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Effects of Soy Protein Isolate on Pasting and Gelling Properties of Corn and Wheat Starches

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ABSTRACT

Starch and Soy Protein Isolate (SPI) have numerous applications in food products mostly as gelling and texturizing agents. The main purpose of this research was to investigate the pasting and gelling properties of the mixtures of starch and various levels of SPI (0, 5, 10, 15, 20 and 25%). To determine the effects of starch sources on the results, wheat and corn starches were tested in this study. It was found that with increasing the quantity of SPI, the viscosities obtained from Rapid Visco Analyser (RVA) including final, holding, and setback decreased while pasting temperature remained unchanged. Increasing the SPI concentrations enhanced the peak viscosity of the wheat starch-SPI samples, while it had opposite effects on corn starch-SPI samples. The colour of both starch-SPI gels became darker and more yellowish with increasing the SPI concentration. Although gel hardness increased during storage for 1 and 3 days at 4˚C, the addition of SPI reduced the hardness of the gels. The residual modulus of the Maxwell model from stress relaxation data showed that gels became softer and less elastic with increasing the SPI concentration. The corn starch-SPI gels exhibited darker color, higher firmness, cohesiveness, springiness, gumminess and chewiness compared to the wheat starch-SPI gels. The results may be useful to obtain the desired quality in food products containing starch and SPI.

Keywords: Carbohydrate, Cereal starch, Starch-protein gel, Starch-protein mixture.

INTRODUCTION

Apart from nutritional benefits, protein and starch from different sources are used in many food products to support textural properties, water uptake, and sensory attributes. Gelation is one of the distinct characteristics of proteins and starch, which occurs when they are heated at above their respective critical temperatures that enable water interactions and network formation (Majzoobi *et al*., 2014a). In many food products such as bakery products, processed meats, noodles, pasta and gluten-free foods, starch and proteins are present naturally or added to support texture and improve nutritional value (Brewer *et al.*, 1992; Siegwein *et al.*, 2011; Majzoobi *et al.*, 2014b). It has been shown that starch and proteins are able to interact with each other through electrostatic forces, hydrogen bonding, van der Waals forces and entanglements. This is because of the numerous hydrophilic groups such as –OH, -NH2, -COOH and –SH in the alkyl side chains of the proteins, which make them capable of forming links with starch (Ingrid *et al.*, 1997; Sopade *et al.*, 2006). Such interactions have a great impact on the quality of the final product. In recent years, the physicochemical properties of starch-protein mixtures have become an interesting research

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topic. For example, the improved gelling properties of cassava starch-whey protein isolate has been reported (Aguilera and Rojas, 1996). Kyaw *et al.* (2001) and Wu *et al.* (2007) showed that during thermal processing of starch-fish protein systems, significant rheological changes occur due to the starch gelatinisation and sol-gel transformation of fish proteins. Interactions between starch and some food proteins, including gluten, meat proteins, fish proteins, casein, gelatine and cereal proteins have been investigated already (Bertolini *et al.*, 2005; Carvalho *et al.*, 2007; Jamilah *et al.*, 2009; Sun *et al.*, 2016). According to these studies, the type of protein and starch and their concentrations have great influence on the measured physical properties including water interaction, pasting, and gelling properties.

Amongst different food proteins, soy proteins have received special attention due to their availability, well balanced amino-acid composition, health benefits (known as a functional protein), ability to improve texture and retain water in the food products (Xiao, 2008; Shao *et al.*, 2009). In addition, soy proteins have great potential in the substitution of animal-based proteins which is important in the production of high-quality meat-free products (Messina and Messina, 2010). Soy Protein Isolate (SPI) is a complex mixture of proteins (90%), mostly globulins with numerous applications in meat-free products, gluten-free foods, cereal-based products, and many other foods in which starch is also present naturally or added as an ingredient (Shao *et al.*, 2009). Therefore, it is important to understand how the combination of starch and SPI can affect pasting and gel properties of the blend. Previous studies have shown some physicochemical aspects of SPI and starch mixtures. Takahashi *et al.* (1983) showed that the swelling power and solubility of potato and sago starches decreased markedly, while gelatinisation temperature increased when soybean protein was added. Mariani *et al.* (2009) investigated the effect of SPI on the thermal, morphological, and mechanical properties of poly Ɛ-caprolactone and corn starch blends. They showed that different combinations of starch and soy protein isolate had lower compression value in comparison with poly Ɛ-caprolactone alone. Siegwein *et al.* (2011) studied the effects of SPI on a starch-based grape confectionery gels made with acid thinned wheat starch. They found that the SPI caused a reduction in hardness, cohesiveness, and gumminess of the product. Li *et al.* (2014) found no chemical interactions between SPI and corn starch when they were heated from 20 to 130˚C. They also indicated that SPI in the blend restricted the corn starch gelatinization, while the presence of corn starch protected the SPI from denaturation. Yu *et al.* (2015) reported that the addition of soybean 7S and 11S globulins to non-waxy corn starch delayed starch retrogradation.

Nevertheless, there is still a lack of information to show the gel properties of starch-SPI mixture which can be helpful in better understanding of the quality of the end products.

The main intention of this research was to investigate the pasting and gelling properties of mixtures of starch-SPI at different levels of SPI during storage for 1 and 3 days at 4˚C. Wheat and corn starches were selected as the two common types of starches in food products. Such information is useful in selecting the appropriate type of starch and SPI concentration in product development and to interpret the changes in the quality of starch-based foods when SPI is incorporated in the formulation.

MATERIALS AND METHODS

Materials

Native wheat starch was purchased from Fars Glucosin Company (Marvdasht, Iran). It contained 0.26% protein, 0.03% fat, 9.48% moisture, 0.05% ash (AACC, 2000) and 25.15% amylose content measured by iodine method (Morrison and Laignelet, 1983). Native corn starch was purchased from Mahshad-e-Yazd

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Company, Yazd, Iran and contained 0.43% protein, 0.02% fat, 8.48% moisture and 0.08% ash (AACC, 2000) and 27.90% amylose content measured by iodine method (Morrison and Laignelet, 1983). The Karen Nutrilife Company (Tehran, Iran) donated SPI contained 4.80% moisture, 3.55% ash, 90.70% protein, and 0.95% fat (AOAC, 2000).

Sample Preparation and Paste Viscosity

Starch (3.00 g) was dry mixed thoroughly with different levels of SPI (0, 5, 10, 15, 20, and 25%, w/w), and added to 25.00 g distilled water and mixed in an RVA canister in order to prevent lumps. Then, the mixtures were subjected to the following heat treatment using a Rapid Visco Analyzer (Starch Master2, Perten, Australia), held at 50°C for 1 minute, heated to 95°C in 3 minutes and 42 seconds, held at 95°C for 2 minutes and 30 seconds, cooled down to 50°C in 3 minutes and 48 seconds, and held at 50°C for 2 minutes. The suspension was stirred at 960 rpm for 10 seconds; then, the paddle speed was reduced to 160 rpm for the rest of the test with a total mixing time of 13 minutes. Viscosity-mixing time graphs indicating pasting temperature, peak viscosity, holding viscosity, final viscosity, breakdown (peak viscosity-holding viscosity) and setback viscosity (final viscosity-holding viscosity) of the samples were obtained from the RVA graph and analysed.

Textural Properties of Gels

The paste obtained at the end of the RVA test was immediately poured into a plexiglass cylindrical mould with 1 cm height and 2 cm diameter, covered with a glass plate to avoid moisture loss and kept at 4°C overnight to obtain starch-SPI gel. A Texture Analyzer (Texture Analyzer, TA Plus, Stable Microsystems, Surrey, England) was used to measure the force-time curves. The gels were compressed with a 4 cm aluminium cylindrical probe at a test speed of 0.25 mm s^{-1} and a trigger force of 3.0 g with 25% deformation level of original sample height in a "Texture Profile Analysis" (TPA) double compression test. Hardness (the maximum force achieved through the first compression cycle), springiness (the ratio of the time duration of force input during the second compression to the first compression), cohesiveness (the ratio of the positive force area under the second compression (A1) to that during the first compression (A2), work (the area under force versus time until maximum force), gumminess (hardness multiplied by cohesiveness), chewiness (cohesiveness multiplied by springiness multiplied by gumminess) and gradient were determined using the Texture Exponent Lite software supplied by the manufacturer (Azizi and Farahnaky, 2013). This test was also performed on gels refrigerated for three days to investigate the effect of different levels of SPI on textural properties of starch gels upon storage.

Stress Relaxation Behaviour

The starch gels (prepared as explained in the previous section) were compressed by 25% with a 4 cm aluminium cylindrical probe at the speed of 2.00 mm s^{-1}. The compression level was kept constant for 120 seconds during which the force was recorded by the Texture Analyser. The generalized Maxwell model was used to analyze stress relaxation data. Most relaxation curves can be fitted by this model with two or three exponential terms (Peleg and Pollak, 1982). This model can be written as follows:

$$E(t) = E_e + \sum_{i=1}^{n} E_i exp\left(-\frac{t}{\tau_i}\right) \quad (1)$$

Where, *E(t)* is the modulus decaying curve determined from experiments, τ_i is the relaxation time of the *i*-th Maxwell element, *t* is the experimental decay time, and *Ee* represents the Equilibrium or residual modulus at the fully decayed state, that is, when all relaxable stress is fully relaxed

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(Campus *et al.*, 2010; Azizi and Farahnaky, 2013).

Data were fitted to Maxwell model by MATLAB 7 software (The MathWorks, Inc., USA), using curve fitting toolbox and Trust-Region algorithm. Then, the degree of fit was judged by R^2 coefficient computed by MATLAB software.

Color Evaluation

The method described by Afshari-Jouybari and Farahnaky (2011) was used to evaluate the color of the gels. In this method, Adobe Photoshop 11 (Adobe Systems Inc., Beijing, China) was used to determine the color differences of the saved JPEG format of the pictures of gels taken by a digital camera (Canon, Model IXUS 75, 7.1 Megapixels, Tokyo, Japan). Resolution, contrast and lightness of all images were set to 300 dots per inch (dpi), 62 (%) and 62 (%), respectively. The Lightness (L-value), blueness-yellowness (b-value) and redness-greenness (a-value) were measured for all gels.

Statistical Analysis

All experiments were conducted in triplicate and a completely randomized design was used. Mean and standard deviation were calculated using Microsoft Excel 2007 (Microsoft Corporation, USA). Analysis Of Variance (ANOVA) was performed and the results were separated using the Multiple Ranges Duncan's test ($P< 0.05$) using statistical software of Statistical Package for Social Science 16 (SPSS) (SPSS, Inc., USA).

RESULTS AND DISCUSSION

Pasting Properties

Table 1 shows the pasting properties of corn and wheat starches in the presence of different levels of SPI. Pasting properties of different starches are affected by granular morphology, amylose content, chemical composition, and molecular structure (Singh *et al.*, 2003; Li *et al.*, 2014) which can be the reason for different pasting behaviours of corn and wheat starches. Upon heating of the starch suspension, starch granules absorb water, swell and mostly amylose molecules leach out of the granules resulting in an increase in the viscosity (Tester *et al.*, 2004). Pasting temperature is the minimum temperature at which the viscosity begins to rise due to the heating. Gel formation of proteins during heating depends on various factors including temperature, pH, and protein concentration which would consequently affect starch water uptake and viscosity (Ziegler and Foegeding, 1990). The results showed that the pasting temperature of both starches increased slightly with addition of SPI, but the changes were not significant ($P< 0.05$). This may indicate that the temperature, heating time, and protein concentration were not adequate for protein deformation, water uptake (Sopade *et al.*, 2006; Chen *et al.*, 2016) and, possibly, interactions with starch molecules. Similarly, Bertolini *et al.* (2005) found no changes in the pasting temperature for wheat, corn and rice starches in the presence of sodium caseinate (milk protein).

With increasing the temperature and heating time, water absorption, swelling of the granules, and diffusion of the starch molecules reached the highest level leading to the peak viscosity (Tester *et al.*, 2004). At this stage, the temperature is high enough for SPI to form a gel, however, gel strength positively depends on the protein concentration. Based on the results, the peak viscosity of the corn starch-SPI mixture increased with the inclusion of 10% SPI and remained constant with a further addition of SPI. However, the viscosity of the wheat starch-SPI mixture decreased with the addition of 10% SPI and then remained unchanged with further addition of SPI. Sopade *et al.* (2006) reported a decrease in

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Table 1. Pasting properties of Corn Starch (CS) and Wheat Starch (WS) prepared with different levels of Soy Protein Isolate (SPI) as measured by the RVA.[a]

SPI (%)	Samples	Pasting temp (°C)	Peak viscosity (cP)	Holding viscosity (cP)	Final viscosity (cP)	Breakdown (cP)	Setback (cP)
0	CS	71.1±4.5^{bcd}	6050±12^{defg}	2264±162de	6454±184^{f}	3785±172^{cd}	4189±68^{g}
	WS	64.0±5.0^{a}	5914±41^{bcde}	3477±272^{h}	8000±100^{g}	2527±235^{a}	4523±272^{g}
5	CS	71.2±4.6^{cd}	6004±61^{cdef}	2597±247^{fg}	6260±43 ^{f}	3317±306^{b}	3662±250^{f}
	WS	67.2±0.4^{abc}	6272±47^{fghi}	2733±186^{g}	6263±185^{f}	3539±233^{bc}	3529±104^{f}
10	CS	74.2±0.1^{d}	6385±78^{hi}	2497±247^{efg}	5703. ±66^{e}	3887±227^{cde}	3206±232^{ef}
	WS	66.5±0.8^{abc}	5612±255^{ab}	2015±15^{bcd}	4798±352^{d}	3597±258^{bc}	2783±352de
15	CS	74.0±0.2^{d}	6495±80^{i}	2338±71^{def}	4113±177^{c}	4157±141de	1775±175^{ab}
	WS	66.3±0.4^{ab}	5725±249^{abcd}	1835±25^{bc}	4207±308^{c}	3890±268^{cde}	2372±290^{cd}
20	CS	74.3±0.3^{d}	6365±127^{ghi}	2038±65^{cd}	3866±125^{bc}	4327±117^{e}	1828±190^{ab}
	WS	66.4±0.3^{abc}	5695±290^{abc}	1697±54^{ab}	3910±129^{bc}	3997±237^{cde}	2212±92^{bc}
25	CS	73.9±0.3^{d}	6123±149^{efgh}	2029±21^{bcd}	3574±207^{ab}	4094±147de	1544 ±227^{a}
	WS	66.2±0.5^{ab}	5432±217^{a}	1500±187^{a}	3212±124^{a}	3932±274^{cde}	1712±277^{a}

[a] Values are the means±standard deviation. Different superscripts within the same column show significant difference (P< 0.05).

peak viscosity of wheat starch-whey protein isolate mixture at various concentrations of protein ranging from 0-100%. Bertolini *et al.* (2005) reported an increase in peak viscosity of wheat, corn, and rice starches but a reduction in the peak viscosity of potato starch in the presence of sodium caseinate. Formation of intermolecular interactions of SPI molecules and their water absorption, their interactions with the leached starch molecules as well as increase in the total solid mass can promote viscosity (Mohamed *et al.*, 2009). However, rupture of the granules and alignment of the macromolecules in the system can cause a decrease in viscosity (Tester *et al.*, 2004) and hence the equilibrium between these two opposite events determines the viscosity at this stage.

Breakdown of the starch-SPI mixture indicates the ability of the matrix composed of the swollen starch granules and the SPI gel to tolerate heating and shear stress. For both samples, an increase in the breakdown viscosity was observed with addition of the SPI concentration. This may be related to the increase of the SPI aggregates and its ability to form a stronger gel with increasing the heating time and concentration as well as more interactions between starch and SPI molecules. Similar results have been reported at different concentrations of whey protein concentrate and whey protein isolate (0-100%) mixed with wheat starch (Sopade *et al.*, 2006).

During cooling of the heated starch-protein mixture, final viscosity increased due to the increase in the molecular entanglement and gelation and was related to retrogradation of starch molecules (Majzoobi *et al.*, 2011). Based on the results, final viscosity and setback of both starch-SPI samples decreased with increasing the level of SPI, which is in agreement with Sopade *et al.* (2006) for wheat starch-whey protein isolate or concentrate. However, Yu *et al.* (2015) indicated that the addition of 50% SPI to corn starch had no effect on starch retrogradation. It is possible that the SPI molecules disrupted the starch molecules to form a well-integrated gel during cooling and hindered retrogradation process.

Except for the peak viscosity, other pasting properties of corn or wheat starch-SPI mixtures showed similar trends with increasing the SPI concentration. However, corn starch-SPI had higher pasting temperature, peak, and holding viscosity than wheat starch-SPI, but presented similar final viscosity, breakdown, and setback.

Textural Properties of the Gels

The textural properties of starch-SPI gels after 1 and 3 days of storage at 4˚C are presented in Table 2. The larger maximum force, gradient, and work values of the control wheat starch gel compared to the control corn starch gel after 1 day storage suggest the firmer texture of wheat starch gel, which is in agreement with previous results (Maphalla and Emmambux, 2016). After storage for 3 days at 4˚C, the firmness of both control gels increased due to the starch retrogradation (Karim *et al.*, 2000). However, corn starch gel had higher rate of retrogradation as both starch gels had a similar maximum force (hardness) at the third day. Addition of SPI to both starches dramatically reduced maximum force, gradient, work, gumminess, and chewiness of gels. It also caused a significant decrease in springiness only when added at 25% (maximum concentration). Similar changes were observed for the samples stored for 3 days. The textural changes could have resulted from direct disruption of the starch network or the hydrated soy protein may have acted as a macromolecular plasticizer, thereby reducing the gel stiffness (Vittadini and Vodovotz, 2003). Another possible explanation can be related to the retention of more water in the gel system due to the increased interactions between SPI with water molecules that happened with increasing the concentration of SPI. In addition, the gel network produced by a

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Table 2. Textural properties of Corn Starch (CS) and Wheat Starch (WS) gels prepared with different levels of Soy Protein Isolate (SPI) kept at 4 °C.[A]

SPI (%)	samples	Maximum force (g)	Gradient (g mm-1)	Work (g mm)	Cohesiveness	Springiness	Gumminess (g)	Chewiness (g)
Textural properties of the gels after 1 day of storage at 4°C								
0	CS	213.56±10.89^{h}	127.35±8.03^{g}	206.04±11.06^{g}	0.950±007^{e}	0.989±0.020^{cd}	202.90±10.55^{h}	190.40±13.60^{h}
	WS	271.18± 7.01^{i}	162.25±5.59^{h}	262.45±27.55^{h}	0.926±0.009^{d}	0.986±0.009^{cd}	251.12±7.04^{i}	229.25±7.86^{i}
5	CS	188.60±7.00^{g}	109.60±3.36^{f}	187.01±9.90^{f}	0.955±0.005^{ef}	0.996±0.004^{d}	180.14±6.71^{g}	171.47±7.03^{g}
	WS	186.10±8.51^{g}	117.85±7.78^{f}	173.23±15.86^{f}	0.903±0.003^{abc}	0.991±0.005^{d}	168.13±8.06^{f}	150.56±7.58^{f}
10	CS	126.02±7.54^{e}	76.82±5.51^{e}	120.56±4.96^{d}	0.957±0.009^{ef}	0.987±0.160^{cd}	120.74±8.08^{e}	114.35±10.10^{e}
	WS	141.33±8.71^{f}	79.59±5.80^{e}	139.39±8.16^{e}	0.899±0.007^{ab}	0.990±0.007^{cd}	127.05±8.38^{e}	113.09±8.35^{e}
15	CS	98.67±9.10^{cd}	57.49±6.22^{cd}	95.64±10.35^{c}	0.945±0.015^{e}	0.979±0.140^{cd}	93.30±8.64^{d}	86.51±9.22^{d}
	WS	108.03±2.78^{d}	63.90±2.71^{d}	100.31±3.34^{c}	0.912±0.008^{bcd}	0.986±0.007^{cd}	98.57±2.58^{d}	88.68±2.90^{d}
20	CS	76.70±1.74^{b}	45.58±4.36^{ab}	73.57±2.73^{ab}	0.939±0.013^{f}	0.970±0.150^{a}	72.08±2.21^{bc}	65.71±2.89^{bc}
	WS	90.56±4.12^{c}	54.06±6.32^{bc}	83.08±5.69^{bc}	0.892±0.010^{a}	0.983±0.0142^{cd}	80.82±3.88^{c}	70.94±4.67^{c}
25	CS	65.56±1.94^{a}	37.50±5.09^{a}	63.60±2.04^{a}	0.919±0.014^{cd}	0.970±0.011^{bc}	60.26±2.20^{a}	53.81±3.08^{ab}
	WS	68.82±2.43^{ab}	41.32±2.11^{a}	63.27±3.18^{a}	0.893±0.013^{a}	0.954±0.014^{ab}	61.52±2.65^{ab}	52.48±3.34^{a}
Textural properties of the gels after 3 days of storage at 4°C								
0	CS	343.86±5.47^{i}	205.35±10.15^{h}	322.78±10.52^{i}	0.930±0.014^{e}	0.999±0.002^{e}	319.73±9.36^{j}	297.16±12.87^{h}
	WS	339.65±14.23^{i}	197.63±24.04^{h}	336.36±18.79^{i}	0.902±0.031^{b}	0.991±0.016^{bc}	306.27±18.06^{i}	274.23±27.09^{g}
5	CS	311.66±4.62^{h}	199.09±7.71^{h}	289.58±12.11^{h}	0.939±0.004^{e}	1.000±0.002^{e}	292.76±3.43^{h}	274.98±2.61^{g}
	WS	215.58±6.54^{f}	130.20±7.68^{ef}	205.92±7.89^{f}	0.903±0.004^{b}	0.986±0.011^{bc}	194.62±5.69^{f}	173.28±6.90^{e}
10	CS	248.08±3.83^{g}	164.52±1.97^{g}	223.83±4.51^{g}	0.945±0.004^{e}	1.000±0.005^{e}	234.51±3.89^{g}	221.57±3.57^{f}
	WS	168.28±3.32^{e}	99.96±4.87^{d}	159.03±7.63^{d}	0.895±0.010^{ab}	0.984±0.009^{ab}	150.58±3.67^{d}	132.61±5.47^{c}
15	CS	205.04±11.29^{f}	131.85±17.16^{f}	186.88±6.04^{e}	0.939±0.006^{e}	0.994±0.004^{bc}	192.43±9.99^{f}	179.57±9.15^{e}
	WS	123.40±6.20^{c}	78.95±9.18^{bc}	111.59±9.53^{b}	0.891±0.013^{ab}	0.970±0.008^{a}	109.94±5.92^{b}	95.05±5.49^{b}
20	CS	176.82±6.01^{e}	113.97±9.79^{de}	161.05±9.16^{d}	0.929±0.006^{e}	0.991±0.009^{bc}	164.34±5.23^{e}	151.40±4.49^{d}
	WS	111.59±4.16^{b}	70.43±8.00^{ab}	104.71±2.23^{b}	0.881±0.008^{a}	0.984±0.013^{ab}	98.25±3.05^{b}	85.10±1.32^{b}
25	CS	143.89±3.52^{d}	96.43±7.55^{cd}	126.47±2.79^{c}	0.925±0.010^{e}	0.998±0.006^{e}	133.15±4.19^{c}	123.02±5.39^{c}
	WS	85.44±1.91^{a}	53.29±4.70^{a}	78.42±2.14^{a}	0.878±0.014^{a}	0.981±0.008^{ab}	74.99±2.46^{a}	64.61±2.83^{a}

[A] Values are the means ± standard deviation. Different superscripts within the same column show significant difference (P< 0.05).

combination of SPI and starch can hold more water and prevent water release during storage (i.e. syneresis). Similar gel weakening effects have been reported for wheat starch-whey protein mixtures (> 55% solids), however, with increasing the whey protein concentration, the gel strength of the mixture increased (Yang *et al.*, 2004). The results are also in agreement with Sopade *et al.* (2006) who found a reduction in gel strength by addition of different levels whey protein isolate and whey protein concentrate to form wheat starch-protein mixture. Previous studies have indicated that the protein and starch concentration in the mixture have a great influence on the gel properties. If the concentration of starch is high enough to form a continuous network, protein aggregates can weaken the gel strength of the mixture (Shim and Mulvaney, 2001; Ravindra *et al.*, 2004; Elgadir *et al.*, 2012). Although the control wheat and corn starch gels showed different textural properties after 1 day of storage, corn starch-SPI gels and wheat starch-SPI gels appeared to have similar textural properties. Nevertheless, after storage for 3 days, corn starch-SPI gels appeared to be firmer (higher maximum force, gradient and work), more cohesive, springy, gummy and chewy compared to the wheat starch-SPI gels. These changes may indicate the development of different levels of interactions between starch molecules, SPI and water molecules in the samples during storage time, which requires further investigation.

Stress Relaxation Behaviour

The values of Equilibrium modulus (E_e), decay modulus that represents elastic component (E_i), and relaxation time (τ_i) were used for analysis of the results (Table 3). The large values of R^2 show the high correlation between the experimental data and fitted data to the Maxwell model. Gels with higher E_e, E_i, and τ_i values and have more rigid, elastic, and solid-like texture (Tang *et al.*, 1998; Herrero *et al.*, 2004; Bhattacharya, 2010). Therefore, the control wheat starch gel was significantly firmer and more solid compared to corn starch gel, in agreement with the results of texture studies (Table 2). With the addition of SPI, the firmness of both samples decreased significantly. The reduction in the E_i with addition of SPI level for both samples indicates the resistance of the sample toward compression prior to relaxation, so, the lower E_i values showed that the sample had a less solid-like texture, hence, the force required for compression decreased (Bhattacharya, 2010). The different percentages of SPI showed no significant effect on τ_1 and τ_2 of each of corn and wheat starch gels, while differences in the source of starch had greater effect on these parameters.

Color

Color of the gels is affected by the internal structure of the gels and the concentration of the macromolecules. The results (Table 4) show that the color parameters of the gels were affected by increasing the concentration of SPI, so that the Lightness (L-value) decreased, yellowness (b-value) increased, but redness (a-value) remained almost unchanged. These changes can be related to the increase in the total concentration of macromolecules in the gel system and their interactions with each other and with water molecules, which can affect light reflection from the surface of the samples. In addition, the existence of natural creamy chromophores in SPI can be contributed to the gel color (Majzoobi *et al.*, 2014b). In general, corn starch gels were more yellowish than wheat starch gels with the same amount of SPI and had lower a-values, but similar lightness. This can be due to the differences of these two gels in terms of molecular size and distribution of starch molecules and their interactions with SPI, which requires more investigation.

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Table 3. Relaxation parameters of Corn Starch (CS) and Wheat Starch (WS) gels prepared with different levels of Soy Protein Isolate (SPI).

SPI (%)	Samples	E_1 (g)	τ_1 (s)	E_2 (g)	τ_2 (s)	E_e (g)	R^2
0	CS	5.767^{efg}	0.576^{a}	4.360^{de}	75.899^{g}	58.905^{h}	0.924
	WS	8.766^{h}	0.745^{ab}	4.294^{de}	63.525^{cde}	79.132^{i}	0.965
5	CS	6.786^{g}	1.246^{e}	3.932^{cde}	61.568^{bcde}	49.403^{f}	0.971
	WS	7.929^{h}	0.806^{bc}	5.500^{f}	57.431^{bcd}	53.400^{g}	0.976
10	CS	4.531^{cd}	0.873^{bcd}	3.118^{bc}	65.257^{ef}	32.058^{d}	0.965
	WS	6.480^{fg}	0.948^{cd}	4.413^{de}	56.930^{bc}	37.803^{e}	0.979
15	CS	4.089^{bc}	0.961^{cd}	3.097^{bc}	64.078^{def}	26.045^{c}	0.968
	WS	5.543^{def}	1.043^{d}	3.718^{cd}	57.734^{bcd}	29.593^{d}	0.979
20	CS	3.413^{ab}	0.984^{cd}	2.216^{a}	70.650^{fg}	20.735^{b}	0.960
	WS	5.320^{de}	1.5154^{f}	4.685^{ef}	48.514^{a}	18.351^{ab}	0.989
25	CS	3.016^{a}	1.038^{d}	2.323^{ab}	64.141^{def}	17.028^{a}	0.964
	WS	5.069^{cde}	1.347^{ef}	2.792^{ab}	56.026^{b}	18.664^{ab}	0.979

[a] Values are the means±standard deviation. Different superscripts within the same column show significant difference ($P< 0.05$).

Table 4. Color parameters of Corn Starch (CS) and Wheat Starch (WS) gels prepared with different levels of Soy Protein Isolate (SPI).[a]

SPI (%)	Samples	L	a	b
0	CS	67.3 ± 0.9^{f}	-8.6 ± 1.7^{b}	15.7 ± 2.2^{c}
	WS	68.0 ± 0.7^{f}	-6.2 ± 0.7^{d}	6.9 ± 0.9^{a}
5	CS	65.7 ± 0.5^{e}	-8.6 ± 0.9^{b}	18.7 ± 1.4^{d}
	WS	65.2 ± 0.9^{e}	-6.8 ± 0.7^{cd}	11.8 ± 1.4^{b}
10	CS	63.4 ± 0.5^{d}	-10.4 ± 1.7^{a}	22.2 ± 1.7^{f}
	WS	64.7 ± 1.0^{e}	-7.3 ± 1.1^{bcd}	15.9 ± 1.4^{c}
15	CS	62.9 ± 0.8^{cd}	-10.4 ± 1.1^{a}	24.3 ± 2.0^{g}
	WS	62.4 ± 0.7^{bcd}	-7.8 ± 1.4^{bcd}	20.2 ± 1.6^{de}
20	CS	63.0 ± 1.1^{cd}	-8.2 ± 2.2^{bc}	25.1 ± 2.4^{gh}
	WS	62.3 ± 0.9^{bc}	-7.0 ± 1.4^{bcd}	21.6 ± 1.3^{ef}
25	CS	61.6 ± 1.3^{b}	-7.1 ± 1.2^{bcd}	26.9 ± 1.7^{hi}
	WS	59.0 ± 1.0^{a}	-7.7 ± 0.9^{bcd}	27.3 ± 1.1^{i}

[a] Values are the means±standard deviation. Different superscripts within the same column show significant difference ($P< 0.05$).

CONCLUSIONS

This study showed that both wheat starch and corn starch can form a gel with SPI upon heating, but no synergic effect on the gel strength was observed. Addition of 0-25% SPI had some effects on pasting properties of both starches. Corn starch-SPI had higher pasting temperature, peak, and holding viscosity than its wheat starch counterpart. However, during cooling stage in the RVA, both starch-SPI samples showed similar final, breakdown, and setback viscosities. Corn starch-SPI gels were generally firmer, more cohesive, gummy, and chewy and presented darker and more yellowish color compared to the wheat starch-SPI gels after storage for 3 days at 4˚C. Corn starch and wheat starch gels showed different textural kinetics over storage at 4˚C. The results suggest that the overall behaviour of both starches in the

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presence of various levels of SPI was similar and differences were mostly due to the intrinsic differences between the two starches. Therefore, in a starch-SPI system, source of starch has a great effect on pasting and physical properties of the gels and hence selection of the suitable type of starch based on the end-product quality is of great importance. Further studies are required to show such effects on other sources of starches and at higher concentrations of SPI.

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اثرات ایزوله پروتیینی سویا بر ویژگی های خمیری شدن و ژل دهی نشاسته های ذرت و گندم

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چکیده

نشاسته و ایزوله پروتیینی سویا (SPI) دارای کاربردهای متعددی در محصولات غذایی هستند و عمدتا به عنوان عوامل ژل دهنده و بافت دهنده استفاده می‌شوند. هدف اصلی از این تحقیق بررسی ویژگی‌های خمیری شدن و ژل دهندگی مخلوطی از نشاسته‌های گندم و ذرت و درصدهای مختلف SPI (۰، ۵، ۱۰، ۱۵، ۲۰ و ۲۰٪) بود. برای تعیین اثرات نوع نشاسته بر نتایج، در این تحقیق نشاسته گندم و ذرت مورد ارزیابی قرار گرفتند. نتایج نشان داد که با افزایش مقدار SPI ویسکوزیته حاصل از دستگاه سنجش سریع ویسکوزیته (RVA) شامل ویسکوزیته‌های نهایی، نگه داشته شده و برگشت کاهش یافت ولی دمای خمیری شدن تغییری نیافت. افزایش درصد SPI باعث افزایش ویسکوزیته اوج نمونه‌های نشاسته گندم-SPI گردید ولی اثرات معکوسی بر نمونه‌های ذرت-SPI نشان داد. با افزایش درصد SPI رنگ هر دو نمونه تیره‌تر و زردتر گردید. گرچه سفتی بافت در طی نگهداری به مدت یک و سه روز در دمای $^{\circ}C$ ۴ افزایش یافت، افزودن SPI باعث کاهش سفتی ژل‌ها شد. تعیین باقیمانده مدول مدل ماکسول حاصل از آزمون تنش-استراحت نشان داد که با افزایش درصد SPI بافت ژل‌ها نرم‌تر و الاستیسته کاهش یافت. ژل‌های نشاسته ذرت-SPI دارای رنگی تیره‌تر بودند و بافتی سفت‌تر، منسجم‌تر، برگشت‌پذیرتر، ژله ای‌ترو غیرقابل جویدن‌تر نسبت به ژل‌های نشاسته گندم و SPI داشتند. این نتایج در بدست آوردن کیفیت مطلوب در محصولات غذایی حاوی نشاسته و SPI می تواند مفید باشد.

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