Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
www.phytojournal.com
JPP 2020; 9(2): 2455-2459
Received: 03-01-2020
Accepted: 12-02-2020

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Study to assess physical properties of different types of kidney beans (*Phaseolus vulgaris*)

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Abstract
Three different varieties of kidney beans (White speckled kidney beans, Red small kidney beans and Black kidney beans) were analysed in this study for their physical properties viz. dimensions (length, width, thickness), arithmetic mean diameter, geometric mean diameter, square mean diameter, equivalent diameter, sphericity, aspect ratio, volume, surface area, shape factor, bulk density, true density, porosity, thousand kernel mass and angle of repose. It was observed that length, width, thickness varied between 1.04-1.7, 0.66-0.79, 0.49-0.58 cm for three varieties of kidney beans, respectively. While the 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, respectively for the three varieties of kidney beans. 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. M_{1000} was lowest for red small kidney beans (240g) and highest for black kidney beans (499g). The angle of repose of three varieties of kidney bean ranged between 21.74-23.79^0.

Keywords: kidney bean, sphericity, aspect ratio, shape factor, square mean diameter, angle of repose, equivalent diameter

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 beans are a very inexpensive form of good protein, they have become popular in many cultures throughout the world.

The term 'kidney bean' refers to the shape of the bean, but it is also true that Native Americans used the bean to treat a variety of kidney and bladder complaints. The bean paste was a vital ingredient in ointments for rheumatism, sciatica, eczema and common skin infections. Kidney beans, also known as haricot bean, common bean, snap bean or navy bean, are valued for their protein- rich (23 per cent) seeds. Seeds are also rich in calcium, phosphorus and iron. The fresh pods and green leaves are used as vegetable. Kidney beans are also known as the chilli beans. These are dark red in colour and visually resemble the shape of a kidney.

Red kidney beans, called as *Rajma* in Hindi and Punjabi, are an integral part of the cuisine in northern region of India. In India, especially in Punjab and other northern states, kidney beans are the quintessential north Indian dish. Prepared as a thick curry with red kidney beans being the chief ingredient and lots of Indian whole spices, the dish is served with hot rice.

On a global basis, around 80% of food energy and about 65% 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. White kidney beans (*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). Turkey has about 155.000 ha of dry bean harvesting area, and 250.000 tons of dry bean production per annual with a yield of 1616 kg/ha of bean (FAO, 2004).

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.

The value of this basic information is not only important to engineers but also to food processors, and other scientists who may exploit these properties and find new uses. The size and shape are, for instance, important in their electrostatic separation from undesirable materials and in the development of sizing and grading machinery. The shape of the material is important for an analytical prediction of its drying behaviour. Bulk density and porosity are 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. 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) [7]. Pumpkin grains (Joshi *et al*., 1993) [13]. Sunflower (Gupta and Das, 1997) [8]. Green gram (Nimkar and Chattopadhyay, 2001) [14]. Pigeon pea (Baryeh and Mangope, 2002) [2]. Black-eyed pea (Unal *et al*., 2006), some grain legume seeds (Altuntas and Demirtola, 2007) and Faba bean.

Despite an extensive search, no published literature was available on the detailed physical properties of white kidney beans 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 beans, 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. 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 beans 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.

Materials and Methods

The study was done in the Food Analysis Laboratory and Process and Food Engineering (UG) laboratory in Department of Agriculture Engineering and Food Technology, S.V. P. University of Agriculture & Technology. Meerut. Studies were conducted to evaluate the various physical properties of kidney bean. The various species of kidney beans viz., white speckled kidney bean (WSKB), red small kidney bean (RSKB), black kidney bean (BKB) were procured from local market of Meerut for the present study. The beans were cleaned manually to remove all foreign matter such as chaff, dust, and stones. Beans were stored in dry and cool place in ambient condition until testing.

The determination of physical properties of agricultural 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. For very small objects like mustard, vegetable seed, they are measured by shadowgraph using overhead projector.

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 beans. The measurements were taken at room temperature.

Diameter

Arithmetic mean diameter (AMD), Geometric mean diameter (GMD), Square mean diameter (SMD) and Equivalent diameter (EQD) of kidney beans were calculated by using the following equations:

$$\textbf{AMD} = \frac{L+W+T}{3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (2.1)$$

$$\textbf{GMD} = (LWT)^{1/3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (2.2)$$

$$\textbf{SMD} = (LW+WT+TL)^{1/2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (2.3)$$

$$\textbf{EQD} = \frac{AMD+GMD+SMD}{3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (2.4)$$

Sphericity

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

$$\textbf{Sphericity} = \frac{(LWT)\ 1/3}{3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (2.5)$$

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

$$\textbf{Volume} = \frac{\pi(GMD)^2 L^2}{6(2L-GMD)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (2.6)$$

$$\textbf{Surface Area} = \frac{\pi(GMD) L^2}{(2L-GMD)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (2.7)$$

Shape Factor

Shape factor (λ) based on volume and surface area of beans was determined (McCabe and Smith, 1984) as;

$$\textbf{Shape Factor} = \frac{a}{b} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (2.8)$$

Where, $a = v/w^3$

$b = s/w^2$

Thousand Kernel Mass

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

Bulk and True Density

The bulk density and true density 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 measure of 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 beans was determined by measuring the mass of gram sample of known volume. The Beans sample was placed in a cylindrical container of volume 250 cm^3. Filling of Beans 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. After the excess had been removed, 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 (ρt, kg/m^3) using following equation (Mohsenin, 1970).

$$de = \left(\frac{6W1000}{1000\pi\rho t}\right)^{1/3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.9)}$$

Porosity

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

$$\varepsilon = \left(1 - \frac{\rho t}{\rho f}\right)\times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.10)}$$

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 raised 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 Kaleemullah (1992).

$$\text{AOR}=\text{Tan}^{-1}\left(\frac{2H}{D}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.11)}$$

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 for selected quality parameters were analyzed for mean and standard deviations using following:

$$S.D = \pm\sqrt{\sum(\boldsymbol{x}+\bar{\boldsymbol{x}})^2} \,/\, n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.12)}$$

Where,
x = individual sample values
$\bar{x}$= mean of individual samples
n = total population of sample

Results and Discussion

The study was undertaken to study the physical properties of Kidney Beans (*Phaseolus vulgaris*). The following physical properties i.e. axial dimension viz. Length (D_1), Width (D_2), Thickness (D_3), 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 were evaluated.

Grain Dimensions of Kidney Beans

Axial Dimensions and Average Diameter

The major dimension (length D_1) for kidney beans was 1.70cm, 1.53 cm & 1.04 for Black, White Speckled & Red small varieties of kidney beans respectively. Intermediate dimensions (Width D_2) was highest for WSKB (0.79cm) followed by BKB (0.76cm), and lowest for (0.66 cm) for RSKB.

Minor dimension (Thickness D_3) was highest for WSKB (0.58cm), BKB (0.54cm), while the lowest for RSKB (0.49cm). The highest Dimensions among the kidney beans were measured highest for BKB followed by WSKB and RSKB. The Arithmetic mean Diameter (AMD) of WSKB ranged between 0.92 to 1.01cm and BKB (0.98 to 1.02cm) whereas that of RSKB ranged between 0.73 - 0.74cm.

The value of Geometric mean Diameter (GMD) ranged between 0.85 to 0.94 for WSKB and 0.69 to 0.70cm for RSKB while for BKB it ranged between 0.87 - 0.91cm.

The value of SMD (Square Mean Diameter) had between (1.52 to 1.68 cm) for WSKB and (1.23 to 1.24cm) for RSKB & it was highest for variety BKB (1.59 to 1.66 cm). The value of Equivalent Diameter (EQD) was highest for variety of BKB and lowest for RSKB.

Volume & Surface Area

The Volume of single grain of kidney bean was highest for the BKB i.e. 0.58. The Surface Area of single grain of kidney bean (3.13 cm^2) was highest for the variety BKB & lowest for RSKB (1.53cm^2).

Sphericity, Aspect Ratio & Shape Factor

The sphericity and Aspect Ratio (AR) of kidney bean was nearly same and it lies between (0.45 - 0.67) for all the three varieties. The sphericity and Aspect Ratio of more than 70% implied that grain was more as spherical & tend to rather roll than Slide Bharadwaj RK 1988. Physical Properties of gram. J.Agric. Engng. Res, 39, pp 259 – 268).

The low value of Aspect Ratio indicated the tendency to slide than to roll. It was observed that the sphericity of small sized seed shows the highest sphericity that's why the value of sphericity is highest for the RSKB and it ranged between (0.65 to 0.68 cm) & it was lowest (0.52 to 0.56) for BKB which is bigger in size than other varieties of kidney bean. The shape factor for RSKB (1.015) gives the high numeric value than WSKB (0.88) and BKB (0.82)

Thousand Kernel Mass

It can be seen that approx. 500gm mass was considered by the 1000 grains of the BKB and for WSKB the thousand Kernel mass ranged between (460g – 468g) and it was lowest for the RSKB i.e. 240.10 gm.

Bulk Density and True Density

The bulk density of all the three varieties of kidney bean was almost the same i.e. WSKB (1.025g/cc), 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 found lowest 1.048g/cc for WSKB

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 followed by BKB (6.21%) and WSKB (2.21%),

Angle of Repose
The angle of repose for the randomly selected grains of different of kidney beans were 23.79 ºC, 23.57 ºC and 21.74 ºc for WSKB, RSKB and BKB respectively.

Table 3.1: Physical Properties of kidney beans

Variety Parameters		WSKB	RSKB	BKB
M.C % d.b.		12.45 ±1.48	12.35 ±0.432	12.90 ±0.725
Dimensions	D_1 (Length) cm	1.53 ±0.040	1.04 ±0.016	1.7 ±0.021
	D_2 (Width) cm	0.79 ±0.071	0.66 ±0.009	0.76 ±0.026
	D_3 (Thickness) cm	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
M_{1000} (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

Where,
WKSB is White Speckled Kidney Beans
RSKB is Red Small Kidney Beans
BKB is Black Kidney Beans

Conclusions
On the basis of results of the study, following conclusions were drawn: The mean dimensions of a grain of WSKB were: length 1.53±0.005, width 0.79±0.071 and thickness 0.58±0.021 for RSKB, length 1.04±0.016, width 0.66±0.009 and thickness 0.49±0.000 and for BKB: length 1.70±0.021, width 0.76±0.026 and thickness 1.00±0.016 at a moisture content (d.b) of 12.45±1.48, 12.35±0.432, 12.90±0.725 respectively and these parameter increased linearly as the moisture content increased after soaking at different temperature for all the varieties. Shape factor of WSKB, RSKB and BKB were: 0.88±0.028, 1.015±0.031 and 0.82±0.014 respectively and the value of Aspect ratio were similar for all three varieties of kidney beans. Thousand grain mass M_{1000} of three varieties studied were lowest for RSKB (240.10±11.42) and highest for BKB (499.08±11.10) and it was (463.73±3.73) for WSKB. The value of Porosity was calculated by using the data on Bulk density and the True density of the beans and the result indicated that the Porosity of the WSKB, RSKB and BKB were 2.21±1.42, 9.07±0.799 and 6.21±0.731 respectively in the specified moisture level at dry condition. The value of angle of repose were highest for WSKB (23.79±0.097) and for RSKB was 23.57±0.758 but it was little lower for the BKB i.e. 21.74±0.765.

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