Kaur *et al.*
Food Production, Processing and Nutrition (2024) 6:18
https://doi.org/10.1186/s43014-023-00194-5

Food Production, Processing and Nutrition

RESEARCH

Open Access

Variety-based physical characterization and pre-gelatinization-induced functional-rheological changes in kidney beans

Jasjot Kaur[1], Rashmi Singh[1], Radhika Bansal[1], Srishti Upadhyay[1], Shivani Desai[1], Yogesh Kumar[2], Gourav Chakraborty[1], Monika Satankar[3] and Vijay Singh Sharanagat[1*]

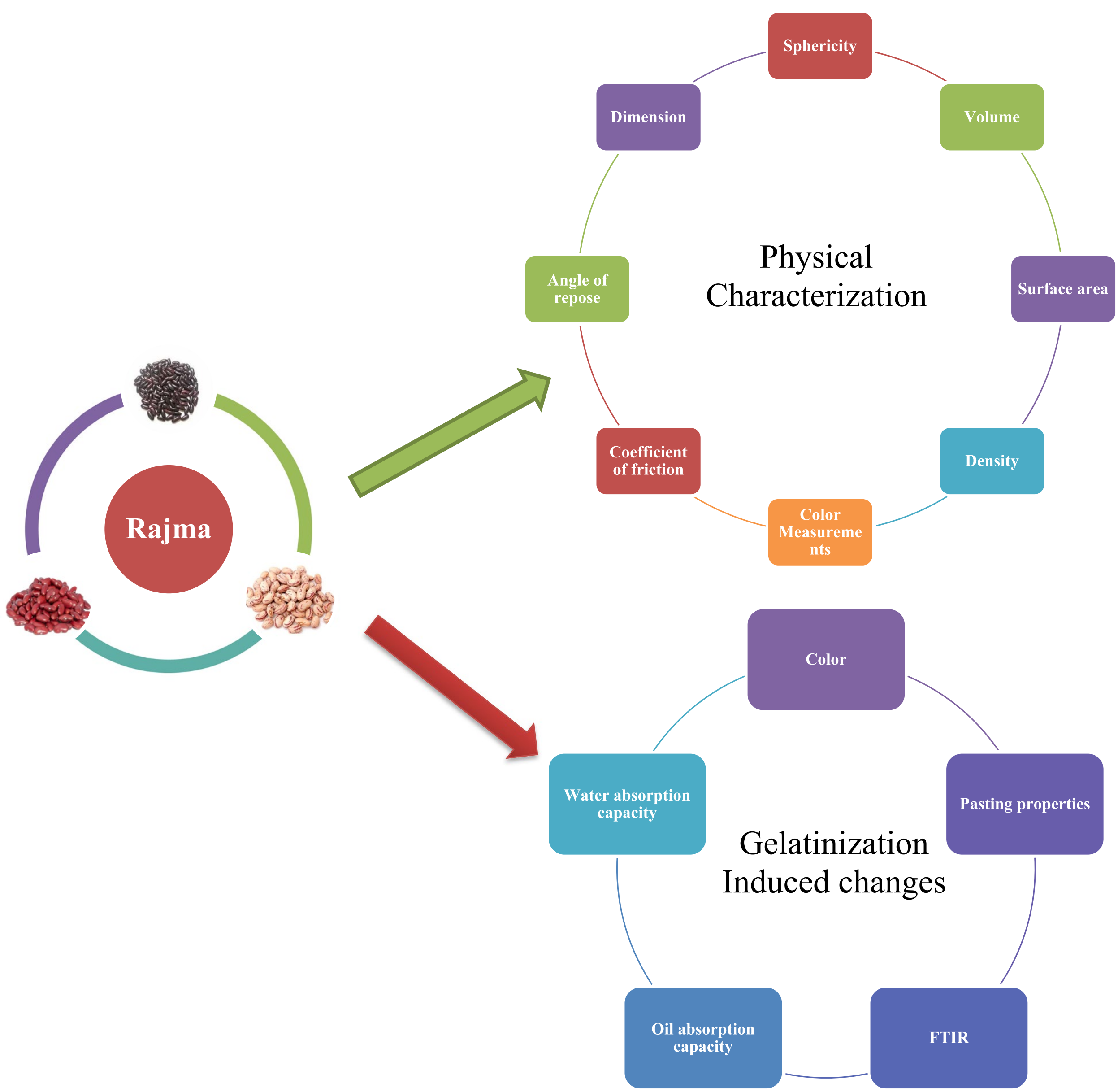
Abstract

In the present study, three varieties of kidney beans (Red Rajma (RR), Rajma Chitra (RC), and Rajma Sharmili (RS)) were physically characterized and the effect of pre-gelatinization by microwave and hot water on functional and pasting properties of flour were studied. A significant difference was observed in the physical properties of all the kidney beans, indicating that they can be easily characterized and identified based on physical properties. Pre-gelatinization treatment led to variation in color, functional and pasting properties of flours. Color parameters L*, b*, chroma, and hue values reduced with the treatment, whereas a* and total color difference (Δ E) values increased. Water absorption capacity (WAC) and oil absorption capacity (OAC) varied in the range of 1.15–1.91% and 1.25–1.75% for microwave and hot water treatment, respectively. The highest value of WAC and OAC was observed for microwave-treated RC and hot water-treated RR, respectively. WAC increases with both treatments, whereas OAC increases only with water bath cooking. Functional group analysis (FTIR) showed no major peaks shifting in water bath treatment, whereas a slight deflation of certain peaks was observed in the case of microwave treatment. Pasting curves showed a significant reduction in peak and final viscosity after pre-gelatinization treatment; however, none of the samples showed any breakdown during cooking.

Keywords Kidney beans, Physical characterization, Pre-gelatinization, Functional-pasting properties, FTIR analysis

*Correspondence:
Vijay Singh Sharanagat
vijaysinghs42@gmail.com
Full list of author information is available at the end of the article

Graphical Abstract



Introduction

The kidney bean is a variety of the common bean (*Phaseolus vulgaris L.*) whose name is due to its kidney-like shape and color (Jati et al. 2013). It is the third major legume crop after soybean and peanut and is commonly grown in Myanmar, India, Brazil, Mexico, and the United Republic of Tanzania. Kidney beans are a gluten-free grain with good functional properties and excellent nutritional components (Khrisanapant et al. 2022). These properties make them a suitable alternative to gluten flour for developing different healthier food products (Bhol & Bosco 2014; Manonmani et al. 2014; Awolu 2017; Inyang et al. 2018). It is also beneficial in protecting against cardiovascular diseases, diabetes, metabolic syndrome, oxidative stress, and various types of cancer (Hayat et al. 2014). However, consuming raw kidney beans can cause extreme nausea, severe vomiting, and diarrhea due to the naturally occurring toxin phytohemagglutinin (a type of lectin) (FDA 2012). To mitigate this issue, the most common approach is to soak the kidney beans for a minimum of 5 h and then cook them at 100 °C for at least 30 min. An alternative method involves boiling kidney beans in water without prior soaking, resulting in pregelatinized beans that can be dried and later used in various food formulations without any risk of toxicity. The pre-gelatinization treatment has emerged as an efficient method to improve kidney beans' cooking efficiency (Li et al. 2022a, b) and different gluten-free products have been developed (Awolu 2017; Chompoorat et al. 2018; Khrisanapant et al. 2022).

Various thermal processing like dry/wet heat treatment, pressure cooking, microwave irradiation, baking, autoclaving and extrusion, and different studies have been exploited by the researchers (Choe et al. 2022; Wainaina et al. 2021). In addition to increasing the nutritional benefits and reducing the anti-nutritional contents, the heat treatment improves the sensorial properties such as color, aroma, taste, and texture (Choe et al. 2022; Wainaina et al. 2021). It also improves the fat binding, water holding, and gelling capacity and is widely used as a thickener for sauces, gravies and a base for dips and soups. Another novel application of pre-treated kidney bean flour is the microencapsulation of bioactive compounds, as it is a rich source of hydrophilic protein (Locali-Pereira et al. 2022). One of the major effects of these cooking pre-treatments is significant changes in starch. The pioneer research on bean starches and the effect of processing on their properties is carried by R. Hoover (Ambigaipalan et al. 2011; Chung et al. 2010; Hoover & Ratnayake 2002; Hoover et al. 1991; Maaran et al. 2014). His findings suggest that the starch granules in beans are much larger than those in wheat or corn, and that they are also more heterogeneous. This makes bean starches more resistant to gelatinization and retrogradation, which are important properties for food processing.

Although there have been many studies on the thermal processing of kidney beans (McWatters & Holmes 1979; Abbey & Ibeh 1988; Prinyawiwatkul et al. 1997; Obatolu et al. 2007; Chakraborty & Bhattacharyya 2014; Ma et al. 2016; Choe et al. 2022), no study has yet compared the effects of different heat treatments on various types of kidney beans. In addition, microwave, considered a novel gelatinization method, is least explored for beans. Therefore, this study aimed to variety-based physical characterization of kidney beans and the effects of pre-gelatinization treatment (hot water bath and microwave treatment) on flour's physical-functional and rheological properties for their potential functional application.

Material and method

Sample collection and evaluation of physical properties

Three different varieties of kidney beans (RR, RC and RS) were procured from the local market in Kundli, Sonipat, Haryana, India. Samples were manually cleaned for impurities and damaged grain. Beans dimensional and shape parameters like length (L), width (W), thickness (T), arithmetic mean diameters (D_a), geometric mean diameters (D_g), square mean diameters (D_s), equivalent diameters (D_e), sphericity (Φ), volume (V) and surface area (S) were determined using Eqs. 1, 2, 3, 4, 5, 6 and 7, respectively according to the method as described by Eşref and Halil (2007). Hundred-grain mass (M_{100}), bulk density (ρ_b), true density (ρ_t), and porosity (ε, Eq. 8) of the samples were measured by the method of Singh and Chandra (2014). Angle of repose (Θ, Eq. 9) and coefficient of friction (μ, Eq. 10) were determined by the method described by Nimesh and Sharanagat (2016).

$$Da = (L + W + T)/3 \quad (1)$$

$$D_g = (L \times W \times T)^{1/3} \quad (2)$$

$$D_s = (LW + WT + TL)^{1/2} \quad (3)$$

$$D_e = \left(D_a + D_g + D_s\right)/3 \quad (4)$$

$$\Phi = D_g/L \quad (5)$$

$$V = 0.25\left[(\pi/6)L(W + T)^2\right] \quad (6)$$

$$S = \left(\pi(LWT)^{1/3}L^2\right)/\left(2L - (LWT)^{1/3}\right) \quad (7)$$

$$\varepsilon = (\rho_t - \rho_b)/\rho_t \times 100 \quad (8)$$

$$\Theta = \tan^{-1}(2H/D) \quad (9)$$

$$\mu = tan(\Theta) \quad (10)$$

Pre-gelatinization of kidney beans

Two different sets of each variety of kidney beans (100 g) samples were dipped in 150 mL of water in a 500 mL beaker. One set of samples was heated in a water bath at 100 °C for 30 min, and the second set of samples was heated in a microwave at 450 W for 30 min followed by drying at 40 °C for 24 h. Pretreated and control samples (Untreated) samples were grounded using a mixer grinder (1800 rpm, 500 W, 2053E Optima, USHA, India) and passed through a 212-micron sieve for further analysis.

Color measurement

The color of the different control and pre-gelatinized kidney beans and flour samples was measured using a Chroma Meter CR-400 (Konica Minolta Optics, Japan). After initial calibration with a standard white surface plate, the color parameters L*, a* and b* values were recorded. Chroma (C) and hue angle (H) were calculated using Eq. 11 and 12, respectively (Karaaslan & Tuncer 2008).

$$C = \sqrt{a*^2 + b*^2} \quad (11)$$

$$H = \tan^{-1}\left(b^*/a^*\right) \quad (12)$$

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

WAC and OAC of powder samples were determined using the method described by Wani et al. (2017a) with slight modification. For WAC, 25 mL of distilled water was mixed with 3 g of sample flour in a pre-weighed centrifuge tube. The sample mixture was properly mixed by vigorously shaking for 5 min and left for 30 min at room temperature to allow water absorption, followed by centrifugation (3000 g, 25 min). The supernatant was drained, and the tubes were dried in the oven at 50 °C for 25 min. Finally, the dried tubes were weighed, and WAC was calculated as per Eq. (13).

$$WAC\left(g/g\right) = \frac{\text{Weight of tube with sample after drying} - \text{Weight } of \text{ tube} - \text{sample weight}}{\text{sample weight}} \quad (13)$$

For OAC, 6 mL of oil and 0.5 g of sample flours were vigorously shaken in pre-weighed centrifuge tubes for 5 min and kept in rest position for 30 min (25 °C). After resting, excess oil was drained, and the tubes were weighed to calculate OAC with Eq. (14).

$$OAC\left(g/g\right)\frac{\text{Weight of tube after removal of excess oil} - \text{Weight of tube} - \text{sample weight}}{\text{sample weight}} \quad (14)$$

Functional group analysis

The change in functional groups with respect to change in variety and treatment was determined using an FTIR (Fourier-transform infrared) spectrometer (ALPHA Bruker, Germany). The ground samples were directly loaded on the ATR plate, and the FTIR spectrum observed was 400–4000 cm^{-1} (24 scans). Before and after each analysis, the ATR plate was cleaned using an alcohol solution and background tests were performed.

Pasting properties

The pasting property of flour of the controlled and treated kidney beans was analyzed using a rheometer (MCR 302, Anton Paar, Austria) (Qiu et al. 2015). In brief, 2 g of starch was mixed with 16.6 mL of distilled water to prepare the suspension. During pasting analysis, the suspension was first held at 50 °C (1 min), then heated to 95 °C (6 °C/min), held at 95 °C (5 min), followed by cooling to 50 °C (6 °C/min) and finally holding at 50 °C for 2 min. The results were analyzed to determine the pasting properties such as pasting viscosity, pasting temperature, peak viscosity, trough viscosity, final viscosity, breakdown viscosity, and setback viscosity.

Statistical analysis

All tests were conducted in triplicates, and the obtained data was represented in mean ± standard deviation. Advanced data analysis was conducted using one-way ANOVA at a significance level of 5% in IBM SPSS Statistics for Windows, Version 22.0. (IBM Corp. Armonk, NY, USA).

Result and discussion

Physical properties of kidney beans

The physical properties of RR, RC and RS were measured and presented in Table 1. The highest and lowest mean values of axial dimensions, arithmetic, geometric, square mean and equivalent mean diameters were observed for RR and RS, respectively. Sphericity was found to be the lowest (0.546) for RR, while RS beans showed the highest sphericity (0.646). RR showed higher volume (421.306 mm^3) and surface area (33.243mm^2) than RC and RS. The highest M_{100} (50.633 g) of RC grains showed bulkiness of grain compared to RR (45.4 g) and RS (22.889 g). However, the bulk density of the kidney beans was almost similar and ranged between 1.115 and 1.204 g/cm^3. The highest and the lowest value of bulk density was found to be 1.204 and 1.115 g/cm^3 for RC and RR grain, respectively. The values of the true density

Table 1 Physical properties of different varieties of kidney beans

Parameters	Variety		
	RR	RC	RS
Dimensions (mm)			
Length	16.786 ± 1.106[a]	15.057 ± 0.955[a]	10.729 ± 0.691[b]
Width	8.353 ± 0.747[a]	7.527 ± 0.247[a]	6.389 ± 0.456[b]
Thickness	5.498 ± 0.527[a]	5.784 ± 0.273[a]	4.863 ± 0.431[a]
D_a (mm)	10.212 ± 0.478[a]	9.456 ± 0.341[a]	7.327 ± 0.311[b]
D_g(mm)	9.169 ± 0.449[a]	8.687 ± 0.248[a]	6.934 ± 0.302[b]
D_s(mm)	16.686 ± 0.595[a]	15.619 ± 0.349[a]	12.320 ± 0.382[b]
D_e (mm)	12.022 ± 0.295[a]	11.254 ± 0.183[b]	8.860 ± 0.193[c]
Sphericity (Fraction)	0.546 ± 0.045[a]	0.577 ± 0.040[a]	0.646 ± 0.050[b]
Volume (mm^3)	421.306 ± 214.159[a]	349.017 ± 171.806[a]	177.725 ± 91.163[b]
Surface area (mm^2)	33.243 ± 5.595[a]	31.163 ± 5.143[a]	26.968 ± 4.893[b]
M100 (g)	45.4 ± 0.651[a]	50.633 ± 0.721[b]	22.889 ± 0.528[c]
ρ_b(g/cm^3)	1.115 ± 0.322[a]	1.168 ± 0.010[b]	1.204 ± 0.282[c]
ρ_t(g/cm^3)	1.214 ± 0.022[a]	1.250 ± 0.027[a]	1.293 ± 0.048[b]
ε(%)	8.903 ± 1.985[a]	6.251 ± 2.269[b]	8.731 ± 3.786[a]
Θ (°)	25.680 ± 0.931[a]	24.667 ± 0.396[a]	19.971 ± 1.302[b]
μ			
Galvanized Iron	0.328 ± 0.228[a]	4.925 ± 3.724[b]	0.042 ± 0.444[c]
Glass	-2.004 ± 1.832[a]	-0.947 ± 0.477[b]	-0.601 ± 0.171[b]
Wood	0.301 ± 0.398[a]	0.917 ± 0.013[b]	0.143 ± 0.102[a]
Color			
L*	19.54 ± 1.80[a]	32.10 ± 1.03[b]	21.44 ± 2.49[a]
a*	7.20 ± 2.21[a]	5.64 ± 0.12[a]	14.37 ± 3.99[b]
b*	-0.52 ± 0.59[a]	8.10 ± 0.53[b]	3.05 ± 1.60[c]
ΔE	8.69 ± 1.22[a]	13.99 ± 0.88[b]	15.51 ± 3.73[b]
Chroma	7.25 ± 2.16[a]	9.87 ± 0.40[a]	14.71 ± 4.23[b]
Hue (°)	-5.65 ± 6.09[a]	55.10 ± 2.18[b]	11.15 ± 3.28[c]

Mean ± standard deviation of triplicate. Values with different superscript a, b, c are significantly different ($p < 0.05$) in row. (RR, RC, and RS- Red Rajma, Rajma Chitra, and Rajma Sharmili, respectively)

of three varieties of kidney beans ranged from 1.293 g/cm^3 to 1.214 g/cm^3. The highest value of true density was recorded for RS as 1.293 g/cm^3 due to its smallest size among the three varieties, followed by RC 1.250 g/cm^3 and the lowest for RR 1.214 g/cm^3. The porosity varied in the range of 6.25% to 8.90%, and the highest and the lowest values were recorded for RR and RC, respectively. The values of the angle of repose of randomly selected kidney beans ranged between 25.680 and 19.971°. RR accounted for the highest angle of repose (25.68°), followed by RC (24.67°) and the lowest for RS (19.97°). The higher value of the angle of repose indicates that the beans can be stacked in a heap without sliding, i.e., less free-flow ability of the bulk materials (Wani et al. 2017b). In contrast, among the three varieties of kidney beans, RS had the lowest and RC had the highest value static coefficient of friction with respect to the three different surfaces. However, the static coefficient of friction was least in the case of glass, possibly due to the polished and smoother surface of the glass that offered lower contact with the grain surface. The static coefficient of friction holds importance while designing hoppers, bins, screw conveyors, pneumatic conveying systems, forage harvesters, and threshers (Kayode et al. 2018; Sahay & Singh 1996).

The values of the surface color of the different varieties of whole kidney beans are tabulated in Table 1. The color values 'L*', 'a*' and 'b*' were observed in the range of 19.54 to 32.10, 5.64 to 14.37 and -0.52 to 8.10, respectively, where the highest value of 'L*', 'a*' and 'b*' was observed for RC, RS and RC, respectively. In addition, the values of ΔE varied significantly and were found in the range of 8.69 to 15.51. The highest value of ΔE was observed for RS and the lowest for RR. The higher value of 'a*' in RS surface indicated the presence of a higher red component, whereas it may be suggested that RR has the darkest color among all the kidney beans due to the largest value of 'L*'. The chroma and hue value for RR, RC and RS was 7.25, 9.87 and 14.71, and -5.65, 55.10 and 11.15, respectively. In conclusion, based on the external color of the kidney beans, they can be differentiated into their varieties, viz. RR, RC and RS. The variations in the physical properties of beans are mainly due to the change in variety and can be used to identify the specific variety as well as to develop the handling and processing machines.

Color of pre-gelatinized flour

Table 2 shows the change in color of pre-gelatinized kidney beans. Microwave treatment showed a prominent effect on color and L* value reduced significantly from 89.29 to 87.33 in RR, 88.22 to 86.93 in RC and 87.08 to 83.44 in RS. In contrast, the L* value of control flour was comparable to that of hot water-treated samples (88.71 for RR and 88.56 for RC), except for RS (83.44). However, both treatments increased the a* value of all the samples, indicating more redness of the sample, while an opposite trend was observed in the b* values. Gelatinization followed by drying led to browning, characterized by decreased L* and increased a* and b* values (Su et al. 2020). After treatment, a significant reduction in the chroma value indicated that the flour became duller than the control. However, the variation in hue values of all the samples was very less and comparable. Ozturk et al. (2009), Siddiq et al. (2010), and Wani et al. (2019) have found the values of color of similar varieties of kidney beans and their respective flours. Similar findings were reported by Li et al. (2022b) for pre-gelatinized kidney beans.

Effect of treatment on functional properties

The functional properties, such as water absorption capacity (WAC) and oil absorption capacity (OAC) of control and pretreated kidney beans, are shown in Fig. 1. There is a significant ($p < 0.05$) difference in the WAC of the three varieties of untreated kidney beans (Control). The RC-C (1.37 g/g) has a significantly higher WAC compared to RR-C (1.16 g/g) and RS-C (1.15 g/g). The findings were supported by Du et al. (2014) for the WAC of different legume flours where WAC varied in the range of 1.17–1.89 g/g. However, a significant ($p < 0.05$) increase in WAC was observed after water bath and microwave treatment compared to the control (Wani et al. 2020). The significant increase in microwaves can be attributed to both the boiling effect and the structural changes caused due to volumetric heating by microwaves. This coincides with the findings of Ma et al. (2011), who reported that boiling exceptionally increases the WAC of many legumes. OAC of control samples of RR-C (1.36 g/g) was significantly ($p < 0.0.5$) higher than that of RCC (1.44 g/g) and RS (1.26 g/g), while RC-C and RS-C were statistically similar ($p > 0.05$). Similar results were reported by Wani et al. (2019) for Shal Raj-1 and SK-R-132 kidney bean cultivators. In addition to that, convectively boiled (water baths) samples had significantly higher ($p > 0.05$) OAC compared to control and microwave boiled. Findings were also supported by Bento et al. (2022) for cooked carioca beans.

WAC influences the cooking, functional and sensory properties of food being processed with protein-rich flours (Du et al. 2014). In contrast, OAC affects the flavor retention, texture, and mouthfeel of food prepared from flour (Amandikwa et al. 2015). The change of OAC and WAC on boiling can be attributed to hydrophilicity and hydrophobicity of the free functional groups. Mainly side chains of protein and carbohydrates present in the flour (Wani et al. 2013). This difference can be explained by the change in the protein composition caused by boiling (Audu & Aremu 2011), denaturation of proteins on heating, which exposes amino acids resulting in increased porosity and fluid entrapment (Catsimpoolas

Table 2 Color parameters of pregelatinized flour of different varieties of kidney beans

Sample	L^*	a^*	b^*	ΔE	Chroma	Hue
RR-C	89.29 ± 0.07^{ax}	1.37 ± 0.06^{ax}	11.24 ± 0.07^{ax}	61.44 ± 0.03^{ax}	11.32 ± 0.07^{ax}	359.03 ± 0.01^{ax}
RR-MW	87.33 ± 0.33^{by}	2.16 ± 0.04^{by}	10.82 ± 0.08^{ay}	58.97 ± 0.40^{by}	11.03 ± 0.08^{by}	358.99 ± 0.01^{by}
RR-WB	88.71 ± 0.09^{az}	1.80 ± 0.06^{cz}	10.57 ± 0.04^{bz}	60.64 ± 0.12^{az}	9.77 ± 0.05^{cz}	358.97 ± 0.01^{az}
RC-C	88.22 ± 0.04^{dx}	1.97 ± 0.02^{dx}	11.95 ± 0.04^{dx}	60.22 ± 0.05^{dx}	12.11 ± 0.04^{dx}	358.99 ± 0.01^{dx}
RC-MW	86.93 ± 0.57^{dy}	2.34 ± 0.08^{ey}	11.26 ± 0.01^{dy}	58.56 ± 0.65^{ey}	11.50 ± 0.02^{ey}	358.96 ± 0.00^{ey}
RC-WB	88.56 ± 0.08^{dz}	1.87 ± 0.03^{dz}	11.37 ± 0.28^{dz}	60.57 ± 0.10^{dz}	11.52 ± 0.28^{dz}	358.99 ± 0.01^{dez}
RS-C	87.08 ± 0.18^{ix}	2.72 ± 0.01^{ix}	9.26 ± 0.04^{ix}	58.38 ± 0.18^{ix}	9.65 ± 0.04^{ix}	359.03 ± 0.01^{ix}
RS-MW	83.67 ± 0.22^{jy}	3.47 ± 0.05^{jy}	8.90 ± 0.05^{jy}	53.83 ± 0.45^{jy}	9.55 ± 0.06^{jy}	358.99 ± 0.01^{ijy}
RS-WB	83.44 ± 0.18^{jz}	3.41 ± 0.07^{iz}	9.16 ± 0.05^{iz}	54.02 ± 0.20^{jz}	10.72 ± 0.04^{iz}	358.97 ± 0.00^{jx}

Mean ± standard deviation of triplicate. Values with different superscript a, b, c, i, j, k are significantly different ($p < 0.05$) in a Treatments, whereas x,y, and z represent the significant differences between varieties

(Initials RR, RC, and RS stand for Red Rajma, Rajma Chitra, and Rajma Sharmili, respectively, followed by C, MW and WB stand for Control, Microwave, and Water bath treatment, respectively)

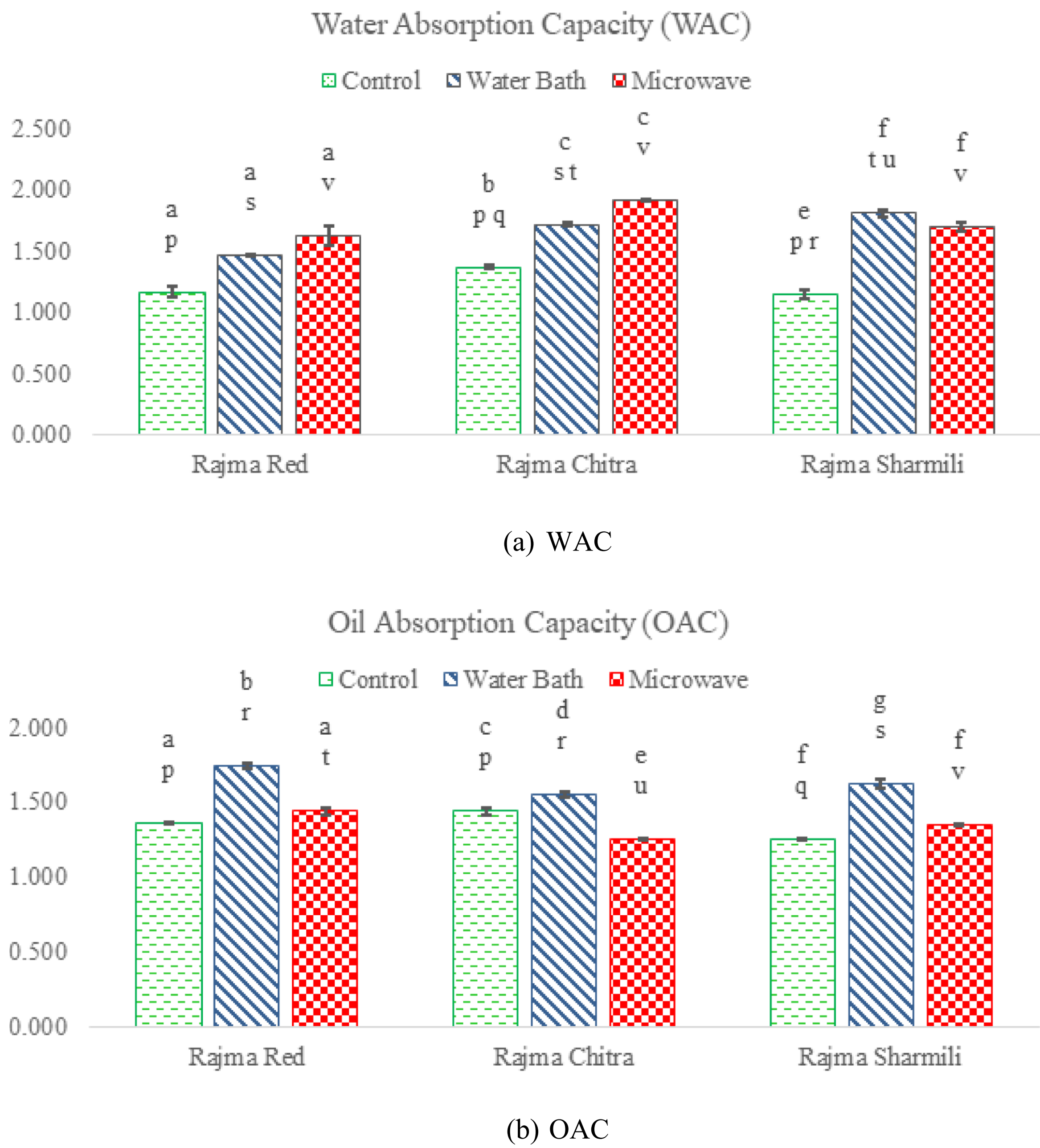


Fig. 1 Graphical representation of functional properties (**a**) WAC and (**b**) OAC of control and pre-gelatinized varieties kidney bean flours. *Bars represent mean values. Letters a – f shows significant difference ($p < 0.05$) between treatments carried out at α = 5%; letters p–v show significant difference ($p < 0.05$) between different varieties at α = 5%)

& Meyer 1970), change in nutritional properties and microstructures of flour (Ma et al. 2011). In addition, heat treatment can cause the formation of pores and voids in materials, which can lead to fluid entrapment (Pathiratne et al. 2015). Thus, it can be concluded that differences in OAC and WAC signify the variation in structure either present inherently in different varieties or caused by different treatments. Moreover, the values of WAC and OAC are often used to conclude the fluid retention of protein-rich flours during processing as well as storage of food products (Kiosseoglou et al., 2011).

Functional group analysis

The FTIR spectra of flour of control, hot water, and microwave-treated varieties of kidney beans are presented in Fig. 2 and analyzed as per Silverstein et al.

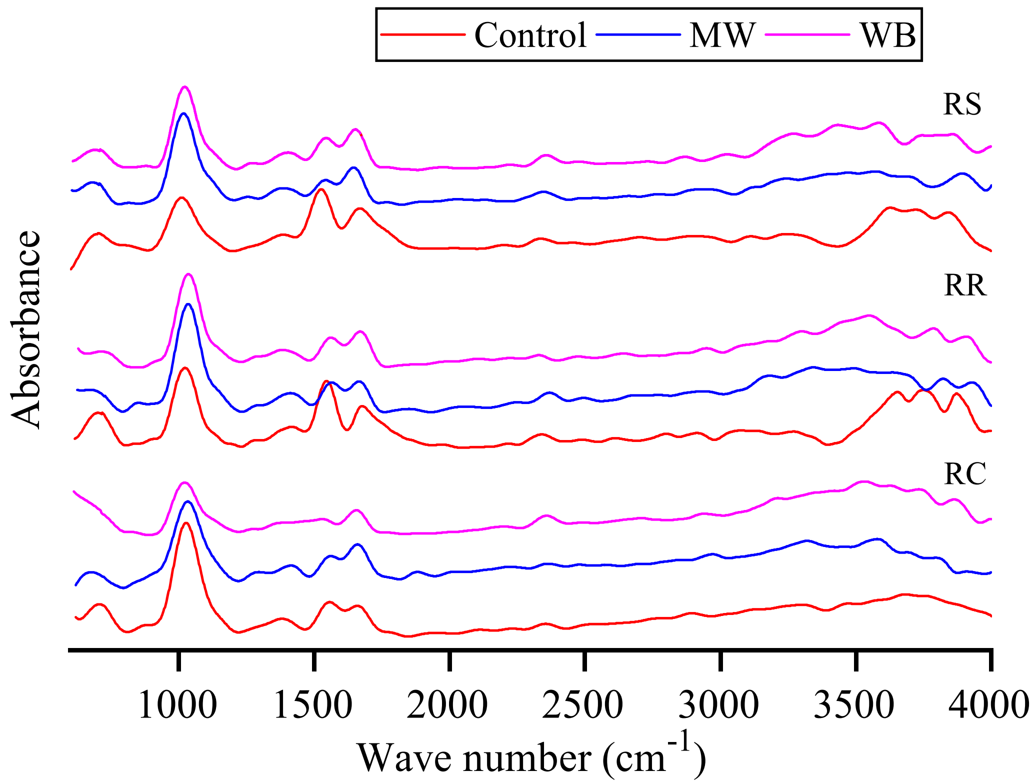


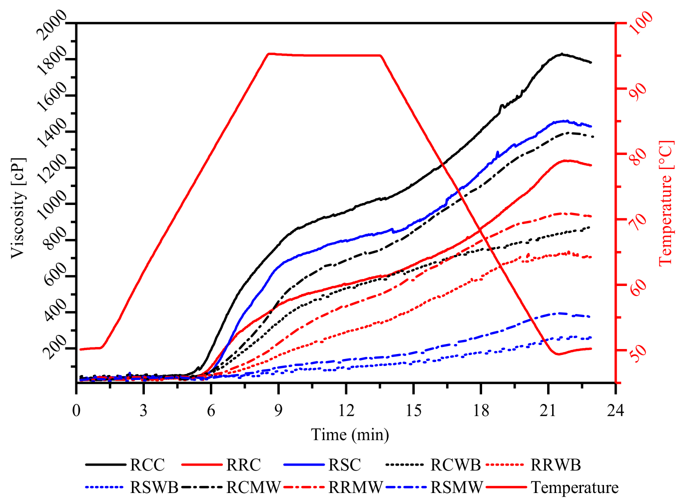
Fig. 2 Variation in FTIR spectra of control and pre-gelatinized varieties kidney bean flours. (Where the initials RC, RR, and RS represent Rajma Chitra, Red Rajma, and Rajma Sharmili respectively; WB, and MW represent water bath, and microwave treatment)

(2015). All three control varieties showed identical absorption patterns, indicating limited changes due to microwave and water bath treatment. However, deflation or loss of certain peaks after 300 cm^{-1} was observed after microwave treatment, possibly due to the disintegration of certain parts of the compound. The lack of a strong absorption band in 900 – 650 cm^{-1} regions implied the nonaromatic structure of the compound. A strong absorption band at 1003 cm^{-1}, 1004 cm^{-1} and 1005 cm^{-1} for RCC, RRC and RSC, respectively, in addition to a broad absorption band near 1370 cm^{-1}, indicated the presence of out of plane symmetrical C-H bending vibrations. Since this was the strongest absorption in the entire spectra, the compound was most likely an alkene. This was further reinforced by medium absorption near 1640 cm^{-1} for each kidney bean variety, which occurs for C=C stretching vibration in unconjugated alkenes. This specifically indicates the presence of monosubstituted alkene, i.e., vinyl group. C-H stretching vibrations were also observed by absorption bands in the 2962 – 2872 cm^{-1} region. A broad and weak absorption band in the 800 – 700 cm^{-1} was due to the presence of C–C stretching vibration or N–H out-of-plane wagging vibration.

The presence of certain functional groups, such as C=O was also ascertained due to absorption near 1540 cm^{-1}. Additionally, multiple less intense absorption bands after 3000 cm^{-1} indicated the presence of O–H and N–H stretching vibration of carboxylic acid and amines due to the proteins present in Rajma. Absorption near 3300 cm^{-1} was linked with intermolecular hydrogen bonding, whereas weak absorption bands in the 2600–2500 cm^{-1} region were likely of S–H stretching vibration. The presence and estimation of different proteins, carbohydrates, fats etc., in 26 different varieties of kidney beans has been reported by Kan et al. (2017).

Pasting properties

The pasting curve and the values of pasting properties of the control and treated flour samples are shown in Fig. 3. The peak viscosity (PV) of the treated flour samples ranged between 73.9 and 626.5 cP, significantly lower than the control samples with PV ranging from 506.7 to 914.8 cP. The reduced PV after treatment indicated less



Sample	Pasting temperature (°C)	Peak viscosity (cP)	Final viscosity (cP)
RR-C	71.39 ± 0.47^{a}	914.8 ± 27.7^{a}	1201.5 ± 25.3^{a}
RR-WB	76.47 ± 0.25^{b}	242.1 ± 10.2^{b}	701.3 ± 4.2^{b}
RR-MW	78.74 ± 0.79^{c}	369.3 ± 31.7^{c}	920.6 ± 19.8^{c}
RC-C	75.78 ± 0.68^{d}	506.7 ± 12.8^{d}	1788.5 ± 14.6^{d}
RC-WB	75.91 ± 0.63^{e}	481.6 ± 15.7^{e}	863.4 ± 20.2^{e}
RC-MW	74.51 ± 0.66^{f}	626.5 ± 87.4^{f}	1371.5 ± 25.8^{f}
RS-C	75.54 ± 0.21^{d}	746.5 ± 38.4^{g}	1425.5 ± 26.6^{g}
RS-WB	79.43 ± 0.86^{g}	73.9 ± 6.4^{h}	250.3 ± 9.9^{h}
RS-MW	75.84 ± 0.81^{d}	122.4 ± 18.3^{i}	369.3 ± 22.3^{i}

Fig. 3 The pasting curve of control and pre-gelatinized varieties kidney bean flours. (RR, RC, and RS stand for Red Rajma, Rajma Chitra, and Rajma Sharmili, respectively, followed by C, MW and WB stand for Control, Microwave, and Water bath treatment, respectively)

swelling of starch molecules due to the destruction of the ordered structure of starch during pre-gelatinization (Dos Santos et al. 2018). The changes in PV of pretreated samples depends on factors like, the amount of leached amylose, granular size, and the presence of rigid, non-fragmented swollen granules (Lan et al. 2008). However, this effect was more prominent in samples pre-gelatinized by the hot water bath method than in microwave-treated samples. It is interesting to notice that none of the tested samples showed any breakdown in the pasting curve that could be due to less granule disintegration and a minor amount of soluble starch leached from the granules during heating and holding time (Kim & Walker 1992). Moreover, the presence of other components (protein, sugar, fiber) in flour could delay the viscosity development and the insufficient time for the subsequent disruption process before cooling and setback (Kweon et al. 2009). The pasting temperature (PT), associated with initiating granular swelling indicated that the treated sample required a significantly higher temperature than the control. The RS-WB showed the highest pasting temperature (79.43 °C), indicating higher resistance of starch granules towards swelling, possibly due to higher amylose content and tighter granule structure (Jan et al. 2016). A strong crystalline structure of starch granules in control samples hindered granule swelling. The higher pasting temperature also indicates the presence of a higher proportion of amylopectin long chains and a lower proportion of short amylopectin chains (Chung et al. 2010). In addition, the strong interactions between amylose and amylopectin reduces the amount of free hydroxyl groups available for hydration and decreases the ingress of water into the granule interior (Ambigaipalan et al. 2011; Chung et al. 2010). The effect of two pre-gelatinization methods on PT varied with kidney bean varieties. The PT of RR-WB was lower than RR-MW, but microwave-treated samples of RC and RS required lower temperatures for granule swelling. Bilbao-Sáinz et al. (2007) reported that conventionally heated wheat starch achieves similar viscosity but requires more time than microwave-heated samples. Microwaves disrupt the crystalline regions of starch, easing the swelling process by allowing easy water penetration to the interior (Kumar et al. 2020), resulting lowest PT (74.51 °C) in RC-MW. Final viscosity (FV), which is the viscosity at the end of the test, followed the trend of PV for all samples. FV of all samples was more than PV without any breakdown, indicated strong re-association and rearrangements of starch molecules. Compared to hot water-heated pre-gelatinized flours, microwave-treated samples facilitated better re-association of starch molecules during the cooling period, leading to high final viscosity (Arinola 2019). However, the undisturbed starch and other components of kidney beans resulted in significantly higher FV than treated samples. Therefore, the presence of other components that might have a considerable effect on PT, PV, and FV should be considered. Similar findings have also been reported by Bento et al. (2022) and Shevkani et al. (2022) for cooked carioca bean (Phaseolus vulgaris L.) flour and uncooked kidney beans (*Phaseolus vulgaris*) flour.

Conclusion

Pre-gelatinization treatment significantly affected the rheological and functional properties of all three varieties of kidney beans. Both microwave and hot water pre-gelatinization significantly improved the WAC, whereas the OAC of kidney bean flours improved with hot water pre-gelatinization, an essential functional property that facilitates flavor retention and enhances mouth feel. The thermal treatment significantly decreased the pasting properties of flours. The microwave treatment showed better color retention, improved WAC, higher ability to form a viscous paste, better re-association of starch molecules during the cooling period, and minimum pasting temperature, making it a suitable method of pre-gelatinization compared to conventional water bath treatment. The findings of heat treatment on the physical properties can be used to develop processing, handling equipment, and varietal identification. However, a deeper understanding of changes in microstructure due to thermal and microwave energy effects and the optimization of the pre-gelatinization process will remain an exciting research area for further studies. Further research is needed to compare the microwave and other novel techniques with the pressure cooking followed for its quality evaluation and sensory analysis.

Acknowledgements
All the authors are thankful to the National Institute of Food Technology Entrepreneurship and Management, Haryana, India, for financial and infrastructural support for conducting the present study.

Authors' contributions
Jasjot Kaur, Rashmi Singh and Radhika Bansal- Experimentation, data collection and draft preparation, Srishti Upadhyay, Shivani Desai, Yogesh Kumar and Gourav Chakraborty- Statistical analysis, experimental design and editing, Monika Sarankar- Revision and editing, Vijay Singh Sharanagat- Guiding, Review and editing.

Funding
No funding received.

Availability of data and materials
All the data material has been presented in the manuscript.

Declarations

Ethics approval and consent to participate
Not required.

Consent for publication
Not applicable.

Competing interests
The authors have no known conflicts of interest to declare.

Author details
[1]Department of Food Engineering, NIFTEM, Kundli, Haryana, India. [2]Department of Food Engineering and Technology, SLIET, Longowal, Punjab, India. [3]Collage of Post-Harvest Technology and Food Processing, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, India.

Received: 15 June 2023 Accepted: 23 September 2023
Published online: 04 April 2024

References

Abbey, B., & Ibeh, G. (1988). Functional properties of raw and heat processed cowpea (Vignaunguiculata, Walp) flour. *Journal of Food Science,53*(6), 1975–1791.

Amandikwa, C., Iwe, M. O., Uzomah, A., & Olawuni, A. I. (2015). Physico-chemical properties of wheat-yam flour composite bread. *Nigerian Food Journal,33*(1), 12–17.

Ambigaipalan, P., Hoover, R., Donner, E., Liu, Q., Jaiswal, S., Chibbar, R., ... & Seetharaman, K. (2011). Structure of faba bean, black bean and pinto bean starches at different levels of granule organization and their physicochemical properties. *Food Research International*, *44*(9), 2962–2974.

Arinola, S. O. (2019). Physicochemical properties of pre-gelatinized and microwave radiated white and red cocoyam (Colocasiaesculenta) starches. *Croatian Journal of Food Science and Technology,11*(2), 251–258.

Audu, S. S., & Aremu, M. O. (2011). Effect of processing on chemical composition of red kidney bean (Phaseolus vulgaris L.) flour. *Pakistan journal of Nutrition,10*(11), 1069–1075.

Awolu, O. O. (2017). Optimization of the functional characteristics, pasting and rheological properties of pearl millet-based composite flour. *Heliyon,3*(2), e00240.

Bento, J. A. C., Morais, D. K., de Berse, R. S., Bassinello, P. Z., Caliari, M., & Júnior, M. S. S. (2022). Functional, thermal, and pasting properties of cooked carioca bean (Phaseolus vulgaris L.) flours. *Applied Food Research,2*(1), 100027.

Bhol, S., & Bosco, S. J. D. (2014). Influence of malted finger millet and red kidney bean flour on quality characteristics of developed bread. *LWT-Food Science and Technology,55*(1), 294–300.

Bilbao-Sáinz, C., Butler, M., Weaver, T., & Bent, J. (2007). Wheat starch gelatinization under microwave irradiation and conduction heating. *Carbohydrate Polymers,69*(2), 224–232.

Catsimpoolas, N., & Meyer, E. (1970). Gelation phenomena of soybean globulins. I. Protein–protein interactions. *Cereal Chemistry,47*, 559–570.

Chakraborty, A., & Bhattacharyya, S. (2014). Thermal processing effects on in vitro Antioxidant activities of five common Indian Pulses. *Journal of Applied Pharmaceutical Science,4*(5), 065–070.

Choe, U., Osorno, J. M., Ohm, J.-B., Chen, B., & Rao, J. (2022). Modification of physicochemical, functional properties, and digestibility of macronutrients in common bean (Phaseolus vulgaris L.) flours by different thermally treated whole seeds. *Food Chemistry,382*, 132570. https://doi.org/10.1016/j.foodchem.2022.132570

Chompoorat, P., Rayas-Duarte, P., Hernández-Estrada, Z. J., Phetcharat, C., & Khamsee, Y. (2018). Effect of heat treatment on rheological properties of red kidney bean gluten free cake batter and its relationship with cupcake quality. *Journal of food science and technology*, 55, 4937–44

Chung, H. J., Liu, Q., & Hoover, R. (2010). Effect of single and dual hydrothermal treatments on the crystalline structure, thermal properties, and nutritional fractions of pea, lentil, and navy bean starches. *Food Research International,43*(2), 501–508.

Dos Santos, T. P. R., Franco, C. M. L., Demiate, I. M., Li, X. H., Garcia, E. L., Jane, J. L., & Leonel, M. (2018). Spray-drying and extrusion processes: Effects on morphology and physicochemical characteristics of starches isolated from Peruvian carrot and cassava. *International Journal of Biological Macromolecules,118*, 1346–1353.

Du, S., Jiang, H., Yu, X., & Jane, J. (2014). Physicochemical and functional properties of whole legume flour. *LWT - Food Science and Technology,55*(1), 308–313.

Eşref, I. ŞI. K., & Halil, Ü. N. A. L. (2007). Moisture-dependent physical properties of white speckled red kidney bean grains. *Journal of Food Engineering,82*(2), 209–216.

FDA (Food and Drug Administration). (2012). *Bad Bug Book, Foodborne Pathogenic Microorganisms and Natural Toxins* (2nd ed.).

Hayat, I., Ahmad, A., Ahmed, A., Khalil, S., &Gulfraz, M. (2014). Exploring the potential of red kidney beans (Phaseolus vulgaris L.) to develop protein based product for food applications. *JAPS: Journal of Animal & Plant Sciences*, *24*(3), 860–868.

Hoover, R., & Ratnayake, W. S. (2002). Starch characteristics of black bean, chick pea, lentil, navy bean and pinto bean cultivars grown in Canada. *Food Chemistry,78*(4), 489–498.

Hoover, R., Rorke, S. C., & Martin, A. M. (1991). Isolation and characterization of lima bean (Phaseolus lunatus) starch. *Journal of Food Biochemistry,15*(2), 117–136.

Inyang, U. E., Daniel, E. A., & Bello, F. A. (2018). Production and quality evaluation of functional biscuits from whole wheat flour supplemented with acha (fonio) and kidney bean flours. *Asian Journal of Agriculture and Food Sciences,6*(6), 193–201.

Jan, R., Saxena, D. C., & Singh, S. (2016). Pasting, thermal, morphological, rheological and structural characteristics of Chenopodium (Chenopodium album) starch. *LWT-Food Science and Technology, 66*, 267–274.

Jati, I. R. A. P., Vadivel, V., & Biesalski, H. K. (2013). Antioxidant activity of anthocyanins in common legume grains. *Bioactive Food as Dietary Interventions for Liver and Gastrointestinal Disease* (pp. 485–497) Academic Press.

Kan, L., Nie, S., Hu, J., Wang, S., Cui, S. W., Li, Y., Xu, S., Wu, Y., Wang, J., Bai, Z., & Xie, M. (2017). Nutrients, phytochemicals and antioxidant activities of 26 kidney bean cultivars. *Food and Chemical Toxicology,108*, 467–477.

Karaaslan, S. N., & Tuncer, I. K. (2008). Development of a drying model for combined microwave-fan-assisted convection drying of spinach. *Biosystems Engineering,100*, 44–52.

Kayode, S. E., Olorunfemi, B. J., & Soyoye, B. O. (2018). Determination of engineering properties of some Nigerian local grain crops. *Int. J. Agric. Biosyst. Eng,3*, 10–18.

Khrisanapant, P., Kebede, B., Leong, S. Y., & Oey, I. (2022). Effects of Hydrothermal Processing on Volatile and Fatty Acids Profile of Cowpeas (Vigna unguiculata), Chickpeas (Cicer arietinum) and Kidney Beans (Phaseolus vulgaris). *Molecules*, 27(23), 8204:1–22.

Kim, C. S., & Walker, C. E. (1992). Changes in starch pasting properties due to sugars and emulsifiers as determined by viscosity measurement. *Journal of Food Science,57*(4), 1009–1013.

Kioseoglou, V., & Paraskevopoulou, A. (2011). Functional and physicochemical properties of pulse proteins (No. IKEEBOOKCH-2019-183, pp. 57-90). Elsevier Science.

Kweon, M., Slade, L., Levine, H., Martin, R., & Souza, E. (2009). Exploration of sugar functionality in sugar-snap and wire-cut cookie baking: Implications for potential sucrose replacement or reduction. *Cereal Chemistry,86*(4), 425–433.

Kumar, Y., Singh, L., Sharanagat, V. S., Patel, A., & Kumar, K. (2020). Effect of microwave treatment (low power and varying time) on potato starch: Microstructure, thermo-functional, pasting and rheological properties. *International Journal of Biological Macromolecules,155*, 27–35.

Lan, H., Hoover, R., Jayakody, L., Liu, Q., Donner, E., Baga, M., ... & Chibbar, R. N. (2008). Impact of annealing on the molecular structure and physicochemical properties of normal, waxy and high amylose bread wheat starches. *Food Chemistry*, *111*(3), 663–675.

Li, M., Wang, B., Lv, W., Lin, R., & Zhao, D. (2022a). Characterization of pre-gelatinized kidney bean (Phaseolus vulgaris L) produced using microwave hot-air flow rolling drying technique. *LWT, 154*, 112673.

Li, M., Wang, B., Lv, W., & Zhao, D. (2022b). Effect of ultrasound pretreatment on the drying kinetics and characteristics of pregelatinized kidney beans based on microwave-assisted drying. *Food Chemistry, 397*, 133806.

Locali-Pereira, A. R., Kubo, M. T. K., Fuzetti, C. G., & Nicoletti, V. R. (2022). Functional Properties of Physically Pretreated Kidney Bean and Mung Bean Flours and Their Performance in Microencapsulation of a Carotenoid-Rich Oil. *Frontiers in Sustainable Food Systems*, *6, 845566, 1-11*.

Ma, Z., Boye, J. I., Azarnia, S., & Simpson, B. K. (2016). Volatile flavor profile of Saskatchewan grown pulses as affected by different thermal processing treatments. *International Journal of Food Properties,19*(10), 2251–2271.

Ma, Z., Boye, J. I., Simpson, B. K., Prasher, S. O., Monpetit, D., & Malcolmson, L. (2011). Thermal processing effects on the functional properties and microstructure of lentil, chickpea, and pea flours. *Food Research International,44*(8), 2534–2544.

Maaran, S., Hoover, R., Donner, E., & Liu, Q. (2014). Composition, structure, morphology and physicochemical properties of lablab bean, navy bean, rice bean, tepary bean and velvet bean starches. *Food Chemistry,152*, 491–499.

Manonmani, D., Bhol, S., & Bosco, S. J. D. (2014). Effect of red kidney bean (Phaseolus vulgaris L.) flour on bread quality. *Open Access Libr. J,1*, 1–6.

McWatters, K., & Holmes, M. (1979). Influence of moist heat on solubility and emulsification properties of soy and peanut flours. *Journal of Food Science,44*(3), 774–776.

Nimesh, A., & Sharanagat, V. (2016). Effect of Moisture Content on Engineering Properties of Chickpea Seed. *Agricultural Engineering Today,40*, 13–21.

Obatolu, V. A., Fasoyiro, S. B., & Ogunsunmi, L. (2007). Processing and functional properties of yam beans (Sphenostylisstenocarpa). *Journal of Food Processing and Preservation,31*(2), 240–249.

Ozturk, I., Kara, M., Yildiz, C., & Ercisli, S. (2009). Physico-mechanical seed properties of the common Turkish bean (Phaseolus vulgaris) cultivars "Hinis" and "Ispir." *New Zealand Journal of Crop and Horticultural Science,37*(1), 41–50.

Pathiratne, S. M., Shand, P. J., Pickard, M., & Wanasundara, J. P. (2015). Generating functional property variation in lentil (Lens culinaris) flour by seed micronization: Effects of seed moisture level and surface temperature. *Food Research International,76*, 122–131.

Prinyawiwatkul, W., Beuchat, L. R., McWatters, K. H., & Phillips, R. D. (1997). Functional properties of cowpea (Vignaunguiculata) flour as affected by soaking, boiling, and fungal fermentation. *Journal of Agricultural and Food Chemistry,45*(2), 480–486.

Qiu, S., Yadav, M. P., Chen, H., Liu, Y., Tatsumi, E., & Yin, L. (2015). Effects of corn fiber gum (CFG) on the pasting and thermal behaviors of maize starch. *Carbohydrate Polymers,115*, 246–252.

Sahay, K. M., & Singh, K. K. (1996). *Unit operations of agricultural processing*. Vikas Publishing House Pvt.

Shevkani, K., Kaur, R., Singh, N., & Hlanze, D. P. (2022). Colour, composition, digestibility, functionality and pasting properties of diverse kidney beans (Phaseolus vulgaris) flours. *Current Research in Food Science,5*, 619–628.

Siddiq, M., Ravi, R., Harte, J. B., & Dolan, K. D. (2010). Physical and functional characteristics of selected dry bean (Phaseolus vulgaris L.) flours. *LWT - Food Science and Technology,43*(2), 232–237.

Silverstein, R. M., Webster, F. X., Kiemle, D. J., & Bryce, D. L. (2015). *Spectrometric identification of organic compounds*. Wiley.

Singh, Y., & Chandra, S. (2014). Evaluation of physical properties of kidney beans (Phaseolus vulgaris). *Food Sci Res J,5*(2), 125–129.

Su, D., Lv, W., Wang, Y., Wang, L., & Li, D. (2020). Influence of microwave hot-air flow rolling dry-blanching on microstructure, water migration and quality of pleurotus eryngii during hot-air drying. *Food Control,114*, 107228.

Wainaina, I., Wafula, E., Sila, D., Kyomugasho, C., Grauwet, T., Van Loey, A., & Hendrickx, M. (2021). Thermal treatment of common beans (Phaseolus vulgaris L.): Factors determining cooking time and its consequences for sensory and nutritional quality. *Comprehensive Reviews in Food Science and Food Safety,20*(4), 3690–3718.

Wani, I. A., Andrabi, S. N., Sogi, D. S., & Hassan, I. (2019). Comparative study of physicochemical and functional properties of flours from kidney bean (Phaseolus vulgaris L.) and green gram (Vignaradiata L.) cultivars grown in Indian temperate climate. *Legume Science,* e11.

Wani, I. A., Andrabi, S. N., Sogi, D. S., & Hassan, I. (2020). 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, 2*(1), e11,1–12.

Wani, I. A., Hamid, H., Hamdani, A. M., Gani, A., & Ashwar, B. A. (2017a). Physicochemical, rheological and antioxidant properties of sweet chestnut (Castanea sativa Mill.) as affected by pan and microwave roasting. *Journal of Advanced Research, 8*(4), 399–405.

Wani, I. A., Sogi, D. S., Wani, A. A., & Gill, B. S. (2013). Physico-chemical and functional properties of flours from Indian kidney bean (Phaseolus vulgaris L.) cultivars. *LWT - Food Science and Technology,53*(1), 278–284.

Wani, I. A., Sogi, D. S., Wani, A. A., & Gill, B. S. (2017b). Physical and cooking characteristics of some Indian kidney bean (Phaseolus vulgaris L.) cultivars. *Journal of the Saudi Society of Agricultural Sciences, 16*(1), 7–15.

Publisher's Note