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Original article

Effects of Fat Replacement by Hydroxypropyl Methylcellulose (HPMC) on the Physicochemical, Textural, and Sensory Properties of Reduced-Fat Soy Sausages

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Summary. In this study, we developed a meat-free sausage using soy protein isolates, without the extrusion processing used in meat alternatives. To improve the texture of soy sausages, hydroxypropyl methylcellulose (HPMC) was added to the soy sausages, and the physicochemical, textural, and sensory properties we compared to that of gluten-added soy sausages. Soy sausages showed a higher moisture content (71.66~74.05%) than meat sausages (55%). For the fatty acid composition, meat sausages showed long-chain fatty acids, while soy sausages showed short-chain and medium-chain fatty acids. The addition of HPMC either decreased or retained the hardness of the soy sausages, depending on the level of HPMC (23.54~31.82 N). In particular, HPMC-added soy sausages exhibited a similar microstructure to that of gluten-added soy sausages, with a smooth outer layer of connective matrix. In the consumer test conducted using check-all-that-apply (CATA) questions, HPMC-added soy sausages appeared to be yellow, gelatinous, and tender in terms of appearance, flavor, and texture, respectively, and were found to be the most preferred samples by consumers compared to meat or soy sausages containing gluten. Based on these results, HPMC seems to improve the overall textural properties of soy sausages, particularly hardness and chewiness, compared to meat sausages or gluten-added soy sausages.

Key words: soy sausage, meat-free sausage, textural properties, hydroxypropyl methylcellulose

Introduction

The consumption of meat analogues is increasing for economic, religious, and personal health reasons (1). In particular, meat analogues have many health benefits against obesity-related diseases, as compared to animal-based foods, which have higher contents of fat, saturated fatty acids, and cholesterols and associations with cardiovascular diseases (2). However, sensory problems such as poor texture, color, and flavor are some limitations for the development of meat analogues. Sausages are made up of comminuted meat products that have both homogeneous appearance and chewable textures (3). Vegetarian sausages, which are made from tofu, nuts, soy protein, vegetables, or any combinations of similar ingredients, are available in some countries (3). Like most meat analogues, vegetarian sausages are shaped, colored, or flavored to replicate the taste and texture of meat as accurately as possible. In terms of texture, sausages require less fibrous textures than other types of meat analogues, such as chicken breasts.

Soybean is the most common ingredient or additive for meat analogues because of its high nutritional value (4). Textured soy protein is commonly used as a raw material for meat analogues because it greatly mimics the texture of meat through the improvement of heat shrinkage and rehydration (5).

Textured soy protein can be produced from soy flour, soy concentrate, and soy protein isolates through the extrusion process (6). During the extrusion process, while the soy protein solidifies in the direction of the molecule to maintain its organization, the soy products are mixed with water, and then extruded while being heated to a higher pressure in order to give a meat-like feeling when chewing (7). The forms and usage of textured soy protein differ depending on the type of soy product. Soy flour and concentrate create a form of granules or chunks that are used for many types of fibrous foods and ground meat products (7), while soy protein isolate (SPI) forms a type of fiber that is used in products such as sausages, chicken-style breasts or nuggets, and products that resemble sliced cooked meats after processing the textured soy proteins (8).

Several types of additives have been added to improve the texture of meat analogues. Gluten plays a key role in determining the unique baking quality of wheat by conferring the water absorption capacity, cohesiveness, viscosity, and elasticity of the dough (9). In meat analogues, gluten is often used to improve the textures as well as a binder in meat products for technological reasons and cost-saving purposes (10). However, the increase in gluten-free foods among the commercially-available products is triggered by the development of a new type of texture improver with functional properties similar to those of gluten. Mixtures of hydrocolloids mimic gluten and provide other functions such as gelatinization, thickening, emulsification, or stabilization of air cells (11). Hydroxypropyl methylcellulose (HPMC), which is obtained by the modification of cellulose, has been used as a texture improver and a gluten replacement because of its unique gelling properties, according to its hydration-dehydration characteristics in the solution state as well as during temperature changes (12). Hydroxypropyl methylcellulose has superior foam stabilization ability, which is considered to be responsible for its gas-holding properties, resulting in greater loaf volumes and better crumb structures of gluten-free breads (11, 13, 14). However, there has not been much research on the use of HPMC in meat analogues to replace gluten or fat. Thus, in this study, we aimed to develop plant-based sausages from soy protein isolates without the use of an extrusion process and with HPMC as a texture improver. Moreover, we aimed to compare the hydroxypropyl methylcellulose-added soy sausages with meat sausages and soy sausages supplemented with gluten in terms of their physicochemical, textural, and sensory properties.

Materials and Methods

Materials

Soy protein isolate and collagen casing (size 28 mm) were purchased from ES Food Material (Essential Supply Food Material Co., Ltd, Gunpo, Korea). Gluten was purchased from Bread Garden (Bread Garden Co., Ltd., Seoul, Korea). Hydroxypropyl methylcellulose (any addy BN 40H; viscosity 400 mPa·s) was supplied by Samsung Fine Chemicals (Samsung Fine Chemical Co., Ltd., Incheon, Korea). Meat and salt were purchased from a local market.

Preparation of sausages

The meat sausages (M) were prepared using 145 g of pork meat, and all soy sausages were prepared using 40 g of SPI, except for the gluten-added soy sausages, which were prepared using 30 g of SPI and 10 g of gluten. For HPMC added soy sausages, three different levels of HPMC were added to the soy sausages as a gluten replacer, based on the SPI weight: 0.5% HPMC (SH1), 1.0% HPMC (SH2), and 1.5% HPMC (SH3). To prepare the sausages, the meat or SPI was blended with 105 mL of distilled water using a glass bar and was mixed at 60 rpm for 1 min using a Kitchen Aid mixer (5K5SS, Kitchen Aid, Benton Harbor, USA). Then, 0.4 g of salt was added to the mixture at 60 rpm for 1 min, and then gluten and HPMC were added and mixed at 60 rpm for 1 min and 82 rpm for 2 min, respectively. The mixed dough was pulverized using a grinder (5K5SS, Kitchen Aid, Benton Harbor, MI, USA) at 82 rpm. The collagen casing (13 cm) was filled with 45 g of mixed through a funnel. The filled sausage was heated for 20 min at 100°C. After boiling, the sausages were drained on a strainer for 30 min at room temperature (20 ± 2°C).

Chemical composition analysis

For analysis of the moisture content, 5 g of the sample was cut to 1 cm thick and incubated at 105°C. An infrared moisture analyzer (MB35, OHAUS, Zurich, Switzerland) was used to measure the moisture content until the weight of the sample ceased to change. The crude protein and crude fat contents of the sausages were determined using the Kjeldahl method (HKD-Pro, Hanil Lab Tech Co., Ltd., Seoul, Korea) and the Soxhlet method (HSOX-6, Hanil Lab Tech Co., Ltd., Seoul, Korea), respectively.

Fatty acid analysis

Fatty acids were measured using gas chromatography-mass spectrometry (GC/MS) (Agilent Technologies Inc., Santa Clare, CA, USA) equipped with a flame ionization detector and a column (60 × 0.32 mm) (J&W Scientific, Folsom, CA, USA) (15). Fatty acid methyl ester (FAME) was prepared using BF3/MeOH (14% boron trifluoride). FAME standard mixture (SMB00937, Sigma-Aldrich, Inc., MO, USA) and cis/trans FAME column performance mix (40495-U, Sigma-Aldrich) were used. The oven temperature was held at 100°C for 1 min, increased from 100°C to 195 °C for 15 min, from 195°C to 210°C for 1 min, and from 210°C to 240°C for 5 min and was held at 240°C for 7.5 min. The temperature of both the injector and detector was 260°C. The flow rate of the helium carrier gas was 1.1 mL/min, the injection volume was 1 mL, and the split ratio was 50:1.

Water holding capacity

The water holding capacity (WHC) of the sausages was determined after freeze-drying the boiled sausages (16). The sample (1 g) was placed in 20 mL of water, and then the suspension was mixed in a vortex mixer and centrifuged at 8,000 rpm for 20 min. The aqueous phase was removed, and the precipitate was weighed. The WHC was calculated by dividing the weight of the bound samples by the weight of the sample.

Color measurement

The color values of the sausages were measured using a colorimeter (CR-400, Minolta Camera Co., Ltd., Tokyo, Japan). The reference values that were used for the lightness (L^*), redness-greyness a^*, and yellow-blueness (b^*) values of the white standard tile were 97.83, –0.02, and 1.79, respect, ively. The chroma (C) indicates the chromaticity ranging from saturation (0) to purity (60) obtained as $\sqrt{a^2+b^2}$, and h expresses hue and was calculated as $a\tan^{-1}(\frac{b^2}{a^2})$ (17).

Texture profile analysis

The textural properties of the sausages were determined using a rheometer (COMPAC-100 , Sun Scientific Co., Ltd., Tokyo, Japan). For the samples (20 × 20 mm), a load cell of 10 kg was used, and a plunger (4.91 cm^2) was used to compress the center to 50% of the original height of the sample at a test speed of 120 mm/s. The hardness, springiness, cohesiveness, chewiness, and adhesiveness were calculated using the software provided by the manufacturer (Rheology Data System 3.0, Sun Scientific Co., Ltd.).

Scanning electron microscopy

Samples (5 mm × 5 mm × 2 mm) were freeze-dried using a freeze-dryer (DRC-1000, EYELA, Tokyo, Japan). The freeze-dried samples were kept in vacuum wrapping to protect against moisture until further use. The surface of the freeze-dried sample was mounted on a specimen holder and coated with gold palladium alloy under vacuum for 90 s using an ion sputter coater (E-1030, Hitachi Co., Ltd., Tokyo, Japan). The morphology was randomly investigated using a scanning electron microscope (S-4700, Hitachi Co., Ltd., Tokyo, Japan). The images were obtained at an accelerating voltage of 15 kV at 200× magnification.

Sensory evaluation

The consumer preference test of the sensory attributes (appearance, flavor, and texture) of the sausages was evaluated by 60 panelists (ages 20 to 30, 30 females and 30 males, no vegetarians) who consumed sausage samples 1 to 2 times over three months. Three types of sausages (meat sausages, gluten-added soy sausages, and HPMC-added soy sausages) were provided to consumers at a controlled temperature (20°C). For the HPMC-added soy sausages, the 1% HPMC-added soy sausages were selected for consumer preference tests based on preliminary tests of moisture content and textural properties. To check the descriptive terms for the sausage samples, check-all-that-apply (CATA) questions were used based on the modified terms of Ares et al. (18) and Perez-Cacho et al. (19). Twenty-one attributes related to appearance, flavor, and texture were provided to consumers for each sample. Terms related to appearance were tightness (the degree of surface tension), acceptability (product acceptability based on its appearance), darker, browning, yellow and oily (visual description of surface fat extrusion). Terms related to flavor were pleasant (palatable flavor), nutty (flavor associated with nuts), rancid (flavor associated with oxidized fat-derived compounds), chemical (flavor associated with chemical additives), gelatinous (no taste or odor), pork (flavor associated with meat), off-flavor (undesirable flavor), and beany (flavor associated with soybeans). Terms related to texture included juiciness (perception of the amount of juice released by the sample during the first bites), tenderness (how easily it is chewed), firmness (force required to bite through the sample), grainyness (size of particles in sample), uniformly (the *uniformity* of taste and texture throughout the *sample when bitten*), cohesiveness (the degree to which the sample can be deformed before it breaks), and chewiness (the number of chews required to masticate samples into a state ready for swallowing). For the consumer preference test, a nine-point hedonic scale (9 = extreme like; and 1 = extreme dislike) was used for three sensory attributes (appearance, flavor, and texture).

Statistical analysis

Data for the analysis of variance (ANOVA) with significance were defined as $p < 0.05$. Significant differences among the mean values were determined using the Duncan's multiple range test. All statistical analyses were performed using SPSS software (version 23.0; SPSS Inc., Quarry Bay, Hong Kong). Principal component analysis was performed to study the relationships among 21 sensory attributes (appearance, flavor, and texture) of sausages using XLSTAT software (version 2013; Addinsoft Inc., NY. USA). All data are shown as the mean of triplicate experiments with their standard deviations, except for fatty acid analysis, which was performed once.

Results and Discussion

Proximate composition and fatty acid profile

Compared to that of meat sausages (moisture: 55.78%, fat: 42.90%, and protein: 57.80%), soy sausages had significantly higher moisture (74.05%) and protein (64.30%) contents, but lower fat content (0.02%) (Table 1) ($p < 0.05$), due to the composition of soy protein isolates (91% crude protein, 0.6 % crude fat, and 6.0% moisture) (20). Based on a the study on pork sausages (21), the reduced fat pork sausages had higher moisture content when the hydrocolloid and soy flour were replaced by fat to improve the textural properties, which showed a similar tendency to our results. With the addition of fat replacement, there was no significant difference in the moisture, fat, and protein contents between the gluten- and HPMC-added sausages, except for that of SH2. The 1% HPMC-added soy sausages had similar moisture contents to that of the soy sausages without additives.

In the fatty acid profiles, the meat sausages showed mostly saturated, long-chain fatty acids such as C15:0, C18:1n-9 Cis, C18:1n-9 trans, and C20:0, which is similar to the results of Leggio et al. (22). In contrast, gluten-added soy sausages showed mainly medium-chain fatty acids such as C12:0, C14:0, and C14:1 (23), and HPMC-added soy sausages showed medium-chain and long-chain fatty acids such as C14:1, C16:0, C16:1, and C17:1 (Table 2). Medium-chain fatty acids have the advantages of rapid metabolism and digestion and lower energy value in terms of human health (24, 25). Furthermore, medium-chain fatty acids affect serum cholesterol concentrations (26). Particularly, meat sausages showed 17 times higher saturated fatty acids (17.40 g/100 g) than that of soy sausages added with gluten (0.13 g/100 g) or 1% HPMC (0.02 g/100 g). Saturation of long-chain fatty acids in meat sausages is associated with healthier food choices; thus, consumers look for plant-based sausages such as soy sausages.

Table 1. Moisture, crude protein and fat content, and water holding capacity of soy sausages added with gluten and hydroxypropyl methylcellulose

Properties (%)	M	S	SG	SH1	SH2	SH3
Moisture	55.78 ± 1.24[c]	74.05 ± 0.16[a]	71.86 ± 0.63[b]	71.72 ± 0.55[b]	73.59 ± 1.35[a]	71.66 ± 0.10[b]
Protein	57.80 ± 3.20[b]	64.30 ± 5.50[ab]	77.20 ± 7.40[a]	79.60 ± 9.50[a]	78.80 ± 5.00[a]	79.00 ± 8.90[a]
Fat	42.90 ± 6.50[a]	0.02 ± 0.10[b]	0.02 ± 0.00[b]	0.03 ± 0.00[b]	0.01 ± 0.00[b]	0.01 ± 0.00[b]
Water holding capacity	55.58 ± 16.17[d]	207.95 ± 4.91[b]	153.68 ± 1.36[c]	232.64 ± 7.21[ab]	251.96 ± 36.96[a]	218.33 ± 9.55[b]

[abc] Different superscripts within the same row are significantly different according to Duncan's multiple range test ($p < 0.05$).
M: meat sausages; S: soy sausages; SG: soy sausage added with gluten; SH1: soy sausage added with 0.5% HPMC; SH2: soy sausage added with 1% HPMC; SH3: soy sausage added with 1.5% HPMC.

Table 2. Fatty acid profile of the meat and soy sausages

Fatty acid (%)	M	SG	SH2
C8:0 (Caprylic acid)	0.00	11.55	0.00
C12:0 (Lauric acid)	0.00	27.98	0.00
C13:0 (Tridecanoic acid)	1.85	8.20	0.00
C14:0 (Myristic acid)	0.00	21.78	5.36
C14:1 (Myristoleic acid)	0.00	30.49	34.04
C15:0 (Pentadecanoic acid)	25.30	0.00	0.00
C16:0 (Palmitic acid)	2.74	0.00	14.64
C16:1 (Palmitoleic acid)	0.00	0.00	32.24
C17:1 (cis-10-heptadecenoic acid)	0.00	0.00	13.73
C18:1n-9 Cis (Oleic acid)	42.71	0.00	0.00
C18:1n-9 trans (Elaidic acid)	12.00	0.00	0.00
C18:2n-6 trans (Linolelaidic acid)	2.88	0.00	0.00
C20:0 (Arachidic acid)	12.53	0.00	0.00
Saturated fatty acid (g/100 g product)	17.40	0.13	0.02
Unsaturated fatty acid (g/100 g product)	10.00	0.05	0.01
Total fatty acid (g/100 g product)	27.40	0.18	0.03

M: meat sausages; SG: soy sausage added with gluten; SH2: soy sausage added with 1% HPMC; SH3: soy sausage added with 1.5% HPMC.

Color

The colors of foods can be changed according to the additives as well as the main ingredients. There were significant ($p < 0.05$) differences between meat sausages and soy sausages (Table 3). Compared to that of meat sausages (L^*: 66.81; a^*: 4.42; b^*: 11.08; and chroma: 71.43), soy sausages had lower L^* (62.66) and a^* (0.05) values, but higher b^* (14.03) and chroma (98.58) values. With addition of fat replacer, soy sausages had an increase in L^* to 66.91 (SG), 65.53 (SH1), 66.96 (SH2), and 66.63 (SH3) ($p < 0.05$). The gluten-added and HPMC-added sausages had a similar darkness compared to that of soy sausages only. In a study on meat-free sausages, the L^* value of the sausage improved with the addition of hydrocolloids

Table 3. Color value of soy sausages added with different levels of hydroxypropyl methylcellulose

Properties	M	S	SG	SH1	SH2	SH3
L^*	66.81 ± 0.21[a]	62.66 ± 1.20[c]	66.91 ± 0.55[a]	65.53 ± 0.76[b]	66.96 ± 0.65[a]	66.63 ± 0.66[ab]
a^*	4.42 ± 0.50[a]	0.05 ± 0.29[c]	0.24 ± 0.10[c]	0.40 ± 0.15[bc]	0.76 ± 0.03[b]	0.42 ± 0.18[bc]
b^*	11.08 ± 0.85[c]	14.03 ± 0.62[b]	15.83 ± 0.78[a]	15.84 ± 0.23[a]	16.82 ± 0.51[a]	16.10 ± 0.76[a]
Chroma	71.43 ± 10.34[c]	98.58 ± 8.59[b]	125.47 ± 12.16[a]	125.61 ± 3.75[a]	141.78 ± 8.57[a]	129.90 ± 12.34[a]
Hue	–0.78 ± 0.47[NS]	0.02 ± 0.04	–1.96 ± 1.94	–1.10 ± 2.65	–1.94 ± 1.68	-1.57 ± 2.70

[abcd] Different superscripts within the same row are significantly different according to Duncan's multiple range test ($p < 0.05$).

[NS]No significant.

M: meat sausages; S: soy sausages; SG: soy sausage added with gluten; SH1: soy sausage added with 0.5% HPMC; SH2: soy sausage added with 1% HPMC; SH3: soy sausage added with 1.5% HPMC.

because of the increase in light scattering caused by the hydration of the hydrocolloids (19, 27). In the case of the a^* value, HPMC-added soy sausages (0.40~0.76) had a higher a^* value than that of gluten-added soy sausages (0.24), which is not different from that of soy sausages only. The addition of gluten and HPMC increased the the b^* and chroma of soy sausages, but there was no significant difference in the b^* and chroma between the gluten- and HPMC-added sausages. There was no significant difference in hue among the sausages ($p > 0.05$).

Water holding capacity

Soy sausages (207.95%) showed four times higher water holding capacity (WHC) than that of meat sausages (55.58%) (Table 1). Based on a study on pork sausages (21), the reduced fat pork sausages had higher moisture content when the soy flour was replaced by fat, which was similar to our results. These results could explain the water retention ability that results from the hydrophilic nature of soy (28). Between the two types of additives, the HPMC-added soy sausages (218.33~251.96%) had a significantly higher value than that of gluten-added soy sausages (153.68%), which is lower than that of soy sausages only. The SH2 treatment (251.96%) had the highest WHC among the three different levels of HPMC. In a study of okara cookie dough (29), the 4% addition of HPMC increased the WHC from 47% to 148%, due to its hydrophilic nature (27). Moreover, the HPMC network formed during cooking could act as a barrier to gas diffusion and, consequently, decrease water vapor losses (30).

Textural properties

The results of the instrumental textural evaluations are shown in Table 4. For hardness, the soy sausages (33.32 N) showed a significantly higher value than meat sausages (18.34 N). With the addition of fat replacer, gluten-added soy sausages (32.37 N) had a similar hardness to that of soy sausages, whereas HPMC-added soy sausages had decreased or increased hardness, depending on the level of HPMC. With increasing levels of HPMC, the hardness was significantly increased from 23.54 N (SH1) to 31.82 N (SH2). However, addition of more than 1.5% HPMC decreased the hardness to 25.87 N (SH3). Hydrocolloids generally increase hardness, as amounts of additives are increased due to chemical interactions between hydrocolloids, causing changes in hardness and moisture content (31). In a study of tofu-based noodles (32), firmness was increased with increasing curdlan. However, when tofu noodles containing tapioca starch were supplemented with curdlan, firmness decreased above a tlhreshold curdlan level, similar to our results. Hardness tended to decrease with the addition of hydrocolloids (> 1%) (33). These results were similar to those of wheat doughnuts, that is, when wheat flour was replaced by soy flour, the hardness increased, but decreased with the addition of 5% HPMC

Table 4. Textural properties of soy sausages added with different levels of hydroxypropyl methylcellulose

Properties	M	S	SG	SH1	SH2	SH3
Hardness (N)	18.34 ± 1.18^{c}	33.32 ± 2.01^{a}	32.37 ± 1.90^{a}	23.54 ± 2.15^{b}	31.82 ± 2.86^{a}	25.87 ± 2.49^{b}
Springiness (mm)	0.82 ± 0.02^{c}	0.95 ± 0.01^{ab}	0.94 ± 0.01^{ab}	0.93 ± 0.00^{b}	0.94 ± 0.01^{ab}	0.96 ± 0.03^{a}
Cohesiveness	0.78 ± 0.01^{b}	0.88 ± 0.01^{a}	0.88 ± 0.01^{a}	0.86 ± 0.01^{a}	0.86 ± 0.03^{a}	0.87 ± 0.02^{a}
Chewiness (N·mm)	14.57 ± 0.83^{c}	29.81 ± 1.73^{a}	28.95 ± 1.39^{a}	20.67 ± 1.74^{b}	27.66 ± 1.52^{a}	22.97 ± 1.74^{b}
Adhesiveness (N·s)	0.00 ± 0.00^{a}	–0.13 ± 0.06^{a}	–0.10 ± 0.10^{a}	–0.07 ± 0.12^{a}	–0.29 ± 0.10^{a}	–0.75 ± 0.50^{b}

^{abc} Different superscripts within the same row are significantly different according to Duncan's multiple range test ($p < 0.05$).

M: meat sausages; S: soy sausages; SG: soy sausage added with gluten; SH1: soy sausage added with 0.5% HPMC; SH2: soy sausage added with 1% HPMC; SH3: soy sausage added with 1.5% HPMC.

due to the high water holding capacity of HPMC (Table 1) (34). Other textural parameters showed similar tendencies, such as hardness. There was no significant ($p > 0.05$) difference in springiness and cohesiveness between that of the gluten-added and HPMC-added soy sausages, even in that of the soy sausages only. On the other hand, the HPMC-added soy sausages (SH1: 20.67 N·mm; SH3: 22.97 N·mm) had a lower chewiness value than that of gluten-added soy sausages (28.95 N·mm), except for that of SH2 (27.66 N·mm), which had a chewiness value similar to that of a gluten replacer. As for adhesiveness, there was no significant difference ($p > 0.05$) among the samples, except SH3, which had the lowest adhesiveness value.

Micrographs

The microstructures of the sausages are shown in **Fig. 1**. The cell walls of the meat sausages (**Fig. 1A**) were complex, with numerous irregularly shaped holes and a smooth connection. Numerous round-shaped small holes were observed in the soy sausages (**Fig. 1B**). Soy sausages showed a more compact and dense protein network, which was related to the higher hardness compared to that of meat sausages (Table 4). On the other hand, gluten-added soy sausages (**Fig. 1C**) had a connective surface with large holes at the cell walls, but fewer holes compared to that of M or S. For the HPMC-added groups, different levels of HPMC addition resulted in different surface structures. Soy sausages added with 0.5% HPMC (**Fig. 1D**) had a tough outer layer and ruptured large holes compared to the other HPMC-added sausages. These ruptured and disconnected holes could be related to a decrease in hardness compared to soy sausages without additives. Soy sausages added with 1% HPMC (**Fig. 1E**) had a connective surface like that of gluten-added soy sausages (**Fig. 1C**). These similar microstructures could be related to the similar hardness and chewiness of SG and SH2 (Table 4). Soy sausages added with 1.5% HPMC (**Fig. 1F**) showed similar porosity to those of S and SH1, which was a mix of ruptured large and small holes with less connective surface, decreasing the hardness of soy sausages upon addition of 1.5% HPMC.

Consumer evaluation

Check-all-that-apply questions related to appearance, flavor, and texture were used for product characterization by consumers (Table 5). For appearance, in meat sausages (M), the most ranked term was oily (*20*), followed by acceptable and browning (*17*), and tight and darker (*14*). For gluten-added soy sausages (SG), yellow (*36*) was the highest ranked term, followed by oily (*7*), and tight and acceptable (*6*). In the 1% HPMC-added soy sausages (SH2), yellow (*39*) was the highest ranked term, followed by oily (*35*) and darker (*5*). The most common term for flavor in meat sausages was pork (*42*), followed by chemical (*7*). In

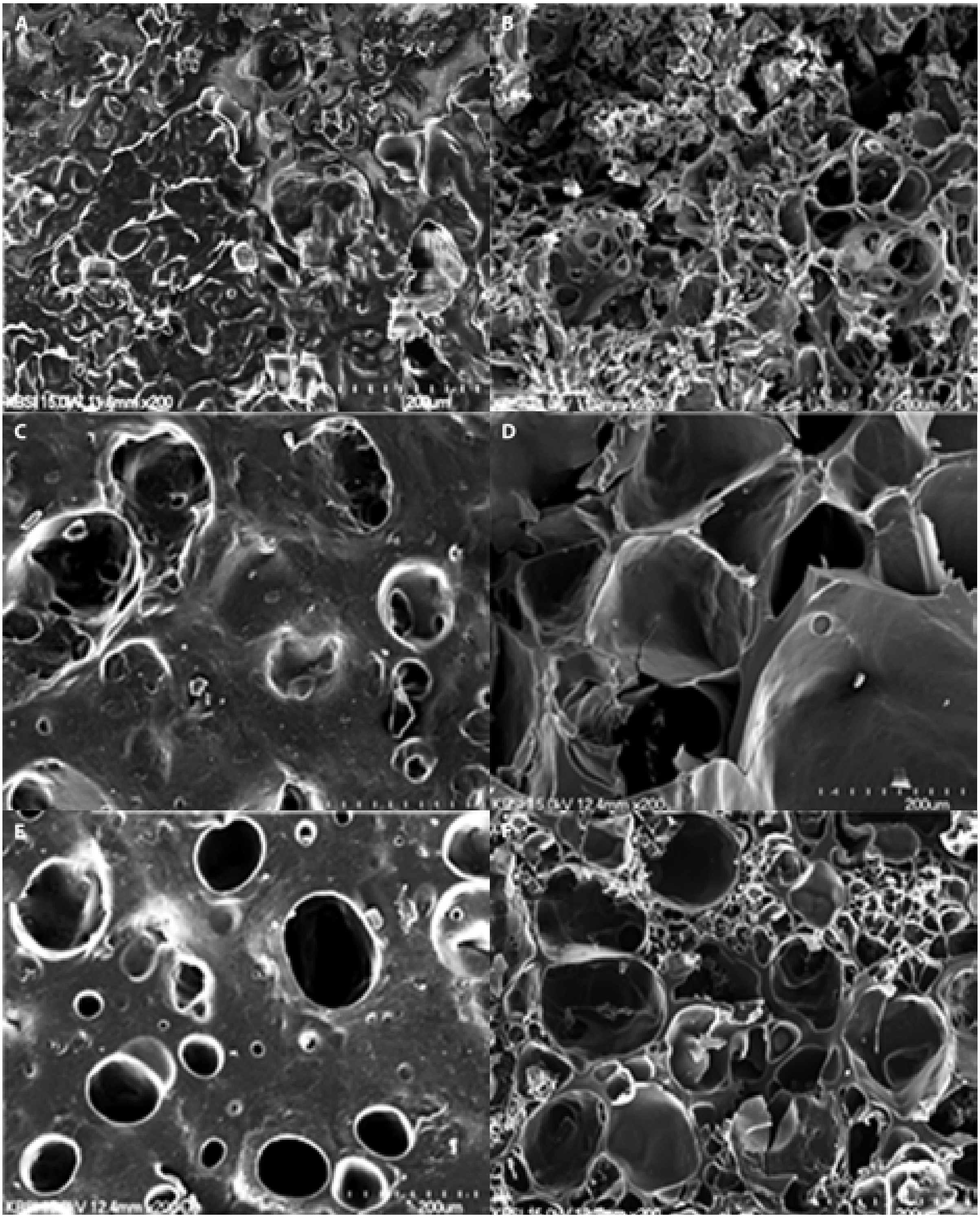

Figure. 1. Micrographs of meat and soy sausages: (A) meat sausages; (B) soy sausages; (C) soy sausage added with gluten; (D) soy sausage added with 0.5% hydroxypropyl methylcellulose (HPMC); (E) soy sausage added with 1% HPMC; and (F) soy sausage added with 1.5% HPMC.

Table 5. Frequency of terms from the check-all-that-apply (CATA) data describing soy sausages

Modality	CATA terms	CATA questions by modality (n = 60)		
		M	SG	SH2
Appearance	Tightly	14	6	3
	Acceptable	17	6	3
	Darker	14	5	5
	Browning	17	3	4
	Yellow	**8**	**36**	**39**
	Oily	**20**	**7**	**35**
Flavor	Pleasant	4	1	1
	Nutty	1	1	0
	Rancid	1	3	5
	Chemical	**7**	**14**	**16**
	Gelatin	**1**	**17**	**33**
	Pork	**42**	**8**	**11**
	Off-flavor	0	8	8
	Beany	**0**	**30**	**0**
Texture	Juiciness	**4**	**6**	**20**
	Tender	**2**	**21**	**19**
	Firmness	16	7	3
	Grainy	**23**	**10**	
	Uniformly	5	7	2
	Cohesive	11	20	12
	Chewiness	18	11	4

M: meat sausages; SG: soy sausage added with gluten; SH2: soy sausage added with 1% hydroxypropyl methylcellulose (HPMC).

SG, beany (*30*) was the most commonly ranked term, followed by gelatin (*17*) and chemical (*14*). In SH2, gelatin (*33*) was the highest ranked term, followed by chemical (*16*) and pork (*11*). The most commonly ranked term for texture in meat sausages was grainy (*23*), followed by chewiness (*18*) and cohesiveness (*11*). In SG, tender (*21*) was the top-ranked term, followed by cohesiveness (*20*) and grainy (*10*). In SH2, juiciness (*20*) was the highest ranked term, followed by tenderness (*19*) and cohesiveness (*12*). The SH2 was ranked highest for juiciness and tenderness, as compared to the other sausage samples, which is similar to the results for moisture content (Table 1). Based on the principal component analysis (**Fig. 2**), the meat sausages (A) were described as pork, browning, pleasant, grainy, chewiness, while the HPMC-added soy sausages (C) were described as juiciness, gelatin, chemical, yellow, and oily. For the consumer preference test (Table 6), all samples had a value of less than five on the 9-hedonic scale. SH2 (4.55~4.75) was the most preferred in appearance, flavor, and texture, followed by M (3.2~3.85) and SG (2.8~3.33). These results were similar with ground pork enhanced with HPMC and konjac flour, which received similar overall preference scores (5.5 ~ 5.7) as normal pork (5.4 on 9-hedonic scale) (35). These results suggest that HPMC was of better quality as a replacement for soy sausages than gluten.

Conclusion

The results indicate that the use of HPMC improved the physicochemical properties and nutritional quality of soy sausages. In particular, the fatty acid composition of soy sausages showed different effects on human health, with medium-chain fatty acids having more benefits as compared to meat sausage that have saturated and long-chain fatty acids. The negative effect of meat analogues such as textural properties can be complemented with HPMC addition, as shown by their similar hardness and chewiness results to that of gluten-added soy sausages. In the microstructure, 1% HPMC-added soy sausages showed a connective structure similar to that of gluten-added soy sausages, which is related to similar texture properties. Moreover, for the CATA sensory attributes, HPMC-added soy sausages were described as juiciness, gelatin, chemical, yellow, and oily, in addition to being the most preferred among consumers. In conclusion, the disadvantages of texture and juiciness, which are the biggest challenges with meat analogues, can be compensated by the use of HPMC in soy-based plant sausages.

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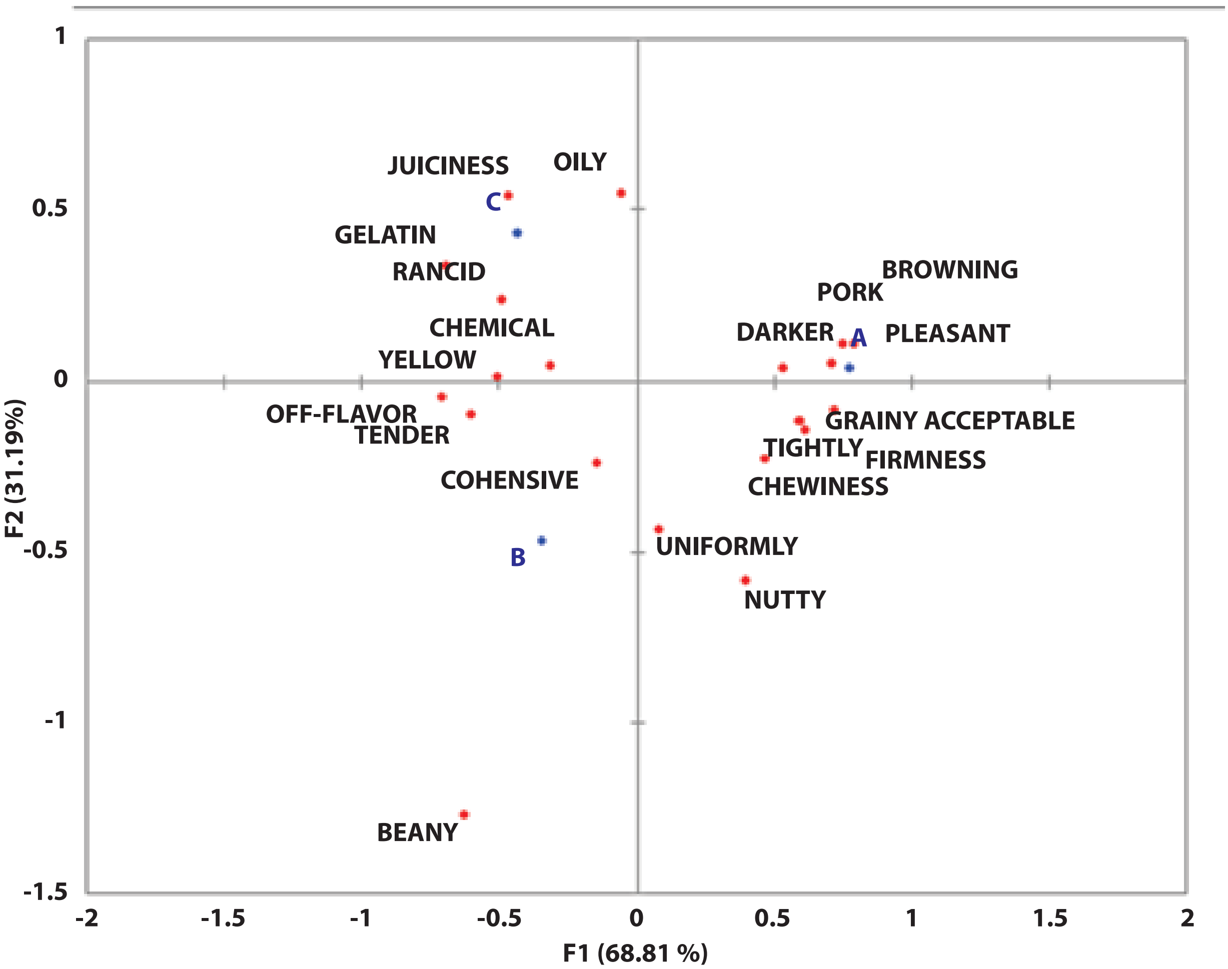

Figure 2. Representation of the samples and the terms in the first and second dimensions of correspondence analysis performed on check-all-that-apply (CATA) data batches. (A) meat sausages; (B) soy sausages added with gluten; (C) soy sausages added with 1% hydroxypropyl methylcellulose (HPMC).

Table 6. Consumer preference for soy sausages added with different levels of hydroxypropyl methylcellulose

Properties	M	SG	SH2
Appearance	3.68^{b}	2.80^{c}	4.73^{a}
Flavor	3.20^{b}	3.15^{b}	4.55^{a}
Texture	3.85^{b}	3.33^{b}	4.75^{a}

[abc]Different superscripts within the same row are significantly different according to Duncan's multiple range test ($p < 0.05$).
M: meat sausages; SG: soy sausage added with gluten; SH2: soy sausage added with 1% HPMC.

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