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Comparative study of the functional, thermal and pasting properties of flours from different field pea (*Pisum sativum* L.) and pigeon pea (*Cajanus cajan* L.) cultivars

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Abstract

Physicochemical, functional, thermal and pasting properties of flours from field pea (LFP-48 and PG-3) and pigeon pea (AL-15 and AL-201) cultivars were determined and related to each other using Pearson correlation and principal component analysis (PCA). Field pea flours (FPF) were significantly ($P < 0.05$) different from pigeon pea flours (PPF) in their lower ash and higher fat and protein contents. FPF also exhibited higher L^*, ΔE value, water solubility index (WSI), oil absorption capacity (OAC), foaming capacity (FC) and lower a^*, b^* value, water absorption index (WAI) and water absorption capacity (WAC) in comparison to PPF. FPF differed significantly from PPF in exhibiting lower transition temperatures (T_o, T_p, T_c), enthalpy of gelatinization (ΔH_{gel}), peak height index (PHI) and higher gelatinization temperature range (R). PCA showed that LFP-48 and PG-3 flours were located at the far left of the score plot with a large negative score, while the AL-15 and AL-201 flours had large positive scores in the first principal component. Several significant correlations between functional, thermal and pasting properties were revealed, both by Pearson correlation and PCA. Pasting properties of the flours, measured using the rapid visco analyzer (RVA), also differed significantly. PPF were observed to have higher pasting temperature (PT), peak viscosity (PV), trough viscosity (TV), breakdown (BV), final viscosity (FV) and lower setback viscosity (SV) as compared to FPF.

Keywords: Flour; Physicochemical; Functional; Thermal; Pasting

1. Introduction

Legumes are the edible fruits or seeds of pod-bearing plants belonging to the family Leguminosae and are widely grown throughout the world (Singh, Kaur, Sandhu, & Sodhi, 2004). Legume seeds are of prime importance in human and animal nutrition, due to their high protein content (20–50%) (Singh, Sandhu, & Kaur, 2004). Grain legumes are also a rich source of vitamins, especially of the B-complex, and minerals such as calcium and iron. Field peas (*Pisum sativum* L.) are grown in a limited area in India, but are extensively grown in northern Europe, USA, Canada, Russia and China (Singh, 1999). Yellow field peas are rich in protein, starch and nutrients, such as fibre, vitamins and minerals, and are well suited to meet the demands of health-conscious consumers (Wang, Daun, & Malcolmson, 2003). Red gram (*Cajanus cajan* L.), also called pigeon pea, is among the important grain legumes and is grown and consumed in the tropics and semi-arid tropics of the world (Singh, 1988). Pigeon peas have potential value as an economic source of high protein (Eneche, 1999).

For efficient utilization and consumer acceptance of legume seed flours, it is desirable to study their functional properties (Adebowale & Lawal, 2004). Successful performance of legume flours as food ingredients depends on the

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functional characteristics and sensory qualities that they impart to the end-product. The functional properties include foaming, emulsification, texture, gelation, water and oil absorption capacities and viscosity (Adebowale & Lawal, 2004). Various investigators, e.g. Chel-Guerrero, Perez-Flores, Bentacur-Ancona, and Davila-Ortiz (2002), Dzudie and Hardy (1996), Kaur and Singh (2005), Narayana and Narasinga Rao (1982, 1984) and Oshodi and Ekperigin (1989) have studied the functional properties of lima bean, mung bean, chickpea, winged bean and pigeon pea flours, respectively. Adebowale and Lawal (2004) reported a comparative study on the functional properties of bambarra groundnut, jack bean and mucuna bean flours. Mueses, Deleon, Matute, and Bressani (1993) conducted experiments to investigate the possibility of processing pigeon pea to yield intermediate flour with good functional characteristics for food product development. Onimawo and Asugo (2004) studied the effects of germination on the nutrient content and functional properties of pigeon pea flour.

Differential scanning calorimetry (DSC) has been used to study thermal properties associated with starch gelatinization (Sandhu, Singh, & Kaur, 2004). Gelatinization, the process by which the internal structure of the granule disintegrates, releasing polysaccharide into the surrounding medium, is accompanied by a variety of changes. When starch granules are heated in water beyond a critical temperature, the granules absorb a large amount of water and swell to many times their original size. Over a critical temperature range, the starch granules undergo an irreversible process, which is marked by crystalline melting, loss of birefringence and starch solubilization (Singh, Sandhu, & Kaur, 2005). The present investigation was undertaken to study and compare the functional, thermal and pasting properties of flours derived from different Indian field pea and pigeon pea cultivars, aiming toward effective utilization of these flours in various food products.

2. Materials and methods

2.1. Materials

Representative samples of two improved field pea (*P. sativum* L.) (LFP-48 and PG-3) and pigeon pea (*C. cajan* L.) cultivars (AL-15 and AL-201) from the 2002 harvest were obtained from Punjab Agricultural University, Ludhiana, India. Seeds from different legume cultivars were ground to pass through sieve no. 72 (British Sieve Standards) to obtain flour. The flour samples were defatted by a solvent extraction process, using *n*-hexane, and then dried at 40 °C in a hot air oven for 3 h and, after cooling, were packed in air-tight containers.

2.1.1. Proximate composition

Flour samples were estimated for their moisture, ash, fat and protein (% N × 6.25) content by employing standard methods of analysis (AOAC, 1990). Studies were conducted in triplicate.

2.2. Physicochemical properties of flours

2.2.1. Colour characteristics

Colour measurements of flour samples were carried out in triplicate, using a Hunter colorimeter Model D 25 optical Sensor (Hunter Associates Laboratory Inc., Reston, VA., USA), on the basis of L^*, a^* and b^* values. A glass cell containing flour was placed above the light source, covered with a white plate and L^*, a^* and b^* colour values were recorded. The instrument (45°/0° geometry, 10° observer) was calibrated against a standard red-coloured reference tile ($L_s = 25.54$, $a_s = 28.89$, $b_s = 12.03$). Total colour difference (ΔE) was calculated by applying the equation

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

The L^* value indicates the lightness, 0–100 representing dark to light. The a^* value gives the degree of the red–green colour, with a higher positive a^* value indicating more red. The b^* value indicates the degree of the yellow–blue colour, with a higher positive b^* value indicating more yellow.

2.2.2. Water absorption index (WAI) and water solubility index (WSI)

WAI and WSI of flours were determined as described previously (Singh, Kaur, & Sandhu, 2005). Flour sample (2.5 g) was dispersed in 30 ml of distilled water, using a glass rod, and cooked at 90 °C for 15 min in a water bath. The cooked paste was cooled to room temperature and transferred to tared centrifuge tubes, and then centrifuged at 3000*g* for 10 min. The supernatant was decanted for determination of its solid content into a tared evaporating dish and the sediment was weighed. The weight of dry solids was recovered by evaporating the supernatant overnight at 110 °C. Triplicate determinations were carried out. WSI and WAI were calculated by the equations:

$$\text{WAI (g/g)} = \frac{\text{Weight of sediment}}{\text{Weight of flour sample}}$$

$$\text{WSI (\%)} = \frac{\text{Weight of dissolved solids in supernatant} \times 100}{\text{Weight of flour sample}}$$

2.2.3. Bulk density

The flour samples were gently filled into 10 ml graduated cylinders, previously tared. The bottom of each cylinder was gently tapped on a laboratory bench several times until there was no further diminution of the sample level after filling to the 10 ml mark. Bulk density was calculated as weight of sample per unit volume of sample (g/ml). Measurements were made in triplicate.

2.3. Functional properties

2.3.1. Water and oil absorption capacities

Water absorption of flours was measured by the centrifugation method of Sosulski (1962). The sample (3.0 g) was dispersed in 25 ml of distilled water and placed in preweighed centrifuge tubes. The dispersions were stirred occasionally, held for 30 min, followed by centrifugation for 25 min at 3000*g*. The supernatant was decanted, excess moisture was removed by draining for 25 min at 50 °C, and the sample was reweighed. For the determination of fat absorption, the method of Lin, Humbert, and Sosulski (1974) was used. Samples (0.5 g) were mixed with 6 ml of corn oil in preweighed centrifuge tubes. The contents were stirred for 1 min with a thin brass wire to disperse the sample in the oil. After a holding period of 30 min, the tubes were centrifuged for 25 min at 3000*g*. The separated oil was then removed with a pipette and the tubes were inverted for 25 min to drain the oil prior to reweighing. Triplicate determinations were carried out and the water and oil absorption capacities were expressed as grammes of water or oil bound per gramme of the sample on a dry basis.

2.3.2. Gelation properties

Gelation properties were studied in triplicate by employing the method of Sathe, Deshpande, and Salunkhe (1982b). Test tubes, containing suspensions of 2%, 4%, 6%, 8%, 10%, 12%, 14%, 16%, 18% and 20% (w/v) of material in 5 ml distilled water, were heated for 1 h in boiling water, followed by rapid cooling under cold running water. The tubes were further cooled at 4 °C for 2 h. The least gelation concentration (LGC) was taken as when the sample in the inverted test tube did not fall down or slip.

2.3.3. Foaming properties

The method of Lin et al. (1974) was used for the determination of foaming capacity (FC) and foam stability (FS) of legume flours. The dispersions of samples (50 ml; 3% w/v) in distilled water were homogenized, using a homogenizer (Yorco, India), at high setting for 2–3 min. The blend was immediately transferred into a graduated cylinder and the homogenizer cup was rinsed with 10 ml of distilled water, which was then added to the graduated cylinder. The volume was recorded before and after whipping. FC was expressed as the volume increase (%) due to whipping. For the determination of FS, foam volume changes in the graduated cylinder were recorded at intervals of 20, 40, 60, and 120 min of storage. Triplicate determinations were carried out.

2.4. Thermal properties

Thermal characteristics of flours were analyzed in triplicate by using a differential scanning calorimeter-821[e] (Mettler Toledo, Switzerland) equipped with a thermal analysis data station. Sample (3.5 mg, dry weight) was loaded into a 40 μl capacity aluminium pan (Mettler, ME-27331) and distilled water was added with the help of a Hamilton micro-syringe to achieve a flour–water suspension containing 70% water. Samples were hermetically sealed and allowed to stand for 1 h at room temperature before heating in the DSC. The DSC analyzer was calibrated using indium and an empty aluminium pan was used as reference. Sample pans were heated at a rate of 10 °C/min from 20 to 100 °C. Onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) and enthalpy of gelatinization (ΔH_{gel}) were calculated automatically. The gelatinization temperature range (R) was computed as ($T_c - T_o$), as described by Vasanthan and Bhatty (1996). Enthalpies were calculated on a dry sample basis. The peak height index (PHI) was calculated by the ratio $\Delta H_{gel}/(T_p - T_o)$, as described by Krueger, Knutson, Inglett, and Walker (1987).

2.5. Pasting properties

Pasting properties of flours were studied by using a rapid visco analyzer (Newport Scientific Pty Ltd., Warriewood NSW 2102, Australia), as described previously (Kaur & Singh, 2005). Viscosity profiles of flours were recorded using flour suspensions (10%, w/w; 28 g total weight). The temperature–time conditions included a heating step from 50 to 95 °C at 6 °C/min (after an equilibration time of 1 min at 50 °C), a holding phase at 95 °C for 5 min, a cooling step from 95 to 50 °C at 6 °C/min and a holding phase at 50 °C for 2 min. Each sample was analyzed in triplicate.

2.6. Statistical analysis

Statistical analysis of the results was done with Minitab statistical software (Minitab Inc., State College, PA, USA). Pearson correlation coefficients (r), for relationships between various flour properties, were calculated. A principle component analysis (PCA) of 18 measured flour properties was carried out to provide a ready means of visualizing the differences and similarities among different legume cultivars in terms of these properties.

3. Results and discussion

3.1. Proximate composition

Proximate composition varied significantly among flours from different field pea and pigeon pea cultivars. The ash, crude fat and protein contents of flours from different legume cultivars ranged between 3.04–3.31%, 0.87–1.93%, and 19.9–26.2%, respectively (Table 1). Since all the flours were defatted, fat contents of less than 2% were observed. Field pea flours (FPF) had lower ash (3.07%) and higher fat (1.90%) and protein (25.9%) contents, than had pigeon pea flours (PPF). Ash, fat and protein contents of 2.72–2.91%, 0.53–1.21%, and 20.6–26.7%, respectively, in chickpea (Kaur & Singh, 2005), 2.9%, 1.4%, and 22.5%, respectively in pigeon pea (Eneche, 1999) and 2.7%, 1.1% and 25.3% in field pea (Sosulski & Youngs, 1979) flours have been reported. Corzo and Fuentes (2004) reported ash, fat, protein contents of 2.4%, 1.67% and 19.5%, respectively in pre-cooked pigeon pea flours.

Table 1
Proximate composition (dry weight basis) and bulk density of field pea and pigeon pea flours[A,B]

Cultivars	Ash (%)	Crude fat (%)	Protein[C] (%)	Bulk density (g/ml)
Field pea				
LFP-48	3.10 ± 0.18[b]	1.86 ± 0.09[bc]	25.6 ± 0.84[bc]	0.541 ± 0.010[b]
PG-3	3.04 ± 0.19[a]	1.93 ± 0.08[c]	26.2 ± 0.72[c]	0.562 ± 0.020[c]
Mean	3.07	1.90	25.9	0.552
Pigeon pea				
AL-15	3.31 ± 0.19[c]	0.87 ± 0.08[a]	24.0 ± 0.67[b]	0.471 ± 0.020[ab]
AL-201	3.11 ± 0.18[b]	0.98 ± 0.07[b]	19.9 ± 0.81[a]	0.467 ± 0.020[a]
Mean	3.21	0.93	22.0	0.469

[A] Means followed by same superscript within a column do not differ significantly ($P < 0.05$).
[B] Mean (±standard deviation) of triplicate analyses.
[C] Total nitrogen × 6.25.

McWatters and Cherry (1977) reported ash, fat and protein contents of soybean, peanut, fieldpea and pecan flours in the ranges 3.8–6.2%, 0.9–1.6%, and 24.2–54.9%, respectively.

3.2. Physicochemical properties

Significant differences were also observed in bulk densities of flours from different legume cultivars (Table 1). Among the flours, FPF showed a higher bulk density (0.541–0.562 g/ml) than did PPF (0.471–0.467 g/ml). Bulk densities of 0.536–0.571 g/ml in chickpea flours (Kaur & Singh, 2005) 0.530 and 0.480 g/ml in winged bean flour and soy isolate, respectively, have been reported (Okezie & Bello, 1988).

Hunter colour values (L^*, a^*, b^* and ΔE) of FPF and PPF are shown in Table 2. Among the legume flours studied, FPF showed a higher L^* parameter (mean value 81.49), indicating their lighter colour than PPF. All the flours showed negative a^* values, indicating the presence of a slight green tint in them. FPF showed a lower a^* value (−4.34), and b^* value (17.34), than did PPF. ΔE (total colour difference) was observed to range from 64.68–65.16 for FPF and 61.64–61.88 for PPF. Kaur and Singh (2005) reported Hunter L^*, a^*, b^* and ΔE values of 81.64–85.41, −0.72 to −1.10, 14.1–20.7 and 64.18–66.96, respectively, for chickpea flours.

The water absorption index (WAI) measures the volume occupied by the starch after swelling in excess water, which maintains the integrity of starch in aqueous dispersion (Marson & Hoseney, 1986). WAI for FPF ranged between 4.84 and 5.01 g/g, whereas PPF showed the value of 5.17–6.11 g/g for the same (Fig. 1). Water solubility index (WSI), which is related to the presence of soluble molecules, differed significantly between various legume flours. WSI values in the range 19.8–20.6 in FPF and 13.7–14.5 in PPF (Fig. 1) were observed. Among the flours, FPF showed lower WAI and higher WSI than did PPF. WAI and WSI of 2.39–2.66 g/g and 20.42–22.89%, respectively, in chickpea flours have been previously reported (Kaur & Singh, 2005). A positive correlation of WSI with ΔE has been revealed by Pearson correlation analysis (Table 5).

The variables subjected to principal component analysis (PCA) are listed in Table 3 and the results of the analysis are shown in Figs. 2 and 3. The PCA plots provide an overview of the similarities and differences between the flours of different legume cultivars, and of the interrelationships between the measured properties. The distance between the locations of any two flours on the score plot is directly proportional to the degree of difference or similarity between them (Fig. 2). The first and the second principal components (PCs) described 74.6% and 17.6% of the variance, respectively. Together, the first two PCs represent 92.1% of the total variability. PCA showed that LFP-48 and PG-3 flours were located at the far left of the score plot

Table 2
Hunter colour values of flours from different field pea and pigeon pea cultivars[A,B]

Cultivars	L^*	a^*	b^*	ΔE value[C]
Field pea				
LFP-48	78.81 ± 1.03[a]	−7.15 ± 0.03[a]	18.86 ± 0.13[c]	64.68 ± 0.9[b]
PG-3	84.17 ± 1.11[b]	−1.53 ± 0.02[d]	15.81 ± 0.14[a]	65.16 ± 1.1[b]
Mean	81.49	−4.34	17.34	64.92
Pigeon pea				
AL-15	77.89 ± 1.21[a]	−3.53 ± 0.03[b]	18.24 ± 0.11[c]	61.88 ± 0.8[a]
AL-201	78.17 ± 1.09[a]	−2.84 ± 0.04[c]	16.83 ± 0.12[b]	61.64 ± 0.9[a]
Mean	78.03	−3.19	17.54	61.76

[A] Means followed by same superscript within a row do not differ significantly ($P < 0.05$).
[B] Mean of triplicate analyses (±standard deviation).
[C] Total colour difference.

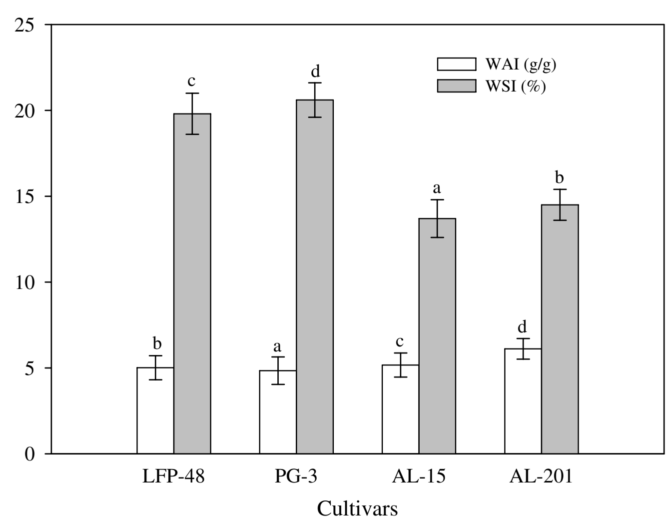

Fig. 1. Water absorption index (WAI) and water solubility index (WSI) of flours from different field pea and pigeon pea cultivars. Values that do not bear the same letter are significantly different ($P < 0.05$). Error bars: standard deviations. Results are means of triplicate determinations.

Table 3
Variables examined with PCA

Description	Variable
Ash content	Ash
Fat content	Fat
Protein content	Protein
Bulk density	BD
Hunter L^* value	L^*
Hunter a^* value	a^*
Hunter b^* value	b^*
Onset transition temperature	T_o
Peak transition temperature	T_p
Enthalpy of gelatinization	ΔH_{gel}
Gelatinization temperature range	R
Pasting temperature	PT
Peak viscosity	PV
Final viscosity	FV
Water absorption capacity	WAC
Oil absorption capacity	OAC
Foaming capacity	FC
Water absorption index	WAI

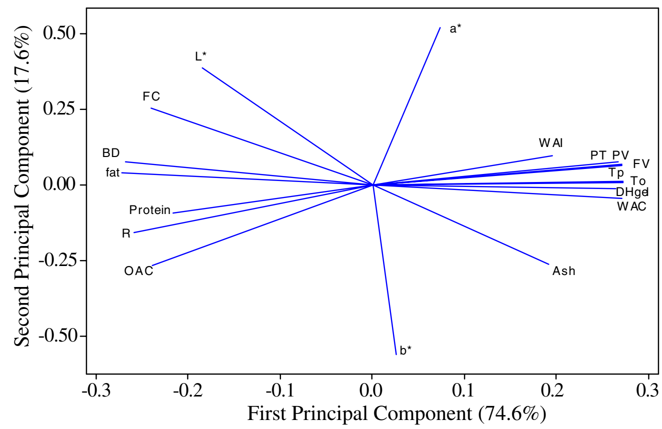

Fig. 3. Principal component analysis: loading plot of PC1 and PC2 describing the variation among the different properties of flours from different field pea and pigeon pea cultivars. A heavy solid line and a second line very close to it indicate two properties that are highly correlated.

with large negative scores, while the AL-15 and AL-201 flours had large positive scores in the first principal component (PC1). The loading plot of the two PCs provided information about correlations between measured physicochemical, functional, thermal and pasting properties (Fig. 3). The properties whose curves lie close to each other on the plot are positively correlated while those whose curves run in opposite directions are negatively correlated. Positive correlations of ash and protein with b^* and negative correlations of fat with a^* and b^* can be observed in the PCA loading plot (Fig. 3).

3.3. Functional properties

Water absorption capacity (WAC) of FPF and PPF ranged from 1.24 to 1.25 and 1.37 to 1.39 g/g, respectively (Fig. 4). Different protein structures and the presence of different hydrophilic carbohydrates might be responsible for variations in the WAC of the flours. WAC values of 138% for pigeonpea flour (Oshodi & Ekperigin, 1989), 1.33–1.47 g/g for chickpea flours (Kaur & Singh, 2005), and 107% for sunflower flour (Venktesh & Prakash, 1993) have been reported. Mizubuti, Junior, Souza, daSilva, and Ida (2000) reported a WAC of 1.2 ml/g of sample in pigeon pea flour. Among the legume flours, PPF showed higher WAC (1.38 g/g) than did FPF (1.245 g/g). According to Hodge and Osman (1976), flours with high water absorption have more hydrophilic constituents, such as polysaccharides.

The oil absorption capacity (OAC) of FPF was observed to be higher (1.06–1.17 g/g) than that of PPF (0.96–0.98 g/g) (Fig. 4). These values are consistent with those previously reported for pigeon pea (1.07 ml/g), soybean (1.24 g/g),

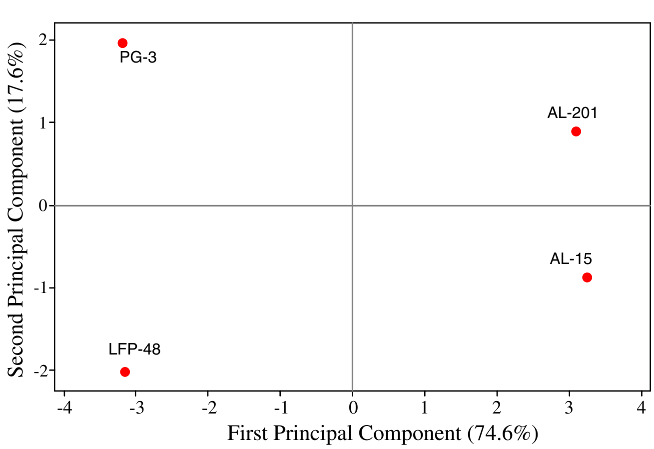

Fig. 2. Principal component analysis: score plot of first principal component (PC1) and second principal component (PC2) describing the overall variation among flours from different field pea and pigeon pea cultivars.

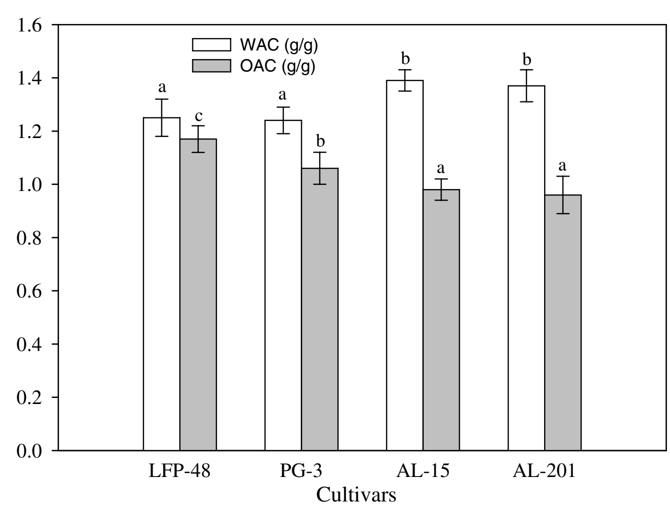

Fig. 4. Water absorption capacity (WAC) and oil absorption capacity (OAC) of flours from different field pea and pigeon pea cultivars. Values that do not bear the same letter are significantly different ($P < 0.05$). Error bars: standard deviations. Results are means of triplicate determinations.

great northern bean (1.0 g/g), and chickpea flours (1.05–1.17 g/g) by Mizubuti et al. (2000), Nath and Narasinga Rao (1981), Sathe and Salunkhe (1981), and Kaur and Singh (2005), respectively. Variations in the presence of non-polar side chains, which might bind the hydrocarbon side chains of oil among the flours, possibly explain difference in the oil binding capacity of the flours (Adebowale & Lawal, 2004). The ability of flours to absorb and retain water and oil may help improve binding of the structure, enhance flavour retention, improve mouthfeel and reduce moisture and fat losses of extended meat products (McWatters & Heaton, 1979). PCA analysis revealed a significant positive correlation of OAC with the protein content and a negative correlation with WAI (Fig. 3).

Least gelation concentration (LGC) for various legume flours ranged from 12% to 14% (Table 4). The lower the LGC, the better is the gelating ability of the protein ingredient (Akintayo, Oshodi, & Esuoso, 1999). PPF formed a firm gel at a significantly higher concentration (14%) than did FPF (12%). The LGC of FPF and PPF observed in the present study were comparable to those of pigeon pea flour (10%) (Onimawo & Asugo, 2004), lupin seed flour (14%) (Sathe et al., 1982b), and great northern bean flour (10%) (Sathe & Salunkhe, 1981). Oshodi and Ekperigin (1989) reported a LGC of 12% in pigeon pea flour. Variations in gelling properties may be ascribed to the ratios of different constituents, such as proteins, carbohydrates and lipids, in different legume flours, suggesting that interactions between such components may also have a significant role in functional properties.

The foaming capacity (FC) and foam stability (FS) of FPF and PPF also differed significantly. The foams produced by legume flours were relatively thick with low foam volume but high FS. The FC of FPF was found to be greater (39.5–42.3%) than that of PPF (34.5–37.3%) (Fig. 5). A FC of 36.0% in pigeon pea flours has been previously reported (Mizubuti et al., 2000). The FC of PPF, observed in the present work, was low compared to the 68% reported by Oshodi and Ekperigin (1989) for PPF. This may be due to the differences in proteins and the concentrations employed. A positive correlation of FC with protein and OAC and negative with WAI can be observed in the PCA loading plot (Fig. 3). FS (3% w/v dispersion) for legume flours was determined by measuring the decrease in volume of foam as a function of time. Foam volume changes, as a function of time, for legume flours, are shown in Fig. 6. Instability of foams is indicated by drainage of liquid from the lamellae and by an increase and then rupture in the size of bubbles (Sathe, Deshpande, & Salunkhe, 1982a). Foams produced by PPF were very thin and contained many large unstable air cells. FPF showed higher FS (∼90%) than did PPF, as their foams did not collapse, even after 120 min of storage, suggesting

Table 4
Least gelation concentration of flours after heating in boiling water for 1 h, followed by cooling for 2 h at 4 °C[a]

Concentration (%)	Cultivars			
	LFP-48	PG-3	AL-15	AL-201
2	–	–	–	–
4	–	–	–	–
6	–	–	–	–
8	–	–	–	–
10	–	–	–	–
12	Gel	Gel	Gel	–
14	Firm gel	Firm gel	Firm gel	Gel
16	Firm gel	Firm gel	Firm gel	Firm gel
18	Very firm gel	Very firm gel	Very firm gel	Firm gel
20	Very firm gel	Very firm gel	Very firm gel	Very firm gel

(–) indicates no gelation.
[a] Mean of triplicate determinations.

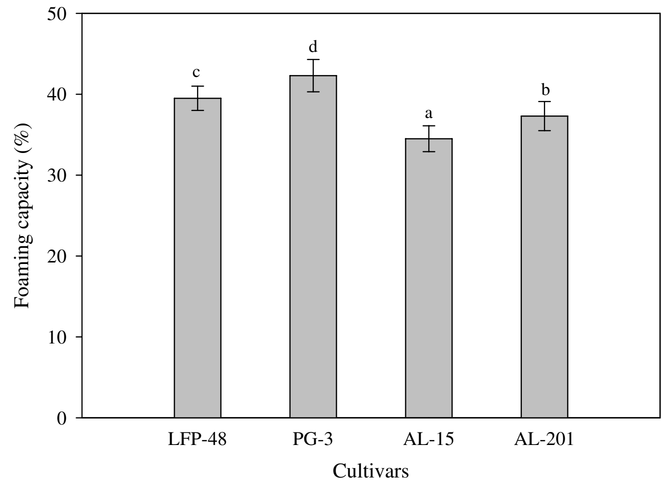

Fig. 5. Foaming capacity (FC) of flours from different field pea and pigeon pea cultivars. Values that do not bear the same letter are significantly different ($P < 0.05$). Error bars: standard deviations. Results are means of triplicate determinations.

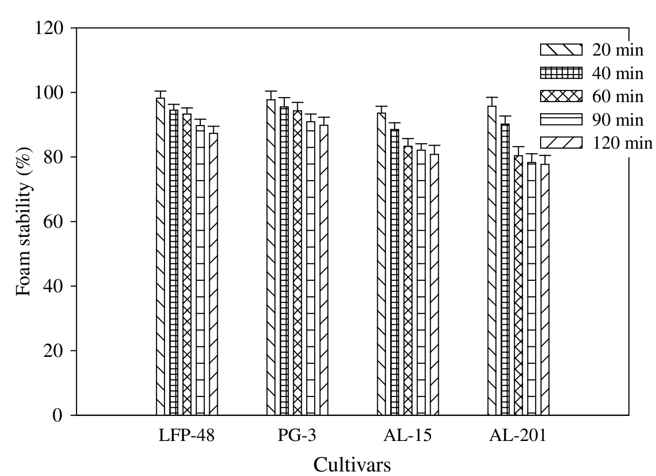

Fig. 6. Foam stability of flours from different field pea and pigeon pea cultivars after 20, 40, 60, 90, and 120 min of storage. Error bars: standard deviations. Results are means of triplicate determinations.

that the native proteins that are soluble in the continuous phase (water) are very surface-active in FPF.

3.4. Thermal properties

The gelatinization temperatures (onset, T_o; peak, T_p; and conclusion, T_c), enthalpy of gelatinization (ΔH_{gel}), peak height index (PHI) and gelatinization range ($T_c - T_o$) for different legume flours are presented in Table 6. Significant differences were observed in T_o, T_p and T_c among various legume flours. Among the flours, FPF showed lower T_o, T_p and T_c (T_o, 59.45 °C; T_p, 65.5 °C; T_c, 74.1 °C) than did PPF (T_o, 75.6 °C; T_p, 82.0 °C; T_c, 87.2 °C). T_o, T_p and T_c in the ranges 65.4–67.9, 70.6–73.3 and 77.0–79.4 °C, respectively, in chickpea flours have been previously reported (Kaur & Singh, 2005). T_o and T_p were negatively correlated with fat and FC ($P < 0.05$) and positively with WAC ($P < 0.01$), as revealed both by Pearson correlation results (Table 5) and PCA loading plot. (Fig. 3). Positive correlations of T_o with T_p ($r = 1.000$) and T_c ($r = 0.997$) were observed. The differences in gelatinization temperatures among the flours may be attributed to differences in size, form and distribution of starch granules in the flours, and to the internal arrangement of starch fractions within the granule (Kaur & Singh, 2005). ΔH_{gel} was observed to be in the range 4.05–4.13 J/g for FPF, and 4.66–4.93 J/g for PPF. PPF showed higher ΔH_{gel} (4.79 J/g) than did FPF (4.09 J/g), suggesting that the double helices that unravel and melt during gelatinization are strongly associated within the native starch granule of PPF. PHI values for various legume flours, differed significantly, ranging from 0.68 in FPF to 0.73–0.76 in PPF. PPF showed significantly higher transition temperatures, ΔH_{gel} and PHI than did FPF. Therefore, more energy was needed (fusion enthalpy) to break the intermolecular bonds in starch granules of PPF to achieve gelatinization. The gelatinization R was observed to be higher (14.6) for FPF than for PPF (11.6). The high R value of FPF suggests the presence of crystallites of varying stability within the crystalline domains of its starch granules. ΔH_{gel} showed a positive

Table 5
Pearson correlation coefficients between various physicochemical, functional, thermal and pasting properties of flours from field pea and pigeon pea cultivars

	Fat	ΔE	WAC	WSI	FC	ΔH_{gel}	T_o	T_p	R	PV	TV
ΔE	0.990**										
WAC	−1.000**	−0.986**									
WSI	0.999**	0.989**	−0.999**								
FC	0.914*	0.885*	−0.921*	0.929*							
ΔH_{gel}	−0.975**	−0.933**	0.979**	−0.971**	−0.903*						
T_o	−0.994**	−0.994**	0.991**	−0.990**	−0.866*	0.956**					
T_p	−0.994**	−0.994**	0.991**	−0.990**	−0.866*	0.958**	1.000**				
R	0.932**	0.906*	−0.931*	0.916*	0.735	−0.949**	−0.946**	−0.948**			
PV	−0.972**	−0.945**	0.973**	−0.962**	−0.828*	0.983**	0.974**	0.975**	−0.989**		
TV	−0.972**	−0.946**	0.971**	−0.961**	−0.821	0.980**	0.975**	0.976**	−0.990**	1.000**	
FV	−0.980**	−0.981**	0.976**	−0.972**	−0.815	0.946**	0.995**	0.995**	−0.967**	0.980**	0.982**

WAC – water absorption capacity; WSI – water solubility index; FC – foaming capacity; T_o – onset gelatinization temperature; T_p – peak gelatinization temperature; ΔH_{gel} – enthalpy of gelatinization; R – gelatinization range; PV – peak viscosity; TV – trough viscosity.
* $P < 0.05$.
** $P < 0.01$.

Table 6
Thermal properties of flours from different field pea and pigeon pea cultivars[A,B]

Cultivars	T_o (°C)	T_p (°C)	T_c (°C)	ΔH_{gel} (J/g)	PHI	R
Field pea						
LFP-48	59.5 ± 0.4^a	65.5 ± 0.5^a	74.8 ± 0.7^b	4.05 ± 0.1^a	0.68 ± 0.05^a	15.3 ± 0.2^c
PG-3	59.4 ± 0.5^a	65.5 ± 0.6^a	73.3 ± 0.8^a	4.13 ± 0.2^{ab}	0.68 ± 0.08^a	13.9 ± 0.5^b
Mean	59.45	65.5	74.1	4.09	0.68	14.6
Pigeon pea						
AL-15	75.3 ± 0.5^b	81.8 ± 0.2^b	86.8 ± 0.6^c	4.93 ± 0.3^c	0.76 ± 0.05^c	11.5 ± 0.5^a
AL-201	75.8 ± 0.6^b	82.2 ± 0.3^b	87.5 ± 0.7^d	4.66 ± 0.2^b	0.73 ± 0.06^b	11.7 ± 0.4^a
Mean	75.6	82.0	87.2	4.79	0.75	11.6

T_o – onset temperature; T_p – peak temperature; T_c – conclusion temperature; ΔH_{gel} – enthalpy of gelatinization (dwb); PHI – peak height index, $\Delta H_{gel}/(T_p - T_o)$; R – gelatinization range ($T_c - T_o$).
[A] Means of triplicate analyses (±standard deviation).
[B] Means followed by same letter within a column do not differ significantly ($P < 0.05$).

Table 7
Pasting properties of flours from different field pea and pigeon pea cultivars[A,B]

Cultivars	Pasting temperature (°C)	Peak viscosity (cP)	Trough viscosity (cP)	Breakdown viscosity (cP)	Final viscosity (cP)	Setback viscosity (cP)
Field pea						
LFP-48	73.9 ± 0.20[a]	1314 ± 13[a]	1122 ± 22[a]	192 ± 9[a]	1832 ± 34[a]	710 ± 11[c]
PG-3	75.4 ± 0.11[ab]	1472 ± 17[b]	1276 ± 18[b]	196 ± 11[a]	1891 ± 28[a]	615 ± 15[ab]
Mean	74.7	1393	1199	194	1862	663
Pigeon pea						
AL-15	83.4 ± 0.14[b]	2042 ± 21[d]	1809 ± 26[d]	233 ± 19[b]	2324 ± 38[b]	515 ± 10[a]
AL-201	83.5 ± 0.21[b]	1946 ± 29[c]	1732 ± 19[c]	214 ± 16[b]	2370 ± 33[b]	638 ± 12[b]
Mean	83.45	1994	1771	224	2347	577

[A] Mean of triplicate analyses (±standard deviation).
[B] Means followed by same letter within a column do not differ significantly ($P < 0.05$).

correlation with T_o ($r = 0.956$) and T_p ($r = 0.958$) and negative with R ($r = -0.949$), as revealed both by Pearson correlation and PCA loading plot (Table 5, Fig. 3).

3.5. Pasting properties

The results of the rapid visco analyzer (RVA) of legume flours are summarized in Table 7. Significant differences were observed in pasting characteristics of different legume flours. Pasting curves of flours from different field pea and pigeon pea are shown in Fig. 7. Among the different legume flours, pasting temperature (PT) for FPF was observed to be lower (73.9–75.4 °C) than that for PPF (83.4–83.5 °C). The high PT of PPF in comparison to FPF indicates the presence of starch that is highly resistant to swelling. PT in the range 73.1–75.2 °C has been previously reported for flours from different chickpea cultivars (Kaur & Singh, 2005). When a sufficient number of granules become swollen, a rapid increase in viscosity occurs, known as peak viscosity (PV). PV of PPF was higher (1946–2042 cP) than that of FPF (1314–1472 cP). Interrelationships among the DSC and RVA parameters were observed. A positive correlation of PV and TV with T_o, T_p and ΔH_{gel} and negative with R has been observed through Pearson correlation results ($P < 0.01$, Table 5). Also, the PT and R values run in opposite directions on the PCA loading plot, suggesting a negative correlation between them (Fig. 3). Breakdown viscosity (BV) value of FPF was lower (192–196 cP), indicating its paste stability, as compared to PPF (214–233 cP). As the mixture was subsequently cooled, viscosity increased. Miles, Morris, Orford, and Ring (1985) reported that increase in final viscosity (FV) might be due to the aggregation of the amylose molecules. Setback viscosity (SV) is a measure of syneresis of starch upon cooling of cooked starch pastes (Singh, Kaur, Sandhu, & Guraya, 2004). FV and SV of different legume flours showed significant variation, ranging from 1832 to 2370 cP and 515 to 710 cP, respectively. FV was positively correlated with PT ($r = 0.998$), PV ($r = 0.980$), TV ($r = 0.982$) and negatively with R ($r = -0.967$). FPF showed lower FV (1862 cP) and higher SV (663 cP), indicating a higher tendency to retrograde than PPF.

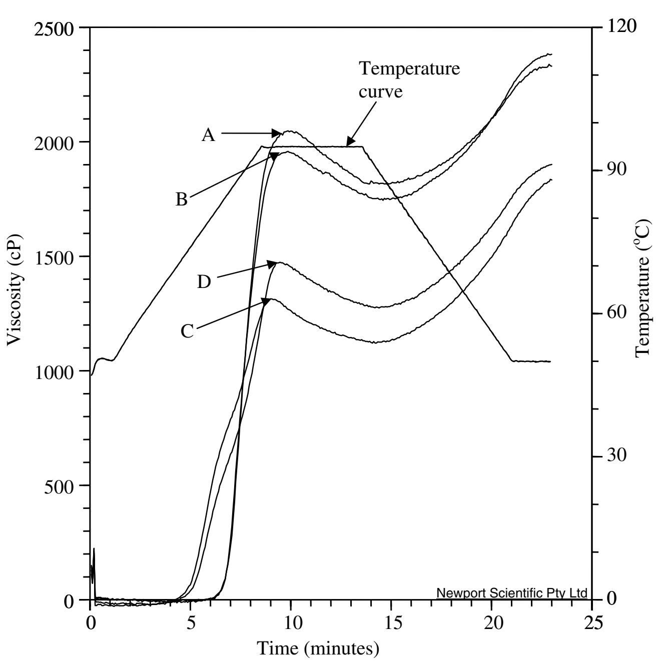

Fig. 7. RVA profiles of flours from different pigeon pea (A) AL-15, (B) AL-201 and field pea, (C) LFP-48, (D) PG-3 cultivars.

4. Conclusion

The physicochemical, functional, thermal and pasting properties of flours from field pea and pigeon pea were evaluated. FPF differed significantly from PPF with respect to composition, WAI, WSI, water and oil absorption, gelation and foaming properties. The foams produced by all legume flours were relatively thick, with low foam volume but good foam stabilities (>80%) after 120 min of storage. The variation in functional properties among legume flours can be ascribed to the varying ratios of protein to starch and other constituents. Significant differences were observed in thermal and pasting properties among various legume flours. The physicochemical and functional properties of flours showed significant dependence on thermal and pasting properties, as revealed by both Pearson correlation and PCA.

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