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FULL LENGTH ARTICLE

Physical and cooking characteristics of some Indian kidney bean (*Phaseolus vulgaris* L.) cultivars

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Abstract Pulses are an essential component of our diet especially in developing world, information on their physical properties is needed for designing the machines, while cooking quality is important for consumer acceptance. Four kidney bean cultivars were evaluated for their composition, physical, cooking and textural properties. Protein, ash and carbohydrate contents varied significantly ($P \leqslant 0.05$) in the range of 22.3–26.7%, 3.5–3.8% and 62.1–65.9%, respectively. Physical properties determined at 10.0% moisture revealed that the length, breadth, thickness and equivalent diameter of seeds varied significantly in the range of 11.45–16.45 mm, 6.65–7.00 mm, 4.70–6.13 mm and 7.31–9.24 mm, respectively. Bulk density varied from 0.78 to 0.81 g/mL and angle of repose from 15.20° to 18.67°. Hydration capacity and swelling capacity of the seeds varied significantly in the range of 0.12–0.42 g/seed and 0.09–0.28 mL/seed, respectively. Cooking time of unsoaked seeds differed significantly from 68.67 to 86.67 min. Soaking of seeds reduced cooking time by 15.33–30.67 min.

1. Introduction

Pulses are edible dry seeds of plants belonging to family Leguminosae. They are used in appreciable amounts for human nutrition. Pulses are cheap and rich sources of proteins and carbohydrates in developing countries (Rehman et al., 2001). They have an increasing use in dietetic formulations in the treatment and prevention of diabetes, cardiovascular diseases, colon cancer, and lowering of blood cholesterol levels (Bhathena and Velasquez, 2002; Kushi et al., 1999). India is the largest producer and consumer of pulses in the world (FAO, 2012) accounting for 33% of the world area and 22% of the world production of pulses. Protein in Indian diet is mainly derived from the pulses whose production has remained almost constant during the last two decades at 10–13 million tons. Owing to the increase in population, the daily per capita protein consumption has progressively decreased, showing alarming situation of malnutrition in the country (Nawab, 2004). Among the pulses, kidney

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bean (*Phaseolus vulgaris* L.) is the most widely produced and consumed in the world and has an important place in human nutrition.

Information regarding the physical properties like size, shape, density, porosity, coefficient of friction of pulse seeds is very important in the design of equipment for harvesting, transporting, cleaning, separating, packaging, storing and processing it into different foods (Sahay and Singh, 1996).

Consumption of pulses is limited due to the presence of several anti-nutritional factors, such as α-galactosides, trypsin and chymotrypsin inhibitors, phytates and lectins that impede the availability of nutrients (Srivastava and Srivastava, 2003; Satya et al., 2010; Wang et al., 2008). Heat treatment of pulses involving cooking and roasting are used to remove antinutritional factors (Gujral et al., 2013). Cooking is the common processing method required to remove antinutritional factors and to ensure acceptable sensory quality of pulses (Klamczynska et al., 2001; Satya et al., 2010). Prior to cooking, pulses are usually soaked in water from few hours to overnight in order to save time and energy to cook (Fernandes et al., 2010). Cooking also causes some physicochemical changes in pulses, including gelatinization of starch, denaturation of proteins, solubilization of some of the polysaccharides, and softening and breakdown of the middle lamella, a cementing material found in the cotyledon (Wani et al., 2013; Vindiola et al., 1986). Factors affecting cooking quality of pulses include cultivar, seed characteristics, composition of seeds, growing location and environment (Bishnoi and Khetarpaul, 1993; Gubbels and Ali-Khan, 1991). Physical properties, such as size and weight, as well as seed coat and cotyledon characteristics, influence pulse cooking quality (Sefa-Dedeh and Stanley, 1979). The objectives of present study were to determine the physical and cooking properties of commonly grown kidney beans cultivars of Kashmir valley of India.

2. Materials and methods

2.1. Materials

Certified seeds of three kidney bean cultivars (*P. vulgaris* L. cv. French Yellow, Contendor, Master Bean) were procured from Sher-e-Kashmir University of Agricultural Sciences and Technology, Shalimar, Srinagar, J&K, India, whereas Local Red cultivar was procured from the local market of Srinagar, J&K, India. Seeds were cleaned from the dirt, foreign material etc and stored at 20 °C until further use. All the reagents used in the study were of analytical grade.

2.2. Composition

Protein (Method 960.10), fat (Method 920.85), crude fiber (Method 962.09) ash (Method 923.03) and moisture (Method 925.10) contents were determined according to standard methods of AOAC (1990). Total carbohydrates excluding crude fiber was calculated by difference (100 minus percentage, protein, fat, ash and crude fiber).

2.3. Physical properties of seeds

Physical properties of seeds were determined at 10% moisture content.

2.3.1. Color

The surface color of seeds was measured using Ultra Scan VIS Hunter Lab (Hunter Associates Laboratory Inc., Reston VA., USA). A glass cell containing seeds was placed against the light source, covered with a black cover and '*L*', '*a*', and '*b*' color values were recorded. Total color difference (ΔE) was calculated as:

$$\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2}$$

2.3.2. Length, width and thickness of seeds

Randomly selected seeds were used to measure length (L), width (W) and thickness (T), three principal dimensions which are in the three mutually perpendicular directions using a Vernier caliper reading to 0.01 mm. Average of ten determinations was reported.

2.3.3. Equivalent diameter

The geometric mean diameter, D_m, was calculated using the following relationship (Mohsenin, 1970). Average of ten determinations was reported.

$$D_m = (\mathrm{LWT})^{1/3}$$

2.3.4. Sphericity

The sphericity (Φ) was calculated as a function of the three principal dimensions as shown below (Mohsenin, 1970) and reported as average of ten determinations.

$$\Phi = [(\mathrm{LWT})^{1/3}/L] \times 100$$

2.3.5. Aspect ratio

The aspect ratio (R_a) of seeds was calculated as follows (Hauhouout-O'hara et al., 2000; Omobuwajo et al., 1999). Average of ten determinations was reported.

$$R_a = W/L$$

2.3.6. Seed volume

The volume, V (mm^3), of the seeds was calculated using the relationship (Mohsenin, 1970) and reported as average of ten determinations.

$$V = \pi B^2 L^2/6(2L - 3)$$

$$\text{where} \quad B = (\mathrm{WT})^{1/2}$$

2.3.7. Surface area of seeds

The surface area, A (mm^2), of the seeds was calculated using the relationship (Mohsenin, 1970). Average of ten determinations was reported.

$$A = \pi B L^2/2L - B$$

2.3.8. Bulk density

Bulk density was determined according to the method of Wani et al. (2013).

2.3.9. True density

True density is the weight per unit volume of individual seed. True density of seeds was determined using the liquid displacement method. Toluene (C_7H_8) was used instead of water because it is absorbed by seeds to a lesser extent. Besides it has low surface tension so that it fills even shallow dips in a seed and its dissolution is low (Mohsenin, 1980).

2.3.10. Porosity

The porosity (ε) of the bulk is the ratio of spaces in the bulk to its bulk volume and was determined by the following equation

$$\varepsilon = 100[1 - (P_b/P_k)]$$

where ε is the porosity in percentage; P_b is bulk density in g/mL and P_k is seed density in g/mL (Mohsenin, 1970; Nimkar and Chattopadhyay, 2001).

2.3.11. Angle of repose

The angle of repose (θ) of seed was determined by a cylindrical tube (smallest diameter 45 mm, biggest diameter 80 mm and height 100 mm) having discharge gate at the bottom . After filling the tube with seed sample, the gate was quickly removed. The height (h) of seed pile above the floor and the radius of the heap (r) were measured and used to determine the angle of response.

$$\theta = \tan^{-1}(h/r)$$

2.3.12. Static coefficient of friction

The static coefficient of friction (μ) was determined for three different structural materials, namely, mica ply, glass and polyethylene according to the method of Gezer et al. (2002). For this measurement one end of the friction surface was attached to an endless screw. The seed was placed on the surface and it was gradually raised by the screw. Vertical and horizontal height values were read from the ruler when the seed started sliding over the surface, then using the tangent value of that angle the coefficient of static friction was found.

$$\mu = \tan\varphi$$

where μ is the static coefficient of friction and φ is the angle of tilt in degrees.

2.3.13. Husk content

This was a measure of the husk content by a manual method of husk removal. A sample (10 g) of seed was soaked in 50 mL water at room temperature (20 °C) overnight. Water was removed and the husk manually removed. Husk and cotyledons were dried separately in an oven at 70 °C overnight and allowed to cool at room temperature for 1 h. Dried and cooled husk was weighed and husk content was calculated.

2.3.14. Hundred seed weight and hundred seed volume

One hundred seeds were manually counted and then weighed on a digital weighing balance with accuracy upto 0.001 mg.

Seed volume was determined by counting one hundred seeds manually and putting them in 50 mL graduated cylinder. 20 mL of double distilled water was added to it seed volume (mL) was determined as:

$$\text{Hundred seed volume} = \text{Total volume} - 20\ \text{mL}$$

2.4. Cooking properties

2.4.1. Swelling capacity and swelling index

The volume of 100 g of seeds was predetermined using a graduated cylinder and they were subsequently soaked overnight in distilled water. The volume of the seeds after soaking was then measured. Swelling capacity and the swelling index were determined (Adebowale et al., 2005).

$$\text{Swelling capacity} = \frac{\text{Volume after soaking} - \text{Volume before soaking}}{\text{Number of seeds}}$$

$$\text{Swelling index} = \frac{\text{Swelling capacity of seeds}}{\text{Volume of one seed}}$$

2.4.2. Hydration capacity and hydration index

Seeds (100 g) were soaked in 100 mL of distilled water in a measuring cylinder and covered with an aluminum foil. The seeds were left to soak for 24 h in room temperature (20 ± 2 °C), drained and excess water was removed using a tissue paper. The weight of the swollen seeds was measured. Hydration capacity and hydration index were calculated (Adebowale et al., 2005).

$$\text{Hydration capacity} = \frac{\text{Weight after soaking} - \text{Weight before soaking}}{\text{Number of seeds}}$$

$$\text{Hydration index} = \frac{\text{Hydration capacity of seeds}}{\text{Weight of one seed}}$$

2.4.3. Cooking time

Distilled water was brought to boil in 500 mL spout less beakers fitted with bulb condenser to prevent loss of water during cooking. 20 g of seeds from each cultivar was separately added to them. Boiling was continued, and samples (4–5 seeds) were withdrawn using a spatula at 5 min intervals upto 30 min and thereafter after every 2 min and tested for softness by pressing between finger and thumb. The time from addition of seeds till achievement of the desirable softness was recorded as the cooking time.

2.4.4. Gruel solid loss

Gruel solid loss was determined according to the method of Wani et al. (2013).

2.4.5. Cooked length–width ratio

The cumulative length and width of 10 seeds were measured after cooking for minimum cooking time. The length–breadth ratio of the 10 cooked seeds was determined by dividing the cumulative length to the cumulative breadth of cooked seeds.

2.4.6. Water uptake ratio

Twenty grams of seeds was cooked in 200 mL of double distilled water for minimum cooking time. The cooked seeds were then removed; drained and surface water on seeds was removed by using filter paper. The samples were weighed and the water uptake ratio was calculated as the ratio of weight gained after cooking to weight before cooking (Hamid et al., 2014).

2.5. Texture profile analysis

Texture of the soaked/cooked seeds was analyzed by using a Texture Analyzer (Model XT2i; Stable Micro Systems Ltd., England). Seeds were placed at its natural rest position on the heavy duty platform of the texture analyzer and texture profile analysis (TPA) test was performed with a disk probe of 75 mm diameter for 70% of compression at a test speed of 2.0 mm min^{-1}. Hardness, cohesiveness, chewiness and adhesiveness were calculated from the TPA curve. Average of ten determinations was reported.

2.6. Statistical analysis

The data reported are averages of triplicate observations, except in some physical and textural properties where data are average of ten observations as specified in methods section. An analysis of variance with a significance level of 5% was done and Duncan's test was applied to determine differences between means using the commercial statistical package (SPSS Inc., Chicago USA). Pearson's correlation coefficients of various properties of seeds were carried out to establish relationship between variables.

3. Results and discussion

3.1. Composition

The proximate composition of kidney beans is presented in Table 1. Moisture content of kidney beans was observed from 10.0% to 10.2%. Ash content was observed in the range of 3.5–3.9% and it varied significantly ($p \leqslant 0.05$) among the cultivars. Protein content varied significantly from 21.8% to 26.2%. Fat and crude fiber content of kidney beans were in the range of 1.7–1.9% and 5.5–6.1%, respectively and did not vary significantly ($p > 0.05$). The highest carbohydrate content (66.5%) was reported for French Yellow and the lowest for Master Bean (62.7%). Significant differences were found in carbohydrate content among the cultivars. Comparable results for composition of kidney bean have been reported (Dzudie and Hardy, 1996; Guzel and Sayar, 2012). The differences in composition of kidney beans could be due to the genetic differences.

3.2. Color

Color values of kidney bean cultivars revealed significant ($p \leqslant 0.05$) differences (Table 1). 'L' value was observed in the range of 33.31–38.90. The highest value of 'L' was observed for Contendor and the lowest for Local Red. 'a' value varied from 3.43 to 8.58 wherein, French Yellow revealed the highest value among the cultivars. 'b' value was in the range of 1.88–7.32. ΔE showed significant differences from 40.34 to 47.99. Highest ΔE was observed for Contendor and lowest for Local Red. Lower 'L' and 'a' values of Local Red cultivar suggest its darker red color. Color values of 'L', 'a' and 'b' in the range of 63.72–77.24, 0.69–4.93 and 9.83–14.84, respectively have been reported for kidney beans (Ozturk et al., 2010, 2009). The differences in reported and observed values might be attributed to the genetic differences.

3.3. Physical properties of seeds

Size is an important physical attribute of seeds used in screening solids to separate foreign materials and heat and mass transfer calculations. Length, width, thickness and equivalent diameter are commonly used measures of size. Length, width and thickness of kidney beans varied significantly ($p \leqslant 0.05$) in the range of 11.45–16.45 mm, 6.65–7.80 mm and 4.70–6.13 mm respectively, (Table 2). Master Bean seeds displayed significantly higher values for length, width and thickness than other cultivars under study. Oomah et al. (2010) reported

Table 1 Composition and color values of kidney bean seeds ($n = 3$).

Parameter	Cultivars			
	French Yellow	Contendor	Master Bean	Local Red
Moisture (%)	10.0 ± 0.04^a	10.1 ± 0.27^a	10.0 ± 0.33^a	10.2 ± 0.24^a
Protein (%)	22.3 ± 0.48^a	21.8 ± 0.49^a	26.2 ± 0.46^b	26.0 ± 0.81^b
Fat (%)	1.7 ± 0.16^a	1.8 ± 0.25^a	1.8 ± 0.21^a	1.9 ± 0.07^a
Ash (%)	3.5 ± 0.09^a	3.9 ± 0.13^b	3.5 ± 0.11^a	3.8 ± 0.16^b
Crude fiber (%)	6.0 ± 0.41^a	6.1 ± 0.54^a	5.8 ± 0.32^a	5.5 ± 0.15^a
Carbohydrates (%)	66.5 ± 0.07^b	66.4 ± 1.15^b	62.7 ± 0.90^a	62.8 ± 0.64^a
Color values				
L	36.59 ± 0.17^c	38.90 ± 0.44^d	35.67 ± 0.67^b	33.31 ± 0.23^a
a	8.58 ± 0.26^d	6.98 ± 0.25^c	3.43 ± 0.21^a	4.66 ± 0.38^b
b	7.04 ± 0.19^c	7.32 ± 0.18^d	4.45 ± 0.27^b	1.88 ± 0.19^a
ΔE	46.08 ± 0.32^c	47.99 ± 0.54^d	43.12 ± 0.80^b	40.34 ± 0.34^a

Composition of seeds is on dry weight basis.
Values expressed are mean ± standard deviation.
Means in the row with different superscript are significantly different at $p \leqslant 0.05$.

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Table 2 Physical properties of kidney bean seeds.

Parameter	Cultivars			
	French Yellow	Contendor	Master Bean	Local Red
Length (mm)	13.95 ± 0.37[b]	16.45 ± 0.69[c]	16.30 ± 0.95[c]	11.45 ± 0.60[a]
Breadth (mm)	7.11 ± 0.38[a]	6.65 ± 0.66[a]	7.80 ± 0.42[b]	7.00 ± 0.47[a]
Thickness (mm)	5.95 ± 0.40[b]	5.79 ± 0.44[b]	6.13 ± 0.74[b]	4.70 ± 0.48[a]
Length breadth ratio	1.97 ± 0.09[b]	2.49 ± 0.21[c]	2.09 ± 0.16[b]	1.64 ± 0.17[a]
Equivalent diameter (mm)	8.40 ± 0.25[b]	8.60 ± 0.53[b]	9.24 ± 0.34[c]	7.31 ± 0.35[a]
Sphericity (%)	60.12 ± 2.83[c]	52.13 ± 1.96[a]	56.44 ± 3.56[b]	63.08 ± 3.97[c]
Aspect Ratio	0.51 ± 0.04[b]	0.40 ± 0.04[a]	0.48 ± 0.04[b]	0.61 ± 0.06[c]
Seed volume (mm^3)	173.23 ± 15.98[b]	183.74 ± 32.38[b]	223.96 ± 27.29[c]	113.83 ± 16.86[a]
Surface area (mm^2)	185.94 ± 11.03[b]	198.00 ± 23.16[b]	224.18 ± 17.58[c]	137.84 ± 13.95[a]
Bulk density (kg/L)	0.80 ± 0.01[b]	0.78 ± 0.00[a]	0.79 ± 0.00[ab]	0.81 ± 0.00[c]
True density (kg/L)	1.27 ± 0.00[b]	1.22 ± 0.01[a]	1.23 ± 0.01[a]	1.23 ± 0.02[a]
Porosity (%)	37.50 ± 0.50[b]	36.31 ± 0.75[b]	35.88 ± 1.21[b]	33.60 ± 0.68[a]
Seed coat (%)	9.72 ± 0.05[a]	9.62 ± 0.50[a]	9.38 ± 0.05[a]	9.27 ± 0.07[a]
100 seed mass (g)	38.27 ± 1.46[b]	39.72 ± 1.61[b]	44.61 ± 0.98[c]	25.16 ± 1.03[a]
100 seed volume (mL)	27.33 ± 1.15[b]	30.00 ± 0.00[c]	37.33 ± 1.15[d]	16.00 ± 0.00[a]
Angle of repose (°)	18.67 ± 0.49[c]	18.31 ± 0.54[c]	15.20 ± 0.57[a]	16.46 ± 0.65[b]
Static coefficient of friction				
Cardboard	0.27 ± 0.04[a]	0.30 ± 0.00[a]	0.29 ± 0.00[a]	0.30 ± 0.01[a]
Mica ply	0.28 ± 0.02[a]	0.25 ± 0.01[a]	0.26 ± 0.00[a]	0.28 ± 0.01[a]
Polythene	0.43 ± 0.02[ab]	0.43 ± 0.01[ab]	0.44 ± 0.02[b]	0.40 ± 0.01[a]

Values expressed are mean ± standard deviation.
Means in the row with different superscript are significantly different at $p \leqslant 0.05$.

Table 3 Cooking properties of kidney bean seeds ($n = 3$).

Parameter	Cultivars			
	French Yellow	Contendor	Master Bean	Local Red
Hydration capacity (g/seed)	0.34 ± 0.01[b]	0.34 ± 0.00[b]	0.42 ± 0.01[c]	0.12 ± 0.00[a]
Hydration index	0.87 ± 0.03[b]	0.88 ± 0.08[b]	0.93 ± 0.01[b]	0.48 ± 0.03[a]
Swelling capacity (ml/seed)	0.27 ± 0.02[c]	0.28 ± 0.01[c]	0.13 ± 0.01[b]	0.09 ± 0.00[a]
Swelling index	0.74 ± 0.05[c]	0.82 ± 0.03[d]	0.30 ± 0.00[a]	0.39 ± 0.03[b]
Cooking time (min) – unsoaked	86.67 ± 1.15[d]	81.33 ± 1.15[c]	68.67 ± 1.15[a]	72.00 ± 2.00[b]
Cooking time (min) – soaking 6 h	63.33 ± 1.15[b]	70.67 ± 1.15[c]	49.33 ± 1.15[a]	70.67 ± 1.15[c]
Cooking time (min) – soaking 12 h	56.00 ± 2.00[c]	66.00 ± 2.00[d]	38.67 ± 1.15[a]	49.33 ± 1.15[b]
Gruel solid loss (%) – unsoaked	15.79 ± 1.11[b]	14.08 ± 0.67[a]	15.75 ± 0.71[b]	14.69 ± 0.45[ab]
Gruel solid loss (%) – soaking 6 h	14.20 ± 0.38[a]	13.07 ± 0.01[a]	14.63 ± 1.79[a]	14.40 ± 0.20[a]
Gruel solid loss (%) – soaking 12 h	13.43 ± 1.11[ab]	12.11 ± 0.33[a]	14.50 ± 0.50[b]	14.12 ± 0.71[b]
Cooked length breadth ratio	1.89 ± 0.05[b]	2.12 ± 0.09[c]	2.13 ± 0.18[c]	1.57 ± 0.09[a]
Water uptake ratio of cooked seeds	2.42 ± 0.01[c]	2.45 ± 0.13[c]	2.28 ± 0.05[b]	2.15 ± 0.02[a]
Elongation ratio	1.35 ± 0.08[b]	1.30 ± 0.11[b]	1.19 ± 0.07[a]	1.30 ± 0.09[b]

Values expressed are mean ± standard deviation.
Means in the row with different superscript are significantly different at $p \leqslant 0.05$.

length, width and thickness in the range of 9.11–13.07 mm, 6.29–8.44 mm and 4.20–5.56 mm respectively for different kidney bean cultivars. Altuntas and Demirtola (2007) reported 16.66 mm length, 8.94 mm width and 7.20 mm thickness for kidney beans. Guzel and Sayar (2012) also reports similar results for white kidney beans. So, our results are in agreement with previous studies. Equivalent diameter of kidney bean seeds was in the range of 7.31–9.24 mm. Master Bean reported the highest and Local Red the lowest equivalent diameter. Equivalent diameter of kidney beans has been reported to vary from 9.71 to 10.21 mm (Altuntas and Demirtola, 2007; Isik and Unal, 2007). These differences in seed size may be due to genetic differences (Hu et al., 2013). Length breadth ratio was observed from 1.64 to 2.49 wherein, Local Red revealed the lowest value and Contendor the highest value.

Shape is also important in heat and mass transfer calculations, screening solids to separate foreign materials, and evaluating the quality of food materials. The shape of a food material is usually expressed in terms of its sphericity and aspect ratio. Sphericity is an expression of a shape of a solid relative to that of a sphere of the same volume. Sphericity varied significantly from 52.13% to 63.08% (Table 2). Local Red showed the highest sphericity while as the lowest was found in Contendor among the cultivars. Sphericity in the range of 79.37–81.67 % for different kidney bean cultivars has been reported by (Oomah et al., 2010). Altuntas and Demirtola

Table 4 Texture properties of kidney bean seeds ($n = 3$).

Parameter	Cultivars			
	French Yellow	Contendor	Master Bean	Local Red
Soaked seeds				
Hardness (kg)	19.44 ± 1.99[a]	34.61 ± 9.69[b]	32.69 ± 9.96[b]	20.26 ± 5.43[a]
Cohesiveness	0.12 ± 0.01[a]	0.13 ± 0.01[a]	0.12 ± 0.02[a]	0.14 ± 0.02[b]
Chewiness	0.76 ± 0.17[a]	1.14 ± 0.26[b]	0.98 ± 0.33[ab]	1.02 ± 0.21[b]
Adhesiveness (kg s)	2.21 ± 0.91[a]	11.09 ± 3.92[b]	15.66 ± 3.42[c]	1.50 ± 0.52[a]
Cooked seeds				
Hardness (kg)	9.63 ± 1.81[a]	11.28 ± 1.99[a]	10.08 ± 0.96[a]	10.77 ± 3.58[a]
Cohesiveness	0.13 ± 0.05[a]	0.13 ± 0.03[a]	0.14 ± 0.02[a]	0.15 ± 0.02[a]
Chewiness	0.35 ± 0.16[a]	0.35 ± 0.14[a]	0.39 ± 0.33[a]	0.40 ± 0.22[a]
Adhesiveness (kg s)	0.17 ± 0.08[a]	0.30 ± 0.10[b]	0.24 ± 0.09[ab]	0.25 ± 0.12[ab]

Values expressed are mean ± standard deviation.
Means in the row with different superscript are significantly different at $p \leqslant 0.05$.

(2007) reported sphericity of 61.03–61.28% for kidney beans. Aspect ratio relates the width to the length of the seed, which is an indicative of its tendency toward being oblong in shape (Omobuwajo et al., 1999). Aspect ratio varied significantly in the range of 0.40–0.61 among the cultivars.

Seed volume and surface area varied significantly and were observed in the range of 113.83–223.96 mm^3 and 137.84–224.18 mm^2, respectively (Table 2). Local Red had the lowest seed volume and surface area while as it was the highest for Master Bean. The values reported here are lower than reported elsewhere (Ozturk et al., 2010; Altuntas and Demirtola, 2007; Ozturk et al., 2009). This might be attributed to smaller size of kidney beans cultivars used in this study than those studied by these authors.

Bulk density is the density of a material when packed or stacked in bulk while as, true density is the density of the solid material excluding the volume of any open and closed pores. The bulk density of a material depends on the solids density and the geometry, size and surface properties of the individual particles. Significant differences were observed in bulk density and true density in the range of 0.78–0.81 kg/L and 1.22–1.27 kg/L, respectively (Table 2). Bulk density and true density of kidney bean cultivars in the range of 0.72–0.87 and 1.23–1.31 kg/L, respectively has been reported (Ozturk et al., 2010, 2009).

Porosity is defined as the volume fraction of the air or the void fraction in the sample. Porosity varied significantly from 33.6% to 37.5% among the kidney bean cultivars (Table 2). Lowest porosity was reported for Local Red cultivar. Porosity of different kidney bean cultivars has been reported in the range of 33.05–40.43% (Ozturk et al., 2010, 2009). So, our results fall within the range reported by these authors. However, the values are lower than reported by other authors (Altuntas and Demirtola, 2007; Isik and Unal, 2007).

Angle of repose is the angle of the maximum slope, at which a heap of any loose solid material will stand without sliding. Angle of repose showed significant differences among the kidney bean cultivars and varied from 15.20° to 18.67° (Table 2). Lowest angle of repose was reported in Master Bean and highest in French Yellow. Angle of repose for different kidney bean cultivars has been reported to vary between 11.66° and 29.62° (Ozturk et al., 2010, 2009; Altuntas and Demirtola, 2007).

Seed coat of kidney bean cultivars displayed non significant differences ($p > 0.05$) and was in the range of 9.27–9.72% (Table 2). 100-seed mass of kidney bean cultivars varied significantly from 25.16 to 44.61 g. The highest seed mass was observed in Master Bean and the lowest in Local Red cultivar. 100 seed mass of dry bean (*P. vulgaris* L.) cultivars have been reported to vary between 20.8 and 58.6 g (Saha et al., 2009; Mkanda et al., 2007). So, our results fall within the range as reported by these authors. 100-seed volume was in the range of 16.0–37.33 mL and it differed significantly among and between the cultivars (Table 2). Master Bean displayed the highest seed volume and Local Red the lowest seed volume.

The static coefficient of friction varied from 0.27 to 0.30 for cardboard, 0.25–0.28 for mica board and 0.40–0.44 for glass (Table 2). Master Bean showed significantly higher coefficient of friction with polythene than other cultivars under study, while as, differences were non-significant with cardboard and mica board. Similar results were reported for kidney beans (Altuntas and Demirtola, 2007; Isik and Unal, 2007).

3.4. Cooking properties

Hydration capacity and hydration index varied significantly ($p \leqslant 0.05$) among the cultivars and were observed in the range of 0.12–0.42 g/seed and 0.48–0.93, respectively (Table 3). Hydration capacity and hydration index of bean cultivars have been reported to vary between 0.31–0.59 g/seed and 0.78–1.25, respectively (Saha et al., 2009). Hydration capacity determines the extent to which seeds absorb water on soaking. It depends upon chemical composition of seed coat and cotyledons (Bewley et al., 2006).

Swelling capacity and swelling index also displayed significant differences among the cultivars. These parameters varied from 0.09 to 0.28 mL/seed and 0.30–0.82, respectively (Table 3). Swelling capacity and swelling index of kidney bean cultivars in the range of 0.30–0.56 mL/seed and 0.91–1.39, respectively have been reported (Saha et al., 2009).

Cooking time of kidney bean cultivars without prior soaking varied significantly ($p \leqslant 0.05$) from 68.67 to 86.67 min (Table 3). The lowest cooking time was found in Master Bean and the highest for French Yellow. Cooking time between 42.4 and 97.8 min has been reported for different beans (Mkanda et al.,

Table 5 Pearson's correlation coefficients between composition, cooking and some physical properties.

	Protein	Fat	Ash	Crude Fiber	Carb.	Bulk density	Porosity	Hyd. Cap.	Swelling Capacity.	Cooking Time	Solid Gruel Loss	Water uptake ratio	Eq. Dia.	Sph.	Grain volume	Grain surface area	Grain seed hardness
Fat	0.192																
Ash	−0.510	−0.398															
Crude fiber	−0.444	0.264	0.188														
Carbohydrate (Carb.)	−0.873[**]	−0.019	0.048	0.377													
Bulk density	0.631	0.112	0.175	−0.395	−0.794[**]												
Porosity	−0.303	0.608[*]	−0.039	0.537	0.517	0.670[**]											
Hydration capacity (Hyd. Cap.)	−0.198	0.102	−0.542	0.414	0.496	−0.829[**]	0.706[*]										
Swelling capacity	−0.709[**]	0.510	0.012	0.595[*]	0.794[**]	−0.616[*]	0.783[**]	0.455									
Cooking time	−0.484	0.753[**]	0.049	0.474	0.532	−0.239	0.680[*]	0.124	0.892[**]								
Solid gruel loss	−0.541	0.404	−0.611[*]	0.107	−0.321	0.111	0.214	0.321	−0.139	−0.058							
Water uptake ratio	−0.635[*]	0.330	−0.130	0.544	0.821[**]	−0.674[*]	0.712[**]	0.601[*]	0.872[**]	0.682[*]	−0.204						
Equivalent diameter (Eq. Dia.)	0.141	0.082	−0.113	0.055	−0.066	0.142	0.014	0.316	0.037	−0.035	0.186	0.046					
Sphericity (Sph.)	−0.055	0.439	−0.624[*]	0.300	0.412	−0.613[*]	0.705[*]	0.756[**]	0.496	0.359	0.363	0.480	−0.351[*]				
Grain volume	0.150	0.096	−0.133	0.058	−0.069	−0.142	0.020	0.321	0.042	−0.032	0.184	0.054	0.994[**]	−0.310			
Grain surface area	0.159	0.064	−0.074	0.033	−0.111	−0.087	−0.043	0.256	0.002	−0.060	0.147	0.014	0.998[**]	−0.380[*]	0.996[**]		
Cooked seed hardness	0.380	−0.489	−0.061	−0.652[*]	−0.446	0.352	−0.664[*]	−0.259	−0.670[*]	−0.717[**]	0.128	−0.629[*]	−0.114	−0.174	−0.106	−0.093	
Cooked seed adhesiveness	0.599[*]	−0.455	−0.065	−0.508	−0.668[*]	0.461	−0.624[*]	−0.309	−0.811[**]	−0.797[**]	−0.046	−0.562	0.034	−0.155	0.031	0.047	0.279

[**] Correlation is significant at the 0.01 level (two tailed).
[*] Correlation is significant at the 0.05 level (two tailed).

2007; Berrios et al., 1999). Cooking time of kidney bean seeds after soaking for 6 h and 12 h varied 49.33–70.67 min and 38.67–66.00 min, respectively. This shows that soaking prior to cooking causes significant ($p \leqslant 0.05$) decrease in cooking time of kidney beans. Similar trend of decrease in cooking time was observed in kidney beans by Berrios et al. (1999). During hydrothermal cooking, gelatinization initiates the changes in starch inside the cells (Vindiola et al., 1986). Breakdown of the middle lamella, leading to the easy separation of cells, had been reported to contribute to the softening of pulses during cooking (Sefa-Dedeh and Stanley, 1978). Many authors had shown that the cells of beans during cooking show separation at the optimum cooking time. Williams et al. (1987) reported that the cooking time is a heritable characteristic for pulses.

Solid gruel loss of unsoaked seeds and seeds soaked for 12 h varied significantly among the cultivars from 14.08% to 15.79% and 12.11–14.50%, respectively (Table 3). However, it varied insignificantly ($p > 0.05$) for kidney bean seeds soaked for 6 h. Solid loss of 5.28–14.98% has been reported for different bean cultivars (Saha et al., 2009) and 7.2–14% for cowpea cultivars (Yeung et al., 2009).

Cooked length breadth ratio showed significant differences among the cultivars and were in the range of 1.57–2.13. Water uptake ratio varied significantly among the cultivars in the range of 2.15–2.45.

3.5. Texture properties

Textural properties of kidney beans soaked overnight were evaluated using texture profile analysis (Table 4). Hardness of soaked seeds varied significantly from 19.44 to 34.61 kg. Contendor displayed the highest hardness while as the lowest was observed in French Yellow. Cohesiveness was observed from 0.12 to 0.14 wherein, Local Red showed the highest value among the cultivars. Chewiness was observed in the range of 0.76–1.14. Adhesiveness varied significantly from 1.50 to 15.66 kg s among the cultivars. Local Red had the highest adhesiveness among the cultivars while as, the lowest was observed in Master Bean.

Texture of cooked kidney bean seeds was also evaluated by texture profile analysis (Table 4). Hardness of cooked kidney bean seeds was observed from 9.63 to 11.28 kg. Hardness of cooked bean cultivars has been reported in the range of 4.65–6.52 kg (Saha et al., 2009). Cohesiveness was observed between 0.13 and 0.15. Chewiness was in the range of 0.24–0.29. Hardness, cohesiveness and chewiness of cooked kidney bean seeds did not show significant ($p > 0.05$) differences among the cultivars. Adhesiveness varied significantly ($p \leqslant 0.05$) among the cultivars between 0.17 and 0.30. Contendor has higher adhesiveness than other cultivars under study.

3.6. Pearson's correlation coefficient between the composition, physical and cooking properties

Pearson's correlation coefficients between various properties of kidney bean seeds are presented in Table 5. Protein content had significant positive correlation with cooked seed adhesiveness ($r = 0.599$, $p \leqslant 0.05$). However, it had significant negative correlations with carbohydrate content ($r = -0.873$, $p \leqslant 0.01$), swelling capacity ($r = -0.709$, $p \leqslant 0.01$) and water uptake ratio ($r = -0.635$, $p \leqslant 0.01$). Fat content was positively correlated with porosity ($r = 0.608$, $p \leqslant 0.05$) and cooking time ($r = 0.753$, $p \leqslant 0.01$). Ash content displayed significant negative correlations with solid gruel loss ($r = -0.611$, $p \leqslant 0.01$) and sphericity ($r = -0.624$, $p \leqslant 0.05$). Significant positive correlation was found between crude fiber and swelling capacity, but crude fiber had negative correlation with cooked seed hardness ($r = -0.652$, $p \leqslant 0.05$). Carbohydrate content showed significant positive correlation with swelling capacity ($r = 0.794$, $p \leqslant 0.01$) and water uptake ($r = 0.821$, $p \leqslant 0.01$); but it had significant negative correlations with bulk density ($r = -0.794$, $p \leqslant 0.05$) and cooked seed hardness ($r = -0.\ 668$, $p \leqslant 0.05$). This may be attributed to higher water absorption by carbohydrates, resulting in high swelling capacity and low seed hardness after cooking. Porosity displayed positive correlations with fat ($r = 0.608$, $p \leqslant 0.05$), hydration capacity, swelling capacity, cooking time, water uptake time and sphericity. However, porosity was negatively correlated with cooked seed hardness and cooked seed adhesiveness. Positive correlation was found between hydration capacity and water uptake ratio ($r = 0.\ 601$, $p \leqslant 0.05$). Swelling capacity had positive correlation with cooking time ($r = 0.892$, $p \leqslant 0.01$), water uptake ratio ($r = 0.872$, $p \leqslant 0.01$) but negative correlation with cooked seed hardness ($r = -0.670$, $p \leqslant 0.05$) and cooked seed adhesiveness ($r = -0.797$, $p \leqslant 0.01$). Water uptake ratio had significant negative correlation with cooked seed hardness. Equivalent diameter positively correlated with grain volume and grain surface area.

4. Conclusion

Kidney bean cultivars had significant differences in composition and color values. Seed dimensions, sphericity, surface area, bulk density and angle of repose were significantly different among the cultivars indicating that these would require some variation in the processing equipment design. Also difference in 100-seed weight and 100-seed volume of the cultivars, suggests that equal quantity of each cultivar would occupy unequal space and the cost of packaging and transportation would be different (if based on space occupied). Master Bean cultivar had better cooking properties due to its shorter cooking time, higher gruel solid loss and higher cooked length breadth ratio than other cultivars. Textural properties like hardness, cohesiveness and chewiness of cooked seeds did not show significant differences among the cultivars, indicating that they have been cooked to the same degree. Cooking time has significant positive correlations with swelling capacity, porosity and fat content. However, it has significant negative correlations with cooked seed adhesiveness and cooked seed hardness.

Conflict of interest

None of the authors have conflict of interest.

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