Preparation of gluten-free rice spaghetti with soy protein isolate using twin-screw extrusion

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Abstract The objective of this study was to investigate the effect of soy protein isolate on functional properties and consumer acceptance of gluten-free rice spaghetti (GFRS) made from rice flour. Dry-milled high-amylose (Chai Nat 1) rice flour was premixed with dry-milled waxy (RD 6) rice flour at a ratio of 90:10 (w/w) with the soy protein isolate (SPI) concentration varying between 0, 2.5, 5.0, 7.5, 10.0 %, db. The GFRS formulation was processed using a co-rotating twin-screw extruder up to 95 °C with a screw speed of 220 rpm, 32 % moisture content, and then dried at 40 °C. The GFRS samples were analyzed by differential scanning calorimetry (DSC), X-ray diffraction, scanning electron microscopy (SEM) and texture parameters. Increasing SPI decreased the starch retrogradation of GFRS, whereas the enthalpy change of the amylose–lipid complex increased and crystallinity decreased. SEM revealed that the surface of GFRS containing SPI was much more porous than that of GFRS without SPI. The cooked GFRS containing 5.0 % SPI showed the best eating quality with increased firmness and tensile strength, and decrease stickiness. The GFRS samples were evaluated on the bases of cooking qualities and sensory evaluation. The results showed that the GFRS containing 5.0 % SPI decrease the cooking time from 17.6 to 13.7 min and cooking loss from 25.4 to 17.0 %. Overall acceptability of

cooked GFRS containing 5.0 % SPI was the highest among all GFRS samples.

Keywords Rice · Soy protein isolate · Gluten- free · Rice spaghetti · Extrusion

Introduction

Celiac disease is one of the most common allergies, which is caused both environment (gluten) and genetic factors (Gujral et al. 2012). The prevalence of celiac disease in the United States and Europe has been estimated to be approximately 1 % of the general population (Niewinski 2008). Gluten corresponds to the major storage protein in wheat and plays an important role in wheat products, such as bread, and pasta. Spaghetti is a popular type of pasta and is made from durum wheat (*Triticum durum* L.) semolina and water kneaded to form dough with a moisture content of around 25–30 % (Marchylo and Dexter 2001). During kneading, a gluten network is formed as a continuous phase in the dough and starch is entrapped in the protein network (Matsuo et al. 1978). The dough is then extruded to form a spaghetti shape at a controlled temperature below 50 °C to optimize the texture of the spaghetti. If the temperature of the extruder barrel rises to above 50 °C, the gluten will be denatured and starch is gelatinized, which will reduce the textural and cooking qualities of spaghetti (Marchylo and Dexter 2001). After extrusion at a low temperature, the spaghetti is then dried at a high temperature, resulting in denaturation of the gluten network and the increased rigidity of the network. When spaghetti is cooked in boiling water, the strong protein network can entrap the starch and the spaghetti will display high firmness, low stickiness and low cooking loss (Zweifel et al. 2003), which are

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characteristics of spaghetti preferred by consumers. Wheat spaghetti, however, contains gluten that causes problems for people with celiac disease. Thus, gluten-free food is a necessity for this group of people. According to the Food and Drug Administration, a gluten-free product is defined as food which contains less than 20 ppm of gluten (U.S. Food and Drug Administration 2015). Moron et al. (2008) developed enzyme-linked immunosorbent assays (ELISAs) to detect gluten in cereal, and gluten is not detectable in rice. Thus rice is good alternative choices for producing gluten-free products. In addition, rice has many advantages, such soft taste, colorless, high digestibility, and low level of sodium (Marco and Rosell 2008).

Generally, traditional rice noodle products are made from long-grain rice flour with intermediate to high amylose content, >22 g/100 g (Fu 2008). The ratio of amylose to amylopectin, which plays a role in creating a starch network, is important for rice noodles. Detchewa et al. (2012) produced rice spaghetti from two rice varieties: high-amylose rice, Chai Nat 1 (CNT1) and waxy-rice, Rice Division 6 (RD 6). Both rice flours were prepared using a dry-milling process. The ratios of dry-milled CNT1 rice flour and RD6 rice flour at 100:0, 95:5, 90:10, 85:15 and 0:100 were studied. Results showed that flour content ratio of CNT1 rice flour to dry-milled RD 6 rice flour at 90:10 (w/w), containing 29 % amylose, demonstrated the optimal tensile strength, cooking time, cooking loss and surface smoothness for rice spaghetti (Detchewa et al. 2012). However, the rice spaghetti was lower of cooking and texture qualities than wheat spaghetti due to absence of gluten network. Many studies have reported that adding protein to gluten-free products can enhance nutrition and functional properties (Takahashi et al. 1986; Friedman and Brandon 2001., Shevkani and Singh 2014, Shevkani et al. 2015). Soybean is a one of legumes, and is considered good source of protein. Soy protein has been reported to reduce cholesterol level and risk of developing cancer, diabetes and obesity (Friedman and Brandon 2001). Adding proteins can improve the functional properties of food products resulting from an interaction between starch and protein. Faubion and Hoseney (1982) studied the effect of soy protein isolate (SPI) on the expansion of extruded wheat starch. Their results showed that the expansion of the extrudate increased when the SPI content was increased from 1 to 8 %, and decreased when the SPI content was higher than 10 %. Takahashi et al. (1986) studied the effect of the addition of SPI on the physical properties of gluten-free potato-starch noodles. They found the potato starch noodles containing 5 % SPI had a greater tensile strength and less adhesiveness or stickiness than the control potato starch noodle without SPI. The cooking quality, cooking time and cooking loss of the starch noodle with 5 % SPI were less than for the control noodles. In addition, many

protein isolates from legumes were used to improve functional properties of gluten-free products. Shevkani and Singh (2014) developed gluten-free muffins from corn starch with protein isolate from kidney bean, field pea, and amaranth. The results showed that the incorporation of protein isolated enhanced the viscoelasticity of batter, resulting in the characteristic of gluten-free muffins were improved. The crumb color of gluten-free muffins depended on the source of proteins. Shevkani et al. (2015) developed gluten-free rice muffin with cowpea protein isolates, which were isolated from white cowpea and red cowpea. They found that the color of gluten-free rice muffins depended the types of cowpea protein isolates, while the adding above 8 % cowpea protein isolate was increased firmness, springiness, cohesiveness and chewiness. However, there is still limited of information of using SPI in gluten-free rice spaghetti. Thus, the aim of this study was to investigate the effects of SPI on morphological, thermal, cooking, texture and sensory properties of gluten-free rice spaghetti (GFRS) as compared with commercial wheat spaghetti.

Materials and methods

Two rice varieties (*Oryza sativa* L.), Indica cultivar: high amylose rice, Chai Nat 1 (CNT1) and waxy rice, Rice Division 6 (RD6) were obtained from The Bureau of Rice Research and Development, Thailand. Both rice samples were milled using dry milling. SPI was purchased from Vicchi Enterprise Co., Ltd. Thailand. Commercial wheat spaghetti (Spaghetti Ristorante 8, F. Divella S.p.A., Italy), made from Durum wheat semolina, was purchased from a local market. All chemical reagents were of analytical grade.

Production of gluten-free rice spaghetti (GFRS)

Rice flour was produced by grinding, polished rice using an Alpine Pin Mill (160 Z, Augsubrg, Germany), passing through a 100 mesh sieve, and then stored in plastic bags. A mixture of dry-milled CNT1 rice flour to waxy rice (RD 6) flour was fixed at 90:10 (w/w) following to a previous study report by Detchewa et al. (2012). SPI was added to the rice flour mixture at different concentrations (0, 2.5, 5.0, 7.5, and 10.0 % w/w db) as shown in Table 1. The rice spaghetti samples were labeled according to the SPI content; for example, GFRS-SPI5.0 referred to gluten-free rice spaghetti containing 95.0 % w/w of the Chai Nat 1 flour and RD 6 rice flour mixture, and 5.0 % (w/w) SPI.

Each rice flour formulation was mixed for 1 h using a cubic mixer (Unique Tools Company, Thailand) and then extruded using a co-rotating twin-screw extruder (Model

Table 1 Nomenclature of gluten-free rice spaghetti (GFRS) and the proportion (% w/w db) of rice flour mixture and soy protein isolate (SPI)

Nomenclature	Dry-milled CNT1 rice flour (%)	Dry-milled RD6 rice flour (%)	SPI (%)
GFRS-SPI0	90.0	10.0	0.0
GFRS-SPI2.5	87.75	9.75	2.5
GFRS-SPI5.0	85.5	9.5	5.0
GFRS-SPI7.5	83.25	9.25	7.5
GFRS-SPI10	81.0	9.0	10.0
Commercial wheat spaghetti		Durum wheat semolina	

EVO25 A120, Clextral®, France). The length to diameter ratio of the barrel was 60:1 and the screw speed was constant at 220 rpm. The die was designed with six 1.5 mm diameter circular holes. The barrel temperature were 40, 70, 95, 95, 95, 80, and 70 °C for the zone 1–6, respectively. The moisture content of the extruded product was 32 %. The extruded rice spaghetti samples were dried in a hot-air oven at 50 °C to attain a final moisture content below 12 % (w/w).

Gluten content

The gliadin content was determined using a monoclonal R5-antibody-based sandwich enzyme-linked immunosorbent assay (ELISA), wheat/gluten (gliadin) ELISA Kit II (Morinaga Institute of Biological Inc., Japan). Assays were performed following standard procedures provided in the company's kit. Ground spaghetti (1.0 g) was mixed with 19 mL of extraction solution (extraction component A and sample buffer) in a polypropylene centrifuge tube and submerged in boiling water (100 °C) for 10 min. The tube was cooled down to an ambient temperature and centrifuged at 3000×g for 20 min. The clear supernatant was collected and diluted 20-fold with a sample extraction solution for the immunoassay and the gluten content of the samples was determined.

Morphological analyzes of spaghetti samples using fluorescent microscopy and scanning microscope

Fluorescent microscope

Spaghetti samples were soaked in water for 4 h. The water was then drained from the samples by sieving. The spaghetti samples were frozen with dry-ice, and cut into 9 µm thick sections using a cryostat (Leica CM 1850-3-1) at −20 °C (Zweifel et al. 2003). The frozen samples were mounted on microscope slides and were stained for protein

with Rodamine B (0.01 g/L). Each sample was examined under a fluorescence microscope (Zeiss axioplan, Germany).

Scanning electron microscopy

The microstructure of the surface of the dried spaghetti was determined using a scanning electron microscope (SEM). Samples were mounted on circular metal stubs using double-sided adhesive carbon tape. The mounted samples were coated with gold and were observed using a JEOL JSM-5300 LV SEM, USA. Micrographs of each sample were taken at 1000× magnification.

Preparation of the samples for differential scanning calorimetry (DSC) and X-ray diffraction

The spaghetti samples were soaked in deionized water for 4 h at room temperature, and then drained in a sieve for 10 min. The drained samples were carefully ground to pass through the 80 mesh sieve. Ethanol (95 % purity) was mixed to the samples at a 5:1 ratio (weight/weight). The supernatant was discarded after centrifuging at 5000×g for 10 min. The residue was suspended in 95 % ethanol and this washing process was repeated twice. The residue was then dried at 40 °C until the moisture content was below 10 %. The sample was ground by a mortar and pestle and passed through a 100 mesh sieve.

Thermal properties

The thermal properties of the dried rice spaghetti and commercial spaghetti samples were determined using a differential scanning calorimeter (DSC, Diamond, Perkin-Elmer, Norwalk, CT). Each sample (4.0 mg, dry basis) was weighed into an aluminum DSC pan, and then deionized water (8 µL) was added to the sample. The sample was heated from 20 to 110 °C at a rate of 10 °C/min. An empty pan was used as the reference control (Patindol et al. 2005).

Crystalline structure using X-ray diffraction

The sample was prepared using the same method as described for DSC analysis. X-ray diffraction measurements of ground spaghetti samples after equilibration in a 100 % relative-humidity chamber for 24 h at room temperature were performed with Siemens D500 diffractometer (Siemens, Madison, WI). The operation setting for the X-ray diffractometer was at 27 mA and 50 kV. The samples were scanned at scanning region of the two-theta angle from range 3–40°. The step size was 0.05 degrees per step. (Song and Jane 2000). The percent crystallinity was determined by the following equation.

$$\% \text{ crystals} = \frac{I_{\text{crystals}}}{I_{\text{crystals}} + I_{\text{amorphous}}}$$

The intensities (I) were obtained using the integrated intensities (areas) measured from the diffraction pattern.

Cooking properties of GFRS and spaghetti

Optimum cooking time and cooking loss were determined following AACC method 66-50.01 (AACC 2010). Spaghetti sample (25 g) was cooked with distilled water (300 mL) in 500 ml Beaker. The optimum cooking time for spaghetti was defined as the time required for the disappearance of the central core was determined by squeezing the spaghetti between two glass plates. Cooking loss was evaluated by determining the amount of solids lost into the cooking water following AACC method 66-50.01 (AACC 2010). Whereas, water adsorption index was measured as the weight increase of spaghetti before and after cooking, and was calculating as percent weight gain with respect to the weight of uncooked spaghetti. The cooking loss and water adsorption index formulas were shown as below.

$$\text{Cooking loss (\%)} = \frac{(\text{Weight of dry matter})}{\text{Weight of uncooked spaghetti}} \times 100$$

$$\text{Water adsorption index (\%)} = \frac{(\text{Weight of cooked spaghetti} - \text{Weight of uncooked spaghetti})}{\text{Weight of uncooked spaghetti}} \times 100$$

Color of GFRS and spaghetti

The cooked spaghetti sample was placed in full petri dish and closed with plastic film. The sample was determined using a CR-300, Minolta Chroma meter (Minolta Co., Ltd., Osaka, Japan) where the L* value indicates blackness to whiteness (0–100); a* value indicates redness (positive) and greenness (negative), and b* value indicates yellowness (positive) and blueness (negative).

Texture analysis of GFRS and spaghetti

The textural characteristics of the spaghetti products were determined using a texture analyser (TA-XT Plus, Stable Micro System, Godalming, England), calibrated for a load cell of 5 kg. The firmness of the spaghetti was measured followed AACC method 66-50.01 (AACC 2010). Five strands of cooked spaghetti were placed in sample holder and cut crosswise using a 1 mm flat perspex knife blade (A/LKB-F). Tensile strength was measured using a spaghetti/noodle tensile rig (A/SPR). A single

strand of each noodle sample was locked in a slotted arm and measured at a test speed of 3.0 mm/s. and the maximum breaking force (N) was recorded. Spaghetti stickiness was determined by the maximum force (N) during lifting of the cylindrical probe (35 mm) from five cooked spaghetti at a test used speed of 2.2 mm/s and 75 % strain (Wang et al. 1999).

Sensory evaluation

The sensory characteristics of rice spaghetti and commercial wheat spaghetti were cooked to optimum cooking time in distilled water, drained, and served to 30 panelists. The 15 g of spaghetti sample was offered and coded with three random digits. The panelists evaluated the spaghetti samples for color, appearance, flavor, texture, and overall acceptability on a 9-point hedonic scale, where 9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like nor dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, and 1 = dislike extremely.

Statistical analysis

All experiments were carried out in duplicate. The mean and standard deviation of the parameters were calculated, and the differences between the formulations were evaluated by analysis of variance (ANOVA), using the SPSS 17.0 statistical software program (SPSS Inc., Chicago, IL, USA), and Duncan Multiple Range Tests to test the significant differences between treatments. Statistical significance was declared at $p < 0.05$.

Results and discussion

Gluten content

The commercial wheat spaghetti contained 167,630 ppm of gluten. Although the gluten content is related to the spaghetti quality (D'Egidio et al. 1990), celiac patients need gluten-free food, containing less than 20 ppm gluten (U.S. Food and Drug Administration 2015). The gluten content of each GFRS sample in this study was less than 1 ppm.

Morphological properties and structural analysis using fluorescent microscopy

The fluorescence micrograph of the cross section of GFRS and commercial wheat spaghetti are shown in Fig. 1. The red area in the fluorescent micrograph represents the protein-rich phase, whereas the black area represents the starch-rich phase. The GFRS and commercial wheat

Fig. 1 Fluorescence micrograph: the cross section of gluten-free rice spaghetti (GFRS) and commercial wheat spaghetti. **a** GFRS-SPI0, **b** GFRS-SPI2.5, **c** GFRS-SPI5.0, **d** GFRS-SPI7.5, **e** GFRS-SPI10, and **f** commercial wheat spaghetti

Fig. 2 Scanning electron micrograph: the surface of gluten-free rice spaghetti (GFRS) and commercial wheat spaghetti. **a** GFRS-SPI0, **b** GFRS-SPI2.5, **c** GFRS-SPI5.0, **d** GFRS-SPI7.5, **e** GFRS-SPI10, and

f commercial wheat spaghetti, *arrows* indicate large starch granules; (LG) and small starch granules (SG)

spaghetti showed phase separation between the protein and starch. GFRS-SPI0 showed minimal protein fractions dispersed in the starch matrix, and a protein network was not observed (Fig. 1a). GFRS-SPI2.5 (Fig. 1b) and GFRS-SPI5.0 (Fig. 1c) showed a homogeneous distribution of protein throughout the rice spaghetti strand. When the SPI concentration increased to 7.5 % in GFRS-SPI7.5 (Fig. 1d) and 10.0 % SPI in GFRS-SPI10 (Fig. 1e), the protein was not as well dispersed. The results suggest that the addition of SPI can produce a protein-starch composite with a good dispersion of protein at a low SPI content, but the dispersion of protein reduced when the protein content was

increased. The distribution of protein in the starch phase can significantly influence the textural properties of GFRS. For commercial wheat spaghetti, (Fig. 1f) the gluten protein network was observed as a continuous phase, encapsulating starch granules.

The microstructure of the surface of GFRS and commercial wheat spaghetti were observed by SEM (Fig. 2). GFRS-SPI0 (Fig. 2a) showed a dense and compact structure of gelatinized starch. GFRS-SPI2.5, GFRS-SPI5.0, GFRS-SPI7.5 and GFRS-SPI10, however, displayed a rough surface, less compact and more porous surfaces (Fig. 2b–e). The surface of the commercial wheat spaghetti

exhibited a surface with starch granules coated by a smooth protein film. The surface of the wheat spaghetti strand was shown the different sizes of starch granules, some small porous and cracks (Fig. 2f).

Thermal properties

The thermal properties of GFRS samples and commercial wheat spaghetti were analyzed using a DSC (Table 2). The GFRS samples showed two peaks: the first peak occurred at a temperatures rang of 48.2 to 67.2 °C, and the second peak occurred at 88.4 to 106.9 °C. The onset, peak, and conclusion gelatinization temperature of CNT1 rice flour were 72.0 ± 0.1 , 77.3 ± 0.1 , and 84.5 ± 0.2 °C, respectively and that of RD6 waxy rice flour were 62.1 ± 0.3 , 67.7 ± 0.3 and 77.6 ± 0.1 °C, respectively. The retrogradation of the CNT1 flour was T_o 44.8 ± 0.1 , T_p 55.8 ± 0.1 , and T_c 65.4 ± 0.7 °C. The retrogradation starch in RD6 rice flour was T_o 45.7 ± 0.4 , T_p 55.5 ± 0.2 , and T_c 61.2 ± 0.2 °C. Thus, the first peak of the GFRS samples corresponded to the dissociation of the retrograded amylopectin of the rice flour samples. None of GFRS samples exhibited the gelatinization peak of the rice starch, because the starch in the GFRS samples had already been completely gelatinized during the extrusion process at temperatures from 40, 70, 85, 95, 95 and 70 °C in barrels 1–6, respectively. It is known that rice noodle products require gelatinized starch to form strands (Fu 2008). The T_o of the retrograded amylopectin of GFRS-SPI0 was lower than that of GFRS-SPI2.5, GFRS-SPI5.0, GFRS-SPI7.5 and GFRS-SPI10. Addition of different levels of SPI caused significant ($p < 0.05$) increases in T_o , whereas T_p and T_c showed no significant differences between GFRS samples. The addition of SPI to GFRS decreased the ΔH of retrograded starch. It was note that the soybean protein

decreased the retrogradation of starch. The decrease in ΔH of retrograded starch could be attributed to the interaction between the protein and starch chain, resulting in reduced starch (Lian et al. 2013). The commercial wheat spaghetti, however, showed a gelatinization peak for wheat starch (56.4–69.0 °C), because the wheat spaghetti was processed at a low temperature, which was different from the GFRS production process. The wheat semolina which contains gluten protein was extruded below 50 °C to protect the gluten from being denatured (Marchylo and Dexter 2001), and gluten provided the structure of the wheat spaghetti.

The second thermal-transition peak (88.4–106.9 °C) was found in the GFRS samples and commercial wheat spaghetti (Table 2). Lamberts et al. (2009) reported the amylose–lipid complex presented peak between 90 and 120 °C. The second peak in spaghetti corresponded to the amylose–lipid complex. Increases in the SPI content of GFRS did not affect T_o , T_p and T_c of the second peak. The ΔH of GFRS containing greater SPI content, however, was larger than was that of the GFRS without SPI. The commercial wheat spaghetti was the largest for amylose–lipid complex content. Zweifel et al. (2000) reported that complex formation in pasta, particularly amylose–lipid complex formation in pasta, particularly amylose–lipid complex formation happens during the drying process.

Crystalline of starch in GFRS and spaghetti

The GFRS samples and the commercial wheat spaghetti were analyzed using x-ray diffraction and the results are shown in Fig. 3. All extruded GFRS samples exhibited peak at 2θ of 20 °, which corresponds to the V-type structure (amylose–lipid complex) of starch (Singh et al. 2014). The total crystallinity measured for the GFRS samples, therefore, include the amylose–lipid complexes,

Table 2 Thermal properties of gluten-free rice spaghetti samples and commercial wheat spaghetti

Samples	Peak 1				Peak 2			
	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (J/g)	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (J/g)
GFRS-SPI0	$48.2 \pm 0.4c$	$58.9 \pm 0.4b$	$66.7 \pm 0.7b$	$1.3 \pm 0.1b$	$88.9 \pm 0.1a$	$99.7 \pm 0.7a$	$104.8 \pm 0.3b$	$0.5 \pm 0.1c$
GFRS-SPI2.5	$50.8 \pm 0.7b$	$59.1 \pm 1.6b$	$66.7 \pm 0.9b$	$1.1 \pm 0.1bc$	$89.7 \pm 0.1a$	$99.2 \pm 0.2a$	$105.4 \pm 0.2ab$	$0.6 \pm 0.1bc$
GFRS-SPI5.0	$51.4 \pm 0.3b$	$58.4 \pm 0.4b$	$66.4 \pm 0.2b$	$1.0 \pm 0.0c$	$89.6 \pm 0.1a$	$99.2 \pm 0.0a$	$106.9 \pm 0.0a$	$0.8 \pm 0.1b$
GFRS-SPI7.5	$51.6 \pm 0.1b$	$58.0 \pm 0.1b$	$66.5 \pm 0.4b$	$0.8 \pm 0.3c$	$89.8 \pm 0.2a$	$99.3 \pm 0.3a$	$105.4 \pm 1.8ab$	$0.8 \pm 0.1b$
GFRS-SPI10	$51.2 \pm 0.2b$	$58.8 \pm 0.0b$	$67.2 \pm 0.1ab$	$0.7 \pm 0.2c$	$89.3 \pm 0.2a$	$99.1 \pm 0.1a$	$105.3 \pm 0.3ab$	$0.8 \pm 0.1b$
Commercial wheat spaghetti	$56.4 \pm 0.7a$	$63.7 \pm 0.9a$	$69.0 \pm 1.4a$	$4.0 \pm 0.2a$	$88.4 \pm 0.5a$	$95.0 \pm 0.3b$	$104.5 \pm 0.0c$	$1.1 \pm 0.0a$

T_o onset temperature; T_p peak temperature; T_c conclusion temperature; and ΔH enthalpy change

SPI Soy Protein Isolate

GFRS gluten-free rice spaghetti

Mean $\pm$ standard deviation. The means for each characteristic followed by a different letter within the same column are significantly different ($p < 0.05$)

Fig. 3 X-ray diffractograms of gluten-free rice spaghetti (GFRS) samples and commercial wheat spaghetti. The percent crystallinity is in parenthesis

and retrograded starch. The crystallinity of GFRS-SPI0, GFRS-SPI2.5, GFRS-SPI5.0, GFRS-SPI7.5 and GFRS-SPI10 were 6.3, 5.4, 4.4, 3.5 and 3.0 %, respectively. The crystallinity of GFRS samples decreased with the increased the content of SPI. The decreases in crystallinity of the GFRS samples correlated with the decrease in the ΔH of dissociated retrograded amylopectin (Table 2). For the commercial wheat spaghetti, the x-ray diffraction pattern exhibited peaks at 15, 17, 18 and 23° (Fig. 3), corresponding to the A-type crystalline structure (Primo-Martín et al. 2007). Semolina wheat starch is known to have an A-type crystalline structure (Zweifel et al. 2000).

Cooking quality of GFRS and spaghetti

Cooking qualities of GFRS and commercial wheat spaghetti are shown in Table 3. There were significant ($p < 0.05$) differences in the optimum cooking time, cooking loss, and water absorption. The optimum cooking-time for the GFRS containing various SPI was in the range of 13.1 to 17.6 min. All GFRS samples containing the different SPI required shorter optimum cooking time than GFRS-SPI0. The microstructure of the surface of GFRS

samples showed that the structure of GFRS-SPI0 was denser and less porous than the GFRS samples with SPI, which might make water penetration more difficult during cooking. The commercial spaghetti showed the shortest optimum cooking-time (12.1 min), possibly resulting from its large number of small pores and cracks (Fig. 2f), which allowed easy water access during cooking.

GFRS-SPI0 had a water adsorption index of 246.2 %, and GFRS-SPI10 had 254.3 %. Increase in the water absorption index of GFRS was found with increases in the amount of SPI, however, the water absorption of the GFRS samples was still lower than that of the commercial wheat spaghetti. The water adsorption index reflected the swelling ability of starch and protein. Altan et al. (2009) reported an increasing water adsorption index for a lesser degree of starch degradation after extrusion. Sudha and Leelavathi (2012) increased the protein content in pasta by adding 0–30 % dehydrated green pea flour, which corresponded to an increased protein content from 9.56 to 16.57 %. This cooked pasta exhibited a higher water adsorption index, from 320.8 to 332.9 %, resulting from increases in the protein content. The GFRS-SPI0 (0 % SPI) had a cooking loss of 25.4 %. With increase in SPI from 0 to 5.0 % (GFRS-SPI5.0), cooking loss decreased to 17.0 %. Whereas, the increase in SPI to 7.5 % (GFRS-SPI7.5) and 10.0 % SPI (GFRS-SPI10) were significantly ($p < 0.05$) increased the cooking loss to 21.0 and 21.8 %. The high cooking loss may be due to a large number of pores as indicated in Fig. 2e. Cooking loss is an important parameter related to consumer acceptance of a pasta product (Kim et al. 2014). The low cooking loss of the commercial wheat spaghetti is due to the fact that the starch and other constituents were encapsulated within the gluten network (Fardet et al. 1999).

Color of GFRS and spaghetti

The color parameters of the GFRS samples are shown in Table 4. The lightness value of the GFRS samples was higher than that of commercial wheat spaghetti. GFRS

Table 3 Cooking quality of gluten-free rice spaghetti samples and commercial wheat spaghetti

Samples	Cooking time (min)	Cooking loss (%)	Water absorption index (%)
GFRS-SPI0	17.6 ± 0.5a	25.4 ± 1.4a	246.2 ± 0.9d
GFRS-SPI2.5	14.7 ± 0.4b	18.1 ± 0.4c	247.6 ± 2.7cd
GFRS-SPI5.0	13.7 ± 0.4c	17.0 ± 0.8c	248.1 ± 1.9c
GFRS-SPI7.5	13.1 ± 0.1d	21.0 ± 0.5b	253.4 ± 1.6b
GFRS-SPI10	13.1 ± 0.1d	21.8 ± 0.5b	254.3 ± 1.7b
Commercial wheat spaghetti	12.1 ± 0.1e	6.8 ± 0.2d	298.3 ± 1.5a

GFRS gluten-free rice spaghetti

SPI soy protein isolate

Mean ± standard deviation. The means for each characteristic followed by a different letter within the same column are significantly different ($p < 0.05$)

Table 4 Color and textural properties of gluten-free rice spaghetti samples and commercial wheat spaghetti

Samples	L*	a*	b*	Firmness (N)	Tensile strength (N)	Stickiness (N)
GFRS-SPI0	75.6 ± 2.4a	−0.6 ± 0.1c	8.0 ± 0.1f	2.23 ± 0.05c	0.07 ± 0.01c	0.40 ± 0.03a
GFRS-SPI2.5	74.9 ± 0.9a	−0.8 ± 0.1b	9.9 ± 0.4e	2.27 ± 0.06c	0.10 ± 0.01b	0.27 ± 0.02b
GFRS-SPI5.0	75.9 ± 0.9a	−0.9 ± 0.1b	11.3 ± 0.1d	2.44 ± 0.08b	0.11 ± 0.02b	0.25 ± 0.05bc
GFRS-SPI7.5	75.8 ± 1.1a	−0.8 ± 0.1b	13.7 ± 0.3c	1.94 ± 0.15d	0.08 ± 0.01c	0.24 ± 0.02bc
GFRS-SPI10	75.7 ± 1.1a	−0.7 ± 0.1b	14.8 ± 0.2b	1.83 ± 0.18d	0.08 ± 0.01c	0.22 ± 0.04c
Commercial wheat spaghetti	71.7 ± 1.0b	−2.3 ± 0.1a	34.3 ± 0.3a	3.85 ± 0.07a	0.30 ± 0.01a	0.10 ± 0.01d

SPI soy protein isolate

GFRS gluten-free rice spaghetti

Mean ± standard deviation. The means for each characteristic followed by a different letter within the same column are significantly different ($p < 0.05$)

Table 5 Sensory evaluation of gluten-free rice spaghetti samples and commercial wheat spaghetti

Samples	Appearance	Color	Flavor	Texture	Overall acceptability
GFRS-SPI0	6.10 ± 0.80c	5.36 ± 0.85c	5.43 ± 0.50c	5.56 ± 0.60c	5.26 ± 0.88d
GFRS-SPI2.5	6.26 ± 0.73c	5.56 ± 0.72c	5.86 ± 1.25bc	5.90 ± 1.24bc	5.86 ± 0.97cd
GFRS-SPI5.0	6.60 ± 0.62b	5.80 ± 0.88b	6.06 ± 1.08b	6.26 ± 0.78b	6.16 ± 0.69b
GFRS-SPI7.5	6.26 ± 0.73bc	5.83 ± 0.37b	5.90 ± 0.80bc	5.63 ± 0.92c	5.63 ± 0.49cd
GFRS-SPI10	6.16 ± 0.53bc	5.83 ± 0.69b	5.53 ± 0.77c	5.60 ± 0.56c	5.56 ± 0.57cd
Commercial wheat spaghetti	8.00 ± 0.69a	8.06 ± 0.64a	7.50 ± 0.57a	7.60 ± 0.72a	7.46 ± 0.68a

SPI soy protein isolate

GFRS gluten-free rice spaghetti

Mean ± standard deviation. The means for each characteristic followed by a different letter within the same column are significantly different ($p < 0.05$)

samples containing SPI had higher yellowness (+b* value) and greenness (−a* value) but the yellowness of all GFRS samples was significantly ($p < 0.05$) lower than that of commercial wheat spaghetti (34.3). The incorporation of soy protein isolate influenced the color of GFRS samples. The increasing yellow color in rice spaghetti might be increased the acceptable score in sensory evaluation due to good apparent (Table 5). Shevkani and Singh (2014) reported the gluten-free muffins made from corn starch with protein isolates from kidney bean, field pea and amaranth. They found that the gluten-free muffin (control) was lowest yellowness (b*value) in crumb, whereas adding protein isolates significantly increased yellowness (b*-value) of crumb.

Textural of GFRS and spaghetti

Effect of SPI on the textural properties of cooked GFRS samples analyzed determined using a Texture Analyser, showed that firmness, tensile strength and stickiness values were affected by the addition of SPI (Table 4). Addition of 5.0 % SPI (GFRS-SPI5.0) increased the firmness at $p < 0.05$; from 2.23 to 2.44 N, and increased

tensile strength at $p < 0.05$, from 0.07 to 0.11 N. However, high proportions of SPI at 7.5 and 10.0 % SPI (GFRS-SPI7.5 and GFRS-SPI10) decreased the firmness and tensile strength. On the other hand, the stickiness of GFRS decreased with increasing proportions of SPI. Takahashi et al. (1986) reported that potato starch noodles had increased tensile strength and decreased stickiness when SPI was added. The greater firmness and tensile strength of GFRS-SPI5.0, observed in this study, suggest that reinforcement of protein and starch matrix might have occurred. The starch and protein composite matrix depends on water availability, the gelation temperature of the continuous phase, the volume fraction of the separated phase and the strength of filler in the continuous phase (Hongspabhas 2010). A concentration of SPI larger than 5.0 % (GFRS-SPI5.0) resulted in reduced firmness and tensile strength of GFRS. This higher protein content in GFRS seems to interfere with the starch gel, resulting in a weakened GFRS structure (Fig. 1). Commercial wheat spaghetti had higher firmness (3.85 N) and lower stickiness (0.10 N) than any of the GFRS. After this wheat spaghetti was cooked, the starch had limited swelling in the continuous gluten network, resulting in the spaghetti

with high firmness and low stickiness (Zweifel et al. 2003; Marti and Pagani 2013).

Sensory quality

Results of the sensory evaluation of GFRS, in terms of appearance, color, flavor, texture, and overall acceptability, are shown in Table 5. Using nine point hedonic scale, the scores for appearance, color, flavor, texture and overall acceptability of the GFRS made from rice flours with different SPI content were significantly ($p < 0.05$) higher than that of the GFRS-SPI0. The GFRS-SPI5.0 received scores above six (like slightly) for appearance, flavor, texture, and overall acceptability. The GFRS-SPI5.0 displayed a good retention of shape, high firmness, high tensile strength, low stickiness, and good flavor, which resulted in higher scores from the taste panel when compared to other GFRS samples. Nevertheless, the commercial wheat spaghetti received the highest scores for all sensory attributes.

Conclusion

Gluten-free rice spaghetti obtained in this study was made from a combination of dry-milled rice flour and SPI using a twin-screw extruder. On the basis of ELISA assays, all rice spaghetti samples contained less than 1 ppm gluten, and it was thus considered a gluten-free food. The addition level of 5.0 % SPI improved the cooking, textural, and sensory properties of the GFRS. The fluorescent micrograph of GFRS-SPI5 showed that the proteins were well distributed in starch, resulting in the increase in firmness and tensile strength. Whereas, scanning electron micrograph of GFRS-SPI5 showed the more porous at surface, resulting in the decrease in cooking time and cooking loss. However, further studies are needed to improve other physical properties of GFRS such as color and texture by adding other proteins or combinations of protein sources to optimize the GFRS formulation and to achieve good GFRS characteristics and sensory properties.

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References

- AACC (2010) Approved methods of analysis. 11th ed. Method 66-50.01. St. Paul, Minnesota
- Altan A, McCarthy KL, Maskan M (2009) Effect of extrusion cooking on functional properties and in vitro starch digestibility of barley-based extrudates from fruit and vegetable by-products. *J Food Sci* 74:E77–E86
- D'Egidio MG, Mariani BM, Nardi S, Novaro P, Cubadda R (1990) Chemical and technological variables and their relationships: a predictive equation for pasta cooking quality. *Cereal Chem* 67:275–281
- Detchewa P, Thongngam M, Naivikul O (2012) Physicochemical and thermal properties of non-waxy rice flour as affected by waxy rice flour and its influence on textural and cooking properties of rice spaghetti. *Int Proc Chem Biol Environ Eng* 39:235–239
- Fardet A, Abecassis J, Hoebler C, Baldwin PM, Buléon A, Bérot S, Barry JL (1999) Influence of technological modifications of the protein network from pasta on in vitro starch degradation. *J Cereal Sci* 30:133–145
- Faubion JM, Hoseney RC (1982) High-temperature short-time extrusion cooking of wheat starch and flour. II. Effect of protein and lipid on extrudate properties. *Cereal Chem* 59:533–537
- Friedman M, Brandon DL (2001) Nutritional and health benefits of soy proteins. *J Agric Food Chem* 49:1069–1086
- Fu BX (2008) Asian noodles: history, classification, raw materials, and processing. *Food Res Int* 41:888–902
- Gujral N, Freeman HJ, Thomson ABR (2012) Celiac disease: prevalence, diagnosis, pathogenesis and treatment. *World J Gastroentero* 18:6036–6059
- Hongspabhas P (2010) Structure changes of multiphase food systems generated by proteins. In: Devahastin S (ed) *Physicochemical aspects of food engineering and processing*. CRC Press, New York, pp 257–281
- Kim Y, Kee JI, Lee S, Yoo S-H (2014) Quality improvement of rice noodle restructured with rice protein isolate and transglutaminase. *Food Chem* 145:409–416
- Lamberts L, Gomand SV, Derycke V, Delcour JA (2009) Presence of amylose crystallites in parboiled rice. *J Agric Food Chem* 57:3210–3216
- Lian X, Zhu W, Wen Y, Li L, Zhao X (2013) Effects of soy protein hydrolysates on maize starch retrogradation studied by IR spectra and ESI-MS analysis. *Int J Biol Macromol* 59:143–150
- Marchylo BA, Dexter JE (2001) Pasta production. In: Owens G (ed) *Cereals processing technology*. Woodhead Publishing Limited, New York, pp 109–130
- Marco C, Rosell CM (2008) Effect of different protein isolates and transglutaminase on rice flour properties. *J Food Eng* 84:132–139
- Marti A, Pagani MA (2013) What can play the role of gluten in gluten free pasta? *Trends Food Sci Technol* 31:63–71
- Matsuo RR, Dexter JE, Dronzek BL (1978) Scanning electron microscopy study of spaghetti processing. *Cereal Chem* 55:744–753
- Moron B, Cebolla A, Manyani H, Alvarez-Maqueda M, Megias M, Thomas MDC, Lopez MC, Sousa C (2008) Sensitive detection of cereal fractions that are toxic to celiac disease patients by using monoclonal antibodies to a main immunogenic wheat peptide. *Am J Clin Nutr* 87:405–414
- Niewinski MM (2008) Advances in celiac disease and gluten-free diet. *J Am Diet Assoc* 108:661–672
- Patindol J, Wang Y-J, J-I Jane (2005) Structure-functionality changes in starch following rough rice storage. *Starch-Stärke* 57:197–207
- Primo-Martín C, Nieuwenhuijzen NH, Hamer RJ, Vliet T (2007) Crystallinity changes in wheat starch during the bread-making process: starch crystallinity in the bread crust. *J Cereal Sci* 45:219–226
- Shevkani K, Singh N (2014) Influence of kidney bean, field pea and amaranth protein isolates on the characteristics of starch-based gluten-free muffins. *Int J Food Sci Technol* 49:2237–2244
- Shevkani K, Kaur A, Kumar S, Singh N (2015) Cowpea protein isolates: functional properties and application in gluten-free rice muffins. *LWT-Food Sci Technol* 63:927–933

- Singh N, Shevkani K, Kaur A, Thakur S, Parmar N, Singh Viridi A (2014) Characteristics of starch obtained at different stages of purification during commercial wet milling of maize. *Starch-Starke* 66:668–677
- Song Y, Jane J (2000) Characterization of barley starches of waxy, normal, and high amylose varieties. *Carbohydr Polym* 41:365–377
- Sudha ML, Leelavathi K (2012) Effect of blends of dehydrated green pea flour and amaranth seed flour on the rheological, microstructure and pasta making quality. *J Food Technol* 49:713–720
- Takahashi S, Hirao K, Watanabe T (1986) Effect of added soybean protein on physico-chemical properties of starch noodles (harasame). *J Jpn Soc Starch Sci* 33:10
- U.S. Food and Drug Administration (2015) Federal register. Final rule; Document 78 FR 47154: Food labeling: gluten-free labeling of foods. <https://www.federalregister.gov/articles/2013/08/05/2013-18813/food-labeling-gluten-free-labeling-of-foods>. Assessed 30 September 2015
- Wang N, Bhirud PR, Sosulski FWR, Tyler T (1999) Pasta-like product from pea flour by twin-screw extrusion. *J Food Sci* 64:671–678
- Zweifel C, Conde-Petit B, Escher F (2000) Thermal modifications of starch during high-temperature drying of pasta. *Cereal Chem* 77:645–651
- Zweifel C, Handschin S, Escher F, Conde-Petit B (2003) Influence of high-temperature drying on structural and textural properties of durum wheat pasta. *Cereal Chem* 80:159–167