2019

Physicochemical properties and rheological behavior of flours and starches from four bean varieties for gluten-free pasta formulation

Hollman Motta Romero

Yue Zhang

Journal of Agriculture and Food Research 1 (2019) 100001

Contents lists available at ScienceDirect

Journal of Agriculture and Food Research

journal homepage: www.journals.elsevier.com/journal-of-agriculture-and-food-research/

Physicochemical properties and rheological behavior of flours and starches from four bean varieties for gluten-free pasta formulation

Hollman Motta Romero [a], Yue Zhang [b,a,*]

[a] Department of Food Science and Technology, University of Nebraska-Lincoln, Lincoln, NE, 68588-6205, USA
[b] School of Food Science and Biotechnology, Zhejiang Gongshang University, Hangzhou, 310018, PR China

ARTICLE INFO

Keywords:
Dry bean
Rheology
Physicochemical properties
Starch
Gluten-free pasta

ABSTRACT

The rheological behavior of gluten-free flour dispersions from four pulse market classes, including great northern, navy, red kidney (*Phaseolus vulgaris* L.), and garbanzo beans (*Cicer arietinum)* were evaluated and compared to soft wheat as a gluten-containing control. Their starches were isolated and the relationships between flour behavior and starch characteristics were studied. Soft wheat (56%) and garbanzo (39%) flours presented higher starch contents than the *Phaseolus vulgaris* beans (33–35%), which resulted in the development of stronger gel network structures. It was found that starch amylose content and granule size affected the swelling and pasting properties of both starches and flours. Rheology tests suggested that garbanzo and navy bean flours developed the strongest structures among the gluten-free samples included. Therefore these were chosen to develop gluten-free pasta. The cooking and texture parameters of these pastas were also studied and compared with soft wheat pasta.

1. Introduction

Dry beans are the dicotyledonous seed of plants belonging to the Leguminosae family, which are widely cultivated all around the world due to their global adaptability and drought tolerance. Although their origin has been traced to Central America and the Andean region of South America, the United States (US) is one of the largest producers of dry edible beans worldwide nowadays. According to the United States Department of Agriculture (USDA), in 2017, around 3.500 million pounds were produced in the US and the exports were valued over 450 million dollars [1]. Among these, *Phaseolus vulgaris* L. varieties such as pinto, navy, great northern, kidney beans, and *Cicer arietinum* (garbanzo bean) are the most common market classes grown in the US.

Dry beans are rich in proteins and minerals and considered a good source of dietary fiber [2]. In addition to their high nutritional value, health benefits such as the reduction of the risk of cardiovascular diseases, obesity, and diabetes have been associated with their consumption [2]. However, the traditional preparation method of beans, involving both long soaking and cooking periods, is seen as tedious and time-consuming by consumers, hence leading to the underutilization of these beans. One alternative to improve the consumption of dry beans is the utilization of bean flours. For instance, bean flours have been incorporated into composite flours to increase the resistant starch content and to improve the protein quality [3].

Similarly, the addition of common bean (*Phaseolus vulgaris* L.) flour to semolina spaghetti decreased the starch digestibility and increased the protein and fiber content of spaghetti [4]. Nevertheless, cooking and sensory attributes such as cooking loss [4], appearance, and texture are simultaneously affected by the addition of legume flours to semolina [5]. Bean flours have also been utilized to develop gluten-free (GF) foods such as pasta in which the nutritional quality is enhanced [6]. However, when compared to traditional wheat products, these GF goods show different texture and cooking quality and are significantly affected by the varieties of beans utilized [5]. Unfortunately, there is limited research on the physicochemical properties of bean flours and the influence of their major components on the functional characteristics of flours, which are essential for the further development of food products made with bean flours.

Starch is one of the major constituents of beans. It represents about 22–45% of the total seed weight [8]. Therefore, due to its presence in such a large proportion, the functional behavior of bean flours might be significantly affected by starch properties such as granule morphology, size, and chemical composition. The characteristics of isolated bean starches have been previously studied [9], and the effect of starch composition on its functional properties has been reported. For instance, the large amylose content of legume starches results in high

* Corresponding author. School of Food Science and Biotechnology, Zhejiang Gongshang University, No.149 Jiaogong Road, Hangzhou, 310018, China.
E-mail address: zhangyue@zjgsu.edu.cn (Y. Zhang).

https://doi.org/10.1016/j.jafr.2019.100001
Received 12 October 2019; Received in revised form 2 November 2019; Accepted 2 November 2019

gelatinization temperatures, restricted swelling, and small or absent breakdown viscosity values [10,11]. Nevertheless, the characteristics of starch have not been correlated to the functionality of the whole bean flours. The study of the physicochemical properties of bean flour from different varieties and the effect of their major constituents on the flour properties are essential for their efficient utilization.

Therefore, this work aimed to characterize the physicochemical properties of starches and flours from four bean varieties, including three *Phaseolus vulgaris* L. (great northern, navy, and red kidney) and one *Cicer arietinum* beans (Garbanzo). The second objective was to understand the relationship between these properties of starch with the rheological behavior of whole bean flours and the quality of resultant pasta.

2. Materials and methods

2.1. Materials

Garbanzo, great northern, navy, red kidney beans, and soft wheat seeds were purchased from a local grocery and proceed into whole bean/wheat flour using a laboratory scale hammer mill, passed through a 40 mesh sieve and stored at 4 °C until utilization. The amylose/amylopectin assay and the total starch (amyloglucosidase/α-amylase) kits were purchased from Megazyme International (Megazyme, Wicklow, Ireland). Other reagents such as sodium hydroxide were purchased from Fisher Scientific (Fair Lawn, NJ).

2.2. Characterization of flours

2.2.1. Proximate composition of flours

Total starch, crude fat and ash content of flours were determined in triplicate following the AACCI 76–13.01 [12], AACCI 30–25.01 [1,13], and AACCI 08–01.01 [1,13], approved methods, respectively. The nitrogen content in flours was determined by the Dumas combustion method using a LECO nitrogen analyzer (LECO Corp, St Joseph, MI). The protein content was determined from the nitrogen content using a conversion factor of 6.25 for beans and 5.7 for wheat.

2.2.2. Rheological properties of flours

Rheological properties of flours were measured using a MCR-301 rotational rheometer (Anton Parr, Graz, Austria) equipped with a 50 mm diameter parallel plate measuring system. The measurements were performed on flour dispersions (10%, solids). The gap size, strain, and frequency were set at 1 mm, 2%, and 1 Hz, respectively. To perform temperature sweep tests, the samples were heated from 40 °C to 95 °C and then cooled down to 25 °C at a rate of 1 °C/min. After temperature sweep tests, samples were held 5 min at 25 °C and a frequency sweep test from 0.1 to 25 HZ was performed to study the viscoelastic properties of the samples after cooling. The exposed edge of the samples was covered with a thin layer of mineral oil to prevent evaporation.

2.2.3. Pasting properties of flour and starches

The pasting properties of bean flours and their isolated starches (section 2.3) were determined using a Brabender Micro Visco-Amylo-Graph (Brabender OHG, Duisburg, Germany). Flour or starch dispersions (10% db; 10.0 g total weight) were equilibrated at 50 °C for 1 min, heated to 95 °C at a 6 °C/min heating rate and held at this temperature for 5 min, then cooled down to 50 °C at a 6 °C/min cooling rate and held at 50 °C for 2 min. The spindle speed was set at 160 rpm.

2.3. Starch extraction and characterization

2.3.1. Starch isolation

In brief, wheat or bean flours were mixed with water in a mass ratio of 1:10. The slurry was adjusted to pH 10 using 1.0 M NaOH and stirred for 1 h to solubilize proteins. Subsequently, the slurry was filtered through a 75-μm-mesh sieve to separate insoluble fiber and was centrifuged at 1600 *g* for 30 min. The aqueous phase was discarded, whereas the bottom white sediment was collected and recovered as the starch portion after washing two times with distilled water. The recovered starch was dried in a forced-air oven at 50 °C overnight. This method was a modification of that followed by Ref. [14].

2.3.2. Amylose content, swelling power, and solubility of starch

The Amylose/Amylopectin assay designed by Megazyme was followed to measure the amylose content of the samples (Megazyme, Wicklow, Ireland). In brief, this procedure relies on the dispersion of starch in dimethyl sulphoxide, selective precipitation of amylopectin by the addition of lectin concanavalin A (Con A), the subsequent enzymatic hydrolysis of amylose to D-glucose and its colorimetric quantification.

For swelling power determination, 10 ml of 5% (w/w) starch dispersions in centrifuge tubes were heated in a water bath at 70 °C for 30 min, and the tubes were periodically vortexed to prevent granules sedimentation. After heating, the samples were cooled down to room temperature and centrifuged (1600 g, 10 min). The pellet was weighed before and after drying in an oven at 100 °C. The supernatant was collected and dried at 100 °C. Swelling power was then calculated as the ratio of the weight of the pellet to the initial starch sample weight. Solubility was calculated as the ratio of solids in the supernatant to the weight of the starch sample (dry basis).

2.3.3. Starch granules size distribution

The size distribution of the granules from soft wheat and bean starches was determined using a Mastersizer 3000 laser diffraction particle size analyzer equipped with a hydro HV dispersion system (Malvern Panalytical Ltd, Malvern, UK) and reported as the volume mean diameter $D_{4,3}$. The samples were suspended in water and stirred at 2000 rpm within the dispersion unit. The refractive and absorption indices were set at 1.53 and 0.1, respectively. All measurements were performed within the 0.1–10% obscuration range and with a 1.33 refractive index for water as the dispersant.

2.3.4. Scanning electron microscopy (SEM)

The morphology of the isolated starch granules was observed using a SU-70 Hitachi scanning electron microscope (Hitachi, Pleasanton, CA) at 10.0 KV electron acceleration voltage. The starch samples were adhered to a conductive carbon tape and dried in a vacuum oven at 3000 Pa at room temperature (21 °C). Subsequently, the samples were mounted onto specimen stubs and coated with a conductive gold layer (<0.5 nm) using a sputter coater (Anatech, Hayward, CA) before imaging.

2.4. Characterization of pasta

2.4.1. Pasta preparation

The minimal water content for dough formation (to obtain a cohesive dough) with wheat or bean flour as the sole ingredient was evaluated and recorded as follows: 60% (w/w, db) for soft wheat, 40% for garbanzo, and 55% navy bean flour, respectively. Wheat and two beans flours were hydrated with distilled water to the minimal water content and then mixed for 10 min using a Kitchen Aid Mixer (St. Joseph, MI) equipped with the paddle attachment to develop the dough. The dough was passed through a pasta press extrusion plate held by the Kitchen Aid to obtain spaghetti. The pasta strands were dried at room temperature for 24 h before other measurements.

2.4.2. Cooking quality of pasta

The cooking quality of pasta was determined by following the AACCI 60–50 approved method. The optimal cooking time was established as the cooking time at which the central white core of a noodle strand disappears when squeezed between two pieces of glass.

To determine the pasta cooking loss, 10 g of each sample were cooked to its optimum, and the cooking water was recovered and evaporated to dryness in a forced air oven at 100 °C for 12 h. The solids were weighted,

and cooking loss reported as the percentage of the original sample before cooking.

To determine the water uptake of pasta, 10 g of pasta were cooked to optimum, rinsed in cold distilled water, and drained in paper towels before being weighed. The water uptake value was calculated as:

$$\text{Water uptake}\left(\%,\ \text{db}\right) = \left(\frac{\text{W(cooked pasta)}}{\text{W (dry pasta)}} - 1\right) \times 100$$

2.4.3. Texture of pasta

To describe the texture of pasta, a texture profile analysis (TPA) was performed using a TA-XT2i Texture Analyzer (Stable Micro Systems Ltd., Surrey, UK). One pasta strand of approximately 7 cm length was placed under a flat-end cylindrical probe (d = 35 mm) and compressed to 70% of its original height. The test and post-test speeds were both fixed at 1 mm/s. Hardness, cohesiveness, and chewiness were calculated from the resulting force versus time diagram. Ten measurements were taken and the average and standard deviation reported.

2.5. Statistical analysis

This study was conducted as a completely randomized design. Each measurement was performed in triplicate and the results reported as the mean ± standard deviation unless otherwise specified. One-way ANOVA tests were carried out to find overall significant differences among the treatment groups and the Tukey's test to separate the means. The statistical analysis was performed using the RStudio Desktop 1.1.453 software (Boston, MA).

3. Results and discussion

3.1. Chemical composition of flours

The proximate compositions of the four bean flours were analyzed and compared to one commercial soft wheat sample (Table 1). As expected, wheat flour was especially different from the bean samples; it presented a significantly higher amount of starch (56.1%) and the lowest protein, lipids, and ash contents. Among the bean samples, significant differences ($p < 0.05$) were found for starch, protein, lipid, and ash contents. Starch content ranged from 33.6 to 39.1%, where garbanzo and navy bean presented the highest and lowest contents, respectively. These results are in agreement with the starch content in legumes within the 22–45% range as reported in previous works. The protein content presented less variation among the beans, great northern bean and navy bean did not significantly differ (~23.0%) and both had a higher content than red kidney (21.8%) and garbanzo (20.3%). The lipids content of garbanzo was the highest among all the samples. [15]; reported similar results when comparing chickpea flours to those of various *Phaseolus vulgaris* beans. The ash content significantly differed among all the samples, with navy and garbanzo beans presenting the highest (4.85%) and lowest (3.23%), respectively. The results suggested that navy bean four contained more inorganic minerals than other bean sources which may mainly come from the skin.

Table 1
Proximate composition of soft wheat and bean flours.[a]

Flour	Starch	Protein	Lipid	Ash
Garbanzo	39.1 ± 0.3^{b}	20.3 ± 0.0^{c}	5.20 ± 0.0^{a}	3.23 ± 0.0^{d}
Great Northern	35.6 ± 0.0^{c}	23.2 ± 0.0^{a}	0.79 ± 0.0^{d}	3.95 ± 0.0^{c}
Red kidney	34.4 ± 0.0^{d}	21.8 ± 0.1^{b}	1.21 ± 0.0^{c}	4.07 ± 0.1^{b}
Navy	33.6 ± 0.7^{d}	23.1 ± 0.1^{a}	1.57 ± 0.0^{b}	4.85 ± 0.0^{a}
Soft wheat	56.1 ± 0.0^{a}	12.7 ± 0.0^{d}	0.72 ± 0.0^{d}	1.63 ± 0.0^{e}

[a] All the contents are expressed in g/100 g (db). Means in the same column with different superscripts indicate statistically significant differences ($p < 0.05$).

3.2. Rheological properties of flours

It is known that the rheological behavior of doughs and the quality attributes of final goods are greatly influenced by the water absorption capacity of flours, which varies among different flour sources [16]. Hence, to simulate a scenario in which all the samples were under the same conditions, the rheological measurements were performed on flour suspensions, that is, in excess of water. A temperature sweep test, in which the samples were heated from 40 °C to 90 °C (Fig. 1A) and cooled back down to 25 °C (Fig. 1B) while applying a constant strain, was applied to the flour suspensions, to understand their rheological behavior under heat treatments such as cooking. In this work, soft wheat flour was included as a gluten-containing control.

As expected, the soft wheat presented the highest storage modulus (G′) values, which was attributed to its significantly higher starch content and the presence of gluten in the flour (Table 1) [17,18]. Garbanzo, which presented the largest starch content among the beans, also presented the highest G′ among the GF flours during the heating stage.

The storage modulus of soft wheat sharply increased at about 60 °C due to the initial swelling of starch granules [19]. On the other hand, bean flours showed a significant G′ increase around 70–75 °C. Since the amylose content of starch is negatively correlated to its pasting temperature [20], the delayed rise of G′ for bean flours can be related to the restricted swelling capacity of starches with higher amylose content [9]. This observation is in line with the amylose content as presented in Table 2 (18.2% for soft wheat while 26.4–30.1% for beans). The starch from garbanzo bean with the lowest amylose content among beans (Table 2), presented an earlier increase of G′ at 68 °C, while the significant increase of G′ in the other three beans was found at 78 °C. The amylose contents in these three beans did not significantly differ (Table 2), supporting our hypothesis that starch amylose content was an important parameter in determining the rheological behavior of these bean flours. However, the rheological behavior of great northern, navy, and red kidney beans, with similar starch and amylose contents, was not identical, thus suggesting that other non-starch components such as protein might also affect the rheological behavior of bean flours.

Proteins are believed to form a matrix network that could entrap and protect the integrity of starch granules [21]. Their presence in flours has also been reported to reduce the water availability to starch and to increase the temperatures at which starch granules start to absorb water [22]. These findings may help to explain the above observation that soft wheat and garbanzo flours with the lowest protein contents presented increases of G′ at lower temperatures.

When the temperature was raised to 80 °C, the G′ of soft wheat decreased due to the melting of crystalline regions, the disruption of the granular structure, and the leakage of amyloses from the starch granules (Fig. 1A) [19]. On the other hand, G′ continuously increased for all the bean flours in the whole period of heating, suggesting that the energy input was insufficient to disrupt the structure of granules from bean starches. Heating the slurries to temperatures above the denaturation temperatures of bean proteins (80–90 °C) [23] could denature the proteins present in the flours, thus leading to the unfolding of their structures and subsequent gelation through hydrophobic interactions and disulfide bonds [24], hence also contributing to the increase of G'.

During the cooling stage (Fig. 1B), the interactions between the leached-out polymers from soft wheat granules brought the hot flour paste to an actual gel, as evidenced by a significant increase of G′ from 475 to 2950 Pa [25]. As shown in Fig. 1A, the wheat starch granular structure was extensively disrupted at high temperature (85–90 °C), which facilitated the lixiviation of amylose and amylopectin from the granules, thus yielding a hot paste rich in free polymers [25]. The higher G′ of soft wheat flour (Fig. 1B) can be attributed to its higher starch content and the crosslinking of abundant free amylose and amylopectin molecules [18]. The gluten portion may also contribute to the stronger network build-up.

Among the beans, the garbanzo paste showed stronger elastic

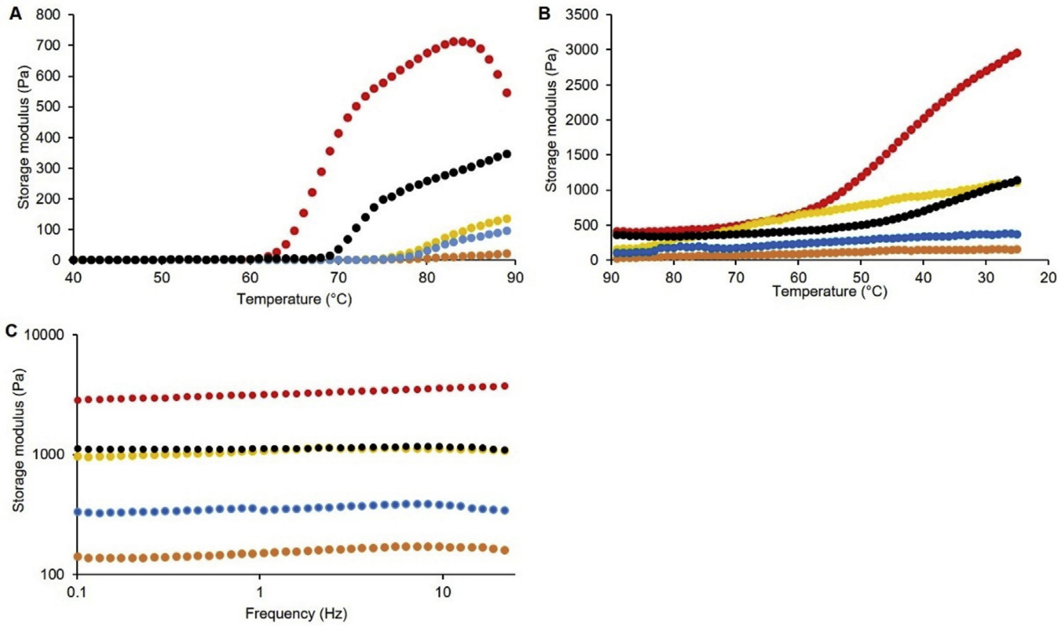

Fig. 1. Viscoelastic behavior of bean and soft wheat flour suspensions (10% solids) as a function of (A) increasing temperature, (B) decreasing temperature, and (C) increasing frequency at 25 °C, respectively. Samples include garbanzo (black), great northern (blue), navy (yellow), red kidney (orange), and soft wheat (red). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Physicochemical properties of starches from soft wheat and beans[a].

Starch	Amylose content %	Swelling power (g/g)	Solubility %	Size distribution (μm)	Granule size $D_{4,3}$ (μm)
Garbanzo	26.4 ± 0.7^b	7.2 ± 0.1^b	4.0 ± 0.1^b	9.2–37.6	20.9 ± 0.6^c
Great Northern	29.5 ± 0.5^a	2.7 ± 0.1^d	1.0 ± 0.1^c	11.9–55.2	26.4 ± 0.4^b
Red kidney	29.6 ± 0.8^a	3.1 ± 0.0^c	1.5 ± 0.1^c	10.5–55.2	26.9 ± 0.4^b
Navy	30.1 ± 0.1^a	3.0 ± 0.0^c	1.0 ± 0.1^c	13.5–55.2	28.0 ± 0.3^a
Soft wheat	18.2 ± 1.0^c	9.6 ± 0.2^a	9.0 ± 0.3^a	2.6–27.6	12.9 ± 1.5^d

[a] Means in the same column with different superscripts indicate statistically significant differences ($p < 0.05$).

properties (higher G′) than red kidney and great northern beans due to its higher starch content (Table 1) and lower starch gelatinization temperature. Nevertheless, navy bean, which showed lower G′ values than garbanzo during heating, presented a rapid linear increase of G′ upon cooling down and ended up with comparable G′ values to garbanzo flour. It has been reported that the presence of native lipids in several crops could interact with amylose and thus hinder the formation of junction zones among amylose molecules [26]. Since garbanzo flour presented a higher content of lipids than navy bean (5.20% vs. 1.57%), these might have hindered the interactions among amylose molecules and decreased the elasticity of the garbanzo flour gels.

To further evaluate the viscoelasticity of the gels formed after the temperature sweep test, a dynamic frequency test was performed over the range of 0.1–25 Hz (Fig. 1C) [18,19]. The low dependence of G′ on frequency of all samples suggested a high stability of these gels [19]. Soft wheat showed higher G′ than the bean samples, confirming a stronger gel network. Within the studied frequency range, navy bean and garbanzo bean showed a similar trend of G′ values, which agrees on the results of the temperature sweep test (Fig. 1B). Red kidney bean flour showed the lowest G′ values in all the rheology measurements, indicating that this flour develops weak networks.

3.3. Physicochemical properties of starches

3.3.1. Swelling power and solubility

To better understand the different rheological behavior of these flours, their starch fractions were isolated and characterized. As shown in Table 2, soft wheat and garbanzo bean starch (with the lowest amylose content) presented significantly higher swelling capacity and solubility than the starches from great northern, navy, and red kidney bean. As postulated before, a higher amylose content implies a closely packaging of amylose polymers within the amorphous regions of the starch granules [9], which restricts the swelling of granules and requires high inputs of energy to start gelatinization [27]. These results agree with our observations on the rheology of flours slurries in that great northern, navy, and red kidney with higher amylose content presented higher gelatinization temperatures than soft wheat and garbanzo flours (Fig. 1A).

The correlations between amylose leaching, the swelling capacity of granules, and starch solubility have been reported previously [27–30]. The leaching of amylose from granules is necessary to facilitate the swelling of amylopectin and the solubilization of starch granules. The higher swelling capacity soft wheat and garbanzo bean starches may indicate relatively weaker interactions between amylose-amylose and amylose-amylopectin molecules than in the other bean starches, thus facilitating the lixiviation of amylose molecules and increasing starch solubility [28,29].

3.3.2. Granule size and morphology

The morphology and size of starch granules are known to significantly affect the swelling and pasting properties of starches [31]. Here, the morphology and size of starch granules were characterized by SEM (Fig. 2) and laser diffraction analysis (Table 2), respectively. All the four bean starch granules had oval to spherical shapes and lacked evidence of serious fissures, which agrees with previous reports [9]. Some striations

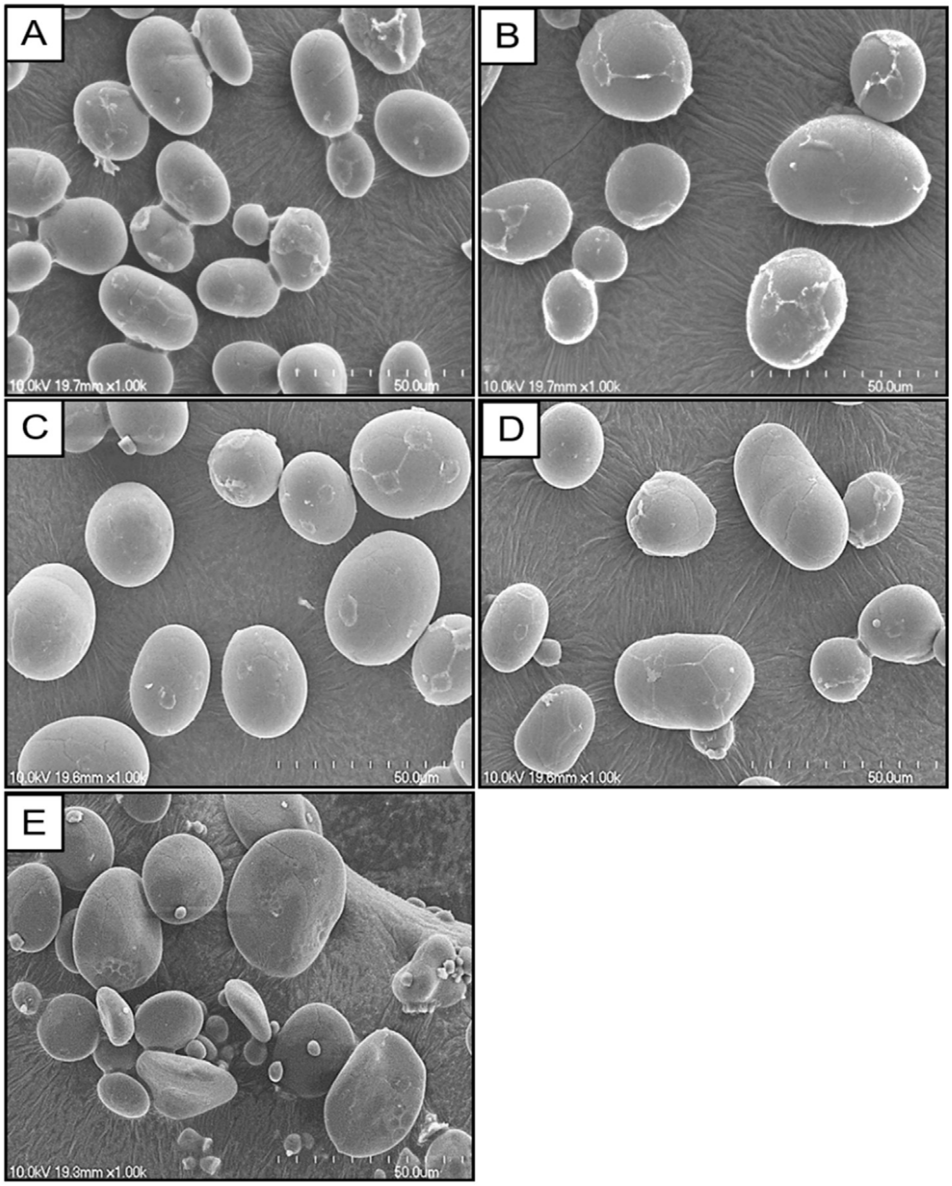

Fig. 2. Scanning electron microscopy images of starch granules isolated from A) Garbanzo, B) Great northern C) Navy, and D) Red kidney bean, E) Soft wheat.

were identified on the surface of granules, probably caused during milling before starch isolation [32]. The laser diffraction results showed that soft wheat starch granules (12.9 μm) were significantly smaller than those from bean starches. As shown in Fig. 2, the granules in soft wheat have a wide size distribution, thus many small granules were observed, which agrees with the laser diffraction measurement. Among the beans, garbanzo presented the smallest granule sizes (20.9 μm), whereas navy bean had the largest granules (28.0 μm) and great northern, and red kidney starch granules did not differ in their size (~26.0 μm). It has been reported that small granules tend to have less amylose content, lower pasting temperatures, and higher swelling capacity than large granules [31,33]. Our results that garbanzo showed highest amylose content and relatively lower swelling capacity may also support this statement. Our results may also indicate that, besides their lower amylose content, the smaller granule size might also play a crucial role in the higher swelling capacity of starch (Table 2) and lower gelatinization temperatures of soft wheat and garbanzo flours (Fig. 1A).

3.3.3. *Pasting properties*

In the present study, the pasting properties of starches and flours were studied using a Brabender Amylograpgh (Fig. S1, see supplementary material). Three parameters, including pasting temperature, peak viscosity, and final viscosity are reported in Table 3.

The pasting viscosity patterns of cereal starches such as soft wheat are classified as type B [11], that their large swelling capacity compromises the structure of granules and makes them susceptible to disruption under shear conditions after the peak viscosity is reached (Fig. S1). On the other hand, the pasting pattern of bean starches is classified as type C [11]. These starches presented a more restricted swelling and their granular structure was resistant to mechanical fragmentation. Therefore, these beans did not show a clear peak viscosity or breakdowns. Similarly, the absence of peak viscosities and gradually increasing viscosities during the holding periods have been reported for different varieties of black bean, navy, pinto (*Phaseolus vulgaris* L.), and chickpea (*Cicer arietinum* L.) starches [8].

As aforementioned, starch granules with smaller granule size and lower amylose require less energy to disrupt the polymer interactions within the granules, which facilitate granule swelling and starch pasting [9]. As expected, the garbanzo starch, with the smallest granules and lowest amylose content, showed the lowest pasting temperature

Table 3
Pasting properties of soft wheat and common bean starches and flours.[a]

Sample	Peak viscosity (Viscosity at 95 °C, mPas)		Final viscosity (mPas)		Pasting temperature (°C)	
	Starch	Flour	Starch	Flour	Starch	Flour
Garbanzo	932.0 ± 13.2[c]	295.0 ± 2.6[b]	1369.7 ± 9 .9[b]	380.7 ± 3.2[d]	70.7 ± 0.4[c]	77.6 ± 0.0[c]
Great Northern	986.0 ± 6.5[b]	255.3 ± 8.4[c]	1328.0 ± 2.6[c]	568.0 ± 7.0[b]	79.5 ± 0.1[a]	81.0 ± 0.7[b]
Red kidney	480.3 ± 4.5[e]	70.7 ± 4.7[e]	706.3 ± 2.3[e]	191.7 ± 8.9[e]	79.5 ± 0.3[a]	86.8 ± 2.3[a]
Navy	1180.0 ± 5.0[a]	115.3 ± 2.9[d]	1478.3 ± 4.7[a]	410.7 ± 7.0[c]	78.4 ± 0.3[a]	87.3 ± 0.1[a]
Soft Wheat	835.4 ± 2.5[d]	451.3 ± 5.3[a]	1266.0 ± 3.5[d]	770.5 ± 7.3[a]	73.9 ± 0.8[b]	78.4 ± 0.3[c]

[a] Means in the same column with different superscripts indicate statistically significant differences ($p < 0.05$).

(70.7 °C) among the beans evaluated. Whereas great northern, navy, and red kidney starches with similar amylose content and granule size had similar pasting temperatures (78.4–79.5 °C). Nevertheless, soft wheat starch, with the least amylose content, presented higher pasting temperature (73.9 °C) than garbanzo starch. The pasting properties of starch might also be affected by amylopectin, especially for the starches with high amylopectin content such as soft wheat [11]. For instance, the long side-chains of wheat amylopectin interact through hydrogen bonds to form compact granule structure with high crystallinity, which requires high inputs of energy to be disrupted, thus increasing the gelatinization temperature [34].

For most starches, the peak viscosity is mainly dictated by their swelling capacity [11]. Nevertheless, in the present work, the peak viscosity did not perfectly correlate to the swelling capacity of the starches. The peak viscosity of garbanzo starch, with a higher swelling capacity, was slightly lower than that of great northern and navy beans (Table 3). Similarly, these three beans showed a higher peak viscosity than soft wheat, which had the highest swelling power (Table 2). It was found that the granule size of starch also affected the peak viscosity. Since larger granules would occupy more space within the measuring systems, they are expected to develop more viscous pastes [35]. Therefore, the larger granule sizes of starches from great northern and navy bean might explain why these starches showed higher peak viscosities than garbanzo starch and soft wheat starch.

During the cooling stage, the re-association of leached-out starch polymers and the interactions between intact remnant granules, dictate the extent of setback and final viscosity [20]. The final viscosity of soft wheat starch was lower than that of garbanzo, great northern, and navy bean starches, which could be attributed to the higher degree of granule disruption during heating, and its lower amylose content, which limited the formation of junction zones [25,36]. This observation is different from our rheological results measured on flours, in which soft wheat flour showed higher G′ values than any bean flour after cooling (Fig. 1B). Nevertheless, the pasting properties of flours were also studied under the same conditions (Table 3), and soft wheat flour showed the highest final viscosity among the five samples, which was in accordance with the rheological test. Thus, confirming that although soft wheat starch did not develop the strongest structures by itself, soft wheat flour formed the strongest gels due to its higher starch content and the presence of gluten.

Among the four beans, navy bean starch with the largest granules, showed the highest final viscosity, followed by garbanzo starch and great northern. Since free amylose molecules are mainly responsible for the formation of junction zones and increase the final viscosity, the low final viscosity values of kidney flour (191.7 mPa▪s) and its starch (706.3 mPa▪s) could be attributed to its limited ability to leach amylose, as evidenced by low swelling capacity and starch solubility [36]. Compared to the isolated starches, all the flours presented lower peak viscosity and final viscosity values, and higher pasting temperatures (Table 3), this might be due to the presence of proteins and other non-starch components in flours, which may compete for water and protecting the integrity of granular structure [21,37]. Therefore, more energy (higher temperature) is required for the gelatinization of starch in the flour. The SEM images (Fig. 2) show some residual proteins deposited on the granule surfaces, which confirms that starch granules were surrounded by a protein matrix in the bean seed before isolation.

3.4. *Cooking quality and textural properties of pasta*

From the above experiments, garbanzo and navy bean flours showed better performance (stronger viscoelastic properties) than great northern and red kidney beans. Therefore, these two bean flours were selected to prepare pasta, and the cooking quality and textural properties of resultant pasta were compared with soft wheat as a gluten-containing control.

Table 4 shows the cooking quality and texture parameters of the pasta samples. Longer cooking was required for the soft wheat pasta to reach its optimum, which might be due to its higher starch content and the presence of gluten. It is known that a strong protein network is formed by cross-linking of glutenin and gliadin which surrounds starch granules and restricts its swelling and gelatinization during cooking [38]. The pasta made from garbanzo flour presented the lowest optimum cooking time (5.5 min), which is in accordance with our rheology and pasting observations that garbanzo flour and starch had lower pasting temperature than the navy bean sample (Fig. 1A, Table 3). The pasta made with navy bean flour showed a slightly higher water uptake than garbanzo pasta (228 vs. 203%), which was inconsistent with the results of starch swelling power (Table 2). In this case, other non-starch components of flour such as proteins might also play an important role in the water uptake of cooked pasta. Since the major storage proteins from wheat, glutenins and gliadins, are rich in cysteine residues, these can form multiple intra- and inter-molecular disulphide bonds to from strong viscoelastic networks under adequate levels of hydration [7]. These interactions allow soft wheat to develop stronger structures than any bean flours since their proteins mostly interact via weak hydrophobic forces [40].

Both bean samples showed higher cooking loss than soft wheat pasta. However, garbanzo bean pasta showed a lower value than the navy bean sample (10.3 vs. 14.92%). The cooking loss for good quality wheat pasta should be lower than 12% [41]. Considering the absence of gluten in the bean pasta, garbanzo bean might be acceptable and comparable to wheat and other commercial gluten-free pasta [6].

The texture parameters for cooked pasta are shown in Table 4. As expected, the two bean pastas showed lower hardness, cohesiveness, and chewiness than the soft wheat sample. The higher hardness, cohesiveness, and chewiness values confirmed that the soft wheat was more elastic and had a stronger structure network than the beans after cooking, which was in accordance with our rheology measurement. For these three parameters, no differences were found between garbanzo and navy bean. As shown in Fig. 1B and C, the gel formed by navy bean flour could generate a structure as strong as garbanzo flour during the cooling stage of temperature sweep and dynamic frequency sweep. Thus, these two flours were expected to develop similar textural properties after cooking.

4. Conclusions

The physicochemical and rheological properties of four bean flours were studied and found to be significantly affected by starch characteristics such as amylose content and granule size. The flours which starches had lower amylose content and smaller granules, i.e., soft wheat and

Table 4
Cooking and texture properties of pasta.[a]

Sample	Cooking time (min)	Water uptake (%, db)	Cooking loss (%, db)	Hardness (N)	Cohesiveness	Chewiness (N)
Garbanzo	5.5 ± 0.7^{c}	203.0 ± 5.0^{b}	10.3 ± 0.1^{b}	10.6 ± 0.9^{b}	0.2 ± 0.0^{b}	1.7 ± 0.3^{b}
Navy	9.5 ± 0.27^{b}	228.0 ± 2.7^{a}	14.9 ± 0.5^{a}	10.5 ± 0.7^{b}	0.2 ± 0.0^{b}	1.5 ± 0.1^{b}
Soft wheat	10.5 ± 0.7^{a}	200.0 ± 1.9^{b}	6.0 ± 0.5^{c}	14.3 ± 2.1^{a}	0.3 ± 0.0^{a}	3.0 ± 0.6^{a}

[a] Means in the same column with different superscripts indicate statistically significant differences ($p < 0.05$).

garbanzo flours, presented lower pasting temperatures. Flours from the *Phaseolus vulgaris* and *Cicer arietinum* beans with high amylose content developed stable hot pastes as evidenced by continuous increasing storage modulus during the entire heating period of a temperature sweep test. Although soft wheat starch did not develop the strongest structures by itself, soft wheat flour developed the strongest networks after a heat treatment due to its higher starch content and the presence of gluten. Our rheology test results also showed that garbanzo and navy bean flours developed equally strong structures and the texture parameters of pasta made from these flours were not significantly different. Therefore, among the bean flours included in this study, garbanzo and navy beans could serve as ingredients to develop gluten-free pasta with better quality.

Declaration of competing interest

The authors declare no competing financial interest.

Acknowledgments

This work is partially funded by the Nebraska Dry Bean Commission with Grant Program No. DB 2016–02.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jafr.2019.100001.

References

[1] USDA, Vegetables and pulses yearbook tables. https://www.ers.usda.gov/data-products/vegetables-and-pulses-data/vegetables-and-pulses-yearbook-tables/#Supply%20and%20Utilization:%20Dry%20Pulse%20Crops, 2018. (Accessed 9 April 2018).
[2] R.N. Tharanathan, S. Mahadevamma, Grain legumes - a boom to human nutrition, Trends Food Sci. Technol. 14 (12) (2003) 507–518, https://doi.org/10.1016/j.tifs.2003.07.002.
[3] F. Sumargo, P. Gulati, S.A. Weier, J. Clarke, D.J. Rose, Effects of processing moisture on the physical properties and in vitro digestibility of starch and protein in extruded brown rice and pinto bean composite flours, Food Chem. 211 (2016) 726–733, https://doi.org/10.1016/j.foodchem.2016.05.097.
[4] J.A. Gallegos-Infante, L.A. Bello-Perez, N.E. Rocha-Guzman, R.F. Gonzalez-Laredo, M. Avila-Ontiveros, Effect of the addition of common bean (*Phaseolus vulgaris* L.) flour on the in vitro digestibility of starch and undigestible carbohydrates in spaghetti, J. Food Sci. 75 (5) (2010) H151–H156, https://doi.org/10.1111/j.1750-3841.2010.01621.x.
[5] Y. Bahnassey, K. Khan, Fortification of spaghetti with edible legumes. II. Rheological, processing, and quality evaluation studies, Cereal Chem. 63 (3) (1986) 216–219.
[6] G. Giuberti, A. Gallo, C. Cerioli, P. Fortunati, F. Masoero, Cooking quality and starch digestibility of gluten-free pasta using new bean flour, Food Chem. 175 (2015) 43–49, https://doi.org/10.1016/j.foodchem.2014.11.127.
[7] P. Belton, Mini review: on the elasticity of wheat gluten, J. Cereal Sci. 29 (2) (1999) 103–107.
[8] R. Hoover, W.S. Ratnayake, Starch characteristics of black bean, chick pea, lentil, navy bean and pinto bean cultivars grown in Canada, Food Chem. 78 (4) (2002) 489–498, https://doi.org/10.1016/S0308-8146(02)00163-2.
[9] R. Hoover, T. Hughes, H.J. Chung, Q. Liu, Composition, molecular structure, properties, and modification of pulse starches: a review, Food Res. Int. 43 (2) (2010) 399–413, https://doi.org/10.1016/j.foodres.2009.09.001.
[10] M. Ma, Y. Wang, M. Wang, J.L. Jane, S.K. Du, Physicochemical properties and in vitro digestibility of legume starches, Food Hydrocolloids 63 (2017) 249–255, https://doi.org/10.1016/j.foodhyd.2016.09.004.
[11] T. Schoch, E. Maywald, Preparation and properties of various legume starches, Cereal Chem. 45 (1968) 564–573.
[12] AACC international, Approved Methods of Analysis. 11th Ed. Method 76–13.01. Total Starch Assay Procedure (Megazyme Amyloglucosidase/alpha-Amylase Method), AACC International, St. Paul, MN, U.S.A, November 8, 1995, https://doi.org/10.1094/AACCIntMethod-76-13.01. Approved.
[13] AACC international, Approved Methods of Analysis. 11th Ed. Method 08–01.01 Ash - Basic Method, AACC International, St. Paul, MN, U.S.A, April 13, 1961, https://doi.org/10.1094/AACCIntMethod-08-01.01. Approved.
[14] M. Piecyk, B. Drużyńska, E. Worobiej, R. Wołosiak, E. Ostrowska-Ligęza, Effect of hydrothermal treatment of runner bean (*Phaseolus coccineus*) seeds and starch isolation on starch digestibility, Food Res. Int. 50 (1) (2013) 428–437, https://doi.org/10.1016/j.foodres.2012.11.003.
[15] S. Du, H. Jiang, X. Yu, J.L. Jane, Physicochemical and functional properties of whole legume flour, LWT - Food Sci. Technol. (Lebensmittel-Wissenschaft -Technol.) 55 (1) (2014) 308–313, https://doi.org/10.1016/j.lwt.2013.06.001.
[16] G. Yazar, O. Duvarci, S. Tavman, J.L. Kokini, Non-linear rheological behavior of gluten-free flour doughs and correlations of LAOS parameters with gluten-free bread properties, J. Cereal Sci. 74 (2017) 28–36, https://doi.org/10.1016/j.jcs.2017.01.008.
[17] A. Salvador, T. Sanz, S. Fiszman, Dynamic rheological characteristics of wheat flour–water doughs. Effect of adding NaCl, sucrose and yeast, Food Hydrocolloids 20 (6) (2006) 780–786, https://doi.org/10.1016/j.foodhyd.2005.07.009.
[18] F. Wu, Y. Meng, N. Yang, H. Tao, X. Xu, Effects of mung bean starch on quality of rice noodles made by direct dry fl our extrusion, LWT - Food Sci. Technol. (Lebensmittel-Wissenschaft -Technol.) 63 (2) (2015) 1199–1205, https://doi.org/10.1016/j.lwt.2015.04.063.
[19] K. Wu, S. Dai, R. Gan, H. Corke, F. Zhu, Thermal and rheological properties of mung bean starch blends with potato, sweet potato, rice, and sorghum starches, Food Bioprocess Technol. 9 (8) (2016) 1408–1421, https://doi.org/10.1007/s11947-016-1730-1.
[20] J. Jane, Y.Y. Chen, L.F. Lee, A.E. McPherson, K.S. Wong, M. Radosavljevic, T. Kasemsuwan, Effects of amylopectin branch chain length and amylose content on the gelatinization and pasting properties of starch, Cereal Chem. 76 (5) (1999) 629–637, https://doi.org/10.1094/CCHEM.1999.76.5.629.
[21] M.I. Saleh, Protein-starch matrix microstructure during rice fl our pastes formation, J. Cereal Sci. 74 (2017) 183–186, https://doi.org/10.1016/j.jcs.2017.02.005.
[22] G. Baxter, C. Blanchard, J. Zhao, Effects of glutelin and globulin on the physicochemical properties of rice starch and flour, J. Cereal Sci. 60 (2) (2014) 414–420, https://doi.org/10.1016/j.jcs.2014.05.002.
[23] X. Rui, J.I. Boye, S. Ribereau, B.K. Simpson, S.O. Prasher, Comparative study of the composition and thermal properties of protein isolates prepared from nine *Phaseolus vulgaris* legume varieties, Food Res. Int. 44 (8) (2011) 2497–2504, https://doi.org/10.1016/j.foodres.2011.01.008.
[24] M.E. Matos, T. Sanz, C.M. Rosell, Establishing the function of proteins on the rheological and quality properties of rice-based gluten-free muffins, Food Hydrocolloids 35 (2014) 150–158, https://doi.org/10.1016/j.foodhyd.2013.05.007.
[25] A.R. Yousefi, S.M. Razavi, Dynamic rheological properties of wheat starch gels as affected by chemical modification and concentration, Starch 67 (2015) 7–8, https://doi.org/10.1002/star.201500005, 2015.
[26] S. Takahashi, P. Seib, Paste and gel properties of prime corn and wheat starches with and without native lipids, Cereal Chem. 65 (6) (1988) 474–483.
[27] R.F. Tester, W.R. Morrison, Swelling and gelatinization of cereal starches. I. Effects of amylopectin, amylose, and lipids, Cereal Chem. 67 (6) (1990) 551–557.
[28] H. Chung, Q. Liu, E. Donner, R. Hoover, T.D. Warkentin, B. Vandenberg, Composition, molecular structure, properties, and in vitro digestibility of starches from newly released Canadian pulse cultivar, Cereal Chem. 85 (4) (2008a) 471–479, https://doi.org/10.1094/CCHEM-85-4-0471.
[29] H. Chung, Q. Liu, R. Hoover, T.D. Warkentin, B. Vandenberg, In vitro starch digestibility, expected glycemic index, and thermal and pasting properties of flours from pea, lentil and chickpea cultivars, Food Chem. 111 (2) (2008b) 316–321, https://doi.org/10.1016/j.foodchem.2008.03.062.
[30] G.E. Vandeputte, V. Derycke, J. Geeroms, J.A. Delcour, Rice starches. II. Structural aspects provide insight into swelling and pasting properties, J. Cereal Sci. 38 (1) (2003) 53–59, https://doi.org/10.1016/S0733-5210(02)00141-8.
[31] N. Lindeboom, P.R. Chang, R.T. Tyler, Analytical, biochemical and physicochemical aspects of starch granule size, with emphasis on small granule starches: a review, Starch 56 (3–4) (2004) 89–99, https://doi.org/10.1002/star.200300218.
[32] P.M. Baldwin, J. Adler, M.C. Davies, C.D. Melia, Starch damage part 1: Characterization of granule damage in ball-milled potato starch study by SEM, Starch 47 (7) (1995) 247–251, https://doi.org/10.1002/star.19950470702.
[33] N. Singh, L. Kaur, Morphological, thermal, rheological and retrogradation properties of potato starch fractions varying in granule size, J. Sci. Food Agric. 84 (10) (2004) 1241–1252, https://doi.org/10.1002/jsfa.1746.

[34] K. Kohyama, J. Matsuki, T. Yasui, T. Sasaki, A differential thermal analysis of the gelatinization and retrogradation of wheat starches with different amylopectin chain lengths, Carbohydrates 58 (1) (2004) 71–77, https://doi.org/10.1016/j.carbpol.2004.06.032.
[35] S. Singh, N. Singh, N. Isono, T. Noda, Relationship of granule size distribution and amylopectin structure with pasting, thermal, and retrogradation properties in wheat starch, J. Agric. Food Chem. 58 (2) (2010) 1180–1188, https://doi.org/10.1021/jf902753f.
[36] L.A. Grant, N. Vignaux, D.C. Doehlert, M.S. Mcmullen, E.M. Elias, S. Kianian, Starch characteristics of waxy and nonwaxy tetraploid (*Triticum turgidum* L. var. durum) wheats, Cereal Chem. 78 (5) (2001) 590–595, https://doi.org/10.1094/CCHEM.2001.78.5.590.
[37] W. Li, G. Wu, Q. Luo, H. Jiang, J. Zheng, S. Ouyang, G. Zhang, Effects of removal of surface proteins on physicochemical and structural properties of A- and B-starch isolated from normal and waxy wheat, J. Food Sci. Technol. 53 (6) (2016) 2673–2685, https://doi.org/10.1007/s13197-016-2239-3.
[38] R.E. Cubadda, M. Carcea, E. Marconi, M.C. Trivisonno, Influence of gluten proteins and drying temperature on the cooking quality of durum wheat pasta, Cereal Chem. 84 (1) (2007) 48–55, https://doi.org/10.1094/CCHEM-84-1-0048.
[40] C. Tang, Thermal denaturation and gelation of vicilin-rich protein isolates from three Phaseolus legumes: a comparative study, LWT-Food Science and Technology 41 (8) (2008) 1380–1388. https://doi:10.1016/j.lwt.2007.08.025.
[41] C. Hoseney, Principles of Cereal Science and Technology, American Association of Cereal Chemists, St. Paul, MN, USA, 1999, pp. 269–274.

SSupplementary material

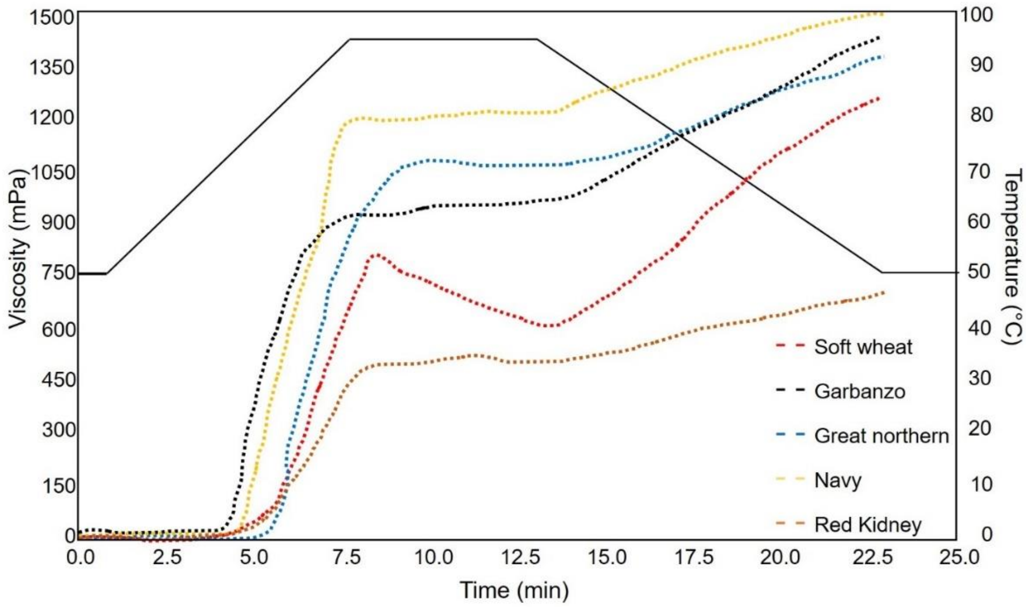

Figure S1. Pasting properties of soft wheat and bean starches (10%, db).