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Textural and cooking qualities of noodles made with soy flour and hydroxypropyl methylcellulose

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Abstract

To develop healthy gluten-free noodles, soy flour was used as a raw material. Hydroxypropyl methylcellulose (HPMC) at different percentages was added to soy flour based on 10% tapioca as a gluten replacement: HPMC at 0% (S), 0.5% (SH1), 1.0% (SH2) and 1.5% (SH3). For soy suspension without any additive, there was no peak viscosity. The addition of tapioca and HPMC increased its peak viscosity to 104 cP and 134 cP, respectively. With the addition of HPMC, the water absorption capacity of the soy noodle was increased from 202% for S to 208% for SH3, while the cooking loss rate was reduced from 24% for S to 22% for SH3. The hardness of the soy noodle was increased from 0.54 N for S to 0.77 N for SH3 which was similar to the hardness of soy noodle with gluten (SG) (0.73 N). SH3 had the highest tensile strength of 439 N/cm^2, followed by SG (359 N/cm^2) and S (188 N/cm^2). Thus, HPMC at 1.5% has potential to replace gluten to develop gluten-free soy-based noodles.

Introduction

Noodle is a staple food made from dough of grain flour that is rolled flat and cut into long thin strips. Wheat flour is the primary ingredient of most noodles. There are also noodles made from rice flour (Kim *et al*., 2011) and other starch flour (Beta and Corke, 2001). The main qualities of noodles that seem to appeal the most to consumer preferences are colour and texture. Typically, noodles made from wheat flour are characterised by a smooth and soft texture. Gluten, the main structure-forming protein in wheat flour, contributes to the elastic characteristics of the dough and the final product (Kovacs *et al*., 2004). However, for individuals suffering from celiac disease and others in the general population who seek to avoid gluten, gluten-free cereal-based products are needed. Due to increasing demand for a greater variety of healthy foods, new types of noodle need to be developed. To enhance protein or fibre contents, wheat flour can be replaced by other grain flour such as oat flour (Kudake *et al*., 2017), millet flour (Dissanayake and Jayawardena, 2016) or soy flour (Collins and Pangloli, 1997).

Soy has a high nutrient content and many health promoting ingredients. Soy protein can meet the daily requirement for protein without increasing the risk of developing cancer, unlike some animal proteins (Anderson *et al*., 1995). Soy flour has been included as a partial substitute for wheat flour (up to 50%) to improve the nutritional values of noodles (Collins and Pangloli, 1997), spaghetti (Shogren and Hareland, 2006), and other pasta products (Limroongreungrat and Huang, 2007). Moreover, soy flour displays several desirable functional properties such as water absorption and foaming capacity of baked products (Shin *et al*., 2013). It can also improve the performance of dough (Park *et al*., 2015). However, soy flour cannot be used as the main ingredient in baked goods or noodles because it lacks gluten and starch. Hydroxypropyl methylcellulose (HPMC), one of the most common water-soluble cellulose derivatives used in food applications, is known to be able to facilitate water absorption, improve sensory characteristics, and soften doughnuts (Kobylanski *et al*., 2004; Shin *et al*., 2013). HPMC has been used as gluten replacer in rice noodles (Lee *et al*., 2012) and bread (Shin *et al*., 2013) to improve their texture. However, no study has reported the development of noodles based on 100% soy flour added with HPMC. Thus, the objective of the present work was to develop gluten-free noodles using soy flour added

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with HPMC as a gluten replacement. Different levels of HPMC were evaluated to determine the appropriate percentage by measuring textural properties and cooking qualities of the resulting noodles.

Materials and methods

Materials

Soy flour (protein content, 33.7 g/100 g; fat content, 19.5 g/100 g, Taekwangkong cultivar; *Glycine max* (L.) Merrill) was purchased from Ssalnongbu (Ssalnongbu Co., Gyeongnam, Korea) and stored at -18°C prior to use. HPMC (Any Addy CN20T, 200,000 mPa/s) was purchased from Samsung Fine Chemicals (Incheon, Gyeonggi-do, Korea). Tapioca was purchased from SWI (Sanfuan Wongse Industries Co., LTD, Thailand) and gluten was purchased from Younglim Chemistry (Incheon, Korea).

Preparation of soy noodle samples

Soy noodle samples were prepared based on the method published by Kim *et al*. (2011) and Xin *et al*. (2018) with slight modification using soy flour (90 g, S) added with HPMC at different percentages (0.5% SH1, 1% SH2, and 1.5% SH3). As a control, gluten-added soy noodles (SG) were prepared with 75 g soy flour and 15 g gluten. Tapioca starch (10 g) was used for all types of noodles. All dry ingredients (except salt) were blended using a mixer (Model 5K5SS, Kitchen Aid, St. Joseph, MI, USA) at low speed (level 1) for 2 min. After adding 3 g salt and 45 mL water (75°C), all ingredients were kneaded at low speed (level 1) for another 2 min. The speed of the mixer was raised up one level for every subsequent minute until it reached the high speed (level 6). It was slowed down by one level for every minute before eventually stopping completely after 15 min of mixing. The dough was placed in a plastic bag to rest for 2 h at room temperature before it was sheeted with a pasta making machine (ATLAS 150, Marcato, Campodarsego, Italy). The same machine was used to slice noodles. Produced noodles were coated thinly with flour to avoid them from sticking. These noodles were dried for 15 h at 55°C in a convection oven (SJ Science Co., Pucheon, Korea), after which they were stored in a propylene bag and refrigerated at 4°C prior to use.

Soy flour pasting property

The pasting properties of soy flour suspension (15 g/100 g) was determined using a Rapid Visco Analyser (RVA, Model 3-D, Newport Scientific Pty Ltd., Warriewood, Australia), interfaced with a computer equipped with Thermocline software. The temperature profile included a temperature holding step at 50°C for 1 min, a linear temperature increase to 95°C at 6°C/ min, a holding step at 95°C for 5 min, a linear temperature decrease to 50°C at 6°C/ min, and a final isothermal step at 50°C for 2 min. To homogenise the sample, the paddle speed was set to 960 rpm for the first 10 s. It was then set to 160 rpm to monitor the viscosity during gelatinisation of the flour suspension. The peak viscosity, pasting temperature, hot pasting viscosity, setback, cool pasting viscosity, and stability ratio were determined from the viscosity profile curve (Yadav *et al*., 2011).

Water absorption capacity and cooking loss

To measure the water absorption capacity and cooking loss, noodles (10 g) were first boiled in 400 mL water for 15 min. To determine the water absorption capacity, the boiled noodles were kept in the boiled water for 0, 5, 10, and 15 min, respectively. The water absorption capacity was calculated as the difference in the weight of cooked noodles versus uncooked noodles expressed as the percentage of the weight of uncooked noodles (Galvez and Resurreccion, 1992). To determine the cooking loss, cooked noodles were rinsed with cold distilled water, drained for 3 min, and then weighed. The cooking loss was calculated as the difference between the weight of noodles after boiling versus uncooked noodles, and expressed as the percentage of the weight of uncooked noodles (AACC, 1995).

Texture profile analysis and tensile test

An instrumental texture profile analysis was carried out for all noodles using a Texture Analyser (TA-XT2, Stable Micro Systems, Surrey, England). The analysis of textural characteristics was based on the procedures described by Champagne *et al*. (1999). To make a compression test, a stainless steel cylinder probe with a diameter of 2 mm was operated at a pre-test speed of 1.0 mm/s, test speed of 1.0 mm/s, and post-test speed of 1.0 mm/s. The instrument was adjusted to achieve 50% compression with a waiting period of 1 s. The parameters recorded from test curves included hardness and chewiness. Measurements were conducted for three times. The tensile test was carried out based on the method described by Zhu *et al*. (2010) with slight modifications using a Texture Analyser (TA-XT2, Stable Micro Systems) equipped with spaghetti/noodle tensile grips (A/SPR, Stable Micro Systems). The noodle strand was wound four times around the parallel friction roller of the grip to anchor samples and avoid slippage. The distance between parallel rollers was 4 cm. The intention was to measure the tension force. Pre-test, test, and post-test speeds were all set at 3.0 mm/s. The maximum force required to break down the strand was termed the maximum tensile strength.

Scanning electron microscopy

The surfaces and cross-sections of dried and cooked noodles (10 × 10 × 10 mm) were freeze-dried using a freeze-dryer (DRC-1000, EYELA, Tokyo, Japan). These freeze-dried samples were kept in a vacuum wrapping until further use. Cross-sections of freeze-dried noodles were mounted on the specimen holder and coated with gold–palladium alloy in vacuum for 90 s. The morphologies of randomly selected sections were investigated using a scanning electron microscope (JSM-5300, JEOL Ltd., Tokyo, Japan). Images were obtained at an accelerating voltage of 30 kV with 350× magnification.

Statistical analysis

All measurements were analysed using one-way Analysis of Variance (ANOVA). The significant differences ($p < 0.05$) among groups of noodles were analysed by Duncan's multiple-range test using SPSS software version 12.0 (SPSS Inc., Chicago, IL, USA).

Results and discussion

Pasting properties of soy flour

The viscosities of soy flour suspension with or without the addition of tapioca and HPMC are shown in Table 1. The gelatinisation temperature of the soy flour suspension was not clearly measurable as there was no peak viscosity (PV), hot paste viscosity (HPV), or setback (SB) due to short amylopectin branch-chains in soybean (Stevenson *et al*., 2006). Only cool paste viscosity (CPV) of 134 cP was observed. It has been reported that when 40% soy flour was replaced by plantain starch (Abioye *et al*., 2011), its pasting viscosity decreased from 330 to 93 cP. During noodle making, such low pasting property of soy flour did not perform well to make good noodle shape. The addition of tapioca starch during the soy noodle manufacturing process improved the viscosity of soy flour suspension (Table 1), which is consistent with results of Lee *et al*. (2012). The soy suspension added with tapioca showed PV of 104 cP, HPV of 100 cP, and SB of 152 cP. In cassava starch and soy blend (Chinma *et al*., 2013), the addition of tapioca is known to be associated with high peak viscosity by decreasing amylose content in the blend. Proteins containing hydrophilic groups are suitable for forming cross links with starch. These cross links might lead to higher paste viscosity (Goel *et al*., 1999). After the addition of tapioca, the CPV of soy suspension also increased to 252 cP. In the present work, tapioca was added to all soy noodle samples at 10% of total soy flour content. With the addition of HPMC, the PV, HPV, SB and CPV increased as compared to only soy or soy suspension added with tapioca flour. These results indicated that soy flour added with HPMC exhibited higher thickening behaviour. The addition of HPMC could decrease the strength of protein-protein interactions but reinforce protein-amylose and protein-amylopectin interactions (Ribotta *et al*., 2007). When the amount of HPMC added was increased from 0.5 to 1.5%, the PV value increased from 118 to 134 cP, and the CPV value increased from 278 to 376 cP. HPV is the rate of breakdown in viscosity to a holding strength. Higher HPV may be related to lower cooking loss, thus providing better eating quality of noodles (Yadav *et al*., 2011). As expected, the cooking loss (Figure 1) decreased with the addition of HPMC. It has been reported that the stability ratio (STABR) has high correlations with HPV and CPV (Beta and Corke, 2001). The results obtained in the present work revealed that 1.5% HPMC added soy suspension yielded the highest STBAR value (0.985) among the samples. The pasting temperature of soy flour suspension added with tapioca and HPMC was between 95 and 96°C.

Table 1. The pasting properties of soy flour suspension added with tapioca and different percentages of HPMC.

Sample	Pasting temperature (°C)	Viscosity (cP)				STABR*
		Peak viscosity	Hot paste	Setback	Cool paste	
soy	–	–	–	–	134	–
soy + tapioca	95.6	104	100	152	252	0.961
soy + tapioca+ 0.5% HPMC	95.7	118	105	173	278	0.890
soy + tapioca+ 1.0% HPMC	95.4	130	130	170	300	1.000
soy + tapioca+ 1.5% HPMC	94.8	134	132	244	376	0.985

*STABR: stability ratio, hot paste viscosity/peak viscosity

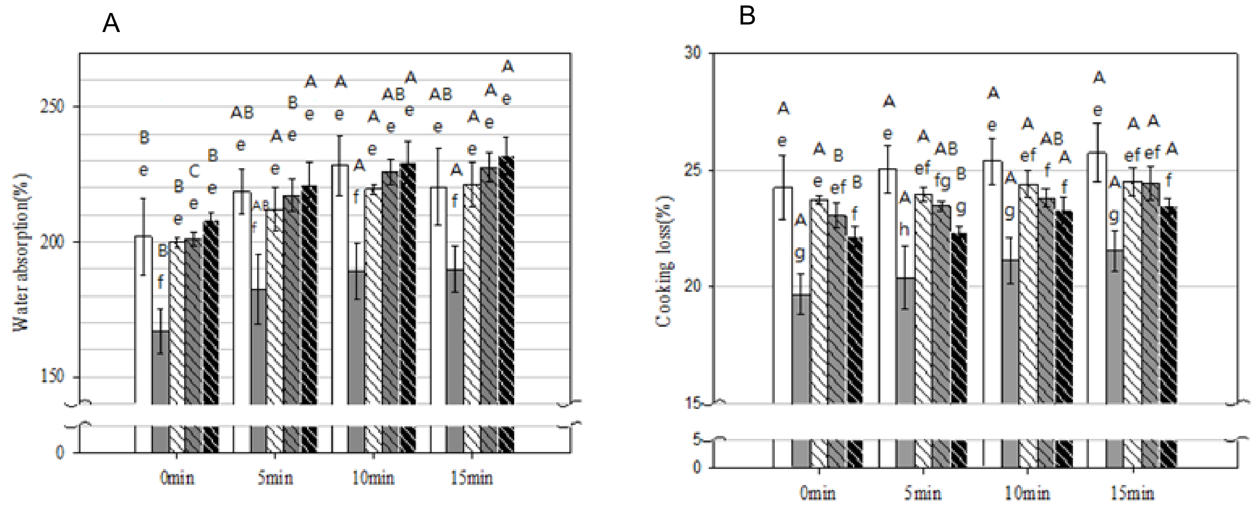

Figure 1. The water absorption and cooking loss of noodles according to the different amount of HPMC. S: Soy noodle ( ), SG: Soy noodle with gluten ( ), SH1: Soy noodle with 0.5 g HPMC( ), SH2: Soy noodle with 1.0 g HPMC( ) SH3: Soy noodle with 1.5 g HPMC( ). ^{ABC}Different superscripts within the same sample are significantly different by Duncan`s multiple range test ($p$ < 0.05). $^{efgh}$Different superscripts within the same time are significantly different by Duncan`s multiple range test (p < 0.05).

Water absorption capacity and cooking loss of soy noodles

Figure 1 shows the water absorption capacity and cooking loss of soy noodles during cooking. Water absorption capacity indicates the degree of noodle hydration. It affects the overall texture of noodles (Yadav *et al*., 2011). Compared to the water absorption capacity of S (202%), gluten addition significantly (p < 0.05) reduced the water absorption capacity of soy noodles, whereas HPMC addition showed different results depending on the amount of HPMC added and the soaking period (Figure 1A). When the soaking time was increased, all samples showed an increase in water absorption capacity, especially during soaking time of 0 to 5 min after cooking. After 10 min of soaking, soy noodles added with HPMC showed lower water absorption capacity than those without the addition of HPMC except SH3 which had the highest water absorption capacity among all samples. In the study of Xin *et al*. (2018), the addition of curdlan (a type of dietary fibre) also decreased the water absorption capacity of noodles because cellulose could lower the hydration power of flour. However, 1.5% HPMC and longer soaking time such as 15 min increased water absorption capacity of noodle. After 15 min of soaking, SH3 had the highest water absorption capacity value (232%), followed by SH2 (228%), SH1 (221%), S (220%), and SG (190%). This result coincided with increased peak viscosity in the RVA study (Table 1). The increase in peak viscosity of soy noodles added with tapioca and HPMC could be related to the increase in water binding capacity through improved gelatinisation (Suhendro *et al*., 2000).

Cooking loss represents the capacity of noodles to maintain the structural integrity during the cooking process (Yadav *et al*., 2011). Compared to wheat noodle, legume and protein flour (pea or soy) fortified noodles and pasta show an increase in cooking loss due to the lack of gluten structure (Limroongreungrat and Huang, 2007). The addition of HPMC and gluten in the present work decreased the cooking loss of soy noodles (Figure 1B). Gluten-added soy noodles had lower percentage of cooking loss (19.7%) while soy noodles added with higher HPMC concentration showed greater initial decrease in cooking loss (SH1: 23.7%, SH2: 23.1%, SH3: 22.1%) compared to the control (24.3%). When soaking time was increased, SH2 and SH3 had greater (p < 0.05) cooking loss, especially after 10 min. However, other samples had no significant increase in cooking loss after 15 min of soaking. High cooking loss which represents high solubility of starch might lead to undesirable eating quality of noodles such as turbid cooking water, low cooking tolerance, and a sticky mouthfeel (Chen *et al*., 2002). These results suggest that HPMC could maintain the structural integrity of soy noodles during the cooking process through high capacity of hydrogen bonding interactions between HPMC and starch.

Textural property of soy noodles

The effects of HPMC addition on textural properties of cooked soy noodles are shown in Table 2. With HPMC addition, the hardness of soy noodles significantly (p < 0.05) increased from 0.54 for S to 0.63 N for SH1 and 0.77 N for SH3. Soy noodles added with 1.5% HPMC and gluten added soy noodles had similar hardness (0.77 N vs. 0.73 N, $p > 0.05$). A similar result was reported for rice-based noodles (Kim *et al*., 2011) and okara cookies (Park *et al*., 2015) added with HPMC. The increased hardness of soy noodles added with HPMC could be related to stronger interaction between water molecules and hydroxyl group of HPMC which could strengthen the interaction between soy and tapioca. Like hardness, chewiness also showed similar trend. Compared to chewiness of S at 0.80 Nm, SH1 showed no difference. However, with the addition of HPMC, the chewiness of soy noodles increased to 1.57 Nm for SH2 and 2.35 Nm for SH3. These values were similar to or higher than the chewiness value of SG (1.73 Nm). Previous research has reported that the addition of cellulose to gluten-free products could significantly increase chewiness (Xin *et al*., 2018). The tensile strength of soy noodles had similar results to hardness (Table 2). The addition of gluten or HPMC increased the tensile strength of cooked soy noodles except for SH1 (208 N/cm^2) which had no significant change in tensile strength as compared to S (188 N/cm^2). Similar results have been observed for tofu noodles added with curdlan (Xin *et al*., 2018) because gums and hydrocolloids could fill the network of structures (Figure 2), thus having a higher resistance to stress (Chen *et al*., 2016). SH2 showed the highest tensile strength (439 N/cm^2), higher than gluten added soy noodle (188 N/cm^2). Thus, adding HPMC into the formulation of soy noodles seemed to have favourable effects on their textural properties, similar to the effects of gluten addition.

Microstructure of soy noodles

The surfaces of soy noodles were examined using scanning electron microscope (Figures 2 A-C). For control soy noodles (Figure 2A), numerous starch granules and holes of various sizes were seen on their surface. Starch granules seemed to have weak attachment to the protein matrix. Such structure would permit rapid penetration of cooking water shown as cooking loss (Figure 1B). Unlike control soy noodles, gluten added soy noodles (Figure 2B) had no layer. Starch granules were shallowly embedded in a protein matrix. There were fewer and smaller holes on their surface as compared to the control. With the addition of 1.5% HPMC (Figure 2C), a thick film of protein matrix covered the starch granules.

Table 2. The textural properties of cooked soy-based noodles added with different amount of HPMC.

	Hardness (N)	Chewiness (Nm)	Tensile strength (N/cm^2)
S	0.54 ± 0.02^c	0.80 ± 0.05^c	188.05 ± 1.1^d
SG	0.73 ± 0.01^a	1.73 ± 0.03^b	358.82 ± 14.27^b
SH1	0.63 ± 0.03^b	0.69 ± 0.03^c	208.21 ± 23.66^d
SH2	0.70 ± 0.02 ^{ab}	1.57 ± 0.04^b	292.72 ± 40.61^c
SH3	0.77 ± 0.08^a	2.35 ± 0.02^a	438.90 ± 41.51^a

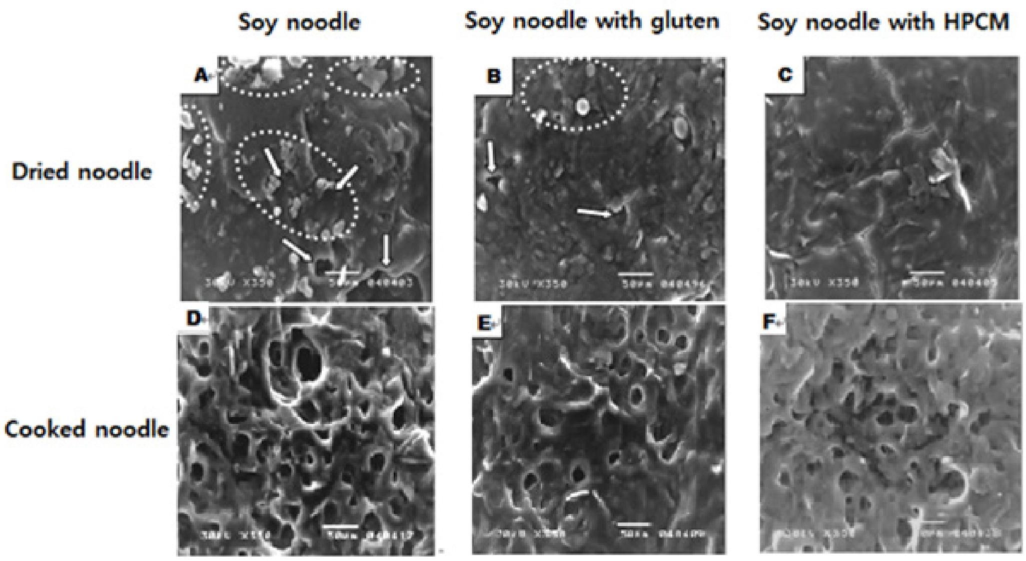

Figure 2. The scanning electron micrographs of the surface of the dried noodles (A-C) and the cross-section of the cooked noodles (D-F). A: Dried soy noodle, B: Dried soy noodle with gluten, C: Dried soy noodle with 1.5% HPMC, D: Cooked soy noodle, E: Cooked soy noodle with gluten, F: Cooked soy noodle with 1.5% HPMC.

Previous research has reported that product added with HPMC appears to have the least void space with more condensed arrangement of smaller holes among dough samples (Park *et al*., 2015). The surface of HPMC added soy noodles was smoother than that of the control, indicating that HPMC could improve the surface connectivity between starch granules for raw noodles. This might explain the increase in the strength of noodles (Table 2). After cooking the soy noodles, the differences in the microstructure among samples became more apparent (Figure 2D-F). The surface of soy noodles was altered from a compact structure with visible starch granules to a more porous structure. Cooking process resulted in gelatinisation and consecutive disruption of starch granules. Therefore, granular structure of starch was hardly observed. Control cooked soy noodles (Figure 2D) exhibited larger and more porous and rough structure of the matrix than gluten added soy noodles (Figure 2E) or HPMC added cooked soy noodles (Figure 2F). The microstructure verified that soy noodles added with HPMC formed a thick film of protein. They had more delicate and sturdy network structure than plain soy noodles or gluten added soy noodles.

Conclusion

To develop protein-enhanced gluten-free noodles, soy flour was used as the main material to prepare noodles (90% of the total weight of noodle). To have good noodle shape, 10% tapioca starch was added. Improved texture properties and cooking quality of soy noodles, particularly cooking loss, were obtained by adding HPMC as a texture improver. The present work demonstrated that the HPMC addition behaved in a way similar to gluten addition. However, the concentration of HPMC is important. It should be controlled to obtain good results. In the present work, 1.5 g HPMC/100 g provided consistent and positive results of quality attributes of soy noodles. Additional research is needed to improve consumer acceptance, particularly qualities related to beany flavour coming from soy flour and mouth feel coming from HPMC that might hinder the new product development.

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