Comparative study of physicochemical and functional properties of flours from kidney bean (*Phaseolus vulgaris* L.) and green gram (*Vigna radiata* L.) cultivars grown in Indian temperate climate

Idrees Ahmed Wani1 | Syed Nowsheen Andrabi1 | Dalbir Singh Sogi2 | Ifra Hassan1

1Department of Food Science & Technology, University of Kashmir, Srinagar, India
2Department of Food Science and Technology, Guru Nanak Dev University, Amritsar, India

**Correspondence**
Idrees Ahmed Wani, Department of Food Science & Technology, University of Kashmir, Srinagar, 190 006, India.
Email: idwani07@gmail.com

**Abstract**
The present work was conducted to study the physicochemical, functional, and morphological characteristics of flours obtained from two kidney bean (Shalimar Rajmah-1 and Shalimar Rajmah 132) and two green gram cultivars (Shalimar Moong-1 [Shal Moong-1] and Shalimar Moong-2 [Shal Moong-2]). Moisture, protein, fat, ash, and carbohydrate contents of flours varied at 13.00–14.00, 14.78–25.02, 1.00–2.00, 3.00–4.00, and 56.98–66.22 g/100 g, respectively. Hunter colour “L,” “a,” and “b” values varied in the range of 71.22–82.65, −1.80 to −0.12, and 15.20–22.85, respectively. Swelling index increased from 2.48 at 50°C to 3.76 at 90°C (bean flour) and 2.5 at 50°C to 5.83 at 90°C (green gram flour). Increase in syneresis and decrease in transmittance of flour gels were observed at 4°C during 120h storage period. A significant (*p* ≤ .05) variation was observed in the peak viscosity (282.0–772.0 cP), trough viscosity (211.0–620 cP), setback viscosity (20.0–112.0 cP), and pasting temperature (67.48–94.93°C). Fourier transform infrared analysis of the flours revealed main absorption bands around 3,275 and 992 cm⁻¹. The lowest and highest gelatinization temperatures were reported in Shal M-2 and Shal Moong-1, respectively. *G′* and *G″* of the flours increased with the increase in frequency depicting gel-like behaviour. The flour particles were oval or elliptical with rough and irregular surfaces.

The study concluded that the green gram flours had higher protein, swelling index, solubility index, syneresis, and pasting properties than had the kidney bean flours. However, higher functional properties like water absorption, foaming, and emulsifying capacities were observed in kidney bean than in green gram flours.

**Keywords**
flour, FTIR, green gram, kidney bean, physicochemical properties

---

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2019 The Authors. Legume Science published by Wiley Periodicals, Inc.

[Legume Science](https://doi.org/10.1002/leg3.11)
1 | INTRODUCTION

Pulses belong to the family Leguminosae. These are rich in nutrients like starch, proteins, fibre, vitamins, minerals, and polyphenols (Tharanathan & Mahadevamma, 2003). After cereals, pulses are considered as important foods for human consumption, being widely produced and consumed throughout the world. These are known to contribute to the nutritional well-being of diversified human diets (Uebersax & Occena, 2003). Due to high protein content (20–40%) and bioavailability, especially when taken with cereals (Oomah, Patras, Rawson, Singh, & Compos-Vega, 2011), these are considered as a poor man’s meat. India is the largest producer of pulses (Gujral, Angurala, Sharma, & Singh, 2011) with the cultivation of about more than 20 species. They contribute to about a quarter of world’s total production (Theertha, Alice, Sujeetha, Abirami, & Alagusundaram, 2014). Among pulses, kidney beans (Phaseolus vulgaris L.) and green gram (Vigna radiata L.) are commonly consumed pulses in Indian diets.

Consumption of beans can be improved by blending beans into flour (Dzudie & Hardy, 1996). The use of flour from different legumes is now gaining the interest of many research workers mainly due to their functional properties (Siddiq, Ravi, Harte, & Dolan, 2010; Singh, Wani, Kaur, & Sogi, 2008; Wani, Sogi, Shihvare, & Gill, 2014). The functional properties of legume flours mainly depend on proteins, carbohydrates, and other components. These include water and oil absorption capacity (WAC and OAC, respectively), foaming, emulsification, texture, gelation, and viscosity, which increase their efficiency and performance in food products. Legume flours find applications in preparation of breads, ready-to-eat breakfast cereals, snacks, frying batters, and others. Throughout the world, kidney beans and green gram have the lowest cost and are the most easily available pulses. The aim of the present study was to investigate and compare the physicochemical, functional, and morphological properties of flour from two kidney bean and two green gram cultivars. The study may provide useful information to consumers and food manufacturers for the development of value-added foods using pulse flour and improving human health.

2 | MATERIALS AND METHODS

2.1 | Materials

Certified seeds of two kidney bean (P. vulgaris L.) namely Shalimar Rajmah-1 and Shalimar Rajmah 132 and two green gram (V. radiata L.) cultivars - Shalimar Moong-1 and Shalimar Moong-2 were procured from Sher-e-Kashmir University of Agricultural Sciences and Technology (SKUAST-K), Shalimar, Srinagar. Seeds were cleaned manually to remove dirt and foreign materials and were stored at 20°C until further use.

2.2 | Methods

2.2.1 | Flour preparation

Seeds of selected cultivars were ground by domestic grinder (Sujata, New Delhi, India). The flours were sieved through 60-mesh screen and then packaged and sealed in polythene zip pouch bags for further use.

2.2.2 | Proximate composition

Moisture (925.10), protein (920.87), fat (920.85), and ash (923.03) contents of starch were determined according to the methods of Association of Official Analytical Chemists (2000). Carbohydrate was calculated from the difference.

2.2.3 | Apparent amylose content

Apparent amylose content of the starch and flour samples was determined by the method of William, Kuzina, and Hlynka (1970). Flour sample (20 mg) was taken, 10 mL of 0.5-M KOH was added, and the suspension was mixed thoroughly. The dispersed sample was transferred to a 100-mL volumetric flask and the volume was made up to the mark with distilled water. An aliquot of the test starch solution (10 mL) was pipetted into a 50-mL volumetric flask, and 5 mL of 0.1-M aqueous HCl was added followed by 0.5 mL of iodine reagent. The volume was diluted to 50 mL and allowed to stand for 5 min. The absorbance was measured at 625 nm (UV Spectrophotometer, U-2900, Hitachi, Tokyo, Japan). The content of amylose was determined from a standard curve developed using standard amylose and amylopectin blends from potato starch.

2.2.4 | Colour

The surface colour of flour was measured according to the method of Andrabi, Wani, Gani, Hamdani, and Masoodi (2015). A glass cell containing uniformly sized flour was placed against the light source; and “L” (lightness), “a” (redness–greenness), and “b” (yellowness–blueness) values were measured after calibration of the equipment with standard black and white tiles.

2.2.5 | Bulk density and tapped density

Bulk density was measured in grams per millilitre as weight of flour per unit volume according to the method of Wani, Sogi, and Gill (2013). The tapped density (g/mL) was measured by gently tapping the cylinder on the bench top from a height of 5 cm until there was no further diminution in the sample level and the volume was noted (Andrabi et al., 2015).
2.2.6 | Swelling and solubility indices

Swelling and solubility indices were measured as per the method of Andrabi et al. (2015). Sample (0.2 g dry weight basis [db]) was taken in a preweighed centrifuge tubes with 10 mL of distilled water. The sample suspensions were then incubated in a water bath for 30 min at 50°C, 60°C, 70°C, 80°C, and 90°C with 5 min. After the samples were cooled to room temperature, the tubes were centrifuged at 5,000×g for 15 min. The supernatant was carefully decanted in preweighed moisture dishes. The increase in weight of centrifuge tubes was expressed as swelling index (g/g). Moisture dishes containing supernatant were dried at 110°C for 12 h and then cooled in desiccators to room temperature. The gain in weight of moisture dishes was expressed as solubility index (g/g).

2.2.7 | Light transmittance (%)

Light transmittance of 1% flour gels was determined according to the method of Wani, Sogi, and Gill (2012). An aqueous starch suspension (1% db) was prepared by heating at 90°C in a water bath (SWB-10L-1-Taiwan) for 30 min with constant stirring at 75 rpm. The suspension was cooled for 1 h at 30°C. The samples were stored for 5 days at 4°C in a refrigerator, and transmittance was determined every 24 h by measuring absorbance at 640 nm against a water blank with an ultraviolet–visible spectrophotometer (U-2900, Hitachi, Tokyo, Japan).

2.2.8 | Syneresis

Syneresis was determined by the modified method of Sofi, Wani, Masoodi, Saba, and Muzaffar (2013). Flour suspensions (6%, w/w db) were heated at 90°C for 30 min in a water bath (SWB-10L-1-Taiwan) with constant stirring at 75 rpm. The starch sample was stored for 0, 24, 48, 72, 96, and 120 h at 4°C in separate tubes each day. Syneresis was measured as per cent amount of water released after centrifugation at 3,000×g for 10 min (5810R, Eppendorf, Hamburg, Germany).

2.2.9 | Pasting properties

The pasting properties of the flours were measured using a Rapid Visco Analyzer (Tech Master, Pertain Instruments Warriewood, Australia) according to the method of Andrabi et al. (2015). An aqueous dispersion of flour on 14% moisture basis (10.7%, w/w; 28.5 g of total weight) was equilibrated at 50°C for 1 min. The dispersion was heated at the rate of 12.2°C/min to 95°C, held for 2.5 min, cooled to 50°C at the rate of 11.8°C/min, and again held at 50°C for 2 min. A constant paddle rotational speed (160 rpm) was used throughout the entire analysis, except for rapid stirring at 960 rpm for the first 10 s to disperse the sample.

2.2.10 | Functional properties

Water absorption capacity (WAC) and Oil absorption capacity (OAC)

WAC and OAC of the samples were determined according to the method of Wani et al. (2015). Flour (2.5 g) on db was mixed with 20 mL of distilled water or mustard oil and then stirred for 30 min at 25°C. The slurry was then centrifuged at 3,000×g for 10 min (5810R, Eppendorf, Hamburg, Germany), and the supernatant was decanted. The gain in weight was expressed as percentage of WA/OAC.

Foam capacity (FC) and foam stability (FS)

The method described by Narayana and Narasinga Rao (1982) was used for the determination of foam capacity (FC) and foam stability (FS). Two grams of the flour sample was added to 50 mL of distilled water at 30 ± 2°C in a 100-mL measuring cylinder. The suspension was mixed and properly shaken by whipping for 3 min in a homogenizer to form foam. The content was transferred into the measuring cylinder, and the volume of the foam after 30 s was recorded. The FC was expressed as a percentage increase in volume:

\[
\text{Foam capacity} (\%) = \frac{\text{Volume after whipping} - \text{Volume before whipping}}{\text{Volume before whipping}} \times 100
\]

The foam volume was recorded 1 hr after whipping to determine the FS as a percentage of the initial foam volume:

\[
\text{Foam stability} (\%) = \frac{\text{Foam volume after standing time (60 min)}}{\text{Initial foam volume}} \times 100
\]

Emulsion capacity and stability

Emulsion activity of samples was determined by the method of Neto, Narain, Silvia, and Bora (2001). The emulsion with 0.2-g sample, 20 mL of distilled water, and 20 mL of oil was prepared in a graduated centrifuge tube. The contents were centrifuged at 2,000×g for 5 min. The ratio of the height of the emulsion layer to the total height of the mixture was calculated as the emulsion activity and expressed in percentage:

\[
\text{Emulsion capacity} (\%) = \frac{\text{Height of emulsion layer (mL)}}{\text{Total height (mL)}} \times 100
\]

Emulsion stability (ES) was recorded after heating the emulsion in centrifuge tube for 0.5 hr, and then the ES as a percentage of the initial emulsion layer was determined:

\[
\text{Emulsion stability} (\%) = \frac{\text{Height of emulsion layer after heating (mL)}}{\text{Height before (mL)}} \times 100
\]

2.2.11 | Rheology of flours

Flour gels (1% w/v) were prepared in distilled water at 90°C, under mechanical stirring for 3 h, followed by cooling to room
temperature before measurements. Rheological measurements were performed using dynamic rheometer (MCR102, Anton Paar) at a temperature of 25°C. All measurements were done at 25°C, using parallel plate geometry (40-mm diameter and 2-mm gap). The dough sample was placed between the plates, and the edges were carefully trimmed with a spatula. The flow experiments were conducted under steady-shear conditions with shear rate ranging from 1 to 100 s⁻¹. For the relaxation of the residual stresses, the dough was rested at room temperature for 10 min before testing. Variations in the key characterization parameters, that is, G' (storage modulus measured in Pa) and G'' (loss modulus measured in Pa), were recorded for samples.

2.2.12 | Thermal properties

The differential scanning calorimetry (DSC) measurements were performed using a differential scanning calorimeter (DSC822, Mettler-Toledo, Switzerland) with a nitrogen atmosphere of 100 mL/min, at a heating rate of 10°C/min, up to a temperature of 250°C. Samples (3.0 mg) were accurately weighed in aluminium pans, double distilled water was added so as to make 70% (w/v) slurry, and the pans were sealed hermetically. The DSC was calibrated using indium, and an empty aluminium pan was used as reference. The thermal parameters, namely, onset (Tₒ), peak (Tₚ), and conclusion (Tₖ) temperature and enthalpy (ΔH), were calculated from the DSC curves.

2.2.13 | Scanning electron microscopy

The samples were coated with a layer of gold palladium after being placed on an adhesive tape attached to a circular aluminium specimen stub. The micrographs of the samples were taken at an accelerator potential of 10 kV using a scanning electron microscope (JSM-6100, JEOL Ltd, Tokyo, Japan).

2.2.14 | Fourier transform infrared analysis

The spectra of the samples were recorded using Fourier transform infrared (FTIR) spectrometer system (Cary 630 FTIR, Agilent Technologies, USA), coupled to an attenuated total reflection (ATR) accessory. Analyses were carried out at room temperature, and spectra were acquired in the range of 3,800–600 cm⁻¹ at a resolution of 4 cm⁻¹, using Resolution Pro software Version 2.5.5 (Agilent Technologies, USA).

2.3 | Statistical analysis

The data reported are averages of triplicate observations except FTIR analysis. An analysis of variance with a significance level of 5% was done except by FTIR analysis, and Duncan’s test was applied to determine the differences between means using the commercial statistical package (SPSS Inc, Chicago, IL).

3 | RESULTS AND DISCUSSIONS

3.1 | Proximate composition

The moisture content of kidney beans and green gram flours varied in the range of 13.30–13.80 g/100 g (Table 1). Differences were significant (p ≤ 0.05) between the two cultivars of the same variety. Results are not comparable with those obtained by Wani, Sogi, Wani, and Gill (2017), who reported the moisture content of four kidney bean cultivars in the range of 10.0–10.20 g/100 g. Protein content varied significantly (p ≤ 0.05) among the different flours, higher in green gram (23.90–25.02 g/100 g) than in kidney beans (18.78–19.80 g/100 g). The ash, fat, and carbohydrate contents of the flours were reported in the range of 3.16–4.25 g/100 g, 1.43–1.85 g/100 g, and 56.46–61.67 g/100 g, respectively. Differences were significant (p ≤ 0.05) between the kidney bean and green gram flours. The results are comparable with the reported values of fat, ash, and carbohydrate content in kidney bean, chickpea, and lentil flours (Wani et al., 2015).

3.2 | Apparent amylose content

Amylose content has an important effect on pasting and thermal properties. Amylose content varied significantly (p ≤ 0.05) between the kidney bean and green gram flours as shown in Table 1. It was found in the range 10.59–15.0 g/100 g, with the highest value in Shalimar Rajmah 1 (Shal Raj-1) and the lowest in Shal Moong-2. The variations may be due to differences in varieties or the growing conditions that affect the proportion of amylose in starch. Starch from kidney bean and green gram cultivars has been reported to contain an amylose content of 34.47–49.28 g/100 g (Andrabi et al., 2015). The results are in agreement with those of Adebooye and Singh (2008) for cow pea flour.

3.3 | Colour

The colour values of kidney bean and green gram flours are presented in Table 1. The L value of the flours varied significantly (p ≤ 0.05) from 71.22 to 82.65. The highest L value was found in Shal Raj-1 and lowest in Shal Moong-2 flour, which indicates more lightness in the former. Wani, Sogi, and Gill (2013) reported L values of the four different kidney bean flours in the range of 81.1–82.0, which is in agreement with the present study. Significant (p ≤ 0.05) variations were also observed in the a and b values of kidney bean and green gram flours. The a values were observed in the range of −0.12 to −2.16, whereas the b values were observed in the range of 15.20 to 22.85. The highest a and b values in Shal Raj-1 and Shal Moong-2 indicated more redness and blueness, respectively, in these two flours. Reported
values are comparable to the \(a\) value (−0.14 to −1.13) but higher than the \(b\) value (7.59 to 9.57) of the starch from similar cultivars (Andrabi et al., 2015). This implies the appearance of pulse flour to be yellower than starch.

### 3.4 Bulk density and tapped density

Bulk density varied significantly (\(p \leq 0.05\)) between the kidney bean and green gram flours (Table 1), although a marginal variation was observed in the bulk density of Shal Raj-1 (0.53 g/mL) and Shalimar Rajmah 132 (SK-R-132; 0.55 g/mL), yet similar values were observed in green gram flours (0.62 g/mL). Tapped density varied significantly (\(p \leq 0.05\)) from 0.69 to 0.80 g/mL between the kidney bean and green gram flours. Bulk and tapped densities are important properties with respect to the packing arrangement and compaction profile of flours. Besides, these properties have an effect on hydration rate of flours, which may in turn affect cooking time. Bulk density of flour from different lentil and kidney bean cultivars are reported to vary in the range of 0.51–0.54 and 0.84–0.94 g/mL, respectively (Kaur & Sandhu, 2010; Wani et al., 2013). The results obtained in the present study are in agreement with the reported range of values. The tapped density is, however, comparable with that of the rice flours (0.65–0.79 g/mL) as reported by Falade and Christopher (2015).

### 3.5 Swelling and solubility indices

Swelling index varied nonsignificantly (\(p > 0.05\)) between the kidney bean flours and significantly (\(p \leq 0.05\)) between the green gram flours throughout the temperature range (50–90°C; Table 2). It increased significantly (\(p \leq 0.05\)) with the increase in temperature at 2.48–3.76, 2.48–3.71, 2.50–5.83, and 3.63–6.24 g/g for Shal Raj-1, SK-R-132, Shalimar Moong-1 (Shal Moong-1), and Shal Moong-2, respectively. A greater increase was observed in the swelling index of green gram flours compared with kidney bean flours with the increase of temperature. It may be attributed to lower amylose and proportionally higher amylpectin of the flours from green gram cultivars. Swelling index of flour is related to gelatinization of starch in which amylpectin fraction has an important role to play. Sofi et al. (2013) reported the swelling index of broad bean starch to increase in the range of 216.0–392.0 g/100 g with the increase in temperature. The values are close to those obtained in the present study when the difference in units is considered. Starch is the major component of the pulse flours, and its swelling increases with the increase in temperature (Sofi et al., 2013) as reported in case of pulse flours in present study. Solubility index increased significantly (\(p \leq 0.05\)) in the range of 0.09–0.52, 0.11–0.52, 0.11–0.50, and 0.11–0.54 g/g for Shal Raj-1, SK-R-132, Shal Moong-1, and Shal Moong-2, respectively (Table 2). This implies a higher solubility of flours at elevated temperatures. The property can be attributed to the increase in the soluble molecules like amylose and albumin upon the increase in temperature, which increases the solubility index (Wani et al., 2014). Almost no significant differences were observed in the solubility among flour samples throughout the temperature range employed. The reported values of solubility index were, however, higher than those reported in broad bean starch (Sofi et al., 2013). This is presumably due to the lower solubility profile of starch as compared with flour.

### 3.6 Light transmittance

Light transmittance of flour gels under study reduced significantly (\(p \leq 0.05\)) during 120 h of refrigerated storage (Table 3). It decreased...
from 2.00–0.80%, 2.60–0.89%, 3.00–0.68%, and 2.20–0.71% for Shal Raj-1, SK-R-132, Shal Moong-1, and Shal Moong-2 cultivars, respectively. Decrease in light transmittance has been reported in different flour gels (Wani et al., 2015). This implies an increase in the turbidity during the storage period. It may be due to the gradual retrogradation of starch in flour gels. The flours with least transmittance may have an application in puddings, sauces, salad dressings, and mayonnaise (Craig, Maningat, Seib, & Hoseney, 1989).

### 3.7 Syneresis

Syneresis varied significantly ($p \leq .05$) among the flours in the range of 29.25–39.85 (at 0-h storage) and 38.53–47.36% (at 120-h storage; Table 3). A higher syneresis was observed in green gram cultivars increasing from 36.50% to 42.00% (Shal Moong-1) and 39.85% to 47.36% (Shal M300) than in kidney bean cultivars, where the reported increase was 32.64–38.53% (Shal Raj-1) and 29.25–40.25% (SK-R-132, Shalimar Rajmah 132).

### TABLE 2 Swelling and solubility indices of kidney bean and green gram flours ($n = 3$)

| Parameter | Kidney bean flour | Green gram flour |
|-----------|------------------|-----------------|
|           | Shal Raj-1 | SK-R-132 | Shal Moong-1 | Shal Moong-2 |
| Swelling index (g/g) | | | | |
| 50°C | $2.48 \pm 0.06_{aP}$ | $2.48 \pm 0.25_{aP}$ | $2.50 \pm 0.09_{aP}$ | $3.63 \pm 0.64_{aP}$ |
| 60°C | $2.71 \pm 0.34_{aP}$ | $2.95 \pm 0.13_{aQ}$ | $4.02 \pm 0.16_{sQ}$ | $4.37 \pm 0.15_{sQ}$ |
| 70°C | $2.82 \pm 0.31_{aP}$ | $3.06 \pm 0.34_{aQ}$ | $4.22 \pm 0.25_{sQ}$ | $4.52 \pm 0.25_{sQ}$ |
| 80°C | $2.85 \pm 0.46_{aR}$ | $3.45 \pm 0.03_{sR}$ | $4.72 \pm 0.77_{sR}$ | $5.54 \pm 0.58_{sR}$ |
| 90°C | $3.76 \pm 0.04_{aS}$ | $3.71 \pm 0.03_{sS}$ | $5.83 \pm 0.25_{sS}$ | $6.24 \pm 0.15_{sS}$ |

| Solubility index (g/g) | | | | |
| 50°C | $0.09 \pm 0.00_{aP}$ | $0.11 \pm 0.03_{aP}$ | $0.11 \pm 0.03_{aP}$ | $0.11 \pm 0.03_{aP}$ |
| 60°C | $0.19 \pm 0.03_{aQ}$ | $0.15 \pm 0.03_{aQ}$ | $0.19 \pm 0.03_{aQ}$ | $0.19 \pm 0.03_{aQ}$ |
| 70°C | $0.19 \pm 0.03_{aQ}$ | $0.19 \pm 0.03_{aQ}$ | $0.24 \pm 0.04_{aQ}$ | $0.17 \pm 0.00_{aQ}$ |
| 80°C | $0.28 \pm 0.03_{aR}$ | $0.24 \pm 0.04_{aR}$ | $0.32 \pm 0.03_{aR}$ | $0.24 \pm 0.04_{aR}$ |
| 90°C | $0.52 \pm 0.01_{aS}$ | $0.52 \pm 0.00_{aS}$ | $0.50 \pm 0.04_{aS}$ | $0.54 \pm 0.03_{aS}$ |

Note. Values expressed are mean ± standard deviation. Means in the row and in the column within a particular parameter with different subscript are significantly different at $p \leq .05$.

Abbreviations: Shal Moong-1, Shalimar Moong-1; Shal Moong-2, Shalimar Moong-2; Shal Raj-1, Shalimar Rajmah 1; SK-R-132, Shalimar Rajmah 132.

### TABLE 3 Light transmittance and syneresis of kidney bean and green gram flours ($n = 3$)

| Parameter | Kidney bean flour | Green gram flour |
|-----------|------------------|-----------------|
|           | Shal Raj-1 | SK-R-132 | Shal Moong-1 | Shal Moong-2 |
| Light transmittance (%) | | | | |
| 0 h | $2.00 \pm 0.01_{aT}$ | $2.60 \pm 0.01_{aT}$ | $3.00 \pm 0.01_{aU}$ | $2.20 \pm 0.01_{aU}$ |
| 24 h | $1.60 \pm 0.01_{aS}$ | $1.85 \pm 0.01_{aS}$ | $2.35 \pm 0.01_{aT}$ | $1.83 \pm 0.01_{aT}$ |
| 48 h | $1.28 \pm 0.02_{aR}$ | $1.14 \pm 0.01_{aR}$ | $1.78 \pm 0.01_{aS}$ | $1.47 \pm 0.01_{aS}$ |
| 72 h | $1.08 \pm 0.01_{aQ}$ | $1.12 \pm 0.01_{aR}$ | $0.87 \pm 0.01_{aQ}$ | $1.27 \pm 0.01_{aQ}$ |
| 96 h | $0.93 \pm 0.01_{aS}$ | $1.01 \pm 0.01_{aQ}$ | $0.78 \pm 0.01_{aQ}$ | $0.90 \pm 0.01_{aQ}$ |
| 120 h | $0.80 \pm 0.01_{aP}$ | $0.89 \pm 0.01_{aP}$ | $0.68 \pm 0.01_{aP}$ | $0.71 \pm 0.01_{aP}$ |

| Syneresis (% water release) | | | | |
| 0 h | $32.64 \pm 0.01_{aP}$ | $29.25 \pm 0.01_{aP}$ | $36.50 \pm 0.01_{aP}$ | $39.85 \pm 0.01_{aP}$ |
| 24 h | $33.34 \pm 0.01_{aP}$ | $31.88 \pm 0.01_{aQ}$ | $38.00 \pm 0.01_{aP}$ | $41.18 \pm 0.01_{aQ}$ |
| 48 h | $34.38 \pm 0.01_{aP}$ | $35.52 \pm 0.01_{aR}$ | $38.00 \pm 0.01_{aP}$ | $42.39 \pm 0.01_{aQ}$ |
| 72 h | $34.38 \pm 0.01_{aP}$ | $36.96 \pm 0.01_{aR}$ | $38.00 \pm 0.01_{aP}$ | $45.77 \pm 0.01_{aS}$ |
| 96 h | $34.70 \pm 0.01_{aQ}$ | $38.93 \pm 0.01_{aQ}$ | $41.29 \pm 0.01_{aQ}$ | $46.40 \pm 0.01_{aS}$ |
| 120 h | $38.53 \pm 0.01_{aR}$ | $40.25 \pm 0.01_{aQ}$ | $42.00 \pm 0.01_{aQ}$ | $47.36 \pm 0.01_{aU}$ |

Note. Values expressed are mean ± standard deviation. Means in the row and in the column within a particular parameter with different subscript are significantly different at $p \leq .05$.

Abbreviations: Shal Moong-1, Shalimar Moong-1; Shal Moong-2, Shalimar Moong-2; Shal Raj-1, Shalimar Rajmah 1; SK-R-132, Shalimar Rajmah 132.
3.8 Pasting properties

Pasting properties of kidney bean and green gram flours are presented in Table 4. Peak and trough viscosity of flours under study varied significantly \((p \leq 0.05)\) in the range of 282.0–772.0 and 71.0–198.0 cP, respectively. The highest values were observed in Shal Moong-1 and the lowest in SK-R-132 cultivar. Trough viscosity indicates the rate of amylase leaching, granule swelling, and the formation of amylase–lipid complexes (Wani et al., 2012). Breakdown and final viscosities varied significantly \((p \leq 0.05)\) in the range of 211.0–620.0 and 102.50–310.0 cP, respectively. The lower breakdown viscosity exhibited by SK-R-132 flour is indicative of its good paste stability and strong shearing resistance. Shal Moong-1 reported the highest value of final viscosity, which can be attributed to its highest amyllose content. The reverse is true for the SK-R-132 flour.

Setback viscosity, an index of retrogradation tendency, was observed in the range of 20.00–112.00 cP for different flour samples. It varied significantly \((p \leq 0.05)\) between the green gram flours and insignificantly \((p > 0.05)\) between kidney bean flours. Retrogradation is due to bonding between the hydrogen acceptor and hydroxyl sites of the starch molecules (Del Rosario & Pontivero, 1983). It is affected by the proportion of amyllose and amylpectin, molecular size, temperature, and pH of the samples. Pasting temperature was observed varying in the range of 67.48–94.93°C, with the highest value in SK-R-132 cultivar flour and lowest in Shal Moong-1. The results are completely different from the observations of Wani, Sogi, and Gill (2013), who studied flours from different kidney bean cultivars. The inherent differences that exist in the physicochemical properties between the different cultivars can be a reason of this variation.

3.9 Functional properties

3.9.1 Water absorption capacity

WAC varied significantly \((p \leq 0.05)\) between the flours from kidney beans but insignificantly \((p > 0.05)\) between the green gram flours (Table 5). Pulse flours exhibited WAC of 1.21–1.53 g/g, wherein a significantly \((p < 0.05)\) higher value was observed in kidney bean cultivars. Higher WAC indicates better performance of kidney bean flours, as it influences the functional and sensory properties in food preparations. It is also indicative of higher proportion of hydrophilic residues in carbohydrate and protein constituents of kidney bean flours (Wani, Sogi, & Gill, 2013). Du, Jiang, Yu, and Jane (2014) reported WAC of lima bean, mung bean, and red kidney bean flour in the range of 1.17–1.67 g/g. The results are in agreement with the reported values.

3.9.2 Oil absorption capacity

OAC did not show significant \((p > 0.05)\) variations among the pulse flours (Table 5). The lowest OAC was found in Shal Moong-2 (1.04 g/g), and the highest was found in Shal Moong-1 (1.19 g/g). Oil is absorbed through capillary action and is physically entrapped by the flours. The difference in particle size, type, and proportion of protein, nonpolar amino acid side chains, and starch constituents may cause the variation in OAC (Sathe, Deshpande, & Salunkhe, 1982). Du et al. (2014) reported the OAC of pinto bean and red kidney bean cultivars in range of 1.03–1.20 g/g, which is in agreement with the present study.

3.9.3 FC and FS

Foams are formed due to the proteins that prevent coalescence of air bubbles by forming an interfacial film. Flours contain surface active tendencies that prevent syneresis rate in black gram flour.
proteins that offer a tendency to form stable foams (Adebowale & Lawal, 2003). FC varied nonsignificantly (p > 0.05) between kidney bean and green gram flours. It may be attributed to the greater extractability of proteins that diffuse rapidly to the air–water surfaces and enhance foaming in the former (Du et al., 2014). The higher FC on either side of pH 4 has been reported in many legume flour gels (Wani, Sogi, & Gill, 2013). Values obtained in the present study are higher than those obtained by Wani, Sogi, Wani, and Gill (2013) in different kidney bean flours when determined at a pH range of 2–10.

### 3.9.4 Emulsion capacity and stability

Emulsion capacity varied significantly (p < 0.05) between kidney bean and green gram cultivars with SK-R-132 exhibiting the highest (77.00%) and Shal Moong-2 exhibiting the lowest (63.00%; Table 5). The results are comparable with those reported by Du et al. (2014) for black eye bean (67.02%), lima bean (63.77%), and red kidney bean (82.46%) flours. ES was observed in the range of 60.00–74.00% and varied significantly (p < 0.05) between the kidney bean and green gram varieties. The highest ES was found in SK-R-132 flour and the lowest in Shal Moond-2. It implies the higher surface activity of kidney bean flour proteins in spite of them being present in lower proportion as compared with green gram flours. Similar values of ES were reported by Oshadi, Ogungbenle, and Oladimeji (1999) for bennised (63.00%) and pearl millet (89.00%). Formation of emulsions is mainly due to the decrease in the interfacial tension of oil droplets in aqueous systems and electrostatic repulsion between them. Protein content of flours plays an important role in the formation of an emulsion, whereas the polysaccharides help to stabilize it by increasing viscosity (Dickinson, 1994). Higher emulsion capacity of kidney bean flours as compared with the green gram flours, in spite of their lower protein content, may be due to the higher proportion of surface active proteins in the former.

### 3.10 Rheology of flours

The results of the oscillatory rheological measurement of pulse flours showed a dependence on frequency as shown in Figure 1. The magnitudes of storage modulus (G’) and loss modulus (G”) increased with the increase in frequency (1–100 s⁻¹), which is a typical gel-like behaviour (Witczak, Korus, Ziobro, & Juszczak, 2010). Throughout the frequency sweep, the flour gels (6.0% w/v) exhibited visco-elastic behaviour as storage modulus was higher than the loss modulus. Variations were, however, observed in the response of pulse flours under study towards the applied stress at a common value of frequency. The gap between storage and loss modulus was the least in SK-R-132 followed by Shal Raj-1. However, a larger and comparable gap was observed between mung bean cultivars. A greater difference between the G’ and G” suggests more pronounced elastic behaviour in Shal Moong-1 and Shal M300. It may be due to the variable protein and polysaccharide content of flours and the interactions between them, which lead to the differences in rheological profile (Harrington, Foegeding, Mulvihill, & Morris, 2009). Comparable results were obtained in the case of wheat flour dough by Georgopoulos, Larsson, and Elasson (2004). This indicates the rheological behaviour of pulse flours to be like of the wheat flour.

### 3.11 Thermal properties

Gelatinization means the irreversible disruption of molecular patterns within a starch granule when heated in excess water. The transition process involves a series of progressive events that take place within...
a narrow temperature range (Ratnayake & Jackson, 2007). Gelatinization temperatures varied insignificantly \((p > .05)\) between the kidney bean and significantly \((p \leq .05)\) between the green gram flours (Table 5). The lowest and the highest gelatinization temperatures were reported in Shal Moong-2 and Shal Moong-1, respectively. It indicates that more energy will be required to initiate gelatinization in the later. The differences are attributed to the amylose–amylopectin proportion, chain length and branches, amylose–lipid complexes, and protein content (Jayakody et al., 2007). Onset temperature \((T_o)\) was recorded as 84.24°C, 84.31°C, 89.70°C, and 83.52°C for Shal Raj-1, SK-R-132, Shal Moong-1, and Shal Moong-2, respectively. \(T_o\) represents the melting of weakest crystallites (Nakazawa & Wang, 2003) in the flour, whereas broad melting peaks indicate a partially crystalline behaviour of its starch polymers. The values of peak temperature \((T_p)\) and conclusion or end set-temperature \((T_c)\) varied at 111.15–117.90°C and 125.49–133.05°C, respectively. Amylose forms complexes with the lipids present in the flour. Such amylose–lipid complexes exhibit very high melting temperatures that range from 80°C to more than 104°C (Wokadala, Ray, & Emmambux, 2012). This may cause the appearance of very high value of \(T_p\) and \(T_c\) in the flours under study, as also reported by Wani, Sogi, and Gill (2013). The results are comparable with the observations of Andrabi et al. (2015), who observed the starch from the similar legume sources, and Wani et al. (2013), who reported on black gram flour.

The melting enthalpies ranged from 10.22 to 12.34 J/g and varied significantly \((p \leq .05)\) among the flours. Reported values are lower than the corresponding values found in the starch from similar cultivars (12.46–15.17 J/g; Andrabi et al., 2015). This variation may be due to the presence of protein–starch matrix in the flour. The starch diluted in the presence of proteins may require less energy to gelatinize than does the pure form.

### 3.12 Scanning electron microscopy

Scanning electron microscopy (SEM) of flours revealed the presence of oval or elliptical granules with rough surfaces and irregular outline
The size of the granules was heterogeneous, ranging in 9–37 μm in length and 7–29 μm in width. The irregularity of flour particles as shown in the SEM images may be due to attached protein bodies or fragments of protein matrix that are disrupted during grinding. It may also be due to the attached mineral and fibre components as reported by Aguilera, Esteban, Benitez, Mollá, and Martín-Cabrejas (2009). This morphology appeared similar to that depicted by SEM images of the flour from different kidney bean cultivars in the work done by Wani et al. (2013).

### 3.13 | ATR–FTIR spectroscopic analysis

The ATR–FTIR spectrum of kidney bean and green gram flours are presented in Figure 3. The prominent absorption band of Shal Raj-1, SK-R-132, Shal Moong-1, and Shal Moong-2 flour samples at 3,274, 3,276, 3,277, and 3,277 cm⁻¹, respectively, represented the stretching of O–H bonds (alcohols and phenols; Vanaja et al., 2013). The second common band of absorption between 2,920 and 2,933 cm⁻¹ in all the samples was associated with the stretching vibrations of C–H bonds. It may include CH, CH₂, and CH₃ stretching and bending vibrations that may be symmetric or asymmetric (Kaéráková, Capek, Sasinkova, Wellner, & Ebringerova, 2000). With small variations in transmittance, deep and strong absorption bands were recorded in all the flours near to 1636 cm⁻¹, which are indicative of the alkene bonds or more precisely the degree of unsaturation. Some researchers also ascribe these bands to the bending vibrations of N–H (1⁺ amines) bond (Senthilkumar & Sivakumar, 2014). The sharp bands around 1,543 and 1,239 cm⁻¹ indicated the stretching of nitro compounds, aliphatic amines and/or amide bonds (Naumann, 2001), respectively. Sharp and strong signals were also recorded close to 992 cm⁻¹. These were assigned to the bending of ²⁹C–H (alkenes) and O–H (carboxylic acids) bonds. The study depicted a common pattern of absorption bands in pulse flours, which indicates a close relationship in their chemical structure.

### 4 | CONCLUSION

Pulse flours were powders with yellowish-white colour and a bluish tint. The higher emulsifying and foaming observed in the flours from kidney beans depicted the greater surface activity of its proteins. This enhances the application of kidney bean flours in products wherein the formation of a foam and/or emulsion is desirable. The flours had good OAC and WAC, which are important for flavour retention and desirable organoleptic properties. Gels exhibited lower stability in refrigerated storage. Significantly higher viscosity profile of Shal Moong-1 flour was recorded in the Rapid Visco Analyzer. The rate of retrogradation was, however, low in kidney bean flours. Higher temperature was required to gelatinize the starch of Shal Moong-1 as per the DSC profile. Rheological properties of pulse flours were close to those of wheat flour. Thus, it can be concluded that pulse flours showed good functional properties to be used in food systems like bakery goods, batters, emulsions, foams, and thickeners.

### ORCID

Idrees Ahmed Wani  
https://orcid.org/0000-0001-5262-0656

### REFERENCES

Adebooye, O. C., & Singh, V. (2008). Physicochemical properties of the flours and starches of two cowpea varieties (Vigna unguiculata (L.) Walp). *Innovative Food Science & Emerging Technologies*, 9, 92–100.
William, P. C., Kuzina, F. D., & Hlynka, I. (1970). A rapid calorimetric procedure for estimating the amylose content of starches and flours. *Cereal Chemistry, 47*, 411–420.

Witczak, M., Korus, J., Ziobro, R., & Juszczak, L. (2010). The effects of maltodextrins on gluten-free dough and quality of bread. *Journal of Food Engineering, 96*, 258–265.

Wokadala, O. C., Ray, S. S., & Emmambux, M. N. (2012). Occurrence of amylose–lipid complexes in teff and maize starch biphasic pastes. *Carbohydrate Polymers, 90*, 616–622.

How to cite this article: Wani IA, Andrabi SN, Sogi DS, Hassan I. Comparative study of physicochemical and functional properties of flours from kidney bean (*Phaseolus vulgaris* L.) and green gram (*Vigna radiata* L.) cultivars grown in Indian temperate climate. *Legume Science*. 2020;2:e11. [https://doi.org/10.1002/leg3.11](https://doi.org/10.1002/leg3.11)