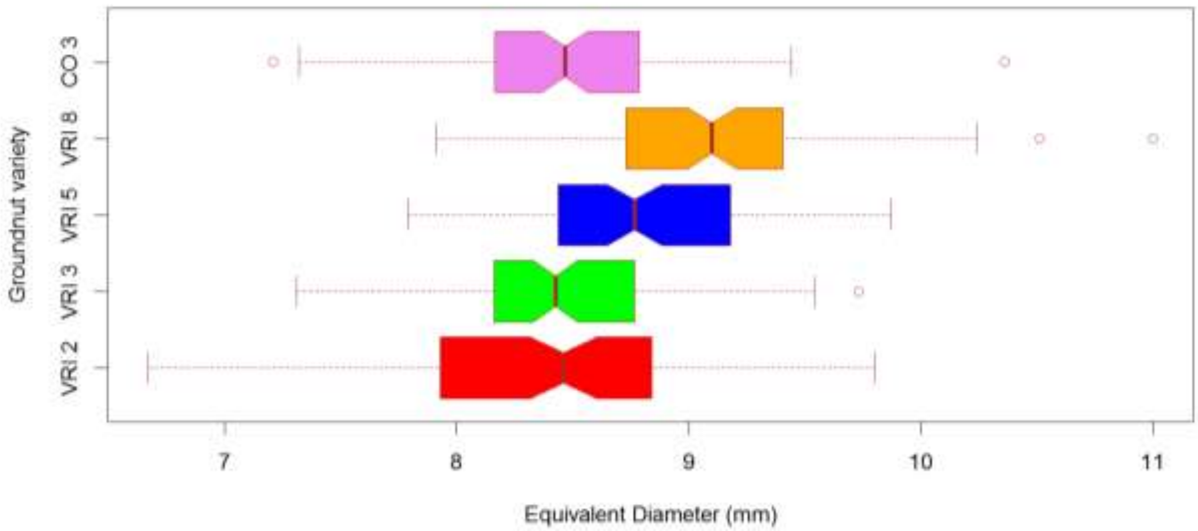

Figure 15 – Frequency distribution of Equivalent Diameter for different groundnut varieties

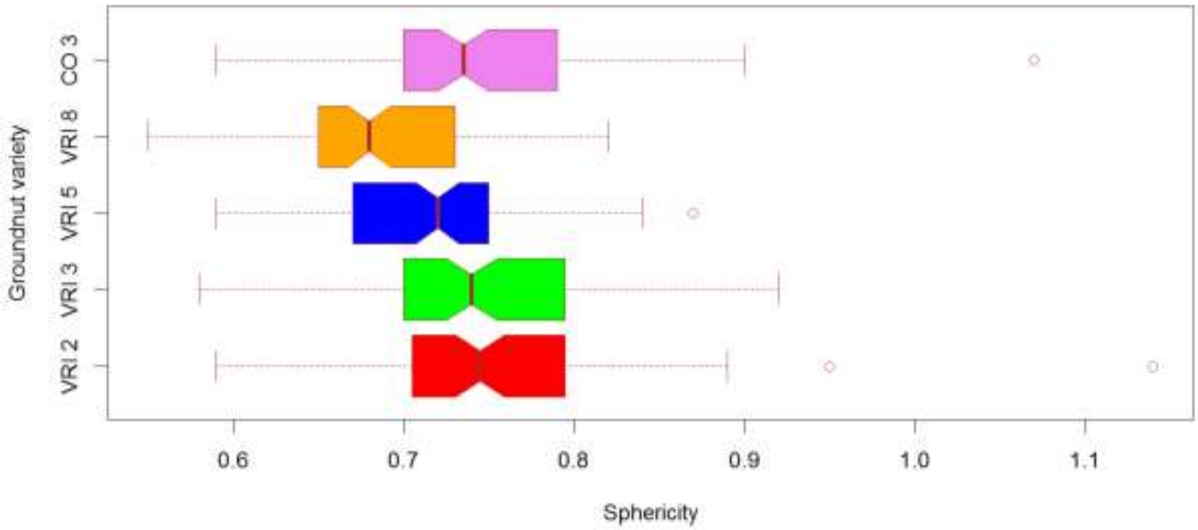

Figure 16 – Frequency distribution of Sphericity for different groundnut varieties

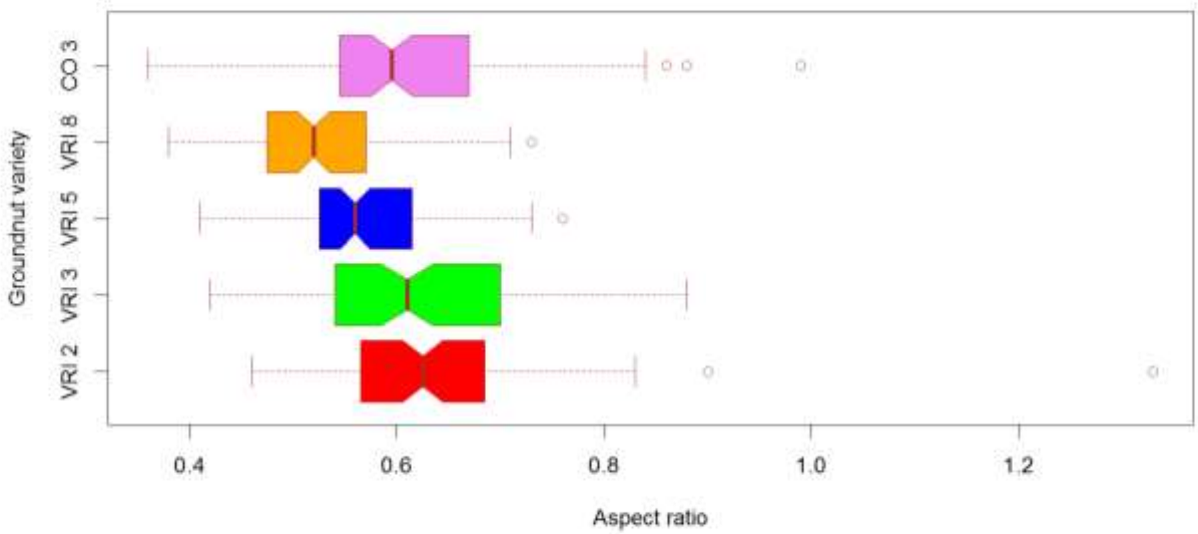

Figure 17 – Frequency distribution of Aspect Ratio for different groundnut varieties

3.10. Volume

Groundnut kernels average maximum volume value was found in VRI 8 variety (171.70 mm^3), followed by VRI 5 (153.43 mm^3), CO 3 (138.34 mm^3), VRI 3 (136.13 mm^3) and the minimum volume value was recorded in VRI 2 (134.05 mm^3) as shown in Table 1. Figure 18 shows that VRI 8 records the highest average volume and for VRI 2 & VRI 8, most of the values lies in second quartile of the boxplot whereas the mean is not located at center. For VRI 3 and CO 3, mean is almost located at center and most values lies in the third quartile of the boxplot. For VRI 5, mean is not located at center and most values lies in the third quartile of the boxplot. Circles in VRI 3, VRI 8 and CO 3 indicate the data which are outlined (skewness) from the normal distribution curves. VRI 2 and VRI 5 were properly lies in the normal distribution curves. Larger seeds results in higher volume (Mpotokwane et al., 2008).

3.11. Surface Area

Groundnut kernels average maximum surface area value was found in VRI 8 variety (318.66 mm^2), followed by VRI 5 (296.15 mm^2), CO 3 (276.12 mm^2), VRI 3 (273.37 mm^2) and the minimum surface area value was recorded in VRI 2 (269.56 mm^2) as shown in Table 1. Figure 19 shows that VRI 8 records the highest average surface area and for VRI 2 & VRI 8, most of the values lies in second quartile of the boxplot whereas the mean is not located at center. For VRI 3 and CO 3, mean is almost located at center and most values lies in the third quartile of the boxplot. For VRI 5, mean is not located at center and most values lies in the third quartile of the boxplot. Circles in VRI 3, VRI 8 and CO 3 indicate the data which are outlined (skewness) from the normal distribution curves. VRI 2 and VRI 5 were properly lies in the normal distribution curves. Larger seeds results in higher surface area (Mpotokwane et al., 2008).

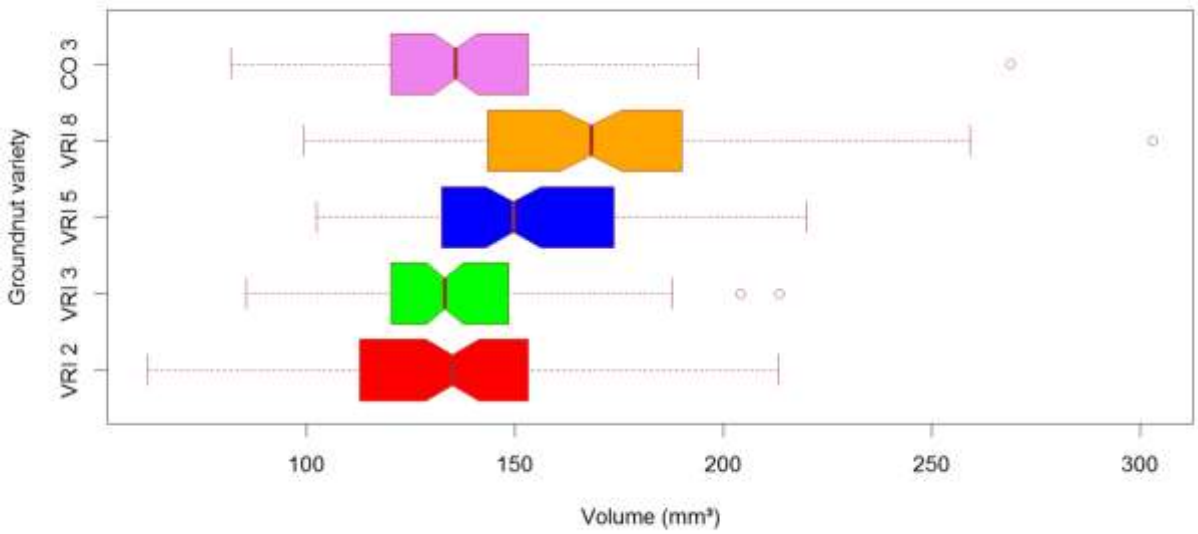

Figure 18 – Frequency distribution of Volume for different groundnut varieties

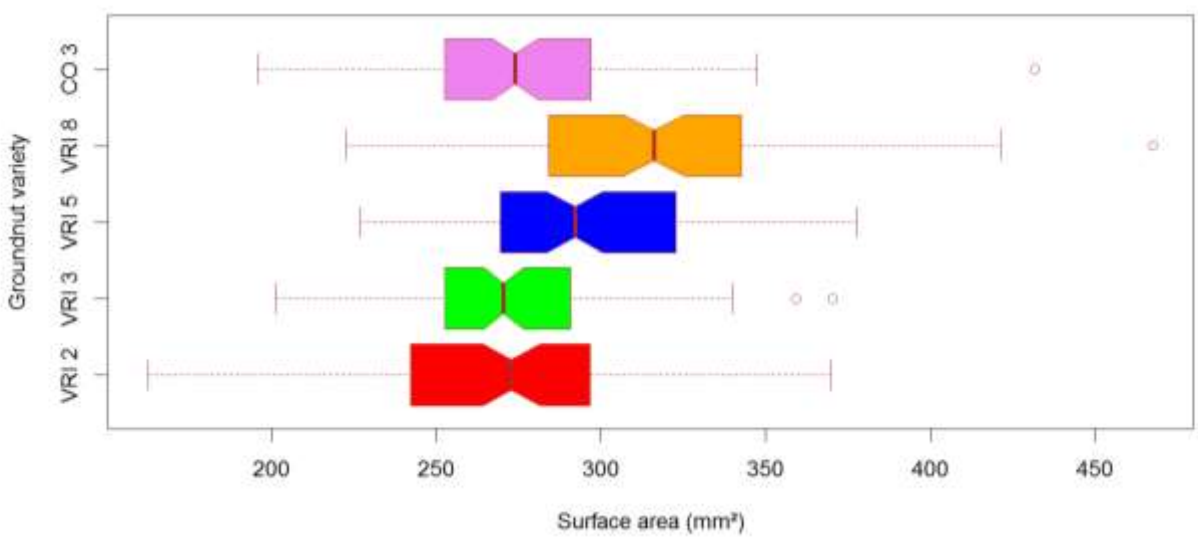

Figure 19 – Frequency distribution of Surface Area for different groundnut varieties

3.12. Shape Factor

Groundnut kernels average maximum shape factor value was found in VRI 2 variety (2.63), followed by VRI 3 (2.62), CO 3 (2.58), VRI 5 (2.51) and the minimum shape factor value was recorded in VRI 8 (2.43) as shown in Table 1. Figure 20 shows that VRI 2 records the highest average shape factor and for VRI 2, VRI 5 and VRI 8, most of the values lies in second quartile of the boxplot whereas the mean is not located at center. For VRI 3 and CO 3, mean is not located at the center and most values lies in the third quartile of the boxplot. Circles in boxplot indicate the data which are outlined (skewness) from the normal distribution curves. Since all the data of each different variety had a value of greater than 1.5, this kernels was observed to be oblong in shape.

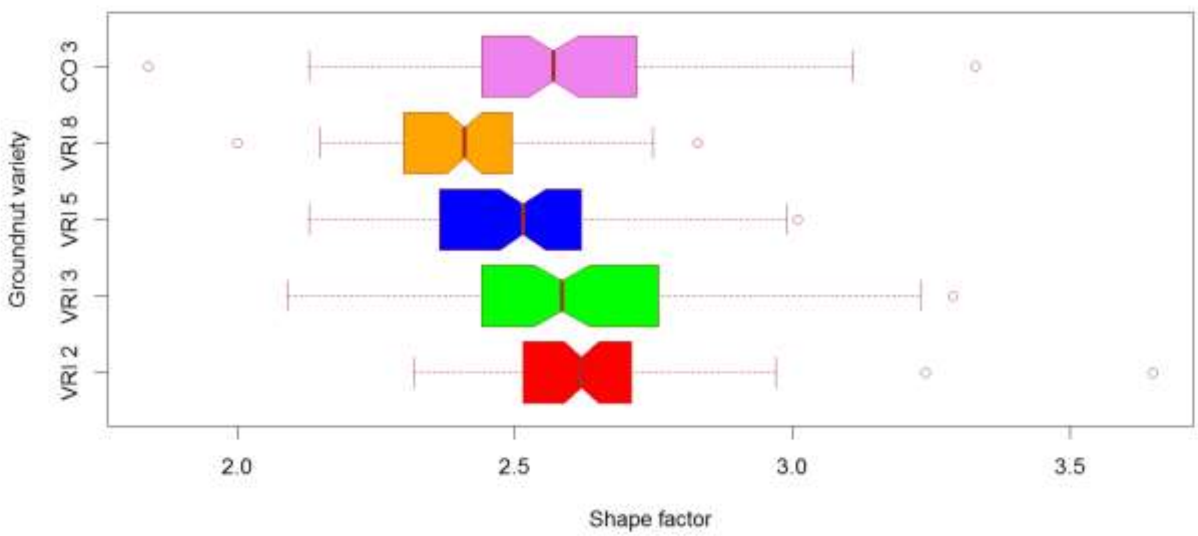

Figure 20 – Frequency distribution of Shape Factor for different groundnut varieties

3.13. Bulk Density (ρ_b)

The gravimetric parameters of groundnut kernels for the five different groundnut varieties are shown in Table 2. Groundnut kernels average maximum bulk density value was found in VRI 2 variety (716.89 kg/m^3), followed by VRI 3 (715.11 kg/m^3), CO 3 (714.21 kg/m^3), VRI 5 (713.15 kg/m^3) and the minimum bulk density value was recorded in VRI 8 (708.06 kg/m^3) as shown in Table 2. Figure 22 shows the average bulk density values for different groundnut varieties. This property is useful when designing the groundnut sheller for evaluating maximum load that seed separators can resist without breaking down during groundnut shelling operation and also used for estimating the aero and hydrodynamic separation of groundnut kernels from foreign material and imposed pressures during design of silo bottoms (Falade & Nwajei, 2015; Ofori et al., 2020).

3.14. True Density (ρ_t)

Groundnut kernels average maximum true density value was found in VRI 2 variety (1575.36 kg/m^3), followed by VRI 3 (1535.45 kg/m^3), CO 3 (1490.53 kg/m^3), VRI 5 (1459.49

kg/m^3) and the minimum true density value was recorded in VRI 8 (1428.36 kg/m^3) as shown in Table 2. Figure 23 shows the average true density values for different groundnut varieties. This property is useful when designing the groundnut sheller for evaluating maximum load that seed separators can resist without breaking down during groundnut shelling operation and also used for estimating the aero and hydrodynamic separation of groundnut kernels from foreign material and imposed pressures during design of silo bottoms (Ofori et al., 2020). Differences in density values of different varieties of groundnut kernels can also be due to variations in their volume, shape and weight characteristics (Jan et al., 2019).

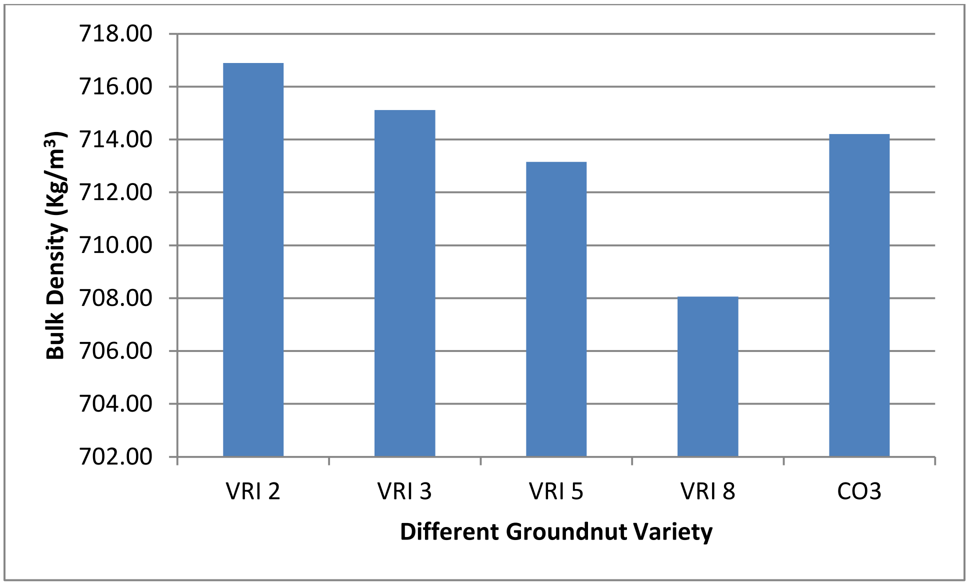

Figure 22 – Bulk Density value for different groundnut varieties

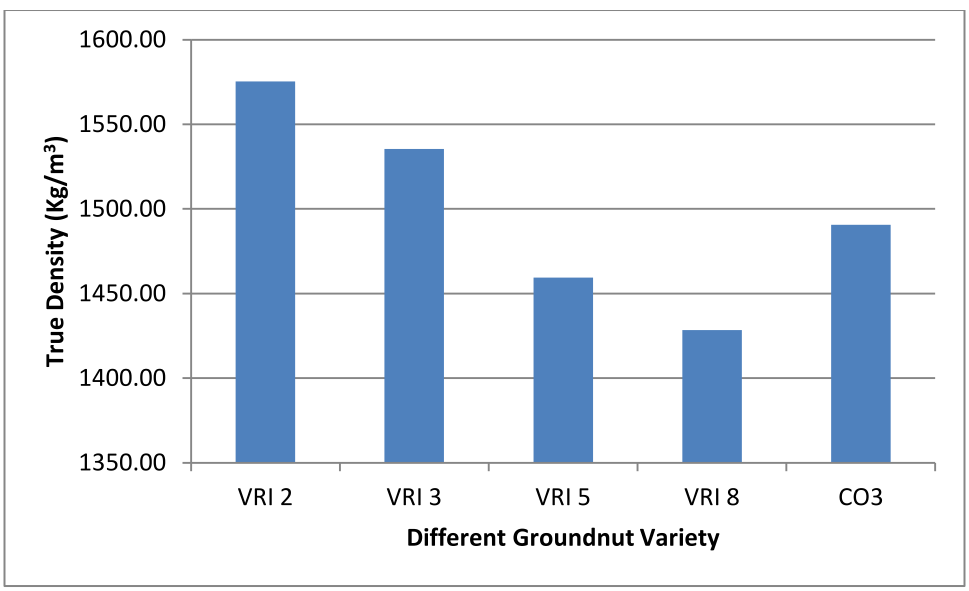

Figure 23 – True Density value for different groundnut varieties

Table 2 - Gravimetric Parameters of different groundnut varieties (Kernels)

S. No.	Parameters	No. of Observations	VRI 2	VRI 3	VRI 5	VRI 8	CO 3
1	Moisture content (w.b.), %		6.5	5.2	6.1	5.2	5.7
	Moisture content (d.b.), %		6.9	5.5	6.5	5.4	6.0
2	1000 Unit Mass, g	10	338.36 ± 5.88	441.89 ± 5.56	573.01 ± 4.85	954.18 ± 4.27	482.89 ± 5.20
3	Bulk density, kg/m^3	10	716.89 ± 24.76	715.11 ± 30.77	713.15 ± 22.07	708.06 ± 24.20	714.21 ± 27.90
4	True density, kg/m^3	10	1575.36 ± 139.30	1535.45 ± 76.20	1459.49 ± 91.19	1428.36 ± 166.15	1490.53 ± 123.38
5	Porosity, %		54.23 ± 3.36	53.28 ± 3.44	50.91 ± 3.86	49.87 ± 5.12	51.83 ± 3.57

*Values represented in table are mean values ±standard deviation values

3.15. Porosity (ε)

Groundnut kernels average maximum porosity value was found in VRI 2 variety (54.23 %), followed by VRI 3 (53.28 %), CO 3 (51.83 %), VRI 5 (50.91 %) and the minimum porosity value was recorded in VRI 8 (49.87 %) as shown in Table 2. Figure 24 shows the porosity values for different groundnut varieties. This property is useful when developing equipment for material handling such as drying, storage, aeration and ventilation and also useful determinant property for estimating material transport in pneumatic conveyors. Porosity is a critical parameter among others for equipment design (Ofori et al., 2020).

3.16. Thousand Unit Mass

Groundnut kernels average maximum thousand unit mass value was found in VRI 8 variety (954.18 g), followed by VRI 5 (573.01 g), CO 3 (482.89 g), VRI 3 (441.89 g) and the minimum thousand unit mass value was recorded in VRI 2 (338.36 g) as shown in Table 2. Figure 25 shows the average thousand unit mass values for different groundnut varieties. The thousand unit mass is useful when calculating the size of grain holder units (hoppers) and shelling compartments of machines for processing and also stability of the machine during operations such as size reduction and planting (Ofori et al., 2020).

3.17. Angle of Repose

The frictional parameters of groundnut kernels for the five different groundnut varieties are showed in Table 3. Groundnut kernels average maximum angle of repose value was found in VRI 8 variety (24.94°), followed by VRI 5 (24.10°), CO 3 (23.55°), VRI 3 (23.52°) and the minimum angle of repose value was recorded in VRI 2 (23.12°) as shown in Table 3. Figure 26 shows the angle of repose values for different groundnut varieties. This results indicates that higher the aspect ratio, lower the angle of repose and larger the seed size, higher the angle of repose. This property is useful while designing planting machine seed hoppers, sieve shaker placement in threshers, silos and storage containers to allow easy sliding of materials (Ofori et al., 2020).

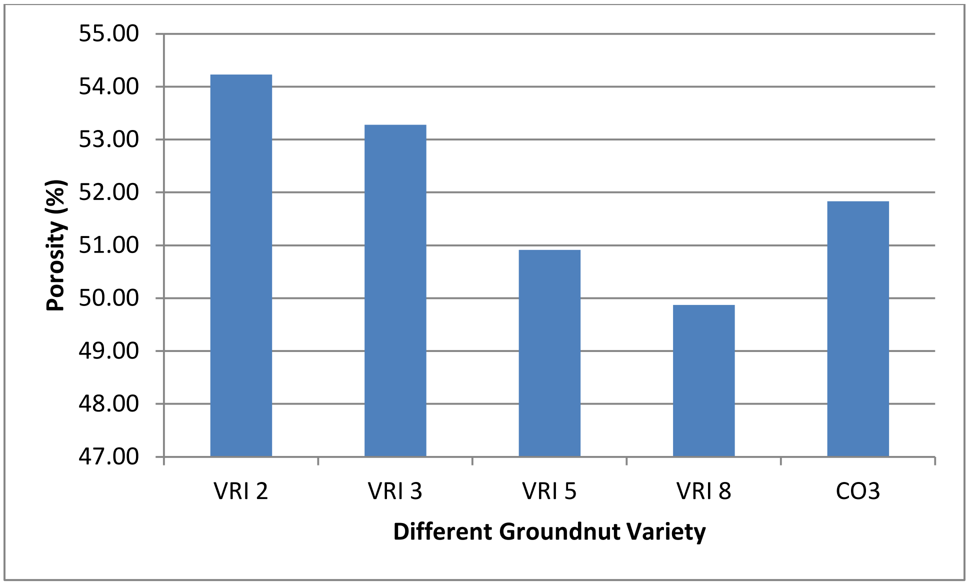

Figure 24 – Porosity value for different groundnut varieties

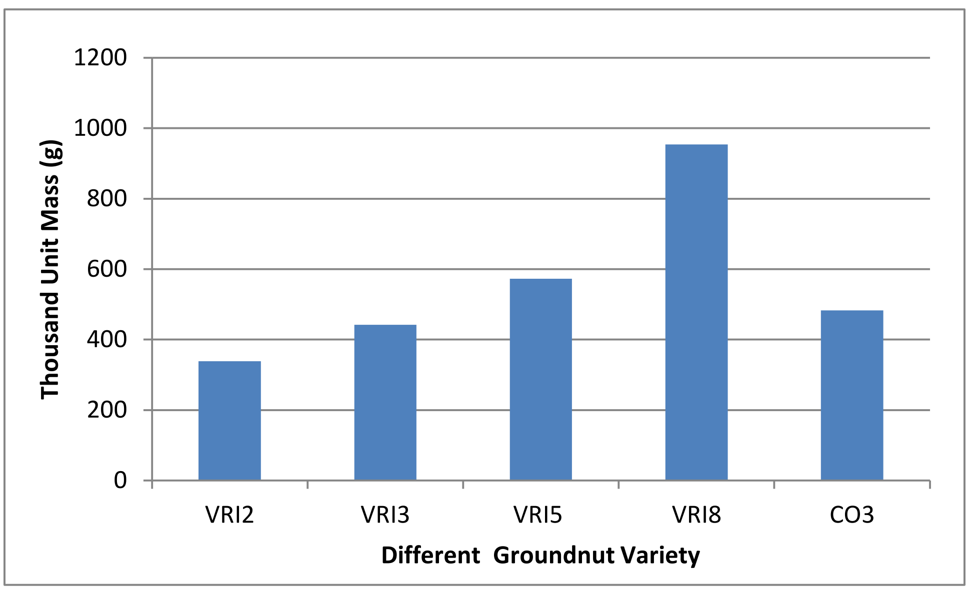

Figure 25 – Thousand Unit Mass value for different groundnut varieties

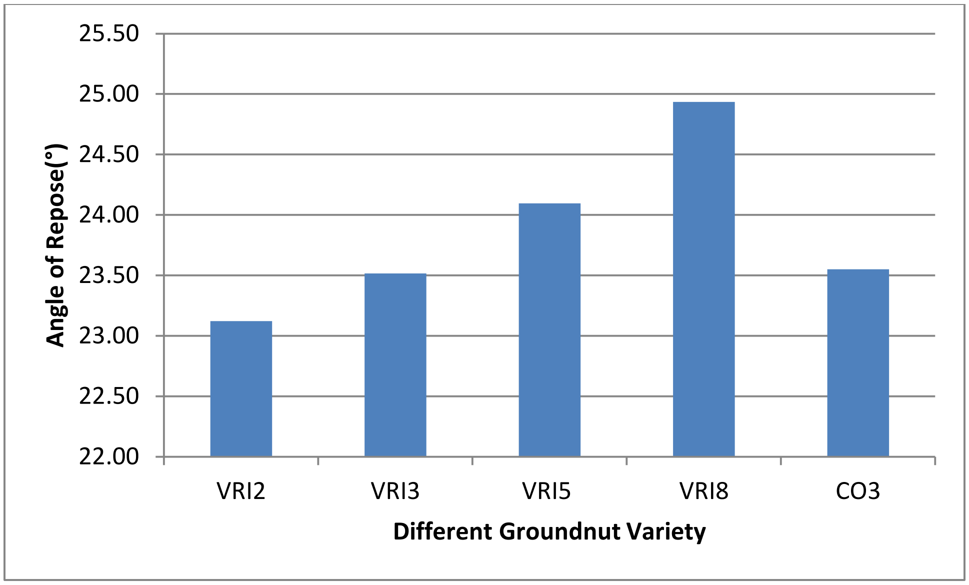

Figure 26 – Angle of Repose value for different groundnut varieties

Table 3 - Frictional Parameters of different groundnut varieties (Kernels)

S.No.	Parameters		No. of Observations	VRI 2	VRI 3	VRI 5	VRI 8	CO 3
1	Average Angle of repose, degrees		10	23.12 ± 0.49	23.52 ± 0.42	24.10 ± 0.70	24.94 ± 0.64	23.55 ± 0.48
2	Average Static coefficient of friction							
	1	Galvanized Iron	10	0.43	0.42	0.43	0.43	0.43
	2	Stainless Steel	10	0.24	0.26	0.28	0.30	0.27
	3	Mild Steel	10	0.48	0.49	0.52	0.52	0.50
	4	Aluminium	10	0.45	0.45	0.47	0.47	0.45
	5	Plywood	10	0.43	0.43	0.46	0.47	0.44
	6	Rubber	10	0.50	0.51	0.56	0.57	0.54

*Values represented in table are mean values ±standard deviation values

3.18. Static Coefficient of Friction

Groundnut kernels average maximum static coefficient of friction value for galvanized iron was found in VRI 2, VRI 5, VRI 8 and CO 3 varieties (0.43) and the minimum static coefficient of friction value was recorded in VRI 3 (0.42) as shown in Table 3. Groundnut kernels average maximum static coefficient of friction value for stainless steel was found in VRI 8 variety (0.30), followed by VRI 5 (0.28), CO 3 (0.27), VRI 3 (0.26) and the minimum static coefficient of friction value was recorded in VRI 2 (0.24) as shown in Table 3. Groundnut kernels average maximum static coefficient of friction value for mild steel was found in VRI 5 and VRI 8 varieties (0.52), followed by CO 3 (0.50), VRI 3 (0.49) and the minimum static coefficient of friction value was recorded in VRI 2 (0.48) as shown in Table 3. Groundnut kernels average maximum static coefficient of friction value for aluminium was found in VRI 5 and VRI 8 varieties (0.47) and the minimum static coefficient of friction value was recorded in VRI 2, VRI 3 and CO 3 varieties (0.45) as shown in Table 3. Groundnut kernels average maximum static coefficient of friction value for plywood was found in VRI 8 variety (0.47), followed by VRI 5 (0.46), CO 3 (0.44) and the minimum static coefficient of friction value was recorded in VRI 2 and VRI 3 varieties (0.43) as shown in Table 3. Groundnut kernels average maximum static coefficient of friction value for rubber was found in VRI 8 variety (0.57), followed by VRI 5 (0.56), CO 3 (0.54), VRI 3 (0.51) and the minimum static coefficient of friction value was recorded in VRI 2 (0.50) as shown in Table 3. This results indicates that the surface which is having more grip gives the higher friction values and the surface with lesser grip values gives lesser friction values and also the larger seeds results in higher friction values and smaller seeds results in lower friction values. Maximum static coefficient of friction was obtained in rubber material for VRI 8 variety of 0.57 and minimum static coefficient of friction was obtained in stainless steel material foe VRI 2 variety of 0.24 respectively. Figure 27 – 32 shows the static coefficient of friction values on different surfaces for different groundnut varieties. This property is useful while designing dimension of hoppers, bunker silos and other bulk solid storage and handling structures. It is a dependent variable needed for selecting materials for fabrication and power required for transporting a given biological material (Ofori et al., 2020).

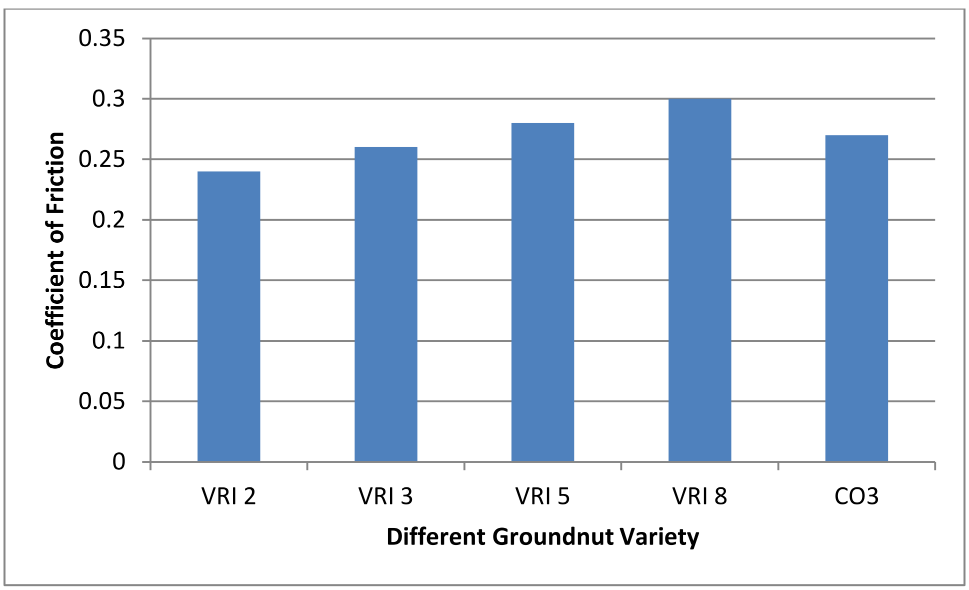

Figure 27 – Static Coefficient of Friction value on Stainless Steel surface for different groundnut varieties

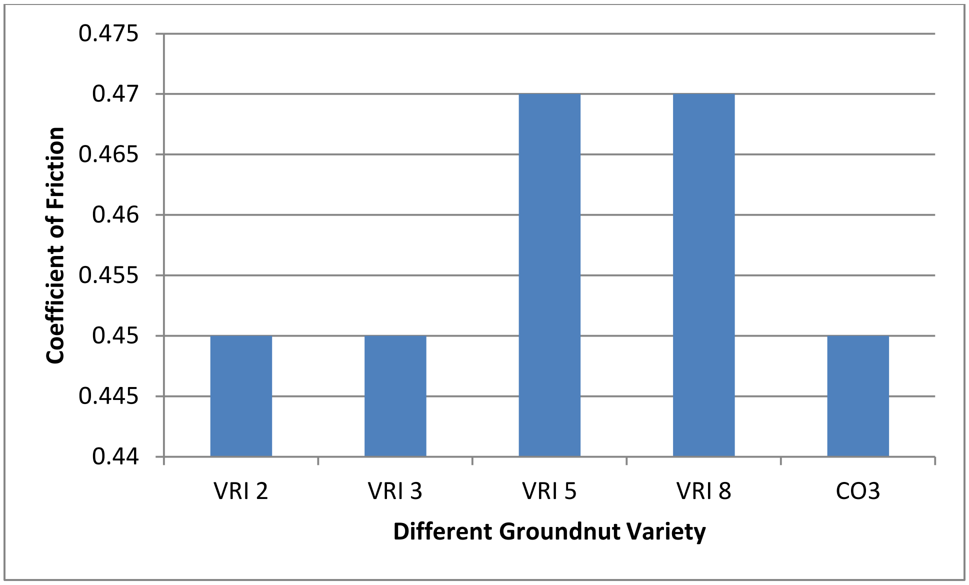

Figure 28 – Static Coefficient of Friction value on Aluminium surface for different groundnut varieties

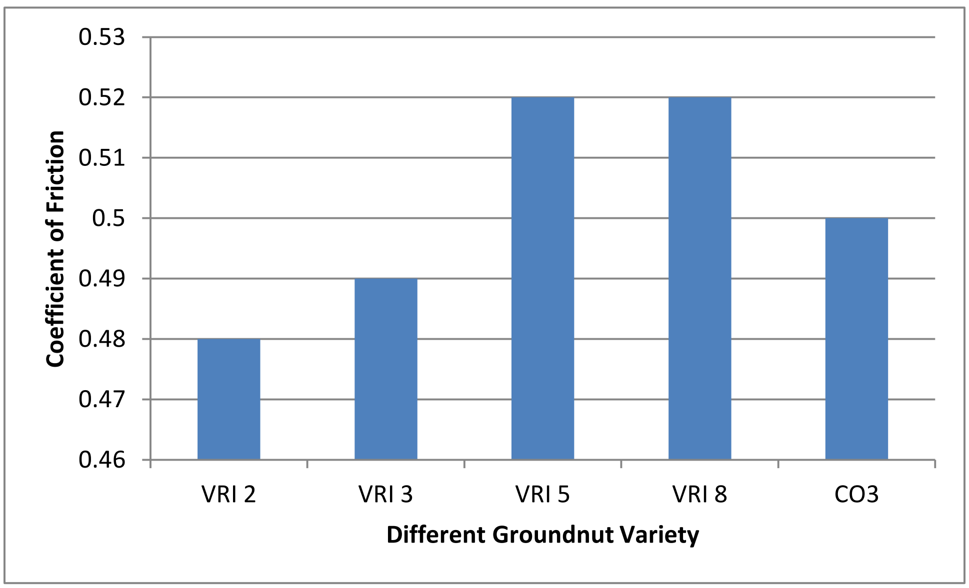

Figure 29 – Static Coefficient of Friction value on Mild Steel surface for different groundnut varieties

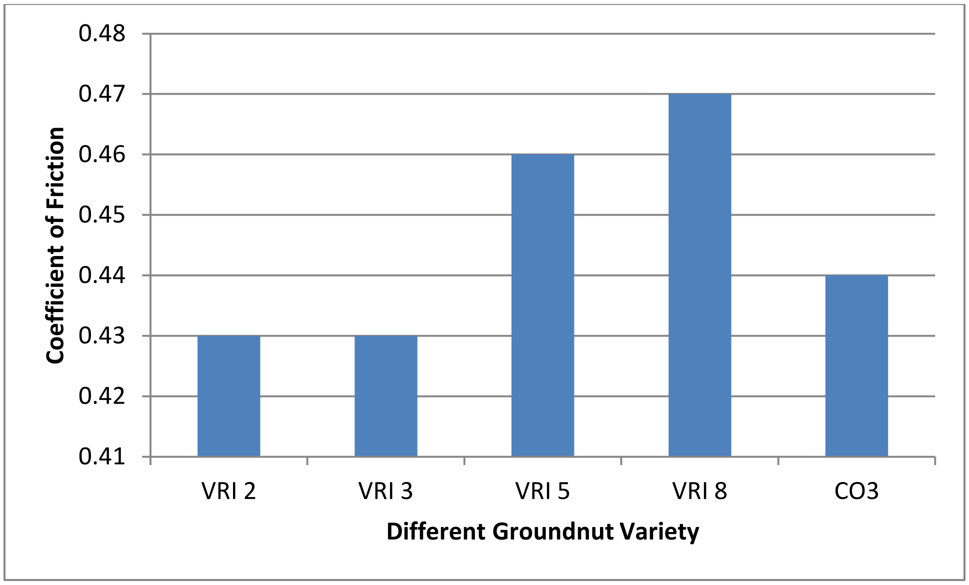

Figure 30 – Static Coefficient of Friction value on Plywood surface for different groundnut varieties

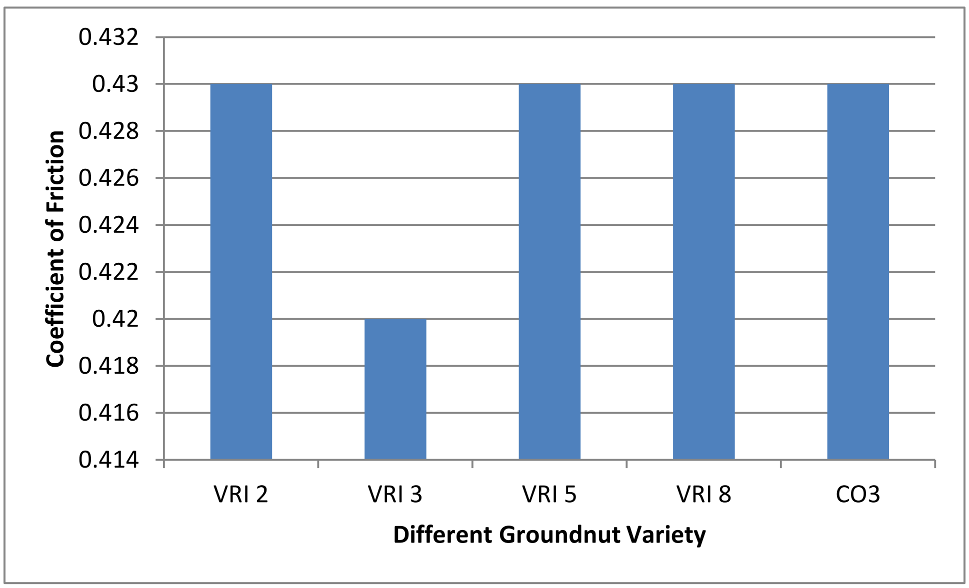

Figure 31 – Static Coefficient of Friction value on Galvanized Iron surface for different groundnut varieties

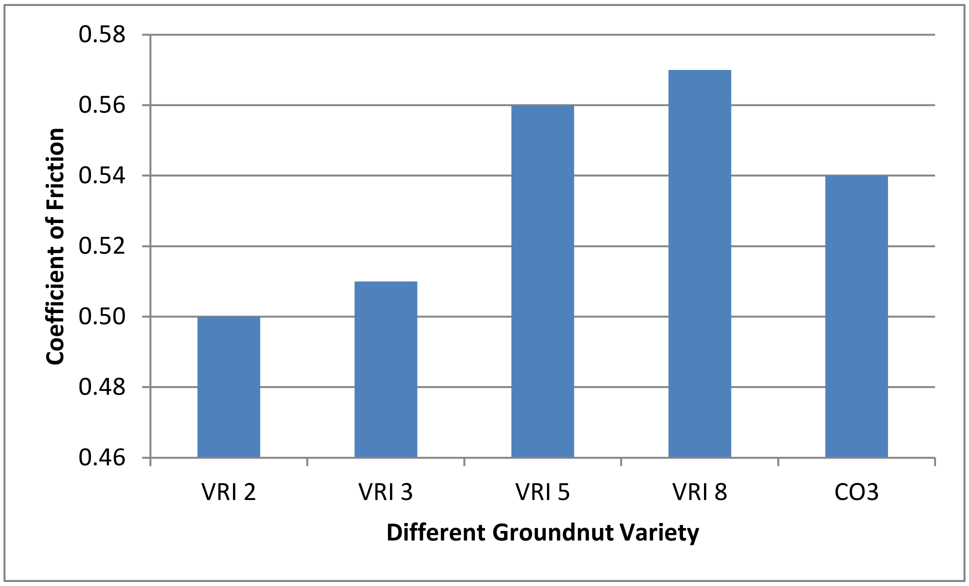

Figure 32 – Static Coefficient of Friction value on Rubber surface for different groundnut varieties

4. Conclusions

This study was undertaken to determine the engineering properties of groundnut kernels of five different varieties *viz.*, VRI 2, VRI 3, VRI 5, VRI 8 and CO 3. It is evident from the study that VRI 8 is larger in Principal dimensions, Arithmetic mean diameter, Geometric mean diameter, Square mean diameter, Equivalent diameter, Volume, Surface area, Thousand unit mass, Angle of repose, Static coefficient of friction (Galvanized iron, Stainless steel, Mild steel, Aluminium, Plywood and Rubber surfaces), whereas it exhibits less Bulk density, True density and Porosity. Equipment designs mostly depends on the engineering properties of groundnut kernels for easy, efficient, proper and economical equipment design and useful to design the agriculture machine in harvesting, threshing, shelling, and postharvest processing operation. The values of length, width, thickness, arithmetic mean diameter, geometric mean diameter, square mean diameter, equivalent diameter, sphericity, aspect ratio, shape factor, volume, surface area, moisture content (d.b.), 1000 unit mass, true density, bulk density, porosity, angle of repose and static coefficient of friction were ranged between 12.39 – 14.69 mm, 7.70 – 7.77 mm, 8.28 – 8.96 mm, 9.47 – 10.48 mm, 9.23 – 10.05 mm, 6.39 – 6.80 mm, 8.36 – 9.11 mm, 0.69 – 0.75, 0.53 – 0.63, 2.43 – 2.63, 134.05 – 171.70 mm^3, 269.56 – 318.66 mm^2, 5.4 – 6.9 %, 338.36 – 954.18 g, 1428.36 – 1575.36 kg/m^3, 708.06 – 716.89 kg/m^3, 49.87 – 54.23 %, 23.12 – 24.94 °, 0.42 – 0.43 for galvanized iron, 0.24 – 0.30 for stainless steel, 0.48 – 0.52 for mild steel, 0.45 – 0.47 for aluminium, 0.43 – 0.47 for plywood and 0.50 – 0.57 for rubber respectively. It is proposed that the engineering properties study to be carried out with effect of moisture content of seeds/grains to know about its characteristics and also useful while designing a machine.

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