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Physical Properties of African Kidney Bean (*Phaseolus vulgaris* L.) and Their Processing Impact

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Abstract

Physical properties of food and bio-materials are required to design systems appropriate for their processing. For this purpose, some physical properties of African kidney bean (*Phaseolus vulgaris* (L.)), were investigated. Various techniques including the micrometer screw gauge; water displacement; correlation; inclined plane and cone methods, were adopted. Results obtained revealed the sample had a major diameter of 0.982 ± 0.66cm; intermediate diameter of 0.724 ± 0.32cm; minor diameter of 0.716 ± 0.28cm; sphericity of 0.082 ± 0.05cm; roundness of 0.0742 ± 0.07cm; bulk volume of 57.237 ± 0.00cm^3; solid volume of 32.0 ± 0.71cm^3; bulk density of 0.708 ± 0.00g/cm^3; solid density of 1.2659 ± 0.64g/cm^3; specific gravity of 1.2659 ± 0.64; porosity of 44.1 ± 1.24%; estimated surface area of 48.750 ± 0.05cm^2. Its coefficients of sliding friction on different surfaces were: plastic, 0.13 ± 0.02; plywood, 0.13 ± 0.01; galvanized metal, 0.10 ± 0.01. The sample had a low an angle of repose of 29.43 ± 0.76º from the cone it formed in its natural rest position which indicated that its processing equipments need not be designed to have steep angles in order to have free flow during operations.

Keywords: *Phaseolus vulgaris* (L.), physical properties, processing, systems, technique.

INTRODUCTION

The African kidney bean (*Phaseolus vulgaris* (L.)) is a herbaceous annual plant that originated in Central and South America and is now cultivated in many parts of the world, for its beans, which can be harvested and even eaten immature, while still in the pod, or when mature and dried [2 - 5]. *P. vulgaris* has both bush and twining forms [2]. The twining variety is more common in this part of the world. It needs to be supported with stakes, and grows up to 4 m long. The plant has trifoliate compound leaves with oval to rhombic leaflets, each up to 16 cm long. The flowers, which may be white, yellow, violet, or red in loose, open unbranched clusters that are shorter than the leaves, develop into linear round to slightly flattened pods up to 15 cm long (Fig. 1).

As the name suggests, the bean is kidney-shaped, smooth, plump, and up to 1.5cm long (Fig. 2). It belongs to the order, *Fabales*; family, *Fabaceae* (legume or bean); genus, *Phaseolus*; and species, *vulgaris* [4 - 5]. Botanically, *Phaseolus vulgare* (L.) is a dicotyledon [6]. It is highly pigmented and comes in various sizes and colours such as dark-red, brown, white, yellow, black, etc. Numerous cultivars and varieties have been developed including string beans, snap beans, black turtle beans, cranberry beans, pinto beans, navy beans, etc [7 - 9].

According to Audu and Aremu [4], the African kidney bean is an excellent source of vegetable proteins, starch, dietary fibre, vitamins (especially the B group) and minerals (particularly potassium, iron, zinc, magnesium, manganese and molybdenum). Natural antioxidants especially anthocyanins are present in the bean. It is very low in fat [10]. Hence, the African kidney bean has the potential of improving the nutritional quality and status of poor diets. However, legumes contain potentially toxic substances and anti-nutritional factors (such as phytate, tannin, saponin, lathyrogen, lectin or phytohaemaglutinin, protease and amylase inhibitors) that can cause food poisoning as well as reduce nutrients' availability and digestibility [11 - 13]. These toxins and anti-nutritive factors must be destroyed by heat during processing [15]. Like soybean, the seed coat (hull) of mature kidney bean-seed is tough and hard. Consequently, it is, traditionally, cooked for several hours, and sometimes, overnight, before it is softened.

Figure 1: *Phaseolus vulgaris* plant with flowers and pods.
Source: Anon. [1]

The design of appropriate systems for the conveyance, storage and processing of agricultural materials and food items requires the knowledge of their engineering properties [15 - 16]. Over the years, several researchers have used various methods in determining the physical and mechanical properties of agricultural materials [16]. Also several investigations have been carried out on the engineering properties of food products [18]. However, scientists are not relenting as they have continued to study suitable methods of determining engineering properties for various classes

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of biomaterials. The physical properties of various food materials such as cashew nuts, melon seeds, groundnuts, locust bean, sorghum, yam, cassava, sunflower seeds, etc., have been documented [14 - 15; 17 – 20]. However, little, if any, is available in literature about the physical properties of *Phaseolus vulgare* (L.).

Figure 2: *Phaseolus vulgaris* seeds.
Source: Author.

Therefore, the objective of this study is to investigate some physical properties of African kidney bean (*Phaseolus vulgaris*) which would be relevant in designing handling, storage and processing systems for it.

MATERIALS AND METHODS

The methodologies applied in this study were earlier adopted by Alonge [17], Davies & Zibokere [21], Mohsenin [22 – 23], Shepherd & Bhardwaj [25], Altuntas & Yildiz [26] and Charkraverty [27].

Source and preparation of sample

The African kidney bean used in this study was purchased from a local farmer in Ikwuano Local Government Area in Abia State of Nigeria. The seeds were cleaned of extraneous materials and sorted by hand. A sample size of hundred viable seeds was selected from the bulk in a random manner aimed at minimizing experimental error. They seeds were labelled 1-100.

Mass

The average sample mass and indeed all weights were obtained with a sensitive electronic balance with 0.01g sensitivity.

Size

Measurements of the three mutually perpendicular axes namely major, intermediate and minor diameters were made with a micrometer screw gauge. Precautions such as the use of a magnifying glass to take readings in order to reduce the occurrence of parallax and ensuring that the gauge does press on the bean-seed before taking readings were observed.

Shape (Roundness and Sphericity)

These shape properties were determined as follows:

Roundness

The roundness was determined by the method of Alonge [17] using equation 1:

Roundness = $\frac{r}{R}$ ---------------------- (1)

where

r = intermediate radius

R = major radius

Sphericity

The method of Mohsenin [22] was applied to determine the sphericity from equation 2:

Sphericity = $\frac{abc^{1/3}}{a}$ or $\left[\frac{bc}{a^2}\right]^{1/3}$ ------- (2)

where

a = major diameter

b = minor diameter

c = intermediate diameter

Volume (Bulk and Solid)

The height which the sample occupied in a 100cm^3 beaker and the internal diameter of the beaker was first determined using a venier calliper. Then the bulk volume was calculated from equation 3:

$V_b = \pi\left[\frac{d_i}{2}\right] h$ --------------------------- (3)

where

d_i = internal diameter of beaker

h = height occupied by sample in the beaker

On the other hand, the solid volume (V_s) of the sample was determined through the water displacement method by measuring the difference in the volumes of water in a measuring cylinder before and after the addition of samples [22 - 23].

Density (Bulk and Solid)

The bulk and solid densities (ρ_b and ρ_s) were calculated applying V_b and V_s in the appropriate density equations.

Specific gravity

The specific gravity (relative density) of sample was determined from equation 4 by calculating the ratio of its solid density and that of water at 4 ºC read off a density vs. temperature table from Weast [24]:

S.G = $\frac{\rho_s}{\rho_w}$ ----------------------------- (4)

where

ρ_s = solid density of sample

ρ_w = density of water at 4 ºC

Porosity

Based on the relationship for porosity by Mohsenin [22] and Shepherd and Bhardwaj [25], the porosity (P_f) was calculated according to equation 5:

$P_f = (1 - \frac{\rho_b}{\rho_s})\times 100$ ------------------ (5)

where

ρ_b = bulk density of the beans

ρ_s = solid density of the beans

Estimated surface area

The estimated surface area (A_s) of the sample was estimated using equation 6:

$A_s = (36\pi)^{1/3}V^{2/3}$------------------------ (6)

where

V = solid volume of sample

Coefficients of sliding friction

The coefficient of sliding friction was measured using an inclined plane. The 100 bean-seeds were split into 10 groups of 10 seeds each. Each group was placed on the inclined surface and the inclination angle (by implication the height) was gradually raised until the seeds started to slide (Fig. 3).

The height and base of the plane at this instant was recorded. These determinations were made in quadruplicate on three surfaces: plywood, plastic and galvanized metal. The tangent of the angle of inclination is the measure of coefficient of friction [22; 25]. Therefore, the coefficient of sliding friction (μ_s) was determined according to Altuntas & Yildiz [26] using equation 7:

$\mu_s = \tan Ø = \frac{h}{b}$-------------------------- (7)

where

Ø = angle of inclination

h = height of inclined plane

b = base of inclined plane

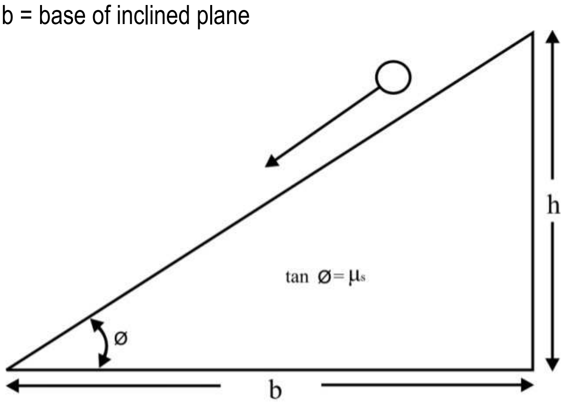

Figure 3: Determination of coefficient of sliding friction by inclined plane method.
Ø = angle of inclination; x = base of inclination; y = height of inclination,

Angle of repose

The angle of repose of the sample was determined by filling the bean-seeds in a cylindrical cup (with a depth of 6.8 cm and internal diameter of 5.45 cm) and allowing it to overflow and form a cone in its natural rest position [27: Fig. 4].

The angle of repose (Ø) was calculated from equation 8:

$Ø = \tan^{-1}\left[\frac{2(a-b)}{c}\right]$------------------ (8)

where

a = depth of cup + height of cone

b = depth of cup

c = internal diameter of cup

Experimental design

The hundred-seed sample size was divided into ten replicates of ten seeds each and measurements of fifteen physical properties (treatments) applied to each replicate at random (with a minimum of quadruplicate observations) in a constant randomized design (CRD).

Statistical analysis

The mean values and the standard deviation (S.D.) for the data recorded were calculated [28].

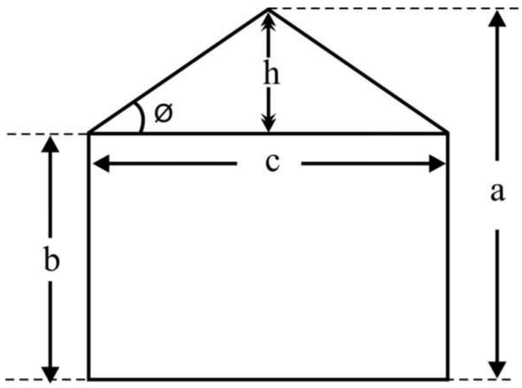

Figure 4: Determination of angle of repose by the cone method.
Ø = angle of repose

RESULTS AND DISCUSSION

The results of the physical properties of the African kidney bean sample investigated are shown on Table 1.

Size

The values for the three principal and mutual dimensions which determined the size of the bean seed were: major diameter, 0.98 ± 0.66 cm (9.80 ± 0.66 mm); intermediate diameter, 0.724 ± 0.32 cm (7.24 ± 0.32 mm); and minor diameter, 0.716 ± 0.28 cm (7.16 ± 0.28 mm).

Shape factors

From the results obtained, the sphericity of the bean sample agrees with the range of 0.700 – 0.778 mm reported by Davies & Zibokere [21] for three varieties of cowpea (*Vigna unguiculata* (L) Walp). The sphericity and roundness of the bean seed did not differ widely. Morphological properties such as roundness and sphericity are used to describe and characterize the shape of a food material. Roundness is a measure of the sharpness of corners of a solid [29], while its sphericity defines the ratio of the surface of a sphere which has the same volume as that of the solid [30], i.e. how the shape of the solid deviates from a sphere [31].

Mass

The average mass of the 100 bean-seed sample of the *Phaseolus vulgare* (L.) used in the study was 40.51 ± 0.01 g.

Volumes

The average bulk volume of the sample was 57.237 ± 0.00 cm^3 while its solid volume was 32.0 ± 0.71 cm^3.

Densities

The bulk density of the sample was 0.708 ± 0.00 g/cm^3 while its solid density was 1.266 ± 0.64 g/cm^3. These results agrees with the range of 0.70349 – 0.72691 g/cm^3 for bulk density and 1.01083 – 1.08312 g/cm^3 for solid density obtained for three varieties of cowpea by Davies & Zibokere [21]. Density of food materials is useful in mathematical conversion of mass to volume. Equally, the density of processed products influences the strength and other characteristics of their package.

Table 1: Physical properties of African kidney bean (*Phaseolus vulgaris*).

S/N Property	No. of Observations	Mini Value	Mean Value	Maxi Value	Standard Deviation
1. Major Diameter (cm)	100	6.24	0.982	10.87	±0.66
2. Intermediate Diameter (cm)	100	6.08	0.724	8.16	±0.32
3. Minor Diameter (cm)	100	6.39	0.716	7.83	±0.28
4. Sphericity (cm)	100	0.072	0.082	0.107	±0.05
5. Roundness (cm)	100	0.0605	0.0742	0.1522	± 0.07
6. Mass (g)	4	40.501	40.51	40.520	±0.01
7. Bulk Volume (cm^3)	4	57.235	57.237	57.238	±0.00
8. Solid Volume (cm^3)	4	31.0	32.0	33.0	±0.71
9. Bulk Density (g/cm^3)	4	0.7076	0.708	0.7079	±0.00
10. Solid Density (g/cm^3)	4	1.3065	1.266	1.2279	±0.64
11. Specific gravity	4	1.3065	1.266	1.2279	±0.64
12. Porosity (%)	4	42.34	44.100	45.84	±1.24
13. Est* Surface Area (cm^2)	4	47.73	48.750	49.76	± 0.71
14. Coefficient of Sliding Friction:					
• Plastic Surface	10	0.0984	0.13	0.184	±0.02
• Plywood Surface	10	0.112	0.13	0.152	±0.01
• Galvanized Metal Surface	10	0.084	0.10	0.124	±0.01
15. Angle of Repose	10	29.632	29.43	30.56	±0.76

*Est = estimated

Specific gravity

The specific gravity (relative density) is defined as the ratio of the mass (or density) of a product to the mass (or density) of equal volume of water at 4°C. The specific gravity of the sample was 1.2660 ± 0.64.

Porosity

With a porosity of 44.1 ± 1.24 %, the sample has a near-average drying capacity. This result differs with a range of 31.40 – 34.89 % obtained for three varieties of cowpea by Davies & Zibokere [21]. Porosity indicates the volume fraction of void or air spaces present in a food structure such as packed bed [29] and are essential in drying and distillation operations.

Estimated surface area

The estimated surface area of the sample gave an average value of 48.750 ± 0.71 cm^2. This result differs with 17.74 – 25.10 cm^2 for three varieties of cowpea by Davies & Zibokere [21]. Surface area is important and useful in packaging, heating, freezing and drying operations since heat transfer is proportional to surface area.

Coefficient of sliding friction

The coefficient of sliding friction of the seed on the three surfaces were low and did not exhibit wide variations possibly as a result of the plump and smooth-bodied nature of the seed which implies that it can be effectively conveyed on various surfaces. The results were not in agreement with 0.3064 ± 0.0123 obtained for three varieties of cowpea by Davies & Zibokere [21] on one of the surfaces (plywood) using the same method of measurement. The coefficient of sliding friction directly or indirectly affects the design of processing machines [32].

Angle of repose

The mean value of the angle of repose for the sample was 29.43 ± 0.76 °. This is similar to 24 – 27 ° reported for three varieties of cowpea by Davies & Zibokere [21]. The implication of this is that it does not require steep angles for conveyance in order to avoid recurrent congestion of lines. This factor together with other mass properties such as volume and density play important roles in defining the flow characteristics of bulk solids during conveyance [33].

CONCLUSION AND RECOMMENDATIONS

The processing of some food and biomaterials had been impeded by the lack of the knowledge of their physical and engineering properties and this has often led to huge losses in cost from massive spoilage, as well as out-of-season scarcity. With a low mean value angle of repose, processing equipments for the sample investigated need not be designed with steep angles in order to have free flow during operations.

Finally, we recommend further investigation of the mechanical properties of *Phaseolus vulgaris* (L.) relevant to its processing considering its nutritional value and concomitant potential to compliment low quality diets.

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