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Original article

A Novel starch from bitter vetch (*Vicia ervilia*) seeds: a comparison of its physicochemical, structural, thermal, rheological and pasting properties with conventional starches

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Summary In this study, a novel starch was isolated from bitter vetch and its chemical composition, morphology, particle size of the granules, swelling power and solubility, Fourier transformed infrared (FTIR) spectroscopy, X-ray diffraction (XRD) and rheological, pasting and thermal properties were compared with conventional starches (corn, potato and chickpea). Micrographs exhibited that bitter vetch starch has oval, kidney or irregularly shaped granules with an average size of 28.5 μm. The XRD showed a C-type pattern with 28.14% crystallinity. Bitter vetch starch had the highest amylose content (33.54%), pasting temperature (77.28 °C) and final viscosity (4983 cP) compared with other starch samples. Also, the storage and loss moduli in bitter vetch starch were higher than corn starch, which suggested bitter vetch starch as a promising new source of starch.

Keywords Bitter vetch starch, legume starch, pasting properties, thermal properties.

Introduction

Legumes (*Leguminosae*) family have 16 000 to 19 000 species and about 750 genera (Hoover & Sosulski, 1991; Hoover *et al*., 2010). The *Vicia* genus is a member of the legumes family with about 160 species spread all over the world (540 761 ha). Bitter vetch (*Vicia ervilia*) is grown annually for its high nutritional value and protein content, high yield, nitrogen fixation capacity and resistance to unfavourable situations like alkaline soils, drought and insects (Sadeghi *et al*., 2009; Arabestani *et al*., 2013). Bitter vetch contains approximately 26% protein, 1.6% fat, 61.2% carbohydrate, 5.9% crude fibre and 3.7% ash (Sadeghi *et al*., 2009; Arabestani *et al*., 2013). Previously, legumes were consumed mainly as whole seeds. However, over the past few years, the interest in the utilisation of their components has been grown and legumes are fractionated into their constituents, that is protein and starch and used for food and industrial applications with unique properties to answer the consumer's demand (Singh *et al*., 2004; Jayakody *et al*., 2007; Miao *et al*., 2009).

Starch is the major component of legumes (45–65%) that has a semi-crystalline granular structure, which is consisted of two major compounds, amylose and amylopectin (Hoover & Ratnayake, 2002; Schmidt *et al*., 2022). Starches have been provided from different sources such as cereals, tubers, rhizomes and legumes with numerous characteristics of easy availability, non-toxicity, inexpensively, biodegradability and appropriate physicochemical properties for industrial applications including food, polymer, pharmaceutical and biomedical industries. Starch has a large variety of applications such as thickening, gelling, coating, adhering, encapsulating and developing biodegradable materials (Joshi *et al*., 2013; Reddy *et al*., 2017). The physicochemical and functional properties such as pasting, gelatinisation, solubility, swelling and rheological characteristics of different starch sources are significantly different which are attributed to the amylose to amylopectin ratio, morphology of starch granules and crystalline structures. These characteristics may influence the use of starch in food and non-food applications (Singh *et al*., 2004; Beech *et al*., 2022). Thus, researchers and manufacturers are looking for new starch sources to fulfil the processing requirements. Bitter vetch starch (BVS) may provide desired characteristics for developing food products and can be considered as a non-conventional source of starch. However, there is almost no information about BVS. Therefore, in this study, the physicochemical and functional features of BVS, as a novel source of starch, were investigated and compared with conventional

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starch sources such as corn starch (CS), potato starch (PS) and chickpea starch (CPS).

Materials and methods

Materials

Bitter vetch (*Vicia ervilia* L.) and chickpea (*Cicer arietinum* L.) grains were purchased locally (Shiraz, Iran). CS and PS were gifts from Behinazma company (Shiraz, Iran). Sodium hydrogen sulphate and dimethylsulfoxide (DMSO) were obtained from Sigma–Aldrich (St. Louis, Mo, USA).

Isolation of bitter vetch and chickpea starches

Bitter vetch or chickpea seeds (500 g) were soaked in 2 L of distilled water at 4 °C for 24 h. To prevent microbial growth and assist in the dissociation of protein–starch matrix 0.2%, w/w sodium hydrogen sulphate was added to water. The smoothen grains were wet-milled in a blender (Parskhazar JBG-610P, Iran) and the resulting slurry passed through a sieve with 100-mesh size. The slurry was settled down for 2 h; subsequently, the supernatant was decanted, and the sediment mixed with distilled water. After centrifugation at 3000 *g* for 10 min, the supernatant was removed, and the upper layer of the pellet scraped off. Then, the settled starch granules were washed and centrifuged three times. Lastly, the obtained starch was dehydrated in the electrical oven for 8 h (45 °C).

Chemical properties

Methods of the American Association of Cereal Chemists (AACC, 2000) were used to determine the chemical composition of BVS. Moisture, protein, fat and ash content were analysed (Methods No. 44–19, 46–10, 30–10 and 08–01 respectively). Determination of apparent amylose was carried out based on the iodine colorimetric method reported by Hoover & Ratnayake (2001).

Morphological properties

Scanning Electron Microscope (TESCAN-Vega 3, Brno, Czech Republic) was used to investigate the morphology of starch granules at accelerating voltage of 10 kV. The images were captured at 300 and 1000× magnifications, and the granule size and diameter were determined using ImageJ software (ImageJ 1.52v, NIH, Bephesda, MA, USA).

X-ray diffraction

The crystalline structure of different starches was investigated by an X-ray diffractometer (XRD) (D8–Advance, Bruker, Karlsruhe, Germany) at 40 mA and 40 kV. The diffractograms were recorded by scanning from diffraction angle of 4 to 40° with a step size of 0.02° and scanning speed of 4°/min at 25°C. The crystallinity of the isolated starches was evaluated by the OriginPro v9.8.0.200 software (Thermo Fisher Scientific Inc., MA, USA) based on the method developed by Ratnayake *et al.* (2001).

Fourier transforms infrared (FTIR) spectroscopy

The FTIR spectra of starches were determined with a spectrophotometer (Tensor II, Bruker, Germany) at 22°C. OriginPro v9.8.0.200 (Thermo Fisher Scientific Inc., MA, USA) was used for experimental curve fitting and baseline correction.

Swelling power (g/g) and solubility (%)

The swelling power (SP) and solubility of samples were calculated according to Sukhija *et al.* (2016). 0.4 g of each starch sample was taken into pre-weighted centrifuge tubes and dispersed in 40 mL distilled water, then heated at 65, 75, 85 and 95°C in a water bath for 30 min under continues stirring. The pastes were cooled down to room temperature and centrifuged at 6000 ***g*** for 5 min. The supernatant was placed in pre-weighted Petri dish and dried at 55 °C overnight. Solubility and SP were determined using the following equations:

$$\text{Solubility}\ (\%) = (\text{mass of dried supernatant}/\text{mass of sample}) \times 100$$

$$\text{SP}\ (\text{g}/\text{g}) = \text{mass of sediment paste} \times 100/\text{mass of sample} \times (100 - \%\text{solubility})$$

Thermal properties

Thermal analysis of samples was performed with a differential scanning calorimeter (Mettler Toledo TGA/DSC1, Switzerland) by the method of Hedayati *et al.* (2020a) with some modifications. 3 mg starch (db) and 10 mg distilled water were mixed in an aluminium pan, sealed and kept at 25 °C overnight for equilibration. Scanning was performed at 25–150°C with a heating rate of 10°C min^{-1}.

Pasting properties

A Rapid Visco Analyzer (RVA) (Starch Master2, Perten, Australia) was used to investigate the pasting behaviour of the starch samples, as described by

Hedayati *et al.* (2020b). Briefly, 3.5 g starch (db) was mixed with 25 g distilled water in an RVA canister. The slurry was preheated at 50°C for 60 s; then, it was heated to 95°C, held for 150 s and cooled to 50°C (the heating and cooling rates were 14°C min^{-1}; the paddle rotation speed was 960 rpm for the first 10s and 160 rpm for the rest of the experiment).

Dynamic rheological properties

Starch slurry (6%, w/w, db) was gelatinised in a water bath for 30 min. at 95 °C and then cooled to 25 °C. The viscoelastic properties of the starch pastes were studied at 22 °C with a rheometer (MCR-302, Anton Paar, Austria) with a cone and plate geometry (1° cone angle, 25 mm cone diameter and 0.052 mm gap size). The linear viscoelastic area of starches was determined with a strain sweep (0.01–100%) at constant frequency (1 Hz). Then, frequency sweep was performed from 0 to 62.83 rad s^{-1} (0.01 to 10 Hz) at the step of 1.0% (in linear viscoelastic area). The rheological parameters including storage (G') and loss (G'') moduli were obtained.

Statistical analysis

All tests were performed three times and data reported as means ± standard deviations. Data were examined with Duncan's multiple range test ($P < 0.05$) and one-way analysis of variance (ANOVA) by SPSS software, version 26 (IBM Company, Chicago, IL, USA).

Results and discussion

Chemical properties

The chemical compositions of starch samples are exhibited in Table 1. The moisture, protein, fat and ash contents of the samples ranged from 7.46–11.10%, 0.31–0.56%, 0.21–0.30% and 0.03–0.10%. BVS had the highest protein (0.56%) and the lowest ash (0.03%) and fat (0.21%) contents, among other starches. The low protein (<0.6%), ash and fat content is an indication of starch purity (Tester *et al.*, 2004). The chemical composition of starches may be influenced by biological origin, environment and agronomic conditions and isolation process methods (Reddy *et al.*, 2017).

The amylose content of the samples was significantly difference ($P < 0.05$). CS and PS had 27.12% and 26.21% amylose, respectively. Generally, legume starches had a high amylose content (Hoover & Sosulski, 1991). The amylose content of CPS was 30.64%. Previously, Singh *et al.* (2004) and Miao *et al.* (2009) demonstrated the amylose content of CPS in the range of 28.60–34.30% and 29.73–31.11%. The amylose content of BVS (33.54%) was greater than other types of starch. This was higher than those represented by Du *et al.* (2014) for pinto bean (32.00%), red kidney bean (32.40%) and corn (31.50%); Joshi *et al.* (2013) for lentil (32.52%), potato (14.93%) and corn (24.78%). Also, similar to faba bean (33.55%) (Zhang *et al.*, 2019). However, lower than black bean (45.40%) and navy bean (43.20%) (Du *et al.*, 2014); and field peas (42.90–43.7%) (Ratnayake *et al.*, 2001). The amylose content had significant effects on swelling, pasting properties, gelatinisation and gel hardness. In addition, starches with high amylose content had more rapid retrogradation and slower hydrolysis rates in comparison with low amylose starches (Du *et al.*, 2014; Zhang *et al.*, 2019).

Granule morphology

The micrographs of starch granules obtained by SEM are exhibited in Fig. 1. CS granules were polygonal-shaped, while the PS granules were oval-shaped with varied sizes. CPS showed small spherical-shaped and large oval granules. Similar findings have been reported by Singh *et al.* (2004) and Waterschoot *et al.* (2015) for these starches. BVS showed oval to kidney or irregularly shaped granules with cracks on some granule surfaces. The shape was similar to other legumes like mung bean (Liu & Shen, 2007). The granule size affects the viscosity and gelatinisation characteristics of starch. Moreover, the internal cracks on the starch granules could enhance the penetration of water (Maache-Rezzoug & Allaf, 2005).

Particle size distribution

The particle size distribution patterns of different starch granules are exhibited in Fig. 1. The size and

Table 1 Chemical compositions of bitter vetch, chickpea, corn and potato starches

Sample	Moisture (%)	Protein (%)	Ash (%)	Fat (%)	Amylose (%)
Bitter vetch	8.10 ± 0.22^{c}	0.56 ± 0.05^{a}	0.03 ± 0.01^{b}	0.21 ± 0.07^{a}	33.54 ± 0.08^{a}
Chickpea	7.46 ± 0.31^{d}	0.31 ± 0.03^{cd}	0.05 ± 0.01^{b}	0.22 ± 0.05^{a}	30.64 ± 0.12^{b}
Corn	11.10 ± 0.14^{a}	0.42 ± 0.05^{b}	0.10 ± 0.03^{a}	0.30 ± 0.05^{a}	27.12 ± 0.02^{c}
Potato	10.21 ± 0.15^{b}	0.35 ± 0.02^{bc}	0.06 ± 0.02^{b}	0.25 ± 0.04^{a}	26.21 ± 0.16^{d}

Means ± standard deviations of triplicate analysis. The means with different lowercases in the same column have significant differences ($P < 0.05$).

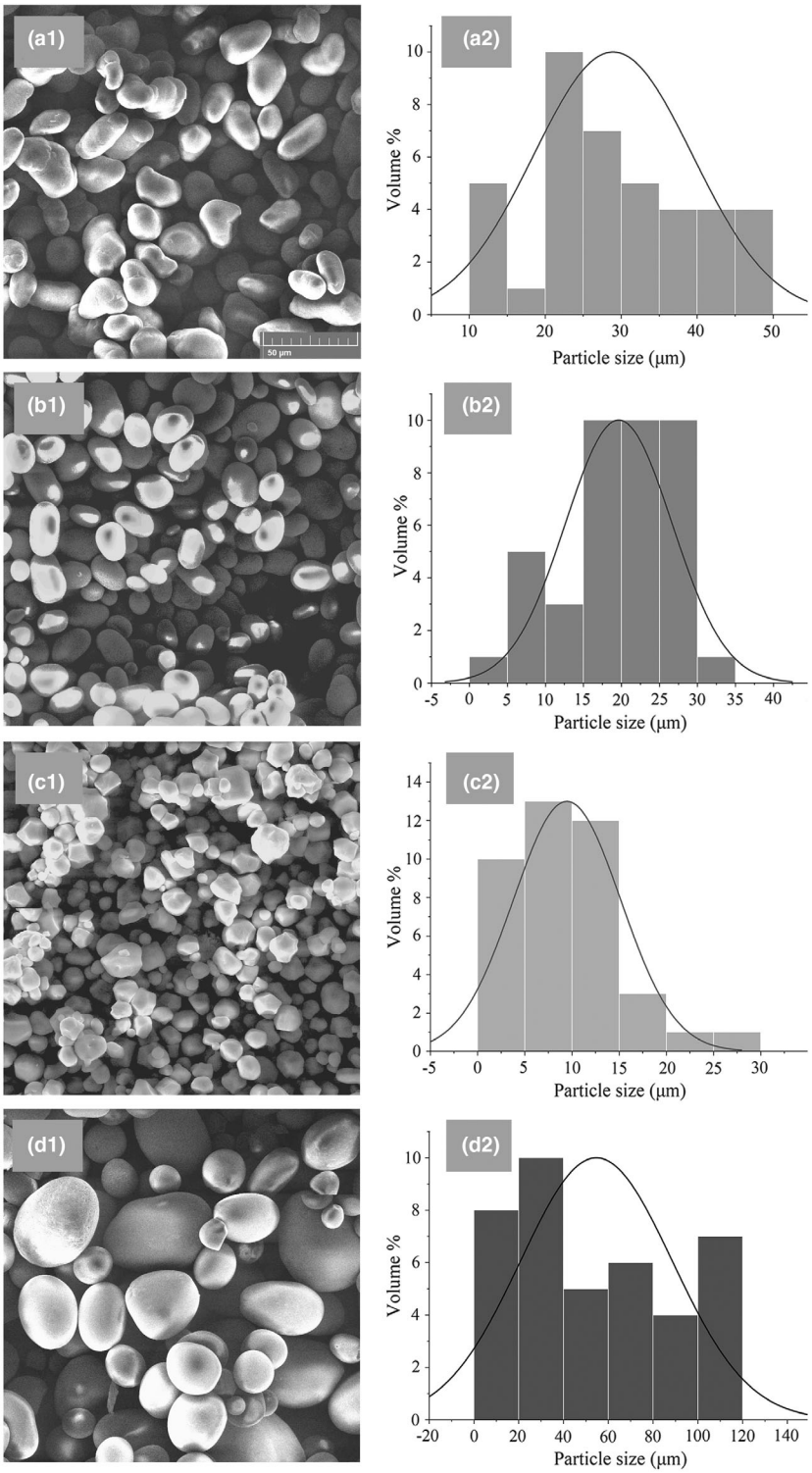

Figure 1 Micrographs and size distribution pattern of starch granules. Scanning electron microscopy (SEM) micrographs of starches at 1000× magnification. Bitter vetch starch (a-1), chickpea starch (b-1), corn starch (c-1), potato starch (d-1). Particle size distribution of bitter vetch starch (a-2), chickpea starch (b-2), corn starch (c-2), potato starch (d-2).

shape of starch granules are greatly varied due to their biological origins. Hoover & Sosulski (1991) reported the granule size of 4–85 μm for legume starches. Also, Tester *et al.* (2004) reported variations in starch granule size ranging from 1 to 100 μm. In the present study, the particle size of the starches studied followed

the order of CS > CPS > BVS > PS. CS showed the smallest particle size, ranging from 1.8 to 28.8 μm (average of 9.3 μm); also, PS showed the largest average granule size of 42.6 μm, and the widest range of particle size distribution, from 7.6 to 114.7 μm. These observations were comparable to other published data (Tester *et al.*, 2004; Joshi *et al.*, 2013; Waterschoot *et al.*, 2015). The particle size distribution of CPS varied from 4.2 to 30.33 μm, with a mean granule size of 20.5 μm. Similar findings for CPS have been represented by Miao *et al.* (2009). BVS showed a size distribution from 10.7 to 49.4 μm and a mean size of 28.5 μm. The BVS was larger than lentil starch (10–45 μm) (Joshi *et al.*, 2013), and common vetch starches (7.77–23.16 μm) (Fu *et al.*, 2020), but it was smaller than adzuki bean starch (45.65 μm) (Joshi *et al.*, 2013; Reddy *et al.*, 2017). The functional and physicochemical attributes of starches is impacted by shape, size and granule's structure. Generally, the difference in the granular shape and size distribution may be related to the plant origin, plant growth environments and the differences in quantity and structure of amylose and amylopectin (Miao *et al.*, 2009; Reddy *et al.*, 2017).

X-ray diffraction

The crystalline patterns of BVS, CPS, CS and PS are displayed in Fig. 2(a). The diffraction patterns of BVS and CPS were almost similar and showed four peaks, a small peak at 5.6° and the more substantial peaks at 15°, 17° and 23°. These characterisations indicated the C-type pattern, which is common in legume starches (Joshi *et al.*, 2013). PS showed B-type (tubers and roots) diffraction pattern with two major peaks at 5.6° and 17°, and the CS exhibited an A-type diffraction pattern with peaks at around 15°, 17°, 18° and 23°. The crystallinity of starches is affected by the moisture content, crystal size, orientation of double helices, amylopectin content, chain length and the degree of interactions in double helices (Reddy *et al.*, 2017). The crystallinity of starched followed the order of PS > CS > BVS > CPS and varied from 28.14 to 30.85% (Fig. 2a), which is similar to previous studies (Tester *et al.*, 2004; Hoover *et al.*, 2010; Joshi *et al.*, 2013). Higher relative crystallinity can be due to the following factors: (i) better orientation of the crystallites; (ii) stronger interaction between double helices and (iii) longer amylopectin chain length (Jayakody *et al.*, 2007; Joshi *et al.*, 2013).

Fourier transformed infrared (FTIR) spectroscopy

The functional groups of BVS, CPS, CS and PS were determined using a FTIR spectrophotometer to elucidate their molecular structure (Fig. 2b). The FTIR spectra of the starches displayed peaks at wave numbers of 857.1–860.8, 924.1–929.0, 993.5–998.4, 1077.5–1081.2, 1149.6–1155.4, 1336.9–1341.7, 1641.3–1643.7, 2929.6–2933.3 and 3294.9–3308.3 cm^{-1}. The principal peaks of BVS and their band assignments were at 3308.3 cm^{-1} (–OH stretching), 2933.3 cm^{-1} (C–H2 stretching), 1643.7 cm^{-1} (water bending), 1340.5 cm^{-1} (CH2 twisting), 1155.4, 1081.2 cm^{-1}, (C–O, C–C stretching and C–O–H bending), 995.9, 929.0 cm^{-1} (α-1,4 glycosidic linkage's skeletal mode vibrations) and 859.6 cm^{-1} (C–O–C stretching and C–H deformation) (Joshi *et al.*, 2013; Reddy *et al.*, 2017). Although the FTIR spectra of all starches were similar, the intensity of the peaks was different, which may be related to the differences in the vibration of functional groups and structures.

Swelling power (SP) and solubility

The SP and solubility of BVS, CPS, CS and PS at different temperatures are shown in Fig. 3. The SP of the samples was increased from 65 to 95 °C in the range of 3.23–10.19, 3.46–11.37, 2.86–13.29 and 6.55–31.9 g g^{-1} for BVS, CPS, CS and PS, respectively. The water solubility was in the range of 1.19–21.93% for the isolated starches at different temperatures. The rapid increase in water solubility at 75–85 °C indicates the melting of starch crystallites. The lower SP of BVS might be attributed to the greater number of crystallites among long amylopectin chains and its higher amylose content (Hoover & Ratnayake, 2002; Miao *et al.*, 2009). The lower SP and higher solubility of legume starches compared with CS and PS may be due to their differences in the granule size distribution, amylose content, lipid complexed amylose chains, amylose and amylopectin ratio, crystallinity and absorption capacity (Jayakody *et al.*, 2007; Wani *et al.*, 2010; Reddy *et al.*, 2017). Moreover, higher SP and solubility of PS compared to CS indicates the weaker internal organisation of PS and the higher fat content in CS.

Thermal properties

The onset (*To*), peak (*Tp*) and conclusion (*Tc*) temperatures, as well as enthalpy (ΔH) and gelatinisation range (*Tc–To*) of different starches are displayed in Table 2. The ranges of *To*, *Tp*, *Tc*, (*Tc–To*) and ΔH of the starches were 69.69–60.37 °C, 73.45–63.25 °C, 77.75–67.09 °C, 4.73–2.38 °C and 12.40–7.57 J g^{-1}, respectively. Gelatinisation is the infraction of granules, melting of amylopectin double helices and loss of crystalline structures in starch granules during heating (Miao *et al.*, 2009). *To*, *Tp* and *Tc* could be affected by numerous factors including the amylose content, ratio of amylose and amylopectin, distribution of short chains of amylopectin, lipid complexed amylose

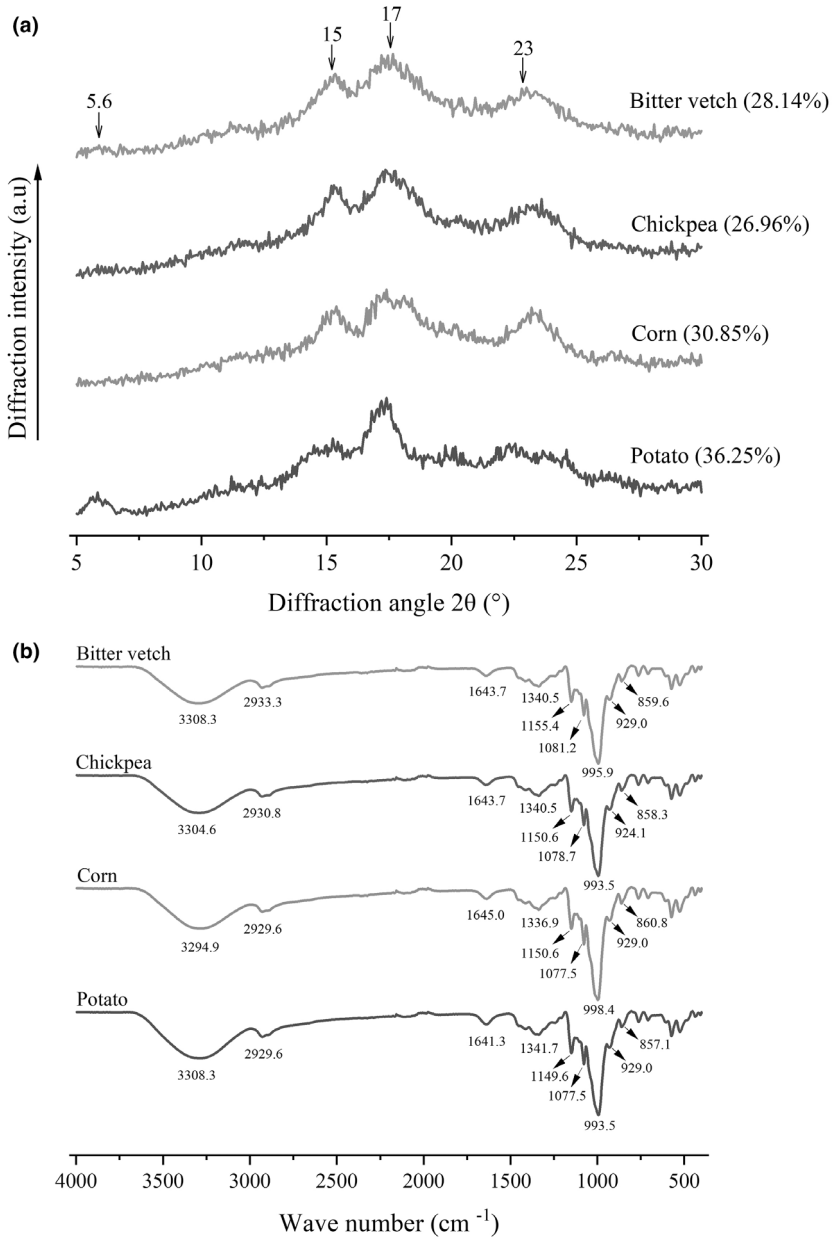

Figure 2 X-ray diffraction pattern and relative crystallinity (a) and FTIR spectra (b) of different starches.

chains, starch molecular structure and starch granule size and shape (Jayakody *et al.*, 2007; Reddy *et al.*, 2017; Fu *et al.*, 2020). The onset, peak, and conclusion gelatinisation temperatures for BVS were 65.82, 70.39 and 72.78 °C, respectively, which are higher than those of CPS and PS gelatinisation temperatures. The higher gelatinisation temperature showed a larger crystal size, longer chains in the crystal or more rigid crystalline structure (Miao *et al.*, 2009). A higher temperature is required to dissociate these chains completely and delayed pasting, which is desired in some product processing, such as retorted canned foods (de la Torre-Gutiérrez *et al.*, 2008). Also, Li *et al.* (2016) have postulated that the gelatinisation temperatures are strongly related to peak temperature (Table 1). PS exhibited higher ΔH and lower gelatinisation temperatures than CS. This can be attributed to their varied granular structure and amylose content (Sing *et al.*, 2002). The ΔH of starch indicates the loss of double-helical order or reveals the crystallinity of amylopectin (Tester & Morrison, 1990; Jayakody *et al.*, 2007). The greater ΔH of PS can be due to larger size of the

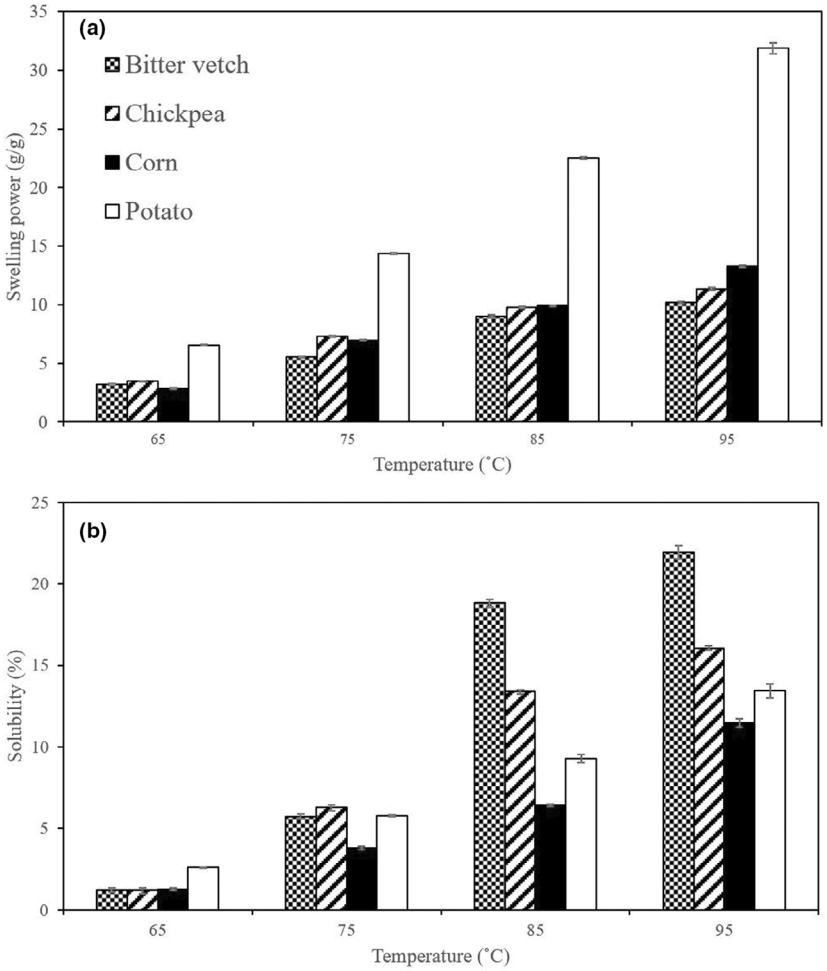

Figure 3 Swelling power (a) and solubility (b) of starch samples at different temperatures.

granules, which needs higher energy for gelatinisation (Fig. 1) or could be related to higher relative crystallinity (Fig. 2a) or lower amylose content (Table 1) (Sing *et al.*, 2002; Reddy *et al.*, 2017; Joshi *et al.*, 2013). Moreover, the higher ΔH of BVS compared with CPS suggests a higher disruption of double helices in CPS during the gelatinisation (Miao *et al.*, 2009). In addition, the lowest gelatinisation range of BVS suggests that there is more crystallinity in granules (Hoover & Ratnayake, 2002).

Pasting properties

The pasting characteristics of BVS, CPS, CS and PS are presented in Table 2. Pasting temperature (PT) of samples varied from 67.29 to 77.28°C. The highest PT for BVS and the lowest for PS were indicated. The higher PT indicates more resistance to swelling and deformation (Singh *et al.*, 2004). Fu *et al.* (2020) demonstrated that rupture and swelling of vetch starches are less than PS, which can play a critical role in the industry. Peak viscosity (PV) is affected by the extent of amylose leaching, granule swelling, and lipid complexed amylose chains (Wani *et al.*, 2010; Joshi *et al.*, 2013). BVS showed the lowest PV (3156 cP). Generally, the high amylose starch granules exhibit low PV (Reddy *et al.*, 2017). Trough viscosity (TV) indicates the reduction in starch viscosity after PV because of the breakdown (BD) of swollen granules during shearing at high temperature (Reddy *et al.*, 2017) which ranged from 1283 to 2656 cP. The BD variation of different starches suggests the difference in the thermal stability of starch and resistance to shearing. Low PV and BD values of BVS indicate that it was resistant to mechanical shear and heat along with continuous cooking, which could be due to its lower SP (Fig. 3a) and deformability of starch granules (Reddy *et al.*, 2017; Fu *et al.*, 2020). Setback (SB) generally indicates the amylose leaching and rapid retrogradation of components in the starch paste (Fu *et al.*, 2020). SB in BVS was 2991 cP, which was higher than other starches. Final viscosity

Table 2 Thermal and pasting properties of bitter vetch, chickpea, corn and potato starches

Properties	Bitter vetch	Chickpea	Corn	Potato
Thermal properties				
T_o (°C)	65.82 ± 0.2^b	62.43 ± 0.4^c	69.69 ± 0.4^a	60.37 ± 0.3^d
T_p (°C)	70.39 ± 0.5^b	67.07 ± 0.6^c	73.45 ± 0.4^a	63.25 ± 0.4^d
T_c (°C)	72.78 ± 0.7^b	71.80 ± 0.4^c	77.75 ± 0.3^a	67.09 ± 0.2^d
$T_c - T_p$ (°C)	2.38 ± 0.2^c	4.73 ± 0.3^a	4.30 ± 0.1^{ab}	3.84 ± 0.1^b
ΔH (J g^{-1})	9.15 ± 0.1^c	7.57 ± 0.3^d	10.85 ± 0.2^b	12.40 ± 0.2^a
Pasting properties				
PT (°C)	77.28 ± 0.02^a	76.56 ± 0.02^b	74.10 ± 0.17^c	67.29 ± 0.13^d
PV (cP)	3156 ± 29^d	3269 ± 25^c	4166 ± 16^b	7535 ± 21^a
BD (cP)	1165 ± 22^d	1322 ± 33^c	1510 ± 31^b	6251 ± 38^a
SB (cP)	2991 ± 33^a	2734 ± 17^b	1597 ± 40^c	1479 ± 33^d
FV (cP)	4983 ± 24^a	4682 ± 21^b	4253 ± 25^c	2762 ± 36^d

Means ± standard deviations of triplicate analysis. Means with different lowercases in the same row have significant differences ($P < 0.05$).

(FV) shows the gel-forming ability of starch after cooking and cooling under low shear (Miao *et al.*, 2009; Fu *et al.*, 2020). All starch samples displayed a moderate viscosity improvement at the end of the cooling time, which is attributed to the aggregation of amylose molecules (Sing *et al.*, 2004). Furthermore, the order of FV for different starches is in accordance with their amylose content (Table 1). These findings are in accordance with the results reported by Joshi *et al.* (2013). BVS had the highest FV among other starches (4983 cP), which can be potentially used in some food processing like canning or wherever strong gelling characteristics are needed in food products (Table 2).

Dynamic rheological properties

The viscoelastic characteristics of different starch gels were evaluated from a dynamic frequency sweep (0–62.83 rad s^{-1}) at 25 °C. The differences in storage (G') and loss (G'') moduli of starch samples are shown in Fig. 4. For viscoelastic materials, G' shows the solid-like and elastic characteristics, whereas G'' represents viscous and liquid-like features (Ghoshal & Kaushal, 2020). The rheological parameters of starch gels depend on frequency, and both G' and G'' increased with an increase in frequency. For all starches, G' values were higher than the G'' values, which indicates more elastic-like behaviour of starch gels than the viscous ones (Ghoshal & Kaushal, 2020). Lower G' and G'' of corn starch, among other starches, indicated a more rigid nature of CS granules, with long chain branches of amylopectin (Singh & Singh, 2003). The varied rheological parameters could be due to varied granular sizes and shapes (Singh & Singh, 2003), amylose and lipid content

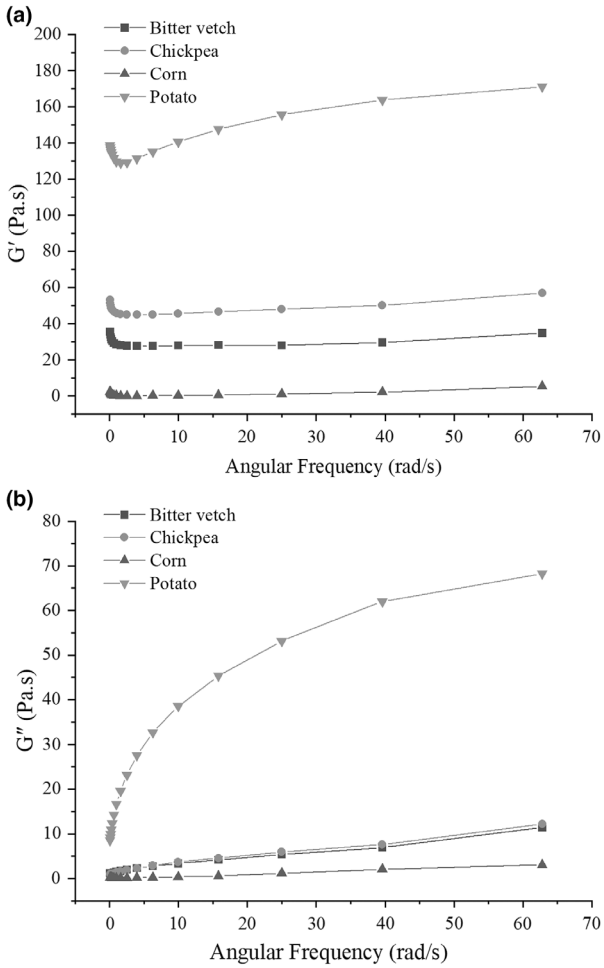

Figure 4 (a) Storage G' and (b) loss G'' modulus properties of different starches.

(Singh *et al.*, 2002) and phosphate monoester content (Singh *et al.*, 2003).

Conclusion

Based on the results of present study, bitter vetch starch (BVS) has great functional properties. The gel-forming ability of BVS is greater than conventional starches which makes it an appropriate option for food products such as gelled desserts that should have a consistent and cohesive gel texture. Moreover, the pasting and gelatinisation temperatures are higher than corn, potato and chickpea starches which indicate the thermal stability of BVS. These properties are desired in processing of retorted canned foods; thus, BVS can be potentially used in these products. In conclusion, the comparison of BVS properties with conventional starches suggested that it can be introduced as a promising source of starch.

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Conflict of interest statement

The authors declare no conflict of interest.

Ethical approval

Ethical approval was not required for this research.

Author contributions

Mohammad Tarahi: Conceptualization (equal); data curation (equal); formal analysis (equal); writing – original draft (equal). **Fakhri Shahidi:** Project administration (equal); supervision (equal); validation (equal); writing – review and editing (equal).

Data availability statement

The data that support the findings of this study are openly available in [repository name e.g. "figshar" at http://doi.org/[doi], reference number [reference number

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