Effect of Tapioca Starch Concentration on Quality and Freeze-Thaw Stability of Fish Sausage

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ABSTRACT

The influence of tapioca starch (TS) concentration on the quality and frozen storage stability of fish sausage was investigated. Fish sausages with different TS concentrations (3.5, 7.0, 10.5 and 14.0%) were prepared from fish flesh of small scale mud carp (*Cirrhina microlepis*) and kept in a freezer after steam-heating for repeated freeze-thaw treatments. The quality of the cooked sausages at selected freeze-thaw cycles (3, 6 and 9) was evaluated. The water holding capacity of fish sausages increased with increasing TS content in the formulations. The sausages containing at least 7.0% TS exhibited significantly lower cooking loss. The maximum shear force, hardness and chewiness of fish sausages increased with increasing TS content ($P < 0.05$). Mean scores of firmness and overall liking of fish sausages containing TS up to 10.5% exhibited no significant difference. After freezing, there was an increase in drip loss and cooking loss with increasing repeated freeze-thaw cycles, but at a selected freeze-thaw cycle, both values decreased with increasing TS content. The shear force, hardness and chewiness of thawed sausages increased with increasing TS content. The results suggested that the TS concentration plays an important role in improving the quality and freeze-thaw stability of fish sausages in the food industry.
Keywords: cooking loss, drip loss, freeze-thaw stability, water holding capacity, texture

INTRODUCTION

Sausage is a product that can be prepared from various types of meat. Fresh comminuted meats and ingredients used as raw materials in the formulation can be modified to yield desirable organoleptic and keeping qualities of the product. In sausage preparation, raw meat batters are formed by chopping meats, along with other ingredients, to form a coarse dispersion of mainly water, fat and protein. After the heating process, the highly viscous sol converts into a viscoelastic solid. Since the cooked sausage is perishable, the storage quality of the product can be maintained in the refrigerator for about 2 wk (Dong *et al.,* 2007). Freezing is used in the food industry to extend the shelf life of the products. However, during frozen storage, the formation of ice crystals can occur and lead to lower binding properties in the products (Dexter *et al.,* 1993).

Starch is one of the food ingredients added into the raw batter mixture during preparation to improve the quality by acting as an agent for adhesion, binding, gelling and moisture retention (Pietrasik, 1999; Aktas and Genccelep, 2006) to maintain the juiciness and tenderness in

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meat products. In addition, starch can partially replace the expensive meat fraction in the formulation with the desired gel characteristics in the product. The characteristics of starch granular swelling, gelatinization and retrogradation during processing and storage are important for controlling the rheological properties of foods (Nishinari *et al.*, 2000). Many researches have reported the addition of starch in various sausages in forms such as corn and potato starch, including modified starch, for evaluation of the properties of bologna-type beef sausage (Aktas and Genccelep, 2006), potato flour and tapioca starch for preparation of pork sausage during refrigerated storage (Ruban *et al*., 2009) or potato starch in low-fat frankfurters (Lurueña-Martínez *et al.*, 2004). Tapioca starch (TS) is an important starch in Thailand. About 2.5 million tonnes of TS was exported in 2009 with a value about 29,500 million baht, which is equivalent to about USD 1,000 million (OAE, 2010). TS is used as a thickener or stabilizer in many products, such as soups, sauces, fruit pies, puddings and meat products. The required functional properties of TS-based products are needed for further application in product development to improve the product quality (Chantaro and Pongsawatmanit, 2010). TS can be used as a filler in sausage to improve the water holding capacity and textural properties of products, such as low fat pork sausage (Lyons *et al*., 1999). Annor-Frempong *et al.* (1996) also reported cassava (tapioca) flour was used as the filler in comminuted meat products. However, information on the TS concentration used in fish sausage is important for gaining an understanding

of fish product development. Therefore, the objective of this study was to evaluate the quality of fish sausage prepared from freshwater fish flesh containing different TS contents (3.5, 7.0, 10.5 and 14.0%). In addition, the changes in quality during frozen storage using repeated freeze-thaw treatment were also determined for investigating the role of the TS concentration in the formulation of fish sausage during frozen storage for further development in the food industry.

MATERIALS AND METHODS

Materials

Freshwater fish (small scale mud carp; *Cirrhina microlepis*) were obtained from the local market under chilled conditions. Fish mince was obtained by separating the fish flesh from the skin and bone immediately on arrival in the laboratory and the mince was kept frozen at -20 °C until use. Commercial TS produced from Chonburi province, Thailand for industrial and local home use was purchased from a local market and used throughout the experiment without any further purification. Moisture, protein and fat contents of the tapioca starch, fish mince and fish sausage were determined according to AOAC (2000) as shown in Table 1. Soy protein isolate (Vicchi, Thailand), sodium tripolyphosphate (STPP; Union Chemical, Thailand) and other food ingredients were purchased from the local market.

Preparation of raw sausage batter and fish sausage containing TS

The formulations for fish sausage

Table 1   Moisture, protein and fat contents of tapioca starch (TS), fish mince and fish sausage containing 10.5 % TS. (Values shown are mean ± standard deviation).

Quality parameter	Tapioca starch	Fish mince	Fish sausage
Moisture content (%, wb)	11.4 ± 0.1	80.2 ± 0.1	66.6 ± 0.2
Protein content (%, wb)	0.15 ± 0.03	13.9 ± 0.2	9.07 ± 0.06
Fat content (%, db)	0.15 ± 0.02	3.33 ± 0.41	11.2 ± 0.5

wb = wet basis; db = dry basis.

preparation (Table 2) were modified from a commercial company and Rahman *et al*. (2007). Each batch (about 900 g) of sausage formulation was prepared with different TS contents. Frozen fish mince was thawed at 4 °C and blended with salt, STPP and about 1/3 ice by weight using a commercial food processor (CombiMax600, Braun, Germany) for 3 ± 0.5 min (temperature of the sample kept below 4 °C). Soy protein isolate was added into the raw batter, followed by a mixture of sucrose, seasoning powders (pepper, garlic powder, nutmeg powder and caraway powder) and 1/3 ice by weight, and further mixed for about 3 ± 0.5 min. Soy bean oil and the rest of the ice/water was added and mixed for 1 min. Starch was added finally and mixed for 1 min at low speed to obtain final raw fish batter. The temperatures of each raw batter sample were controlled to be lower than 13 °C in all cases at the end of mixing. All raw batter samples were kept in the refrigerator (3 ± 2 °C) for 1 h before stuffing into 16 mm diameter cellulose casing (Celpack, USA) using a sausage stuffer. The fish sausages were linked into 7.0 ± 0.5 cm lengths, steam-cooked for 10 min with the internal temperature higher than 72 °C and cooled in cold water at 4 °C for 10 min. All sausages were kept in a refrigerator controlled at 3 ± 2 °C for one night before quality analysis.

The raw batter samples were analyzed for water holding capacity (WHC) whereas the sausages were evaluated for water holding capacity, processing yield, cooking loss, shear force, texture profile analysis (TPA) and sensory evaluation.

Freeze-thaw stability treatment of fish sausages containing TS

Fish sausages with different TS concentrations were kept overnight at 3 ± 2 °C and were stored in the freezer (-20 °C) for 22 h and thawed in a refrigerator (8ˇ10 °C) for 2 h repeatedly up to nine cycles for freeze-thaw stability evaluation. The sausages were sampled from selected freeze-thaw cycles (3, 6 and 9). Drip loss, cooking loss, shear force and TPA measurements of the repeated freeze-thawed sausages were evaluated.

Determination of fish batter and fish sausage quality

The WHC of each raw batter sample was determined by weighing an homogenized raw batter sample (W_o; approximately 5 g) into a 50 mL centrifuge, then adding 10 mL distilled water, and centrifuging at $\times 2000$ *g* for 10 min under controlled temperature (15 °C). The supernatant was decanted and the final sample weight (W_f)

Table 2   Formulations for preparing raw batter (100 g).

Ingredients	Tapioca starch levels			
	3.5%	7.0%	10.5%	14.0%
Fish mince	60.35	56.85	53.35	49.85
Tapioca starch	3.50	7.00	10.50	14.00
Water added as ice	20.00	20.00	20.00	20.00
Salt (NaCl)	2.00	2.00	2.00	2.00
Sugar	2.77	2.77	2.77	2.77
Sodium tripolyphosphate (STPP)	0.50	0.50	0.50	0.50
Soy bean oil	7.50	7.50	7.50	7.50
Soy protein isolate	2.00	2.00	2.00	2.00
Seasoning powder	1.38	1.38	1.38	1.38

was determined. The WHC (expressed by grams of H$_2$O absorbed per gram of batter) was calculated as a percentage of the weight difference between the raw batter and its final weight after centrifugation using Equation 1 (Lin and Huang, 2003):

$$WHC = (W_o - W_f) / W_o \qquad (1)$$

where: W_o = initial homogenized raw batter sample weight (g)

W_f = final batter sample weight after centrifugation (g)

The higher the WHC value, the more water is bound and therefore, the higher the water holding ability of the batter.

The processing yield of each sausage with different TS levels was evaluated by a modified method of Lurueña-Martínez *et al*. (2004). The weight difference between the sausages before and after steam-heating for 10 min (keeping at 3 ± 2 °C) for 24 h was determined. The processing yield was calculated as a percentage of the weight difference based on the initial weight before heating.

The WHC of the cooked sausages with different TS concentrations was determined by cutting the sausages into small pieces (0.7˜1.0 cm^3 cubes; about 10 g $\pm$ 0.1 mg), and centrifuging at $\times7500$ *g* for 30 min at 4 °C (Verbeken *et al*., 2005; Ayadi *et al*., 2009). The WHC (%) was calculated using Equation 1.

Cooking loss was determined by initially grilling each sausage on a preheated frying pan without cooking oil for 10 min to achieve a core temperature of the sausage of at least 75 °C (modified from Tan *et al*., 2006). Cooking loss (%) was calculated as a percentage of the weight difference of the sausage before and after grilling based on the weight before grilling.

Shear force was determined by initially holding the sausages at room temperature (25 °C) for 1 h. Then, within 1 h, the casing was peeled off and the sausage was cut into 30 mm lengths to obtain cylinders (16 mm diameter) from the center of the sausage link. Three cylinders from 3 sausage links were evaluated using a texture analyzer (TA-500, Lloyd Instruments Ltd., UK) equipped with the texture NEXYGEN™ software program (Ametek, Inc., UK) with a 5 kN load cell. A Warner-Bratzler shear fixture (60 ° V-shaped blade) under compression mode with a cross-head speed of 100 mm/min was applied. The maximum force (N) to cut through the cross section (16 mm diameter) of the sample (referred to as the shear force) was recorded (Cofrades *et al.,* 2000).

Texture profile analysis (TPA) was determined initially by holding fish sausages containing different TS contents at 25 °C and cutting them into cylinders (15 mm in height and 16 mm in diameter) 1 h before the TPA measurement using the same texture analyzer (TA-500, Lloyd Instruments Ltd., UK) as earlier. A standard double-cycle program was used to compress the samples to 30% compression (4.5 mm) of the original sample height at a speed of 30 mm/min using a 50 mm diameter probe (modified from Pongsawatmanit *et al*., 2007). At least 5 cylinder samples were measured to obtain an average value for all TPA parameters (hardness, cohesiveness, springiness, chewiness, gumminess) for each formulation.

Sensory evaluation of the fish sausages containing different TS contents was performed using an affective test involving 30 untrained panelists (the students and staff of the Department of Product Development, Kasetsart University). The sausages were steam-cooked at 85˜90 °C for 10 min, cut into 10 mm lengths, kept in a plastic container and served within 20 min while hot. Each sausage formulation was placed in a white plastic cup (2 pieces per formulation) with a three-digit code and individually presented at room temperature on a tray in a random order to each assessor. Drinking water was provided to minimize any residual effect before a panelist tested each new sample. Each panelist was asked to determine liking scores for appearance, color, juiciness,

firmness, tenderness and overall liking of each sample using a 9-point hedonic scale (1 = dislike extremely, 5 = neither dislike nor like, and 9 = like extremely).

Quality of fish sausage in repeated freeze-thaw stability treatment

The drip loss of frozen fish sausages was reported as a percentage of the weight difference before and after thawing at 8˜10 °C for 4 h based on the initial frozen weight. The cooking loss, shear force and TPA measurements were carried out according to the methods mentioned above.

Statistical analysis

All measurements were carried out using three replications. The results were reported as the mean ± standard deviation and subjected to analysis of variance (ANOVA) using SPSS V.12 statistical software (SPSS (Thailand) Co., Ltd.). Differences between the means of sausage qualities containing different TS contents were determined using Duncan s multiple range test (DMRT) and significance was defined at $P < 0.05$.

RESULTS AND DISCUSSION

Quality of fish sausage containing different TS contents

The WHC of raw fish batters prepared from different formulations by replacing fish mince with TS (3.5, 7, 10.5 and 14%) were

evaluated. A higher WHC value indicates more water is bound. The WHC of the raw batter was lower with increasing TS content, and was significantly lower when the addition of TS was greater than or equal to 10.5% due to the lower protein content from the fish mince in the formulation with the higher raw starch substitution. The concentrations of TS used in each fish sausage formulation exhibited no effect on the processing yields ($P > 0.05$; Table 3).

Prior to heating, adding starch in the formulation decreased the water-holding capacity of the raw batter. After cooking, the WHC of the fish sausage samples increased with increasing TS (Table 3; $P < 0.05$). The addition of TS caused an increase in WHC in the cooked sausages due to the starch gelatinization binding more water in the fish sausage system during steam heating. The higher WHC resulted in a lower cooking loss (8.8˜8.9%) in grilled sausages containing greater than or equal to 7% TST(Table 3; $P < 0.05$). The decrease in cooking loss with increasing TS in bologna sausage or meat products was also observed by Colmenero *et al.* (1996) and Annor-Frempong *et al.* (1996), respectively. The results suggested that TS addition (TS ≥ 7%) reduced the cooking loss because of the better absorption of the water added by the starch during formulation and the starch gelatinization during heating (Aktas, 2006).

The shear forces of the fish sausage samples were determined using the Warner-

Table 3 Water holding capacity (WHC) of raw batter, processing yield, WHC and cooking loss of fish sausages containing different TS contents.

Tapioca starch (%)	WHC of raw batter (gram H_2O / gram batter)	Processing yield (%)	WHC of sausage (%)	Cooking loss (%)
3.5	0.174±0.011[b]	97.25±0.36[a]	96.46±0.39[a]	9.98±0.26[b]
7.0	0.159±0.010[b]	97.33±0.08[a]	98.08±0.14[b]	8.91±0.38[a]
10.5	0.105±0.013[a]	97.17±0.33[a]	98.69±0.08[c]	8.81±0.11[a]
14.0	0.089±0.004[a]	97.40±0.59[a]	99.12±0.01[c]	8.79±0.14[a]

Mean ± standard deviation values followed by different lower case letters within the same column are significantly different ($P < 0.05$) by Duncan s multiple range test.

Bratzler shear fixture with a 60 ° V-shaped blade under compression and shearing completely through the samples. The tenderness of the samples was recorded as the maximum force (N) to cut through the cross section (16 mm diameter) of the sample (referred to as the shear force). The shear force exhibited higher values with increasing TS contents (Table 4; $P < 0.05$). This indicated that fish sausages containing higher TS contents required a higher force to shear due to the higher WHC of the cooked sausages resulting from the added gelatinized TS.

Texture profile analysis (TPA) is a very useful technique for evaluating food quality in product development. In the present study, the hardness values of fish sausages (defined as the maximum force of the first compression to 30% deformation of the original sample height) increased significantly with increasing TS contents (Table 4; $P < 0.05$) from about 7 to 12 N in the sausages containing TS from 3.5 to 14%, respectively. Cohesiveness, another TPA parameter, was also determined from the area of work during the second compression divided by the area of work during the first compression (Bourne, 2002). Cohesiveness indicates how well the product withstands a second deformation relative to how it behaved under the first deformation. In the present study, for all sausages containing 3.5 to 14% TS, there was no significant difference ($P > 0.05$; Table 4) among the cohesiveness values which were about 0.56˜0.58.

This indicated that the concentration of the added TS had no effect on the cohesiveness of the fish sausages.

Springiness (mm) was defined as the length to which a sample recovers in height during the time that elapses between the end of the first compression cycle and the start of the second compression cycle. There was no significant difference ($P > 0.05$; Table 4) in the springiness values of the sausages that ranged between about 3.9 and 4.1, indicating the TS concentration in the sausage formulation did not influence the elasticity of the samples. Gumminess is a quantity used to simulate the energy required to disintegrate a semi-solid food and is calculated by the product of (multiplying) TPA hardness and cohesiveness (Bourne, 2002); the values increased with increasing TS levels in the fish sausages (Table 4; $P < 0.05$). Chewiness refers to the energy required to chew a solid sample to a steady state of swallowing and was obtained from the product of hardness, cohesiveness and springiness, which is equivalent to the product of gumminess and springiness. As expected, the chewiness also increased with increasing TS contents (Table 4; $P < 0.05$) with the same trend as hardness, as the TS concentration revealed no effect on the cohesiveness and springiness of sausages. However, there was no significant difference in all stated TPA parameters of sausages containing 7 and 10.5% TS.

Table 4 Shear force and texture profile analysis parameters of fish sausages containing different tapioca starch contents.

Tapioca starch (%)	Shear force (N)	Hardness (N)	Cohesiveness (-)	Springiness (mm)	Gumminess (N)	Chewiness (N mm)
3.5	7.96±0.13[c]	6.95±0.45[c]	0.56±0.06[a]	4.10±0.29[a]	3.87±0.45[c]	15.9±1.8[c]
7.0	8.78±0.13[b]	8.44±0.36[b]	0.58±0.02[a]	4.08±0.24[a]	4.86±0.24[b]	19.8±1.2[b]
10.5	8.87±0.36[b]	8.96±0.61[b]	0.56±0.02[a]	3.92±0.24[a]	5.04±0.24[b]	19.7±1.2[b]
14.0	9.54±0.30[a]	11.54±0.48[a]	0.57±0.02[a]	4.11±0.23[a]	6.58±0.37[a]	27.1±2.3[a]

Mean ± standard deviation values followed by different lower case letters within the same column are significantly different ($P < 0.05$) by Duncan s multiple range test.

Table 5 shows the liking scores from the sensory evaluation carried out by untrained panelists of the sensory attributes (appearance, color, juiciness, firmness, tenderness and overall liking) in the fish sausages containing 3.5 to 14% TS using the 9-point hedonic scale. The scores for appearance and color were about 7.0˘7.2 and 6.8˘6.9, respectively, with no significant difference among the sausages containing different TS concentrations. The liking scores for firmness and overall for the sausages containing 14%TS exhibited the lowest values and were significantly different from those obtained from the sausages containing the lower TS concentrations (3.5˘10.5%). The overall liking scores of the sausages containing 3.5 to 10.5% TS contents were about 6.9˘7.1 (like moderately) and exhibited no significant difference. The results indicated that the higher amount of TS added to the fish sausage formulations increased the shear force, hardness, gumminess and chewiness values (Table 4). The added starch enhanced the formation of stronger heat-induced structures through the swelling of the starch granules embedded in the protein gel matrix of the sausage (Colmenero *et al.*, 1996). However, the addition of 14% TS in the sausage formulation was too high based on this level of addition, producing the highest values for shear force, hardness and chewiness and receiving the lowest overall liking score. The liking scores of the samples were about 7 (like moderately) in the samples containing 3.5 to 10.5% TS.

Quality of fish sausage in repeated freeze-thaw stability treatment

Freezing is a method used to extend the shelf life of many perishable products. Therefore, freeze-thaw stability is important in the food industry. Thermal fluctuations and consequent phase changes of water during the cold chain storage are the main causes of deterioration in frozen food, especially in the gel matrix of the product, leading to changes in functional properties such as gel behavior (Pongsawatmanit *et al.*, 2006). The combined effect of TS concentration and frozen storage on the quality of fish sausages was investigated using repeated freeze-thaw treatment. Since freezing and frozen storage caused a loss of water-binding properties in the sausage systems, the effect of freeze-thaw treatments was more pronounced in the samples with lower TS concentration as indicated by the higher drip-loss values (Figure 1a). The drip loss increased with an increased number of freeze-thaw cycles due to water exudation from the thawed products. However, the drip-loss values decreased with increasing concentration of TS for any number of freeze-thaw cycles, indicating a greater extent of water binding with gelatinized starch molecules in the fish sausages. After grilling the thawed sausages on a hot frying pan for 10 min, the cooking-loss values of thawed samples were significantly higher than those of unfrozen samples (freeze-thaw cycle = 0) at the same TS concentration in the product, but the values were
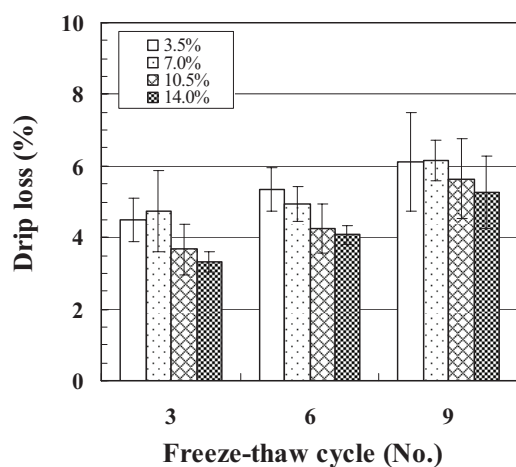
Table 5 Mean liking scores of fish sausages containing different tapioca starch contents.

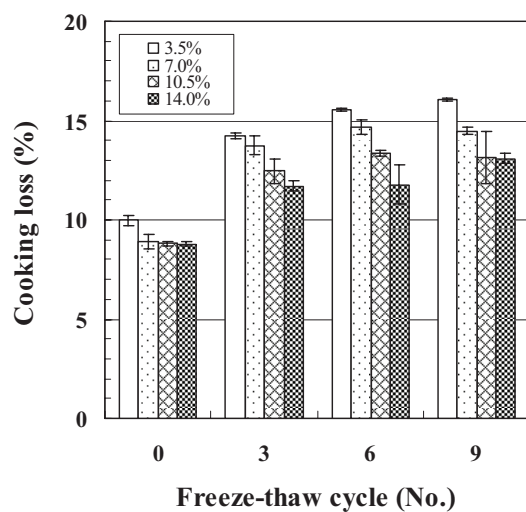| Tapioca starch (%)	Appearance	Color	Juiciness	Firmness	Tenderness	Overall liking
3.5	7.0±0.8[a]	6.9±0.9[a]	7.1±0.9[a]	7.0±1.3[a]	7.1±1.0[a]	7.1±0.7[a]
7.0	7.2±0.8[a]	6.9±1.2[a]	6.4±1.0[b]	6.6±1.1[a]	6.7±1.2[ab]	6.9±0.9[a]
10.5	7.1±0.9[a]	6.8±1.0[a]	6.3±1.0[b]	6.7±1.2[a]	6.4±1.4[b]	6.9±0.9[a]
14.0	7.1±0.8[a]	6.8±1.1[a]	5.3±1.2[c]	5.3±1.4[b]	5.4±1.2[c]	5.4±1.2[b]

Mean ± standard deviation values (n=30) followed by different lower case letters within the same column are significantly different ($P < 0.05$) by Duncan s multiple range test.
Liking scores are based on a 9-point hedonic scale (1 = dislike extremely, 5 = neither dislike nor like, and 9 = like extremely).

not significantly different with an increased number of freeze-thaw cycles in sausages containing 7.0% TS or more (Figure 1b). The results confirmed that the ability of the binding function of gelatinized TS in the fish sausages to improve freeze-thaw stability depends on the

amount of TS added in the formulation (Figure 1), which was also reported by Colmenero *et al.* (1996) and Dexter *et al.* (1993) in other meat products.

The shear force of all sausages with different TS concentrations was significantly higher after freezing and thawing compared with unfrozen samples (freeze-thaw cycle = 0). At the same TS content level, the shear force values revealed no significant difference with an increased number of freeze-thaw cycles (Figure 2). The formulation with 14% TS exhibited the significantly highest shear force among the samples containing 3.5ˇ14% TS at any selected freeze-thaw cycle. When the TPA measurements were carried out, the hardness values of all thawed sausages containing different TS contents were significantly higher than those without freezing treatment (Figure 3a). At a selected freeze-thaw cycle, the hardness increased with increasing TS content. However, the hardness values of sausages containing 3.5, 7 and 10.5% TS were not
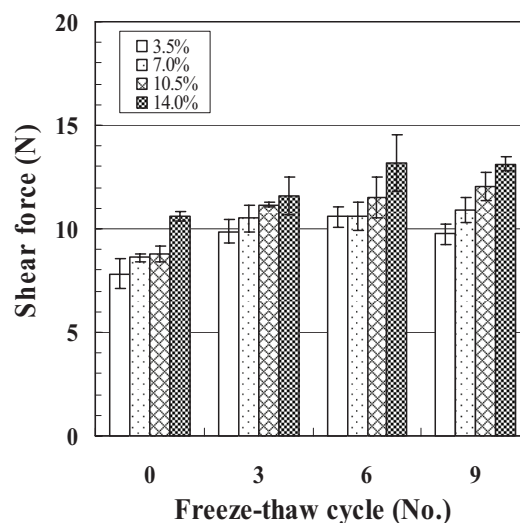

(a)

(b)

Figure 1 Mean drip loss (a) and cooking loss (b) of thawed sausages containing different tapioca starch concentrations as a function of number of freeze-thaw cycles. The vertical bars represent standard deviations.

Figure 2 Mean shear force of thawed sausages containing different tapioca starch concentrations as a function of number of freeze-thaw cycles. The vertical bars represent standard deviations.

significantly different with an increased number of freeze-thaw cycles. Chewiness values of the thawed samples from repeated freeze-thaw treatment involving 3, 6 and 9 cycles were higher than in unfrozen samples and increased with increasing TS contents (Figure 3b). The shear force or TPA hardness and chewiness of the sausages containing different TS contents increased after
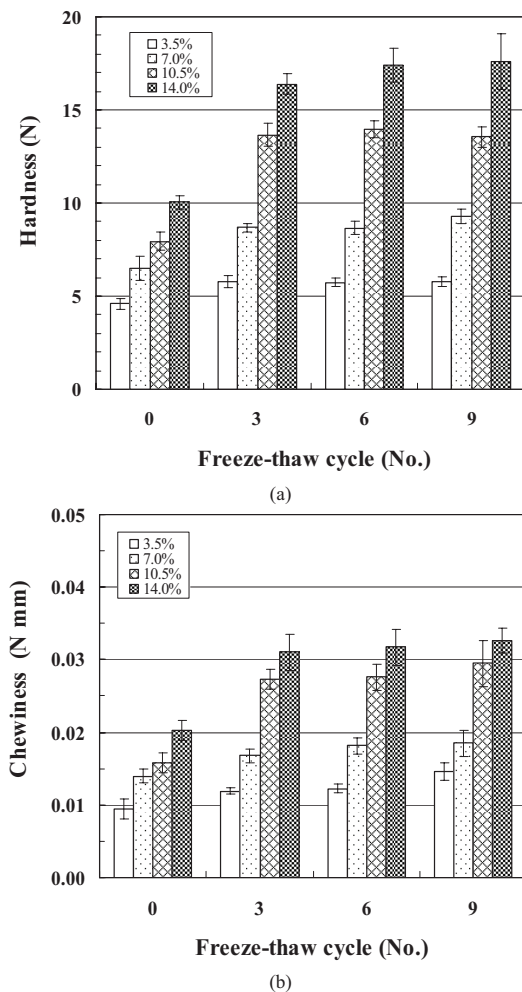
freezing and frozen storage, and the extent of the increase depended on the TS concentration. Higher values of the texture parameters were also reported in frozen bologna sausages (Colmenero *et al.*, 1996). The higher starch substitution for fish mince leading to lower effective concentrations of the fish protein forming the gel or emulsion matrix in the sausages may have enhanced the formation of stronger heat-induced structures from starch granules within the casing. In addition, the gelatinized starch may have affected the gel texture during repeated freeze-thaw treatments as indicated by the lower drip loss and higher texture parameters with increasing TS concentrations.

Starch-free sausage was excluded in the present study. However, from a previous preliminary test, the fish sausages without TS substitution exhibited the highest drip-loss values compared with those containing 3.5 to 14% TS. In addition, the overall liking score was lower than those with 3.5˘7% TS addition. Since the repeated freeze-thaw cycle treatment is a method used for accelerating the deteriorative changes in frozen products, the quality and final sensory evaluation of the sausages obtained from long-term frozen storage will be further investigated.

CONCLUSION

The TS concentration added into the formulation affected the fish sausage quality. Incorporation of 7.0% TS or more into the fish batter improved the WHC of fish sausage with reduced cooking loss. The maximum shear force, hardness and chewiness of fish sausages increased with increasing TS content. According to sensory evaluation, 10.5% TS could be added into the formulation for controlling water binding properties without affecting the overall liking, as the mean scores of the fish sausages exhibited no significant difference. Under frozen storage, the drip loss and cooking loss of thawed sausages decreased with increasing TS. The drip loss

Figure 3 Mean texture profile analysis hardness (a) and chewiness (b) of thawed sausages containing different tapioca starch concentrations as a function of number of freeze-thaw cycles. The vertical bars represent standard deviations.

increased with an increased number of repeated freeze-thaw cycles. The shear force, hardness and chewiness of thawed sausages increased with increasing TS contents. Therefore, TS can be used in the formulation for altering the quality and freeze-thaw stability of fish sausage.

ACKNOWLEDGEMENTS

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