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Evaluation of physical properties of kidney beans (*Phaseolus vulgaris*)

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The research work was conducted on the physical properties of three species of kidney bean (White speckled kidney bean, Red small kidney bean and Black kidney bean). Length, width, thickness varied between 1.04-1.7, 0.66-0.79, 0.49-0.58 cm for three species of kidney bean, respectively. Arithmetic mean diameter, geometric mean diameter, square mean diameter and equivalent diameter were 0.73-1.00, 0.70-0.96, 1.23-1.62, and 0.88-1.19 cm^2, respectively. Sphericity and aspect ratio ranged between 0.56-0.67 and 0.45-0.64 for kidney bean, respectively. Porosity (%) as a function of bulk density and true density were 2.21-9.07(%), respectively. Volume, surface area and shape factor varied between 0.20-0.58, 1.53-3.47 and 0.88-1.015 cm, respectively. Thousand kernel mass (M_{1000}) were lowest for red small kidney bean (240 g) and highest for black kidney bean (499 g). The angle of repose of three varieties of kidney bean ranged between 21.74 to 23.79^0.

Key Words : Kidney bean, Physical properties, Shape factor, Square mean diameter

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INTRODUCTION

Kidney bean (*Phaseolus vulgaris*), a grain legume, is one of the neglected tropical legumes that can be used to fortify cereal-based diets especially in developing countries, because of its high protein content. It is also a rich source of vitamin. As bean are a very inexpensive form of good protein, they have become popular in many cultures throughout the world. Kidney bean, also known as haricot bean, common bean, snap bean or navy bean, are valued for their protein-rich (23%) seeds. Seeds are also rich in calcium, phosphorus and iron. The fresh pods and green leaves are used as vegetable. Kidney bean are also known as the chilli bean. These are dark red in colour and visually resemble the shape of a kidney. The bean paste was a vital ingredient in ointments for rheumatism, sciatica, eczema and common skin infections.

Red kidney bean, called as Rajma in Hindi and Punjabi, are an integral part of the cuisine in northern region of India. On a global basis, around 80 per cent of food energy and about 65 per cent of food proteins are supplied by plant foods. Legumes are major group of plant foods that make a significant contribution to human and animal food supply (Sathe *et al.*, 2002). White kidney bean (*Phaseolus vulgaris* L.) are a cultivated plant grown for fresh and dry consumption and a common raw material in the canned food industry. On average, the bean contains 21.7 g protein, 0.75 g oil, 55.2 g total carbohydrates, 131.6 mg calcium, 7.6 mg iron and 1293.5 mg potassium per 250 ml (dry) (Nutritional Values, 2006).

The engineering (physical and mechanical) properties constitute important and essential data in the design of machines, storage structures and processes. The value of this basic information is not only important to engineers but also to food scientists, processors, and other scientists who may exploit these properties and find new uses. The size and shape

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are, for instance, important in their electrostatic separation from undesirable materials and in the development of sizing and grading machinery (Mohsenin, 1970). The shape of the material is important for an analytical prediction of its drying behaviour. Bulk density and porosity are the major considerations in designing near-ambient drying and aeration systems, as these properties affect the resistance to airflow of the stored mass. The theories used to predict the structural loads for storage structures have bulk density as a basic parameter. The angle of repose is important in designing the equipment for mass flow and structures for storage. The frictional characteristics are important for the proper design of agricultural product handling equipment (Kaleemullah and Kailappan, 2003). The major moisture-dependent physical properties of biological materials are shape and size, densities, porosity, mass of grains and friction against various surfaces. These properties have been studied for various crops such as soybean (Deshpande *et al.*, 1993), pumpkin grains (Joshi *et al.*, 1993), sunflower (Gupta and Das, 1997), green gram (Nimkar and Chattopadhyay, 2001), pigeonpea (Baryeh and Mangope, 2002), black-eyed pea (Unal *et al.*, 2006), some grain legume seeds (Altuntas and Demirtola, 2007) and faba bean (Altuntas and Yildiz, 2007).

Despite an extensive search, no published literature was available on the detailed physical properties of white kidney bean and their dependency on operation parameters that would be useful for the design of processing machineries. In order to design equipment and facilities for the handling, conveying, separation, drying, aeration, storing and processing of white kidney bean, it is necessary to know their physical properties as a function of moisture content. Surface area and volume of legume seeds is an important physical characteristic in processes such as harvesting, cleaning, separation, handling, aeration, drying, storing, milling, cooking and germination (Igathinathane and Chattopadhyay, 1998). Geometric parameters of legume seeds are important for germination process as well, bigger bean seeds germinate faster than smaller and medium ones. Large seeded cultivars of Azuki bean exhibit slower water absorption than smaller ones. Owing to the irregularities and variation in shapes, surface profiles and dimensions of specific food materials, it is very difficult to evaluate their actual surface areas. For food materials, such as seeds, grains, fruits or vegetables that are irregular in shape, complete specification of shape requires an infinite number of measurements.

The shapes of most natural food materials generally resemble some of the regular geometrical objects, and this feature is utilized in the theoretical estimation of the surface area utilizing certain numerical techniques. Often three measurements along the mutually perpendicular axes, namely, length, width, and thickness are used to specify the shape of the food material. The knowledge of physical properties of food materials is of importance to plant breeders, engineers, machine manufacturers, food scientists, processors, and consumers. The data on physical properties are used in designing relevant machines and equipment for harvesting, handling, transportation, separating, aeration, sizing, storing, packing and the other processing. The data have also been used for assessing the product quality.

METHODOLOGY

The investigation was undertaken at the Food Analysis Laboratory and Process and Food Engineering laboratory in Department of Agricultural Engineering and Food Technology, S.V.P. University of Agriculture and Technology, Meerut (India). Studies were conducted to evaluate the physical properties of kidney bean. The species of kidney bean *viz.*, white speckled kidney bean (WSKB), red small kidney bean (RSKB), black kidney bean (BKB) were procured from local market for the present study. The bean were cleaned manually to remove all foreign matter such as chaff, dust and stones. They were stored in dry and cool place in ambient condition until further study. The determination of physical properties of food materials is much complex because of their irregular shape and variability in size. Presently no single standard method is applied in determining the physical dimensions of agricultural products (Waziri and Mittal, 1983). The procedures for determination of physical properties of kidney bean are discussed below:

Moisture content :

Initial moisture content of samples was determined by hot air oven drying method as recommended by AOAC (2000).

Grain dimensions :

The average grain dimension was measured by picking 10 grains randomly. The three linear dimensions namely length (L), Width (W) and Thickness (T) were measured using a Vernier caliper (least count 0.01mm) for all kidney bean. The measurements were taken under ambient conditions.

Diameter :

Arithmetic mean diameter (AMD), Geometric mean diameter (GMD), Square mean diameter (SMD) and Equivalent diameter (EQD) of kidney bean were calculated by using the following equations (Mohsenin, 1986). Geometric mean diameter (grain size) of grain is the cube root of product of three semi-axis of grain. Three major principles axes of grain were measured by Vernier callipers having least count of 0.01 mm. The grain size or GMD of grains was calculated by using by the following relationship.

$$\mathbf{AMD} = \frac{\mathbf{L + W + T}}{\mathbf{3}} \quad ......(1)$$

$$\mathbf{GMD} = (\mathbf{LWT})^{\frac{1}{3}} \quad ......(2)$$

$$\mathbf{SMD} = (\mathbf{LW} + \mathbf{WT} + \mathbf{TL})^{\frac{1}{2}} \quad ......(3)$$

$$\mathbf{EQD} = \frac{\mathbf{AMD} + \mathbf{GMD} + \mathbf{SMD}}{3} \quad ......(4)$$

Sphericity :

The sphericity (Φ) of grains was calculated by using the following relationship given by (Mohsenin, 1970) :

$$\mathbf{Sphercity}\ (\Phi) = \frac{(\mathbf{LWT})^{\frac{1}{3}}}{\mathbf{L}} \quad ......(5)$$

Volume and surface area :

Major dimensions of the grain was used to calculate the volume (V) and surface area (S) of a single bean (Jain and Bal, 1997) given as below :

$$\mathbf{Volume} = \frac{\pi(\mathbf{GMD})^2 L^2}{6(2L - \mathbf{GMD})} \quad ......(6)$$

$$\mathbf{Surface\ area}\ Z\ \frac{\pi(\mathbf{GMD})\mathbf{L}^2}{(2L - \mathbf{GMD})} \quad ......(7)$$

Shape factor :

Shape factor (λ) based on volume and surface area of bean was determined as recommended by McCabe and Smith (1984).

$$\mathbf{Shape\ factor} = \frac{\mathbf{a}}{\mathbf{b}} \quad ......(8)$$

where,

$$\mathbf{a} = \frac{\mathbf{v}}{\mathbf{w}^3}$$

$$\mathbf{b} = \frac{\mathbf{s}}{\mathbf{w}^2}$$

Thousand kernel mass :

About one kilogram of kidney bean was divided in two equal portion 1000 kernel mass (TKM) of kidney bean was randomly picked from each portion and separately weighed using a digital electronic balance(least count 0.001 mg).

Bulk and true density :

The bulk density (ρ_b) and true density (ρ_t) are the measure of the quality of grain. Bulk density of grain is the ratio of mass of grain to its bulk volume. True density is the ratio of the mass of grain to its actual volume. The bulk volume (including pore spaces between grains) of grain is greater than actual volume (without pore spaces between grains). So, bulk density of grain is smaller than that of true density. The bulk density of bean was determined by measuring the mass of grain sample of known volume. The bean sample was placed in a cylindrical container of volume 250 cm^3. Filling of bean in the cylinder for density was obtained by gently tapping the cylinder vertically down to a table 30 times in the same manner in all measurements. The excess grains on the top of the cylinder were removed by sliding a string along the top edge of the cylinder. Thereafter, the mass of the grain sample was measured by an electronic balance.

True density or substance density was determined by toluene displacement method in order to avoid absorption of water during the experiment (Rahman, 1995). The measurements were done at room temperature and replicated three times at each moisture content. The average diameter of equivalent sphere (D_e, m) was calculated in terms of mass of 1000 grain (W_{1000}, kg) and true density (ρ_t, kg/m^3) using following equation (Mohsenin, 1970).

$$\mathbf{De} = \left(\frac{\mathbf{6w1000}}{\mathbf{1000}\pi\rho_t}\right)^{\frac{1}{3}} \quad ......(9)$$

Porosity :

The total porosity (ε) was determined by using the formula (Mohsenin, 1970).

$$\varepsilon = \left(\mathbf{1} - \frac{\rho_b}{\rho_t}\right) \times \mathbf{100} \quad ......(10)$$

Angle of repose :

The Angle of Repose (AOR) was determined by using a topless and bottomless cylinder of 10 cm diameter and 15 cm height. The cylinder was placed on a table and filled it with grams and raise slowly until it form a cone. The diameter (D) and height (H) of cone was recorded. The angle of repose (AOR) was calculated by using the formula as recommended by Kaleemullah (1992).

$$\mathbf{AOR} = \mathbf{Tan}^{-1}\left(\frac{2H}{D}\right) \quad ......(11)$$

Standard deviation :

The best and most commonly used statistical evaluation of the precision of analytical data is the standard deviation. The standard deviation measures the spread of the experimental values and gives a good indication of how close the values are to each other (Chandel, 1998). The data obtained of selected parameters were analyzed for mean and standard deviations using following :

$$\mathbf{S.D.} = \frac{\pm\sqrt{\sum\left(\mathbf{x} - \bar{\mathbf{x}}\right)^2}}{\mathbf{n}} \quad ......(12)$$

where,
x= individual sample value
$\bar{x}$ = mean of individual samples
n= total population of samples.

OBSERVATIONS AND ASSESSMENT

The physical properties of kidney bean (*Phaseolus vulgaris*) included axial dimension *viz.*, length (L), width (W), thickness (T), AMD, GMD, SMD, EQD and moisture content, volume, surface area, sphericity, aspect ratio, shape factor, thousand grain mass, bulk density, true density, porosity and angle of repose evaluated.

Axial dimensions :

The major dimension (length, L) for kidney bean was 1.70 cm, 1.53 cm and 1.04 for black, white speckled and red small species of kidney bean, respectively. Intermediate dimensions (Width W) was highest for WSKB (0.79 cm) followed by BKB (0.76 cm) and lowest (0.66 cm) for RSKB. Minor dimension (thickness T) was highest for WSKB (0.58 cm), followed by BKB (0.54 cm), while the lowest for RSKB (0.49 cm). The highest dimensions among the kidney bean were measured highest for BKB followed by WSKB and RSKB.

Diameter :

The arithmetic mean diameter (AMD) was observed highest for BKB (1.00 cm) followed by WSKB (0.96 cm) and lowest for RSKB (0.73 cm). The geometric mean diameter (GMD) of kidney bean ranged 0.70 to 0.96 cm. The highest GMD was found for BKB (0.96 cm) followed WSKB (0.88 cm) and lowest for RSKB (0.70 cm). The SMD (square mean diameter) had calculated highest for BKB (1.62 cm) followed by WSKB (1.59 cm) and lowest for RSKB (1.23 cm). The value of equivalent diameter (EQD) was highest for variety of BKB and lowest for RSKB.

Volume and surface area :

The volume of single grain of kidney bean was highest for BKB (0.58 cm^3) and lowest for RSKB (0.20 cm^3). The surface area of single grain of kidney bean was found highest (3.47 cm^2) for BKB and lowest for RSKB (1.53cm^2).

Sphericity, aspect ratio and shape factor :

The sphericity and aspect ratio (AR) of kidney bean was nearly same and it lies between (0.45 to 0.67) for all the three species. The sphericity and aspect ratio of more than 70 per cent implied that grain was more as spherical and tend to rather roll than slide (Dutta *et al.*, 1988). The low value of aspect ratio indicated the tendency to slide than to roll. It was observed that the sphericity of small sized seed showed the highest sphericity that's why, the value of sphericity was highest for the RSKB (0.67) and lowest 0.56 for BKB which is bigger in size than other species of kidney bean. The shape factor for RSKB was found the high numeric value (1.015) than WSKB (0.88) and BKB (0.82).

Table 1 : Physical properties of kidney bean

Variety → Parameters ↓		WSKB	RSKB	BKB
M.C (%) (d.b.)		12.45 ±1.48	12.35 ±0.432	12.90 ±0.725
Dimensions	L (length)	1.53 ±0.040	1.04 ±0.016	1.7 ±0.021
(cm)	W (width)	0.79 ±0.071	0.66 ±0.009	0.76 ±0.026
	T (thickness)	0.58 ±0.021	0.49 ±0.00	0.54 ±0.014
AMD(cm)		0.96 ±0.037	0.73 ±0.004	1.00 ±0.016
GMD(cm)		0.88 ±0.038	0.70 ±0.004	0.96 ±0.091
SMD(cm)		1.59 ±0.067	1.23 ±0.004	1.62 ±0.028
EQD(cm)		1.15 ±0.046	0.88 ±0.004	1.19 ±0.032
Volume(cm^3)		0.44 ±0.051	0.20 ±0.004	0.58 ±0.138
Surface area(cm^2)		2.91 ±0.13	1.53 ±0.117	3.47 ±0.561
Sphericity		0.6 ±0.037	0.67 ±0.012	0.56 ±0.049
Aspect ratio		0.53 ±0.038	0.64 ±0.021	0.45 ±0.012
Shape factor		0.88±0.028	1.015±0.031	0.82±0.014
M1000(g)		463.73±3.73	240.10 ±11.42	499.08 ±11.10
Bulk density(g/cc)		1.025 ±0.006	1.041 ±0.004	1.01 ±0.013
True density(g/cc)		1.048 ±0.008	1.145 ±0.008	1.072 ±0.006
Porosity (%)		2.21 ±1.42	9.07 ±0.799	6.21 ±0.731
Angle of repose		23.79 ±0.097	23.57 ±0.758	21.74 ±0.765

(WSKB = white speckled kidney beans, RSKB = red small kidney beans, BKB = black kidney beans)
AMD= arithmetic mean diameter, GMD = geometric mean diameter, SMD = square mean diameter, EQD = Equivalent diameter

Thousand kernel mass:

Thousand kernel mass was estimated by using 500 g grain. The thousand kernel mass ranged 240.10-499.08g and it was noticed that lowest mass for RSKB (240.10 g) and highest for BKB (499.08g).

Bulk density and true density :

The bulk density of all the three varieties of kidney bean was almost the same with minute variations and highest for WSKB (1.025g/cc) followed by RSKB (1.04g/cc) and BKB (1.01g/cc). The value of true density was 1.145g/cc for RSKB, 1.072g/cc for BKB and was found lowest 1.048g/cc for WSKB. WSKB had lowest bulk density due to larger size of the grains.

Porosity :

Since the porosity depends on the bulk as well as true density. The porosity of RSKB was found to be highest (9.07 %) and it was followed by BKB (6.21 %) and WSKB (2.21 %). The porosity of kidney bean depends on the size and shape only. It was observed that lowest size kidney bean represent the highest porosity for them.

Angle of repose :

The angle of repose for the randomly selected grains of different species of kidney bean were 23.79^{o}, 23.57^{o} and 21.74^{o} for WSKB, RSKB and BKB, respectively.

Conclusion :

White speckled kidney bean (WSKB) was found of highest value for axial dimension (width and thickness) and angle of repose while red small kidney bean (RSKB) had highest value of spehercity, aspect ratio, shape factor, bulk density, true density and porosity. The physical properties like moisture content, axial dimension (length), AMD, GMD, SMD, EQD, volume, surface area and thousand kernel mass were calculated highest for black kidney bean (BKB). It seems that the physical properties *i.e.* AMD, GMD, SMD, EQD, volume surface area depend on axial dimension (length) but angle of repose on axial dimension (width and thickness) only. The present study also revealed that another physical properties *i.e.* spherecity, aspect ratio, shape factor, bulk density, true density and porosity depended on the lowest volume of the grain in case of RSKB.

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