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Colour, composition, digestibility, functionality and pasting properties of diverse kidney beans (*Phaseolus vulgaris*) flours

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ABSTRACT

The present work evaluated nine diverse kidney bean accessions for colour, composition, digestibility, protein profile, starch crystallinity, techno-functional properties, pasting properties and microstructure with the objective of identifying key attributes affecting their digestibility and functionality. The accessions exhibited dry matter digestibility, resistant starch (RS) content, water absorption capacity, fat absorption capacity, emulsifying activity index (EAI), foaming capacity (FC) and foam stability (FS) of 14.6–47.2%, 32.0–50.5%, 1.7–2.7 g/g, 1.4–1.7 g/g, 50.1–70.1 m^2/g, 70.8–98.3% and 82.4–91.3%, respectively. Starch-lipid complexes (SLC), proteins and non-starch carbohydrates contributed to lower starch and dry matter-digestibility. Principal component analysis revealed positive relation of emulsification, foaming and water absorption capacity with proteins, starch, RS and ash-content while negative with crystallinity and amount of lipids, non-starch carbohydrates and digestible starch. Hydration ability of proteins promoted foaming whereas flour with lower *vicilins* level was less surface active and exhibited the lowest EAI, FC and FS. Pasting temperature related positively with SLC, while average starch granule size was in strong positive relationship with RS content, peak viscosity and breakdown viscosity. The results could be useful for enhanced utilization of kidney beans in different foods.

1. Introduction

Pulses are inexpensive source of proteins, complex carbohydrates, vitamins, minerals and many health-benefitting phytochemicals (Shevkani et al., 2022). The inclusion of pulses in diets is generally recommended for healthy aging, obesity prevention, diabetes management, relieving constipation and reducing the risk of chronic diseases including coronary artery diseases and some cancers (Brennan et al., 2016; Shevkani and Chourasia, 2021). Pulses also are considered important to 1) meet increasing demands of dietary proteins for growing population of the world, 2) overcome challenges of protein-energy malnutrition, 3) improving soil-fertility and 4) reducing the emission of greenhouse gases (Henchion et al., 2017).

Pulses are used as an ingredient in the preparation of traditional and novel foods (*e.g.* soups, spreads, snacks, breakfast foods, pasta, etc.) to improve their nutritive value and technological properties (Sozer et al., 2017; Escobedo and Mojica, 2021). Also, they can find applications in specialized products (*e.g.* low/reduced-calorie/dietetic foods and gluten-free products) because of the absence of allergic gluten proteins and presence of fibre and resistant starch (RS) in considerable amounts (Singh, 2017). However, the successful application of pulses in such products will depend on their overall digestibility and techno-functional properties (water absorption capacity, fat absorption capacity, emulsifying properties, foaming properties and viscosity development) that depend in turn on their composition and the characteristics of their major components (Sreerama et al., 2012).

Kidney bean (*Phaseolus vulgaris*; KB) is one of the most popular pulses. It is an important source of dietary proteins and other nutrients in many countries of the world (Mishra et al., 2017). Different cultivars of KB have been investigated for physicochemical, hydration, cooking, textural and nutritional properties (Kaur et al., 2009; Sharma et al., 2015). Few studies on functional properties of KB cultivars have also been conducted (Siddiq et al., 2010; Gupta et al., 2018; Guldiken et al., 2021). However, the functionality of diverse beans and their accessions is not fully explored (Singh, 2017), Also, the intake of pulses has not incremented much during the last decades (Escobedo and Mojica, 2021). Therefore, studies on digestibility and techno-functional characterization of diverse KB accessions is important for 1) enhancing utilization of this pulse in different food systems through identification of accessions with specific functionality, 2) highlighting the key attributes affecting

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digestibility and functionality and 3) elucidating the mechanisms behind these associations. In light of the above, the present study was conducted to analyse colour, composition, protein profiling, starch crystallinity, microstructure, digestibility, functional and pasting properties of flours from diverse KB accessions.

2. Materials and methods

2.1. Materials

Nine KB (EC-590329, EC-572723, EC-590326, Pi-244719, Pi-312296, Pi-249554, PLB-10-1, PLB-14-1 and IC-382213) accessions grown at Regional Station, National Bureau of Plant Genetic Resources, Shimla were used for this study. These accessions varied for grain colour from light yellowish-white and yellowish-grey to dark red. The grains were cleaned and ground to pass all through a sieve with 250 μm aperture to produce flours, which were stored at 4 °C in air tight polyethylene terephthalate jars till analysed.

2.2. Colour and composition

Colour parameters of different accessions (grains) and their flours were measured using Ultra Scan VIS Hunter Lab (Hunter Associates Laboratory Inc., U.S.A.). Colour parameters were L^* (darkness/lightness), a^* (greenness/redness) and b^* (blueness/yellowness). Ash, fat and protein (N × 6.25) content were estimated on dry basis following standard AOAC (1990) methods. Total carbohydrate content was calculated as difference. Total starch content was estimated using an assay kit (K-RSTAR, Megazyme, Ireland), while non-starch carbohydrates (NSC) content was determined as the difference between total carbohydrates and total starch content.

2.3. Sodium dodecyl sulphate polyacrylamide gel electrophoresis

Proteins were extracted following the method of Kaur et al. (2013) with slight modifications. Briefly, flours (200 mg) were weighed in micro-centrifuge tubes. Extraction buffer (1.0 ml) containing 50 mM Tris (pH 7.8), Triton X-100 (0.5%) and Dithiothreitol (2 mM) was mixed with flours in the micro-centrifuge tubes. After an incubation of 2 h at 4 °C with intermittent vortexing, the tubes were centrifuged at 10,000×*g* for 30 min (4 °C). The supernatants were boiled for 5 min and then centrifuged at 13,600×*g* for 10 min at room temperature. Total proteins in the supernatants were estimated using Bradford's kit (Genei, Banglore, India). Sodium dodecyl sulphate polyacrylamide gel electrophoresis (SDS-PAGE) was performed according to the method of Laemmli (1970) at a constant current of 35 mA employing resolving and stacking gels of 12% and 5%, respectively. The resolved gels were stained overnight with 0.25% Coomassie Brilliant Blue R-250 and de-stained with 20% methanol and 10% acetic acid solution.

2.4. X-ray diffraction

X-ray diffractograms of flours equilibrated at 100% relative humidity (at 25 °C for 72 h) were recorded using an X-ray diffractometer (7000, Shimadzu, Japan), operating at 45 kV and 40 mA. Flours were analysed at room temperature over a 2θ range from 4 to 30° with step size of 0.02° (Shevkani et al., 2014). Relative crystallinity was computed following the method of Roa et al. (2014) using Origin software (2022, OriginLab Corporation, Northampton, USA).

2.5. Scanning electron microscopy

Microstructure of flours was studied using a scanning electron microscope (Merlin, Carl Zeiss, Germany). Flours were adhered to stubs using a double-sided carbon tape and viewed at 5 kV and 1400X after being coated with gold using a sputter coater (Quorum Technologies, Lewes, UK).

2.6. Starch and dry matter-digestibility

Resistant starch (RS) and digestible starch (DS) content were determined using an assay kit (K-RSTAR, Megazyme, Ireland) based on AOAC-2002.02, AACC 32–40.01 and Codex Type-II methods. *In-vitro* dry matter digestibility was determined employing the method described by Odjo et al. (2018). Briefly, 500 mg flour was dispersed with 20 ml phosphate buffer (0.1 M, pH 6.0) and 8 ml hydrochloric acid solution (8 mL, 0.2 M). The pH of the dispersion was adjusted to 2.0 with 1 M hydrochloric acid or sodium hydroxide solution and 1 ml each of freshly prepared pepsin (25 g/l; P7000, Sigma-Aldrich) and chloramphenicol-solution (0.5 g/100 ml ethanol; Sigma-Aldrich) were added to the dispersions. The dispersions were then incubated at 39 °C for 2 h with gently shaking in a water bath shaker (Remi, India). Following pepsin hydrolysis, 8 ml phosphate buffer solution (0.2 M, pH 6.8) and 4 ml of sodium hydroxide solution (0.6 M) were added, pH was adjusted to 6.8 (with 1 M hydrochloric acid or sodium hydroxide solution) and 2 ml freshly prepared pancreatin solution (100 g/l; P1750, Sigma-Aldrich) was added. The mixture was then incubated at 39 °C for 4 h with gentle shaking in water bath shaker. Following pancreatin hydrolysis, centrifugation was done at 3220×*g* for 10 min to collect residue. The residue was dried at 60 °C for 72 h. The weight of dried residue was subtracted from the dry weight of flour to determine the weight of digestible matter. Dry matter digestibility was calculated as the percentage of digestible matter in flours.

2.7. Functional properties

Water and fat absorption capacity (WAC and FAC, respectively), emulsifying activity index (EAI), foaming capacity (FC) and foam stability (FS) were determined following the methods elaborated elsewhere (Shevkani et al., 2015a).

2.8. Pasting properties

Pasting properties were determined using a Rapid Visco-Analyzer (Newport Scientific Pvt. Ltd., Warriewood, NSW, Australia). Viscosity profiles of suspensions (flour/water, 3.0:25.0 g) were recorded during heating (50–95 °C) after an equilibration time of 1 min at 50 °C, holding (95 °C) and cooling (95-50 °C) as described earlier (Singh et al., 2014). Parameters recorded were pasting temperature (PT), peak viscosity (PV), breakdown viscosity (BV), final viscosity (FV) and setback viscosity (SV).

2.9. Statistical analysis

The data reported are mean of triplicate observations except percent crystallinity that was measured in duplicate. The data was subjected to analysis of variance (ANOVA) employing Duncan's test ($P < 0.05$) and principal component analysis (PCA) using Minitab Statistical Software (State College, PA, USA).

3. Results and discussion

3.1. Colour properties

L^* a^* and b^* values of KB accessions varied in the range from 37.1 to 76.5, −0.2 to 11.4 and −0.7 to 12.4, respectively. Pi-244719 showed the lowest L^* value (37.1) with a^* and b^* value close to zero (−0.2 and −0.7, respectively) implying the darkest colour of grains. The grains of PLB-14-1 were reddish in colour with L^*, a^* and b^* values of 43.4, 11.4 and 9.7, respectively, while PLB-10-1 were dark reddish-brown in appearance with colour values of 38.8, 6.5 and 1.8, respectively (Table 1). EC-590329 and EC-590326, in comparison, were yellowish-

Table 1
Colour properties of grains and flours of diverse kidney bean accessions.

Accession	Grains			Flours		
	L^*	a^*	b^*	L^*	a^*	b^*
EC-590329	76.5 ± 0.1^{j}	0.8 ± 0.0^{b}	11.7 ± 0.7^{g}	91.4 ± 0.1^{f}	0.1 ± 0.0^{c}	8.3 ± 0.0^{e}
EC-572723	37.7 ± 0.4^{a}	4.3 ± 0.5^{e}	1.2 ± 0.3^{b}	83.5 ± 0.1^{a}	1.9 ± 0.0^{g}	5.6 ± 0.0^{b}
EC-590326	72.4 ± 0.2^{i}	1.1 ± 0.1^{b}	12.4 ± 0.0^{g}	91.2 ± 0.1^{f}	-0.3 ± 0.0^{b}	7.8 ± 0.0^{d}
Pi-244719	37.1 ± 0.0^{a}	-0.2 ± 0.0^{a}	-0.7 ± 0.0^{a}	85.5 ± 0.2^{c}	0.1 ± 0.0^{c}	5.1 ± 0.1^{a}
Pi-312296	45.6 ± 0.7^{e}	5.0 ± 0.1^{f}	8.4 ± 0.5^{de}	86.4 ± 0.0^{d}	0.8 ± 0.0^{d}	6.9 ± 0.0^{c}
Pi-249554	56.4 ± 0.8^{f}	2.9 ± 0.1^{c}	8.8 ± 0.0^{e}	86.3 ± 0.6^{d}	0.9 ± 0.0^{d}	7.7 ± 0.0^{d}
PLB-10-1	38.8 ± 0.5^{b}	6.5 ± 0.4^{i}	1.8 ± 0.4^{b}	86.5 ± 0.3^{d}	1.1 ± 0.0^{e}	7.2 ± 0.1^{c}
PLB-14-1	43.4 ± 0.3^{c}	11.4 ± 0.7^{k}	9.7 ± 0.7^{f}	85.5 ± 0.1^{c}	1.9 ± 0.0^{g}	9.9 ± 0.2^{f}
IC-382213	44.3 ± 0.1^{d}	7.6 ± 0.4^{j}	8.9 ± 0.4^{e}	84.7 ± 0.2^{b}	1.7 ± 0.0^{f}	7.7 ± 0.0^{d}

Values shown are mean ± SD. Values with same superscript in a column did not differ significantly ($P < 0.05$).

white to pale yellow in colour with higher L^*, b^* (72.4–76.5 and 11.7–12.2, respectively) and lower a^* values (0.8–1.1). Pulse grain colour is mainly a property of type and amount of pigments (*e.g.* tannins and anthocyanins) present in seedcoat and it depends primarily on plant genetics (Díaz et al., 2010). Wide variation in L^*, a^* and b^* values (19.6 to 80.5, −0.1 to 14.3 and −1.0 to 20.3, respectively) has been reported earlier for grains of different bean cultivars/lines (Mojica et al., 2015; Sharma et al., 2015).

Grinding of grains to flours significantly changed colour properties (Table 1). In general, flours were lighter and less reddish than respective grains as they exhibited higher L^* (83.5–91.4) and lower a^* values (−0.3 to 1.9). The exposure of cotyledon contents after grinding of grains may be the possible reason of differences in colour parameters amongst flour and grains. However, b^* value of flour differed from respective grains depending on accession. EC-572723, Pi-244719 and PLB-10-1 flours showed higher yellowness (5.6, 5.1 and 7.2, respectively) than their respective grains (1.2, −0.7 and 1.8, respectively), whereas that from other accessions showed lower b^* values (except PLB-14-1 flour, which had b^* value similar to grains). In general, EC-590329 and EC-590326 flours showed the highest lightness ($L^* = 91.4$ and 91.2, respectively), which indicated that they may be preferred over other accessions for enrichment of foods owing to lighter colour. Meanwhile, PLB-14–1 may find applications in foods where yellow colour is desirable (*e.g.* pasta products) because of the highest b^* value (9.9).

3.2. Composition

Starch was the most abundant component in KB accessions (34.0–56.0%) followed by proteins (21.7–27.3%), NSC (11.4–33.3%), ash (3.7–4.8%) and lipids (1.5–3.2%). PLB-14-1 showed the highest protein content, while EC-590326, Pi-244719, Pi-312296 and EC-590329 had higher starch and lower NSC content than other accessions (Table 2). The difference in the genetic makeup of accessions was possibly attributable for variations in chemical composition. However, the composition was in agreement of previous reports for different pulses. Du et al. (2014) reported starch, protein, lipids and ash content of 42.86–54.58%, 22.37–28.05%, 1.14–6.63% and 2.91–4.30%, respectively for different pulses. Similarly, Ai et al. (2017) reported 34.4–44.5% starch and 19.1–26.6% proteins in flours from different bean varieties. PCA revealed associations between composition and colour properties. NSC content of accessions related positively with redness as a^* and NSC were closely located on the PCA loading plot (Fig. 1), whereas starch content contributed to lightness as it related positively with L^* value of flours. Increase in L^* values from 92.0 to 97.4 has been reported previously for starches after successive purification (Singh et al., 2014).

3.3. Protein profile

Kidney bean proteins were characterized by the presence of 23–25 polypeptides of molecular weight (MW) ranging from ≈96 to ≈15 kDa with major subunits of ≈96, ≈78, ≈76, ≈55, 47-40, ≈32, ≈26, and ≈21 kDa (Fig. 2). Polypeptides of 40-32 kDa and 17-15 kDa were also present as minor proteins. The results of SDS-PAGE were in agreement of a previous report on KB (Parmar et al., 2017) in which polypeptides of 15–91 kDa were reported for harder-to-cook and easy-to-cook grains. The most accumulated polypeptides of 47-40 kDa along with that of 57-54 kDa might ascribe to *vicilins* (7S-globulin) which were reported as trimeric proteins comprising identical/non-identical subunits of 50–70 kDa held together by non-covalent hydrophobic interactions (Aluko et al., 1997; Vatansever et al., 2020). This was in corroboration of the findings of Rui et al. (2011) and Shevkani et al. (2015b) for KB proteins. The polypeptides of ≈21 kDa and ≈37–38 kDa might have come from legumins (11-12S proteins) which were hexameric proteins with monomeric units (60–65 kDa) made of disulphide-bonded acidic and basic subunits of ≈40 kDa and ≈20 kDa, respectively (Shevkani et al., 2019). The polypeptides of 32-27 kDa might have come from lectins/phytohemagglutinins and trypsin inhibitor (Makri and Doxastakis, 2006; Macedo et al., 2007) which occurred in KB in significant levels and possessed several bioactive properties (Singh, 2017). The electrophoretic analysis also highlighted differences amongst KB accessions for polypeptide composition. IC-382213 contained *vicilins* in relatively lower levels as evidenced from lesser accumulation (lesser intensity of bands) of the polypeptides of 57-54 kDa and 47-40 kDa (Fig. 2). Pi-249554 showed lower accumulation of medium MW (76-55 kDa) polypeptide subunits. Pi-312296 and Pi-249554 showed lesser accumulation of ≈32 kDa subunit than other accessions, while EC-572723, EC-590326 and PLB-10-1 were characterized by lesser accumulation of ≈28 kDa subunits. However, additional bands between 66 kDa and 70 kDa were observed for EC-590329 only.

Table 2
Composition of diverse kidney bean accessions.

Accession	Protein content (%)	Lipid content (%)	Ash content (%)	Total carbohydrates (%)	Starch content (%)	Non-starch carbohydrates (%)
EC-590329	23.0 ± 0.3^{b}	2.5 ± 0.0^{e}	4.7 ± 0.3^{f}	69.8 ± 0.5^{e}	54.9 ± 0.7^{d}	14.9 ± 0.2^{b}
EC-572723	25.6 ± 0.1^{e}	2.2 ± 0.1^{d}	4.0 ± 0.1^{e}	68.3 ± 0.1^{cd}	40.7 ± 1.1^{b}	27.5 ± 0.3^{d}
EC-590326	25.5 ± 0.4^{e}	2.5 ± 0.0^{e}	3.9 ± 0.2^{e}	68.2 ± 0.1^{cd}	56.0 ± 0.5^{d}	12.2 ± 0.6^{a}
Pi-244719	26.8 ± 0.6^{f}	1.6 ± 0.1^{b}	4.3 ± 1.0^{ef}	67.4 ± 0.2^{b}	56.0 ± 1.4^{d}	11.4 ± 1.0^{a}
Pi-312296	26.4 ± 0.0^{f}	1.6 ± 0.1^{b}	4.5 ± 0.6^{f}	67.5 ± 0.4^{b}	55.7 ± 0.1^{d}	11.8 ± 0.1^{a}
Pi-249554	26.9 ± 0.3^{f}	1.9 ± 0.1^{c}	4.8 ± 0.6^{f}	66.4 ± 0.2^{a}	50.1 ± 0.8^{c}	16.3 ± 0.9^{c}
PLB-10-1	26.0 ± 0.0^{ef}	1.9 ± 0.0^{c}	3.7 ± 0.2^{de}	68.4 ± 0.1^{d}	40.5 ± 0.2^{b}	27.8 ± 0.2^{d}
PLB-14-1	27.3 ± 0.0^{g}	1.5 ± 0.0^{b}	3.9 ± 0.1^{e}	67.3 ± 0.0^{b}	34.0 ± 0.1^{a}	33.3 ± 0.1^{f}
IC-382213	21.7 ± 0.3^{a}	3.2 ± 0.1^{f}	4.2 ± 0.3^{ef}	70.9 ± 1.0^{fg}	40.4 ± 1.7^{b}	30.4 ± 1.6^{e}

Values shown are mean ± SD. Values with same superscript in a column did not differ significantly ($P < 0.05$).

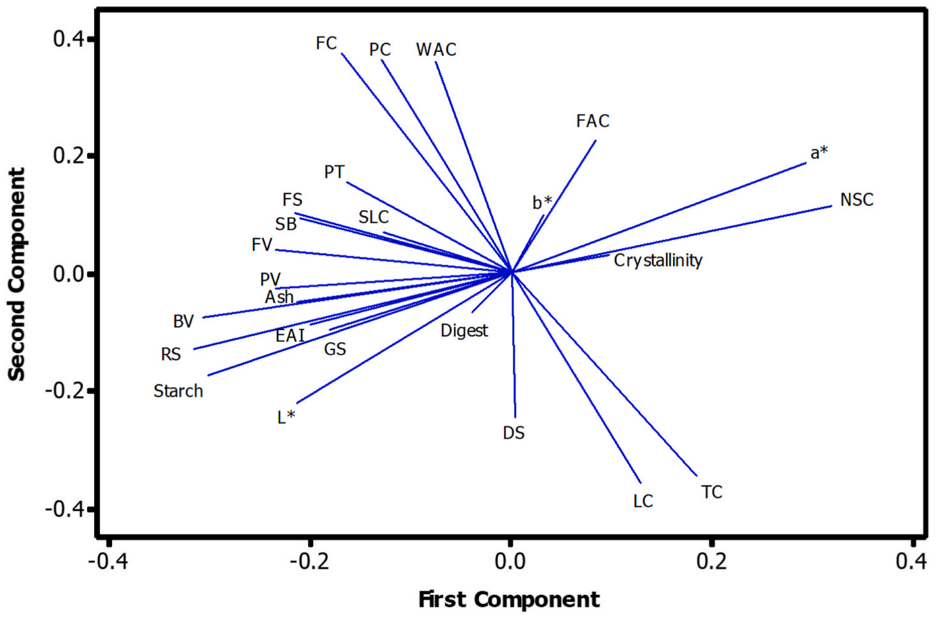

Fig. 1. Principal component analysis loading plot describing the relationship between various properties of diverse kidney bean accessions.AC = ash content; BV = breakdown viscosity; Digest = dry matter digestibility; DS = digestible starch; EAI = emulsifying activity index; FAC = fat absorption capacity; FC = foaming capacity; FS = foam stability; FV = final viscosity; LC = lipids content; NSC = non-starch carbohydrate content; PC = protein content; PV = peak viscosity; RS = resistant starch; SB = setback viscosity; SLC = starch lipid complexes; TC = total carbohydrate content; WAC = water absorption capacity.

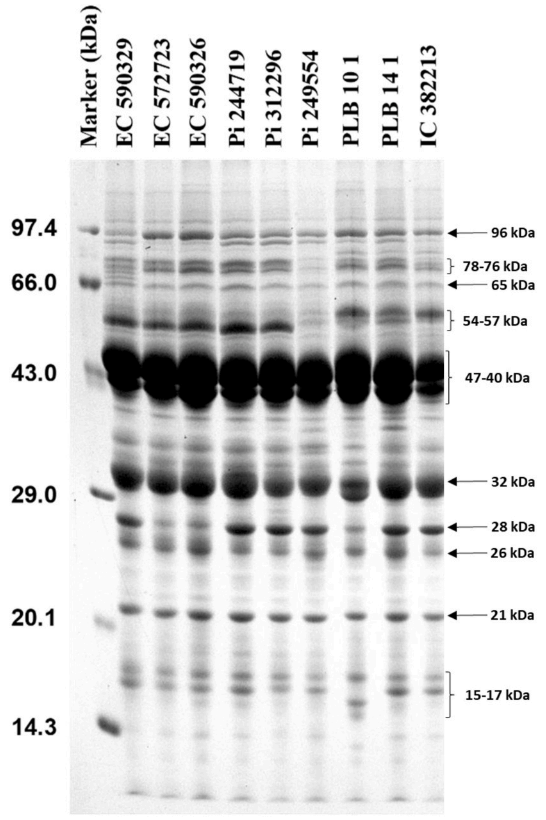

Fig. 2. SDS-PAGE profile of proteins from diverse kidney bean accessions.

3.4. X-ray diffraction pattern and starch crystallinity

The X-ray diffraction analysis of KB accessions highlighted ‘A-type’ pattern with crystalline peaks at ≈15°, ≈17°, ≈18° and ≈23° 2θ with minor peak at ≈9° 2θ (Fig. 3). Similar diffractograms were also reported earlier for starch/flours of different cereals, pseudocereals and beans (Roa et al., 2014; Singh et al., 2014; Wang and Ratnayake, 2014; Shevkani et al., 2014; Waterschoot et al., 2015; Zhang et al., 2019).

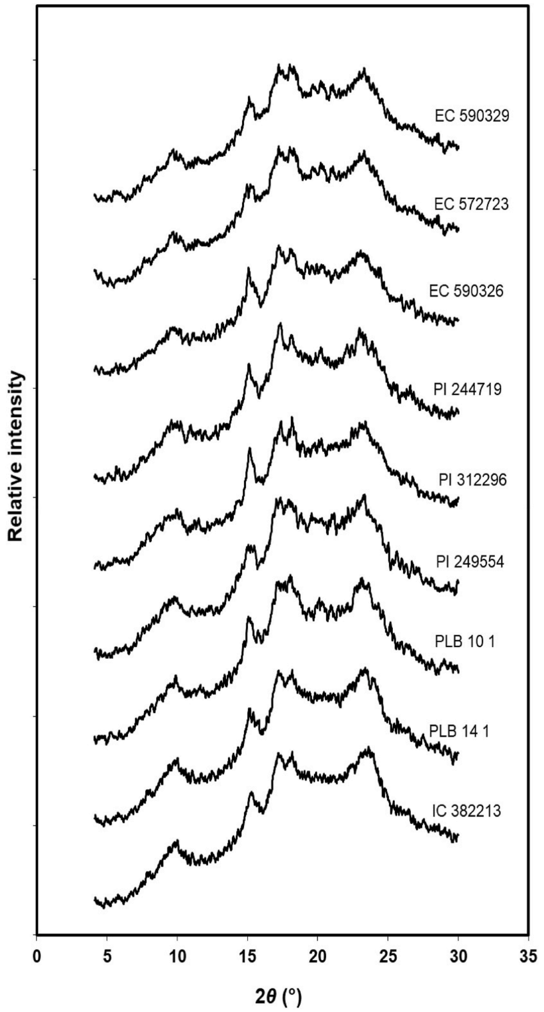

Fig. 3. X-ray diffraction pattern of flours from diverse kidney bean accessions.

Percentage crystallinity for different accessions varied between 13.8% and 20.2% which was lower than that reported for bean starches (18.2–23.8%) by Wang and Ratnayake (2014). The semicrystalline structure of starches was attributed to the hierarchical organization of glucan chains (particularly long chains of amylopectin molecules) within granules (Waterschoot et al., 2015; Wang and Ratnayake, 2014). A positive relationship of long amylopectin chains with starch crystallinity has been reported previously for KB and amaranth accessions/cultivars (Singh et al., 2012; Shevkani et al., 2021a), hence, variation in percentage crystallinity amongst different accessions might be due to the differences in amylopectin structure. The accessions also exhibited weak diffraction at $2\theta = 20^\circ$, indicating the presence of *V*-type starch-lipid complexes (Zobel et al., 1988), the proportion (percentage contribution to the area of crystalline peaks) of which varied between 1.57% and 5.22%.

3.5. Microstructure

The microstructure of KB accessions was characterized by the presence of spherical to oblong/elliptical granular structures (11.4–44.9 μm) along with smaller particles (1.7–3.7 μm) and irregularly-shaped cellular fragments (Fig. 4). The granular structures were possibly starch granules, whereas smaller spheres likely represented protein bodies. The occurrence of starch granules of 7–37 μm together with relatively small spherical protein bodies of 2–4 μm has been reported for different pulses (Acevedo et al., 2017; Ma et al., 2017; Shevkani et al., 2021b). In general, the granules were intact and embedded partly or completely within protein matrix and surrounded with small particles which were spherical to irregular in shape. However, the granules in EC-590329, Pi-244719 and Pi-312296 appeared embedded/coated with protein bodies and protein matrix to a relatively greater extent (Fig. 4). The average size of granules ranged from 22.9 μm (Pi-312296) and 28.2 μm (EC-590329) which was in agreement of Ma et al. (2017) who reported average granule size of 18.6–27.8 μm for different pulses starches.

3.6. Digestibility

Dry matter digestibility, RS and DS content of flours from different KB accessions are presented in Fig. 5. In general, flours showed high RS (32.0–50.5%) and low DS-content (2.1–8.5%). RS content of 13.4–36.0% for beans and 36.7–50.6% for lentils had been reported (Chung et al., 2008; Ai et al., 2017; Lu et al., 2018). RS refers to the portion of starch that resists action of amylolytic enzymes. The consumption of RS has been associated with prevention/management of diabetes and obesity, treatment of kidney diseases and reduced risk of certain cancers (Lockyer and Nugent, 2017). Therefore, high RS content of Pi-244719 (50.5%), EC-590329 (49.6%), EC-590326 (49.4%), Pi-312296 (49.2%) and Pi-249554 (44.5%) highlighted their usefulness in nutraceutical/health-benefitting foods. PCA revealed positive relation of relative proportion of *V*-type starch-lipid complexes with RS while negative with DS content of accessions (Fig. 1). This highlighted the contribution of starch-lipid complexes towards increased resistance of granules to enzymatic hydrolysis. In addition, RS also related positively with total starch and ash content of accessions (Fig. 1). Cappa et al. (2018) also reported positive correlation between RS and total starch content for dry beans.

The accessions also differed widely for dry matter digestibility. In general, flours were only partially digestible (dry matter digestibility = 14.6–47.2%). Amongst different flours, EC-572723 showed the highest dry matter digestibility (47.2%). PLB-10-1 and PLB-14-1, on the other hand, were least digestible (14.6% and 14.8%, respectively). Therefore, these accessions (PLB-10-1 and PLB-14-1) may be considered for calorie-restricted dietetic foods suitable for obese and diabetic individuals. PCA revealed a negative relation of dry matter digestibility and DS content with percent crystallinity, NSC and protein content (Fig. 1). This highlighted that proteins, non-starch polysaccharides and sugars contributed to reduced starch and overall-digestibility of accessions possibly through strengthening flour matrices that made starch granules inaccessible to enzymes (Lu et al., 2018). High resistance of cereals and pulse flours to enzymatic hydrolysis has been attributed to a number of factors including stronger protein and fibre matrices (Srichuwong et al., 2017; Setia et al., 2019; Guldiken et al., 2021). Low porosity of cotyledon cell wall, relating to its composition and characteristics, was demonstrated to affect starch digestibility by limiting diffusion of digestive enzymes (Li et al., 2019). Gradual increase in RS content (from 7.5% to 12.7%) and decrease in rapidly digestible starch content (from 73.1% to 51.5%) with the mixing of maize starch with pectin (0–10%) was also reported by Ma et al. (2019). Similarly, increase in starch digestibility of rice (decrease in RS content from 6.35% to 4.30% with increasing degree of milling from 0% to 12%) was also attributed to the removal of proteins, lipids and fibre during milling (Wang et al., 2021).

3.7. Techno-functional properties

Emulsifying activity index, FC and FS of KB flours varied in the range from 50.1 m^2/g to 70.1 m^2/g, 70.8%–98.3% and 82.4%–91.3%, respectively (Fig. 6). EAI, FC and FS of 39.6–61.7 m^2/g, 9.7–26.7% and 42.9–80%, respectively were reported earlier for ungerminated/germinated lentil and horse gram flours (Ghumman et al., 2016). Amongst different flours, EC-590326 showed the highest EAI (70.1 m^2/g), while the highest FC (98.3%) and FS (91.3%) were observed for Pi-249554 and PLB-10-1, respectively. In general, KB accessions were superior to soybean flours for foaming properties (FC = 18–88% and FS = 16–37%) as reported recently (Shevkani et al., 2021b). This implied the potential of beans in replacing soybean flours/meals in processed products requiring aeration/leavening *e.g.* ice-creams, mousses, muffins, chiffon cakes, whipped toppings, etc. PCA revealed a positive relation of emulsifying and foaming properties with protein, ash and RS-content and negative with crystallinity and lipids, total carbohydrate and NSC-content (Fig. 1). Emulsions and foams are two-phase systems which require surface active agents in order to attain thermodynamic stability. In general, emulsifying and foaming properties of pulse ingredients are attributed to proteins and their ability to reduce surface tension after being adsorbed quickly at the oil-water or air-liquid interface. During emulsification and whipping, proteins migrate to interface where they undergo reorientation and form strong cohesive interfacial membranes. This contribute to emulsification and foaming depending on the ability of the interfacial films to withstand mechanical shocks during storage and handling (Damodaran, 2017). Lipids, on the other hand, being more surface active than proteins, can impair foaming by readily adsorbing at the interface and inhibiting adsorption of proteins (Damodaran, 2017). Therefore, it may be inferred that the presence of greater amount of proteins in beans promoted emulsification and foaming through contributing strength to the interfacial films and behaving as surface active molecules, while NSC and lipids possibly inhibited adsorption of proteins at the interface. Chen et al. (2019) also showed improvement in emulsifying properties of pea proteins with increasing protein concentration from 1.0 to 30 mg/ml, while Toews and Wang (2013) reported higher foaming for pulse protein concentrates obtained after defatting. In addition, the variability in emulsifying and foaming properties may also be attributed to the differences in protein profiling as IC-382213 flour with the least accumulation of *vicilins* showed the lowest EAI, FC and FS (61.4 m^2/g, 84.5% and 88.4%, respectively). This might ascribe to higher surface activity of *vicilins* attributing to the ease of reorientation at the interface as a result of lower MW and greater flexibility in structure (Chen et al., 2019). Kimura et al. (2008) also reported high emulsifying properties for *vicilins* from pulses.

Water absorption capacity of flours of different KB accessions varied in the ranged from 1.7 to 2.7 g/g. The highest WAC was observed for PLB-14-1 (Fig. 6), which suggested its suitability in the processing of viscous foods, such as soups, gravies, custards, sauces, and batters

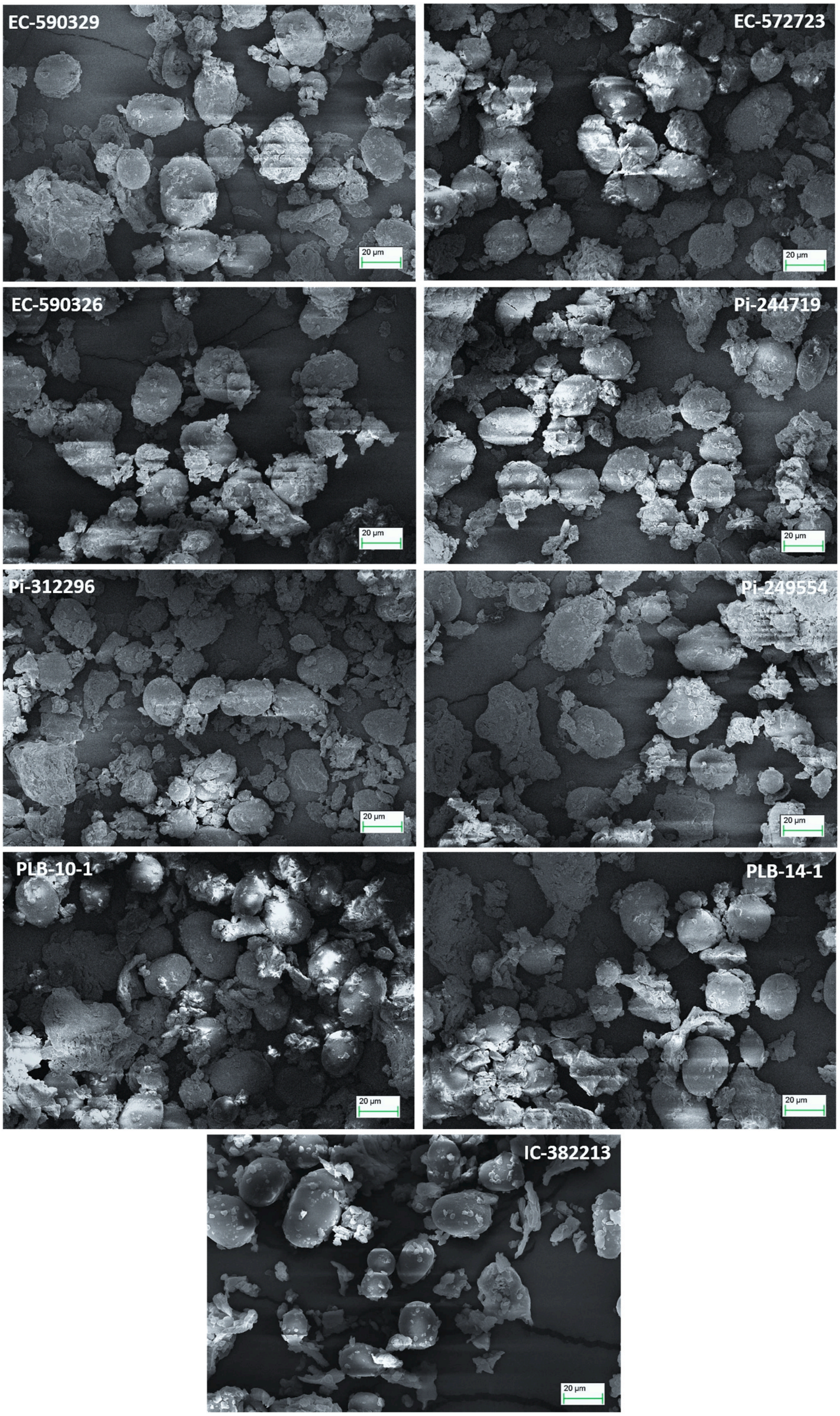

Fig. 4. Scanning electron micrograms of diverse kidney bean accessions.

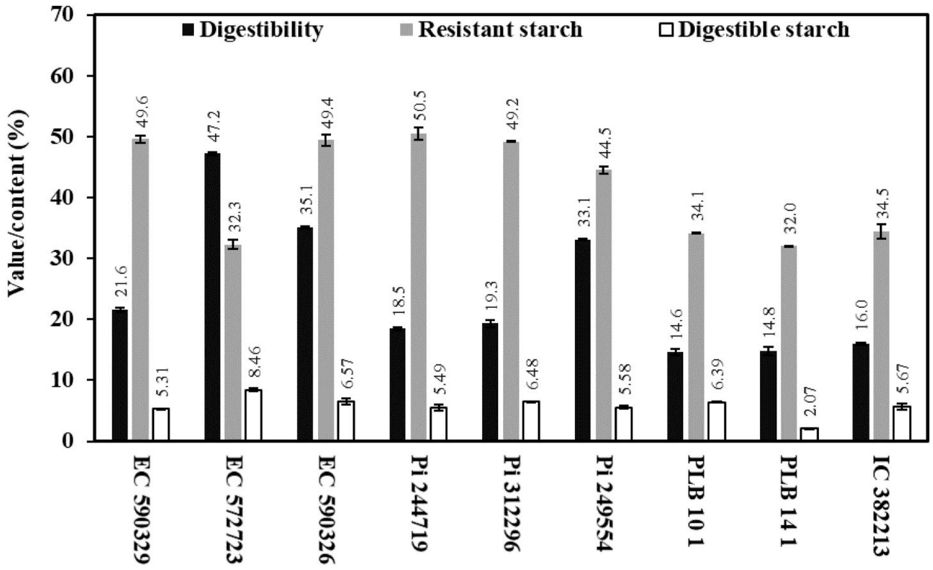

Fig. 5. Dry matter digestibility, resistant starch content and digestible starch content of diverse kidney bean accessions.

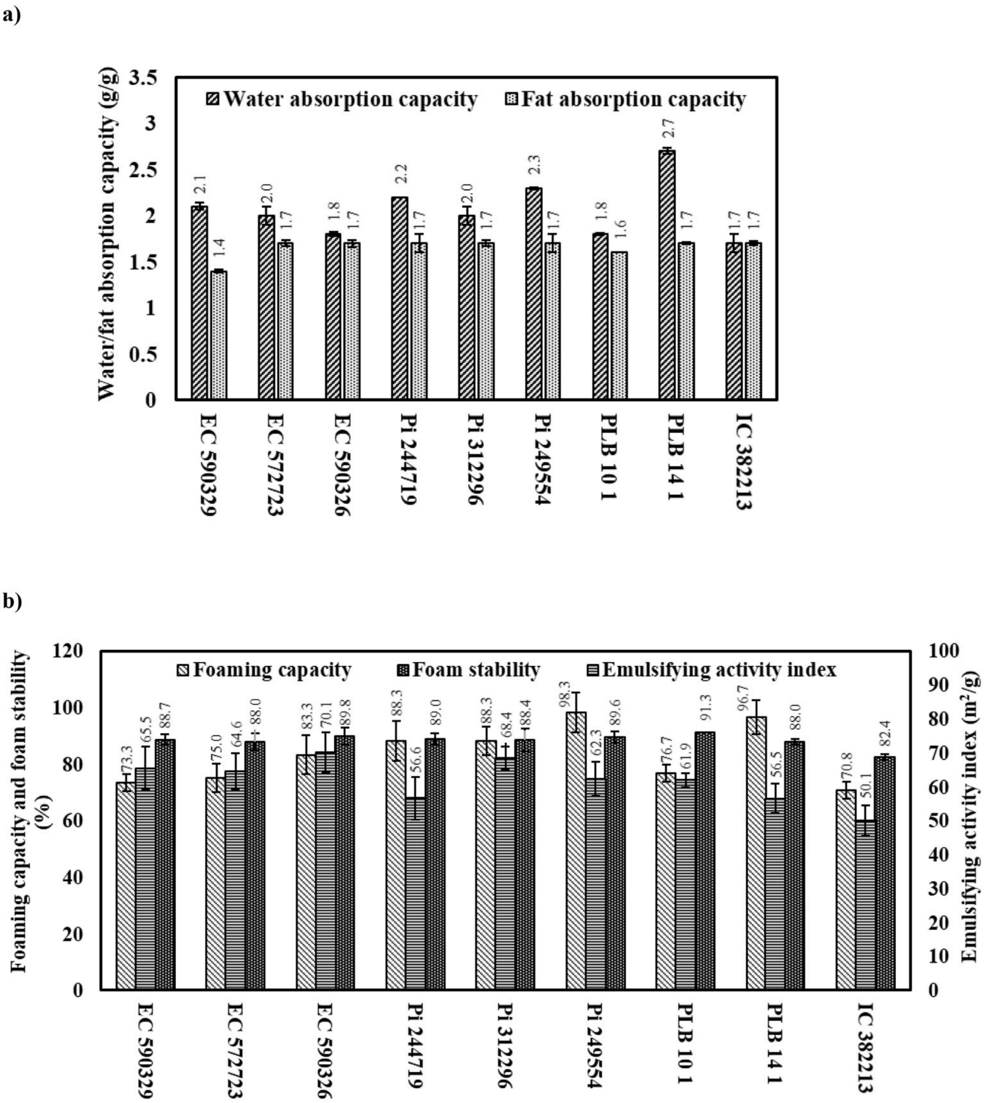

Fig. 6. Techno-functional properties of flours from diverse kidney bean accessions (a: water and fat absorption capacity; b: emulsifying and foaming properties.

(Sreerama et al., 2012). WAC of 1.7–2.7 g/g for dry bean and 1.39–1.75 g/g for navy bean flours had been reported by Cappa et al. (2018) and Guldiken et al. (2021), respectively. FAC is another important techno-functional property of proteins in flours that contributes to mouthfeel, flavour retention, palatability and shelf-life of foods through retardation of fat loss. The FAC varied only marginally between 1.4 g/g and 1.7 g/g amongst different accessions. Nonetheless, FAC of KB accessions compared favourably to that of dry beans (1.0–1.5 g/g), navy beans (0.92–1.01 g/g), pigeon pea (1.10–1.3 ml/g) and soybean (1.11 g/g) flours (Cappa et al., 2018; Guldiken et al., 2021; Tiwari et al., 2008; Shevkani et al., 2021b). PCA revealed positive relation of WAC and FAC with protein content, while negative with lipids, starch and total carbohydrate-content (Fig. 1). As the WAC and FAC of flours are dependent on the ability of components to interact with water and lipid molecules through polar/charged and nonpolar side chains of amino acid, respectively, it appeared that bean proteins provided hydrophobic non-polar and polar/charged groups for interacting with oil or water, whereas the presence of high amounts of lipids and carbohydrates hindered the availability of such functional groups. However, PCA also revealed a positive relation of FAC with NSC content. This suggested possible contribution of NSC (*e.g.* non-starch polysaccharides) towards oil absorption. Higher values of FAC for fibre concentrate (9.89 g/g) than rice flour (1.53 g/g) was reported by Singh et al. (2016). The WAC also related positively with FC and FS of flours on PCA loading plot (Fig. 1). This highlighted that the ability of proteins to get hydrated may promote their foamability. Positive relation of WAC with foaming properties had been reported for flours of split dehulled pulses (Shevkani et al., 2021b).

3.8. *Pasting properties*

Bean flours also differed significantly for pasting properties (Table 3). PT (the minimum temperature at which viscosity began to rise steeply), PV (the point of maximum swelling of starch granules), BV (the susceptibility of swollen granules to disintegrate during heating and shearing), FV (the viscosity of cooled flour paste) and SV (the increase in paste viscosity during cooling as a result of reassociation of gelatinized starch and interaction amongst paste components) varied in the range from 79.2 °C to 84.3 °C, 372 cP to 1015 cP, 30 cP to 67 cP, 1088 cP to 2385 cP and 658 cP to 1428 cP, respectively. Pi-312296, EC-590326 and PLB-14-1 showed higher PT than other accessions, while Pi-249554, Pi-244719 and EC-590329 showed higher PV, FV and SV. IC-382213 and EC-572723 showed lower BV, hence, may be considered suitable in foods requiring viscosity increase after cooking, *e.g.* soups and sauces. Meanwhile, EC-590326 with the lowest SV may be useful in foods (*e.g.* gels/sauces and gravies) in which retrogradation during cooling may deteriorate the product quality. In contrast, Pi-249554 with the highest FV and SV may be useful in enrichment of pastas, where the organized structure formed as a consequence of the reassociation of dissociated starch chains may contribute to the quality of final product (Lucisano et al., 2012).

Table 3
Pasting properties of diverse kidney bean accessions.

Accession	Pasting temperature (°C)	Peak viscosity (cP)	Breakdown viscosity (cP)	Final viscosity (cP)	Setback viscosity (cP)
EC-590329	81.4 ± 0.18^{b}	996 ± 16^{e}	62 ± 0.7^{d}	1954 ± 35^{d}	1019 ± 18^{c}
EC-572723	79.2 ± 1.06^{a}	372 ± 21^{a}	33 ± 3.5^{a}	1156 ± 66^{a}	817 ± 89^{bc}
EC-590326	83.9 ± 0.45^{cd}	677 ± 18^{c}	67 ± 2.8^{e}	1268 ± 29^{b}	658 ± 49^{a}
Pi-244719	82.0 ± 0.39^{b}	1007 ± 12^{e}	54 ± 2.7^{c}	1962 ± 57^{d}	1010 ± 63^{c}
Pi-312296	84.3 ± 0.41^{d}	631 ± 11^{c}	51 ± 4.9^{c}	1336 ± 28^{c}	755 ± 21^{b}
Pi-249554	83.0 ± 0.93^{c}	1015 ± 23^{e}	58 ± 6.8^{c}	2385 ± 23^{e}	1428 ± 8^{d}
PLB-10-1	82.1 ± 0.1^{b}	416 ± 5^{b}	56 ± 3.5^{c}	1088 ± 18^{a}	728 ± 17^{b}
PLB-14-1	83.4 ± 0.2^{cd}	651 ± 15^{c}	41 ± 3.2^{b}	1375 ± 31^{c}	766 ± 25^{b}
IC-382213	81.5 ± 0.2^{b}	734 ± 14^{d}	30 ± 2.1^{a}	1405 ± 25^{c}	701 ± 9^{ab}

Values shown are mean ± SD. Values with same superscript in a column did not differ significantly ($P < 0.05$).

Pasting properties of flours are generally attributed to the content and characteristics of starches. This association was also observed in the present work as pasting parameters (PT, PV, BV, FV and SV) related positively with total starch and RS content of accessions (Fig. 1). However, at the same time, the pasting parameters were also observed to be in positive relation with average granule size and WAC and in negative relation with lipid content of accessions (Fig. 1). This suggested that larger granules in flours contributed to greater viscosity development possibly due to their ability to occupy more volume in pastes through swelling to a greater degree (Kaur et al., 2016), whereas flour lipids delayed gelatinization and restricted granular swelling possibly through impairing water absorption which reduced leaching of components from swollen granules during cooking and limited association of the leached components during cooling of pastes. Carbas et al. (2018) also reported a negative correlation of PV with lipids content of rice-bean blends. PCA also revealed a positive relation of pasting parameters with the proportion of starch-lipids complexes, though the relationship was stronger with PT. Srichuwong et al. (2017) also reported the contribution of starch-lipids towards increased PT of whole grain cereals and pseudo-cereals. In addition, the protective effects of non-starch polysaccharides and sugars on granular swelling, leaching and molecular re-association was also revealed by PCA as pasting parameters related negatively with total carbohydrates and NSC content (Fig. 1). Ma et al. (2019) also reported lower BV and SV for starch-pectin blends than starch alone and attributed the same to the interactions of pectin with amylose. In previous works, lower BV was observed for maize dry milling fractions and amaranth starches with higher proteins and lipid-content (Shevkani et al., 2014, Shevkani et al., 2021a). However, in the present study, BV did not appear to relate with the amount of proteins, but positively with starch content and average granule size while negatively with total carbohydrates and NSC-content, besides starch crystallinity and lipid content. This highlighted the possible contribution of bean NSC in providing the granules greater stability that made them to disintegrate less during pasting.

4. Conclusion

Bean accessions differed for composition, protein profile, digestibility, pasting and techno-functionality. Proteins and NSC were observed as major contributors to lower-starch and dry matter digestibility that contributed to reduced digestibility through strengthening flour matrices. Hydration ability of proteins promoted foaming while NSC and lipids reduced the same likely through inhibiting the adsorption of proteins at the interface. Paste viscosities of bean flours were attributed mainly to starches, while lipids and NSC suppressed granular swelling, restricted leaching during cooking and inhibited reassociation amongst paste components during cooling by making interaction with unravelled starch chains.

CRediT authorship contribution statement

Khetan Shevkani: Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Ravneet Kaur:** Formal analysis, Investigation. **Narpinder Singh:** Formal analysis, Supervision, Writing – review & editing. **Dinhle P. Hlanze:** Formal analysis, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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