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Effect of different types of low sweetness sugar on physicochemical properties of threadfin bream surimi (*Nemipterus* spp.) during frozen storage

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Abstract: The effects of different types of low-sweetness sugar (lactitol, maltodexrin, palatinit, polydextrose, trehalose) on the physicochemical properties of threadfin bream (*Nemipterus* spp.) surimi during six months of frozen storage were investigated. The characteristics analyzed were moisture content, pH, water-holding capacity, whiteness, folding test, gel strength, expressible moisture, and texture profile analyses. Generally, the cryoprotective effectiveness decreased as the storage time increased. Polydextrose was able to maintain a water-holding capacity of 77.0%, 98.6% whiteness, a folding test value of 100%, and a gel strength of 53.6% compared with its initial value during six months of frozen storage. Meanwhile, sucrose was able to maintain a water-holding capacity of 80.3%, 98.6% whiteness, a folding test value of 75%, and a gel strength of 56.8% compared with its initial value. Raw surimi was able to maintain water holding capacity of 62.2%, 98.7% whiteness, a folding test value of 75%, and a gel strength of 36.0% compared with its initial value. It is suggested that, polydextrose as a potential alternative cryoprotectant to replace other low-sweetness sugars.

Keywords: Cryoprotectant, denaturation, frozen storage, low-sweetness sugar, myofibrillar protein

Introduction

Surimi is composed of stabilized myofibrillar proteins obtained from fish flesh that has been mechanically deboned, washed with water, mixed with cryoprotectants, and then frozen (Park and Morrisey, 2000). It has some functional properties such as gel-forming ability and water-holding capacity (Somjit *et al*., 2005). These functional properties are affected by the quality of myofibrillar protein. Currently, frozen storage is the most important and effective technique used to preserve surimi (Pan *et al*., 2010). However, the denaturation of protein, especially myofibrillar protein, still occurs and causes surimi to eventually lose its properties during frozen storage. To avoid this deleterious effect during frozen storage, cryoprotectants are being added to surimi (Okada, 1992).

Generally, the most commonly cryoprotectant used is sucrose and sorbitol (1:1) with 0.3% polyphosphate added as a synergist (Yoon and Lee, 1990; MacDonald and Lanier, 1991). Nevertheless, this cryoprotectant imparts a sweet taste and high calorie value to surimi (Carvajal *et al.*, 1999). Many studies have been conducted to overcome this problem by using low-sweetness sugar as an alternative. Sych *et al*. (1990) reported that lactitol, palatinit, and polydextrose stabilize cod surimi equally well as does a sucrose/sorbitol mixture. Pan *et al*. (2010) reported that trehalose (6%)/polyphosphate (0.3%) shows the greatest protective effect on grass carp surimi over sucrose (4%)/sorbitol (4%) during 25 weeks of frozen storage. Meanwhile, Carvajal *et al*. (1999) reported that maltodextrin exerts good cryoprotection over fish muscle at -200 during 3 months of frozen storage.

Previously, only a few studies related with cryoprotective effects of different types of low-sweetness sugars on marine tropical fish have been reported. Hence, the objectives of this work were to investigate the effect of low-sweetness sugar on the physicochemical properties of threadfin bream surimi and to investigate the potential of low-sweetness sugar as a cryoprotectant alternative to sucrose.

Materials and Methods

Sample preparation

Threadfin bream (*Nemipterus* spp) surimi preparation was performed at the surimi manufacturing plant QL Food Sdn. Bhd. located in Hutan Melintang, Perak, Malaysia, according to normal commercial procedure. The low intensity-sweetness sugars used

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Table 1. Low-sweetness sugars used to treat surimi

Surimi blocks	Treatments
A	Raw surimi (without any cryoprotectant)
B	6% sucrose + 0.3% sodium tripolyphosphate
C	6% lactitol + 0.3% sodium tripolyphosphate
D	6% maltodextrin + 0.3% sodium tripolyphosphate
E	6% palatinit + 0.3% sodium tripolyphosphate
F	6% polydextrose + 0.3% sodium tripolyphosphate
G	6% sorbitol + 0.3% sodium tripolyphosphate
H	6% trehalose + 0.3% sodium tripolyphosphate

in this experiment are shown in Table 1. After mixing, surimi was packed in polyethylene bags; each package weighed 10 kg and was frozen using a contact plate freezer. Frozen surimi blocks were then immediately transported to the School of Industrial Technology Universiti Sains Malaysia by a refrigerated truck.

Frozen storage analysis

Every month for six months consecutively, the samples were removed from the freezer and thawed overnight in a chiller at 40^{0}C prior to analysis. The characteristics analyzed were moisture content, pH, water holding capacity, whiteness, folding test, gel strength, expressible moisture, and texture profile.

Moisture content

Moisture content was determined according to AOAC (2000) method. Surimi was weighed 5 gram (X) and put the sample in moisture disk which previously dried at 1050^{0}C. The sample was dried in the oven for 24 h at the temperature 1050^{0}C. After 24 h, the sample was cooled in desiccator and weighed soon after reaching room temperature (Y). The moisture content was calculated by the following the formulation below:

$$Moisture\ content\ (\%) = 100 - \left[\frac{(X-Y)}{X} \times 100\right]$$

pH

The pH of surimi was determined in triplicate according to Lanier (1992). The sample was weighed for 5 gram, added with distilled water 45 ml, and then homogenized by using homogenizer at 7000 rpm (IKA®T25 digital ultra-turrax®, Germany). The pH of homogenate was measured using a pH meter (microprocessor pH meter, HANNA Instruments, Mauritius).

Water holding capacity (WHC)

Water holding capacity was determined according to Sultanbawa and Li-Chan (1998) in triplicate. 10 grams of surimi was homogenized with 40 ml distilled water using a homogenizer at 7000 rpm (IKA®T25 digital ultra-turrax®, Germany). The homogenate was weighed (X) and placed in 50 ml centrifuge tube and centrifuged for 5 min at 3500 g. After centrifugation, the supernatant was decanted and pellet was weighed (Y). Water holding capacity was calculated according the following formula:

$$WHC\ (\%) = \left(\frac{X-Y}{X}\right) \times 100$$

Whiteness intensity

Surimi was weighed into 400 g portions and mixed with 0.3% of salt using a silent cutter (Stephan, Germany) for 2 min to produce a homogenous sol. The sol was placed into a polyvinylidine casing with a diameter of 2.5 cm using a stuffer (Amrapali pure stainless steel size no. 7, India). The surimi sol was subjected to heating at 360^{0}C for 30 min in a water bath (WB-22 DAIHAN, Korea), followed by heating at 900^{0}C for 10 min in a water bath according to the procedure of Park *et al*. (1988). The surimi gels were then cooled directly on ice for 30 min and equilibrated to room temperature for 1 h prior to analysis (Nowsad *et al*., 2000a). Whiteness intensity of surimi gels was measured using a calorimeter (Minolta Spectrophotometer, Model CM-3500d, Osaka, Japan). The measurement of L*, a* and b* was performed in triplicate. Whiteness intensity was calculated using the following equation (Park, 2005):

$$Whiteness = 100 - [(100 - L^*)^2 + a^{*2} + b^{*2}]^{1/2}$$

Folding test

The folding test was determined according to Lanier (1992). Surimi gel was slice uniformly with the thickness 2 mm. The slice was folded slowly to observe the degree of elasticity before it cracks. The subjective scale to describe the degree of folding strength used was as: (1) breaks by finger pressure, (2) cracks immediately when folded in half, (3) cracks gradually when folded in half, (4) no cracks showing after folding in half and (5) no cracks showing after folding twice.

Gel strength

Gel strength was measured using the standard puncture test according to Lanier (1992) and Nielsen

Table 2. Changes in moisture (%) content of threadfin bream surimi with different cryoprotectants during six months of frozen storage.

Month	Raw	Sucrose	Lactitol	Maltodextrin	Palatinit	Polydextrose	Sorbitol	Trehalose
0	81.09±0.26^{aA}	76.23±0.00^{aE}	77.00±0.36^{aC}	76.95±0.04^{aCD}	77.61±0.07^{aB}	76.58±0.10^{aDE}	76.57±0.00^{aDE}	76.73±0.00^{aCD}
1	80.64±0.15^{bA}	76.15±0.10^{abF}	76.93±0.13^{aC}	76.88±0.02^{aC}	77.47±0.00^{abB}	76.47±0.03^{abDE}	76.34±0.12^{bEF}	76.67±0.00^{abD}
2	80.62±0.02^{bA}	76.15±0.00^{abG}	76.82±0.02^{abC}	76.58±0.09^{bDE}	77.43±0.03^{bB}	76.44±0.17^{abEF}	76.32±0.01^{bF}	76.67±0.04^{abCD}
3	80.43±0.17^{bcA}	76.07±0.01^{bE}	76.69±0.01^{abcC}	76.57±0.11^{bC}	77.37±0.05^{bB}	76.33±0.01^{bcD}	76.27±0.05^{bcDE}	76.63±0.10^{abcC}
4	80.34±0.14^{bcA}	76.05±0.05^{bG}	76.54±0.06^{bcCD}	76.46±0.00^{bcDE}	77.35±0.06^{bB}	76.31±0.01^{bcEF}	76.19±0.03^{cFG}	76.62±0.02^{abcC}
5	80.18±0.11^{cA}	75.90±0.04^{cE}	76.49±0.07^{bcC}	76.42±0.03^{cC}	77.35±0.03^{bB}	76.23±0.03^{cD}	76.15±0.04^{cdD}	76.56±0.10^{bcC}
6	79.75±0.04^{dA}	75.83±0.00^{cF}	76.44±0.00^{cC}	76.22±0.02^{dD}	77.32±0.14^{bB}	76.17±0.02^{cDE}	76.05±0.01^{dE}	76.50±0.08^{cC}

Different superscript small letters in the same column indicate a significant difference. Different superscript capitalized letters in the same row indicate a significant difference ($P<0.05$). Values shown are averages of triplicate analyses of duplicate surimi blocks

and Pigott (1994). The polyvinylidine casing was removed and the gels were cut to 2.5 cm long sections. The gels were made in triplicate and two measurements were made for each gel, one each at the top and at the bottom. The breaking force (g) and deformation distance (cm) were measured by using a texture analyzer (TA-TXplus Stable Micro Systems, United Kingdom) equipped with ¼'' spherical plunger (P/0.25s) with the distance 30 mm, force 5 g and 5 kg load cell. Gel strength was obtained by multiplying force (g) and distance (mm).

Expressible moisture

Expressible moisture was measured in triplicate according to the method established by Park and Lin (2005). Surimi gel was slice with the thickness 5 mm and weight (Z). The sample was then placed between two pieces of Whatman paper No.1 which had previously weighed (X1, Y1). The slice sample was pressed using standard weight (5 kg) for 2 min. The paper was then removed and weight again (X2, Y2). Expressible moisture was calculated using the following equation:

$$Expressible\ moisture\ (\%) = \frac{[(X_2 - X_1) + (Y_2 - Y_1)]}{Z} \times 100$$

Texture profile analyzer (TPA)

Texture profile analysis (TPA) of surimi gel was performed with a TA-Hdi Texture Analyser (Texture Analyzer Model TA, United Kingdom) and a 25 kg load cell. Surimi gels were cut using knife (0.25 mm diameter) in cylinders of 25 mm diameter and 25 mm length. Each cylinder was compressed using probe 75 (P.75) compression platen with the distance 35 mm and trigger force 10 g for 2 s. From the TPA curves, the following texture attributes were obtained: hardness, cohesiveness, springiness, gumminess and chewiness. Hardness attribute was defined by peak force during the first compression cycle. Cohesiveness attribute was calculated as the ratio of the area under the second curve to the area under the first curve. Springiness attribute was defined as a ratio of distance of the second area at second compression and the first area at first compression. Gumminess attribute was obtained by multiplying hardness and cohesiveness. Chewiness attribute was obtained by multiplying gumminess and springiness (Tabilo-Munizaga and Barbosa-Cánovas, 2004).

Statistical analysis

The experiments were conducted in two replications; each replication was performed in triplicate. Data were subjected to analysis of variance (ANOVA) at a 5% significance level. A comparison of means was performed by Duncan's test to determine the significant difference between the treatments at $P < (0.05)$.

Result and Discussion

Changes in moisture content

The average moisture content of each surimi treatment is shown in Table 2. Raw surimi showed the highest moisture content (81.0%). In the present study, moisture content of surimi prepared with different types of added low-sweetness sugar as a cryoprotectant is ranging from 76.05-77.61%. According to Lee (1985), moisture content of industrial surimi (without addition cryoprotectant) should be less than 85% and less than 82% for high

Table 3. Changes in pH of threadfin bream surimi with different cryoprotectants during six months of frozen storage.

Month	Raw	Sucrose	Lactitol	Maltodextrin	Palatinit	Polydextrose	Sorbitol	Trehalose
0	6.98 ± 0.01^{aB}	7.04 ± 0.01^{aA}	7.07 ± 0.00^{aA}	6.99 ± 0.03^{aB}	7.06 ± 0.02^{aA}	7.05 ± 0.02^{aA}	7.05 ± 0.00^{aA}	7.04 ± 0.01^{aA}
3	6.90 ± 0.06^{abB}	6.87 ± 0.01^{bB}	7.05 ± 0.01^{aA}	6.90 ± 0.01^{aB}	7.05 ± 0.00^{aA}	7.01 ± 0.04^{aA}	7.01 ± 0.01^{aA}	7.03 ± 0.01^{aA}
6	6.55 ± 0.04^{bC}	6.64 ± 0.01^{cdB}	6.69 ± 0.06^{bA}	6.57 ± 0.05^{bBC}	6.66 ± 0.00^{bA}	6.66 ± 0.00^{bA}	6.66 ± 0.01^{bA}	6.66 ± 0.01^{bA}

Different superscript small letters in the same column indicate a significant difference. Different superscript capitalized letters in the same row indicate a significant difference ($P<0.05$). Values shown are averages of triplicate analyses of duplicate surimi blocks.

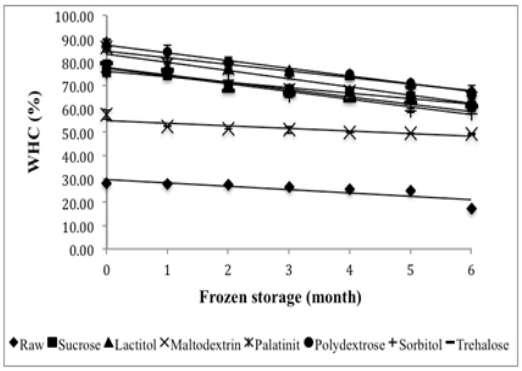

Figure 1. Changes in water-holding capacity of threadfin bream surimi with different cryoprotectants during six months of frozen storage. Values shown are averages of triplicate analyses of duplicate surimi blocks. Data are shown as the mean ± SD.

grade surimi (Lee, 1985). Park and Lin (2005) have suggested that the range of moisture content of commercial surimi is 72-77%, while the majority falls between 73-76%. The moisture contents of surimi prepared in this study were comparatively similar to what Park and Lin (2005) documented.

Generally, the moisture content of each treatment decreased as the storage time increased, and were significantly different ($P<0.05$). Raw surimi showed the highest reduction in moisture content (1.65%). Meanwhile, the reductions in surimi treated with sucrose, lactitol, maltodextrin, palatinit, polydextrose, sorbitol, and trehalose were 0.53%, 0.73%, 0.94%, 0.38%, 0.54%, 0.68%, and 0.30%, respectively. The decrease in the moisture content of surimi was due to dehydration process. Matsumoto (1980) and Matsumoto and Noguchi (1992) suggested that the dehydration of protein molecules is caused by the migration of water molecules to form ice crystals. The denaturation of myofibrillar proteins through aggregation and unfolding is triggered by this phenomenon. The use of a cryoprotectant increases the hydration of protein molecules and decreases the aggregation of the proteins. As a result, a drastic reduction in moisture content could be prevented.

Changes in pH

The myofibrillar proteins of various animal species are more stable at neutral pH. pH level affects not only the denaturation rate at high temperature but also the denaturation rate during frozen storage (Matsumoto and Noguchi, 1992). The pH value for each treatment is shown in Table 3. Before frozen storage, raw surimi had a pH level below 7.0. Meanwhile the pH level of surimi samples that used a cryoprotectant started to decrease after 3 months of frozen storage.

pH is one of the most important factors in producing strong elastic surimi gels. The optimal pH for strong gelation is approximately 7.0-7.5 for white meat fishes (Chung *et al*., 1994; Ni *et al*., 2001). Matsumoto and Noguchi (1992) suggested that myofibrillar protein at a pH below 6.5 becomes unstable and rapidly loses its ATPase activity, which is an indicator of gel forming ability. In the present study, raw surimi treated with maltodextrin showed the lowest value of gel strength after 6 months of storage.

Raw surimi showed the highest percentage of reduction in pH (6.16%). However, all treated-surimi recorded lower pH values than the raw one. The percentage reduction of pH of surimi treated with sucrose, lactitol, maltodextrin, palatinit, polydextrose, sorbitol, and trehalose were 5.64%, 5.27%, 5.94%, 5.70%, 5.56%, 5.60%, and 5.37%, respectively. The pH drops may possibly due to the build-up of lactic acid from glycogen as a result of glycolysis. The ultimate pH is reached when glycolysis ceases and is usually around 5.5. Therefore, a pH of 5.5 is the lowest possible ultimate pH. If an animal is starved or stressed before slaughter, a higher ultimate pH will not be obtained and will affect the water holding capacity (Vaclavik and Christian, 2008). It is suggested that cryoprotectants were able to protect excessive glycolysis that causes the reduction of pH in surimi.

Changes in water holding capacity (WHC)

The water holding capacity (WHC) usually reflects the extent of denaturation of proteins and the water content (Shaviklo, 2006). The WHC of each treatment is shown in Figure 1. The figure shows that each cryoprotectant imparted a different cryoprotection effect on the WHC during the freezing process ($P<0.05$). Raw surimi and maltodextrin showed the lowest WHC. Lactitol and polydextrose

exhibited the highest WHC during six months frozen storage.

Generally, WHC of all treatments significantly decreased as the storage time increased ($P<0.05$). The initial WHC of raw surimi and surimi treated with sucrose, lactitol, maltodextrin, palatinit, polydextrose, sorbitol, and trehalose were 28.12%, 76.46%, 88.50%, 57.50%, 86.25%, 87.50%, 75.72%, and 79.75%, respectively. However, after 6 months of storage, the WHC values were reduced to 17.50%, 61.42%, 67.85%, 49.41%, 64.62%, 67.37%, 57.87%, and 61.20%, respectively for raw surimi and surimi treated with sucrose, lactitol, maltodextrin, palatinit, polydextrose, sorbitol, and trehalose. A similar decreasing trend was also reported by Martinez (1989) for surimi made from cod aged on ice for 14 days.

Ohkuma *et al.* (2008) reported that the functional properties of myofibrillar proteins in surimi (such as gel forming ability and water-holding capacity) are lost because the proteins undergo unfolding and aggregation during processing and storage. Meanwhile, Marianski (2009) suggested that the addition of phosphate increases the WHC of proteins and prevents water loss during cooking. Phosphates are able to open the structure of proteins, which helps them to hold even more water. Earlier, Julavittayanukul *et al.* (2006) reported that ionic strength is enhanced by phosphate anions, resulting in an increase in water-holding capacity by the direct binding of water to phosphate anions and by the repulsion of protein groups due to the predominance of negative charges on the protein groups. In other study, Vaclavik and Christian (2008) suggested that the WHC will be excellent if a high ultimate pH is reached. Because many proteins are not close to their isoelectric points, they are therefore able to bind to more water. Thus, raw surimi and surimi treated with maltodextrin showed the lowest WHC among the tested samples because their pH fell below the range of 7-7.5 after zero months of frozen storage. In conclusion, surimi treated with cryoprotectants generally showed higher WHC than raw surimi. Among cryoprotectants used, lactitol and polydextrose were able to maintain higher WHC after six months of frozen storage.

Changes in gel whiteness

Color is one of the characteristics that are used in grading surimi besides other characteristics, such as gel strength, water content, pH, and impurities (Burden *et al.*, 2004). Color in foods can be caused by several factors including pigment, the influence of heat on sugar (caramel), the reaction between sugars and amino acids (Maillard), and the mixing of

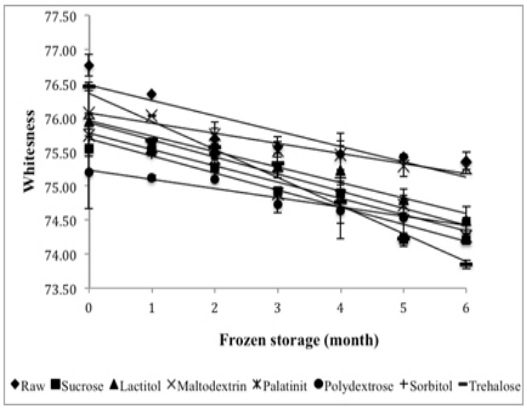

Figure 2. Changes in whiteness of surimi gel with different cryoprotectants during six months of frozen storage.Values shown are averages of triplicate analyses of duplicate surimi blocks. Data are shown as the mean ± SD.

other materials. Sahin and Sumnu (2006) suggested that color is one of the important quality attributes of foods. Although it does not necessarily reflect nutrition, flavor, or functional value, it determines the acceptability of a product by consumers.

The whiteness of all surimi samples is shown in Figure 2. Results show the whiteness of all the samples was in the range from 73.85 to 76.77. In comparison with the study by Benjakul *et al.* (2005), the whiteness values of some tropical fish surimi in Thailand treated with sorbitol/sucrose (1:1) were in the range of 70.35 to 82.01 during 24 weeks of frozen storage. After six months of frozen storage, raw surimi exhibited the highest whiteness value, which was significantly different ($P<0.05$) among the other samples. The addition of a cryoprotectant affects the color of surimi. Generally, the whiteness of all the samples significantly decreased ($P<0.05$) as the storage time increased. The decreasing trend in this study is in agreement with the result reported by Benjakul *et al*. (2005) for surimi gels from croacker, lizardfish, threadfin bream, and bigeye snapper mixed with 4% sucrose and 4% sorbitol. However, the trehalose-treated samples exhibited a higher whiteness value that decreased faster during storage. The polydextrose-treated sample had the lowest value in whiteness but could maintain its whiteness after six of months of frozen storage as well as the sucrose, lactitol and maltodextrin treatments.

The lowest whiteness value in surimi gel containing sugar was postulated to be due to the Maillard reaction during the preparation of surimi gel. Sugar has reducing carbonyl groups, which participate in the Maillard reaction (Chung and Min, 2004). The mechanism of the reaction is the binding

Table 4. Changes in folding test of threadfin bream surimi with different cryoprotectants during six months of frozen storage.

Month	Raw	Sucrose	Lactitol	Maltodextrin	Palatinit	Polydextrose	Sorbitol	Trehalose
1	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}
2	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}
3	3±0.00^{bA}	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}
4	3±0.00^{bA}	4±0.00^{aA}	4±0.00^{aA}	3±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}
5	3±0.00^{bA}	4±0.00^{aA}	4±0.00^{aA}	3±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}
6	3±0.00^{bA}	3±0.00^{aA}	3±0.00^{aA}	3±0.00^{aA}	4±0.00^{aA}	4±0.00^{aA}	3±0.00^{bA}	4±0.00^{aA}

Different superscript small letters in the same column indicate a significant difference. Different superscript capitalized letters in the same row indicate a significant difference ($P<0.05$). Values shown are averages of triplicate analyses of duplicate surimi blocks.

of free aldehyde or keton end-groups of carbohydrates to the free amine group of lysine or arginine on proteins. Sugars that participate in this reaction are called reducing sugars (Best, 2006).

The decrease in whiteness intensity was probably due to the adduction of pigment proteins, particularly oxidized pigment to muscle proteins (Benjakul *et al.,* 2005). Additionally, lipid oxidation in muscle during frozen storage might induce cross-linking of the pigment proteins and muscle proteins via the free radical process (Saeed *et al*., 1999). As a consequence, those pigments may not have been removed effectively by the washing process and may have been retained in the surimi. This typically results in the decrease in whiteness of surimi (Benjakul *et al.,* 2005).

Changes in folding test

Elasticity, an extremely important sensory attribute of surimi, has been traditionally graded using the folding test (Botta, 1995). The folding test was used to measure the gel quality of the product (Hsu, 1995). The folding test scores of surimi samples are shown in Table 4. Surimi that featured a cryoprotectant had a folding test score that was higher than that of raw surimi. This finding indicates that the cryoprotectant is effective in maintaining the integrity of myofibrillar proteins during frozen storage. Result shows, all samples had high folding test scores (4), which means that they were able to fold in half without any cracking. Nowsad *et al*. (2000a) reported that the folding test could reflect gel degradation very efficiently in kamaboko prepared from Alaska pollack surimi. Salt also contributes to folding test scores. At a concentration of 1% to 3%, salt increases folding test scores (University of Alaska Fairbanks, 1990).

The folding test scores of raw surimi decreased

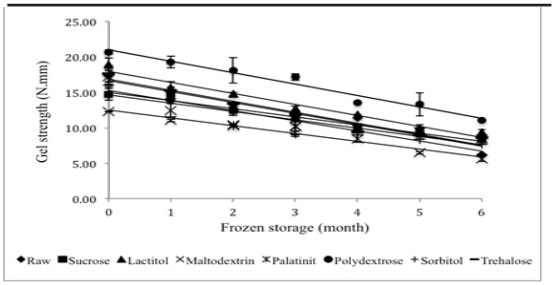

Figure 3. Changes in gel strength of surimi gel with different cryoprotectants during six months of frozen storage. Values shown are averages of triplicate analyses of duplicate surimi blocks. Data are shown as the mean ± SD.

after 3 months of storage. Meanwhile, the other samples treated with sugar were able to maintain their folding test scores. Surimi treated with maltodextrin showed the highest decrease in folding test score after 4 month of frozen storage, followed by surimi treated with sucrose, lactitol, and sorbitol after 6 month of storage. Surimi mixed with palatinit, polydextrose and trehalose maintained its folding test score from four to six months of frozen storage. Nowsad *et al*. (2000b) also reported that spent hen surimi treated with sucrose and sorbitol was able to maintain its folding test score between four and six months of frozen storage. These results provide information about the cryoprotection effect of sugar on folding test score during frozen storage.

Changes in gel strength

The gel strengths of the samples are shown in Figure 3. The measurement of gel quality reflects the quality of the raw material, the effect of washing cycles on the concentration of actin and myosin, and any changes brought about by frozen storage (Hall and Ahmad, 1997). The gel strengths all the samples were in the range 5.60 – 20.64 N.mm during six months of frozen storage and were significantly different ($P<0.05$) among all the samples. Mahawanich et al. (2010) reported that the gel strength of red tilapia surimi treated with sucrose and sorbitol was in the range 0.57-0.85 N.mm, lower than the results in this study. The cryoprotective effect each cryoprotectant exerted was different due to the freezing process. Polydextrose showed the highest gel strength among the samples and was able to maintain higher gel strength until six months of frozen storage compared with sucrose and the other treatments. Zhou *et al*. (2010) reported that polydextrose protects darce surimi with its ability to prevent the decrease in gel strength during 26 weeks of frozen storage. The lowest gel strength was observed for maltodextrin. The same result was also reported by Medina and Garrote (2002) that suribí surimi gel treated with maltodextrin/sorbitol showed a lower resistance than

surimi treated with a sucrose/sorbitol mixture from 4 to 180 days of storage.

The decreasing gel strength was significantly different (P<0.05) among the treatments until six months of frozen storage. The initial gel strength values for raw surimi, sucrose, lactitol, maltodextrin, palatinit, polydextrose, sorbitol, and trehalose were 17.36, 14.69, 18.90, 12.26, 17.18, 20.64, 16.05, and 17.62 N.mm, respectively, and the final gel strength values were 6.25, 8.34, 9.41, 5.59, 8.45, 11.05, 7.70, and 8.62 N.mm, respectively. The decreasing trend in gel strength has also been observed in grass carp surimi during 25 weeks of frozen storage (Pan et al., 2010).

Gel-forming ability is a direct indicator of the quality of fish proteins. Salt linkages, hydrogen bonds, disulfide bonds and hydrophobic interactions are the main types of bonds that contribute to the building of a network structure during gelation (Sen, 2005). Myosin is responsible for the gel-forming ability of surimi. The denaturation of myosin can lead to a decrease in gel-forming ability (Pan *et al*., 2010). Benjakul *et al*. (2002) suggested that a decrease in gel strength is related to a decrease in water-holding capacity. Thus, the gel strength of surimi treated with maltodextrin was the lowest compared to that of the other cryoprotectants.

pH is also used primarily as an indirect measurement of gel-forming ability (Lanier, 1992). Thus, the decrease in gel strength was correlated to decreasing pH surimi as shown in Table 3. In the present study, polydextrose showed an excellent value after six months of frozen storage, which indicates that polydextrose could maintain protein integrity, especially that of myosin, during six months of frozen storage.

Changes in expressible moisture

Expressible moisture is correlated to water holding capacity. High expressible moisture indicates poor water-holding capacity (Chaijan *et al*., 2006). The expressible moisture values of all the samples are shown in Figure 4. Generally, the expressible moisture of all the samples increased as the storage increased and was significantly different (P<0.05) from month to month. The similar result was reported by Mahawanich *et al*. (2010). They found that the expressible moisture of tilapia surimi gel mixed with sucrose and sorbitol increases during 9 months of frozen storage. The range of expressible moisture for all the samples was 2.38-13.42% and was significantly different (P<0.05) among the samples during six months of frozen storage. Mawanich *et al.* (2010) reported that the expressible moisture of

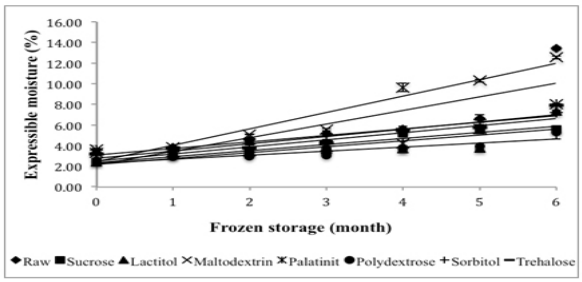

Figure 4. Changes in expressible moisture of surimi gel with different cryoprotectants during six months of frozen storage. Values shown are averages of triplicate analyses of duplicate surimi blocks. Data are shown as the mean ± SD.

surimi gel prepared from tilapia surimi mixed with sucrose and sorbitol was in the range 9.59-12.92% during 9 months of frozen storage and began with a higher expressible moisture than the samples used in this study.

The initial expressible moisture values of raw surimi and surimi treated with sucrose, lactitol, maltodextrin, palatinit, polydextrose, sorbitol, and trehalose were3.32%, 2.44%, 2.38%, 3.60%, 3.29%, 2.56%, 3.59%, and 3.22%, respectively, while the final values were 13.42%, 5.62%, 7.30%, 12.57%, 8.05%, 5.27%, 7.24%, and 7.90%, respectively. Sorbitol and polydextrose were able to maintain the lowest expressible moisture after six months of frozen storage with an increase of 50.36% and 51.41%, respectively, from their initial values. Raw surimi had the highest percentage increase of 75.26%. Among the other cryoprotectants, maltodextrin had the highest percentage increase of 71.34%. Sucrose exhibited an increase in expressible moisture of 56.67%, which was higher than that of sorbitol and polydextrose.

The highest percentage increase in expressible moisture was observed for raw surimi and maltodextrin, which was caused by the autolytic degradation of fish protein during storage. As a result, surimi gel formed a poor gel matrix with lower water holding capacity, resulting in higher expressible moisture (Benjakul *et al.*, 1997). This finding agrees with the result reported by Mahawanich *et al.* (2010), who stated that the expressible moisture of gel produced from red tilapia surimi up to 9 months of frozen storage increased as the storage time increased. According to the results of this study, sorbitol and polydextrose were able to maintain the sharp decrease in expressible moisture during six months of frozen storage.

Changes in texture profile

The hardness of surimi is shown in Figure 5. The hardness values of all the samples were in the range 29.52 – 93.72 N and were significantly different among the samples (P<0.05). Dey and Dora (2010) reported

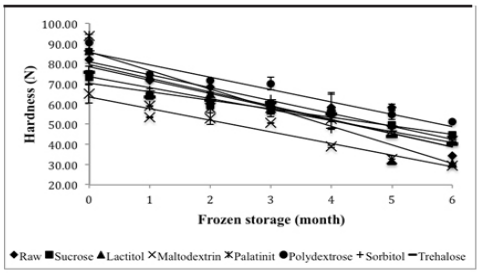

Figure 5. Changes in hardness of surimi gel with different cryoprotectants during six months of frozen storage. Values shown are averages of triplicate analyses of duplicate surimi blocks. Data are shown as the mean ± SD.

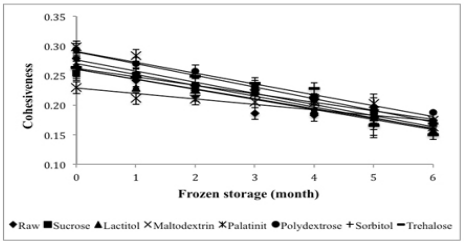

Figure 6. Changes in cohesiveness of surimi gel with different cryoprotectants during six months of frozen storage. Values shown are averages of triplicate analyses of duplicate surimi blocks. Data are shown as the mean ± SD.

that the hardness of surimi gel prepared from croaker fish mixed with sucrose and sorbitol was in the range 5.88-17.65 N during 180 days frozen storage, which is lower than the results in this study. Generally, the hardness of all the samples decreased ($P<0.05$) as the storage time increased. Palatinit showed the highest value at zero months, followed by polydextrose. During frozen storage, polydextrose was seen to be able to maintain the highest hardness among the samples. The lowest hardness value was observed for surimi treated with maltodextrin. Meanwhile, surimi with added sucrose showed a hardness value below that treated with polydextrose.

Ha *et al*. (2001) reported that moisture affects the hardness of fish paste containing *Agaricus bisporus*. Kang *et al.* (2010) also reported that lower moisture in surimi-like beef results in stronger gel hardness. Martinez (1989) suggested that the protein content of surimi samples is known to have a great influence on the hardness of the gels made from surimi, while the protein quality influences their elasticity. It was presumed that the polydextrose-treated sample was able to retain its hardness after six months of frozen storage.

Cohesiveness is defined as the work done to break down the internal bonds in surimi (Luo *et al*., 2010). The cohesiveness value affects the hardness value of surimi gel; the sample that has the highest cohesiveness will have the highest hardness. The cohesiveness values of the surimi samples are presented in Figure 6. The cohesiveness values all the samples were in the range 0.15 – 0.30 and were generally significantly different ($P<0.05$) from each other. Dey and Dora (2010) reported that the cohesiveness value of surimi gel prepared from croaker fish treated with sucrose and sorbitol was in the range 0.5-0.9 during 180 days frozen storage, which is lower than the results in this study. The decreasing value of cohesiveness was shown to be significantly different ($P<0.05$) between samples during six months of frozen storage.

Before frozen storage, palatinit showed the highest value for cohesiveness, followed by polydextrose. Maltodextrin had the lowest value for cohesiveness. Polydextrose was seen to be able to maintain the highest value for cohesiveness until the end of frozen storage. Tabilo-Munizaga and Barbosa-Cánovas (2004) reported that a cohesiveness value close to 1 indicates sample recovery after the first compression. The cohesiveness value was far from 1 for all treatments in this study, indicating that the sample was recovered after the first compression. In the present study, polydextrose demonstrated its potential as a cryoprotectant in maintaining the cohesiveness of surimi gel.

Springiness is defined as the rate at which a deformed surimi recovers its initial condition (Luo *et al*., 2010). The springiness of surimi samples is shown in Figure 7. The springiness values were in the range 0.26 – 0.71 and were significantly different ($P<0.05$) among the samples. Dey and Dora (2010) reported that the springiness value of surimi gel prepared from croaker fish treated with sucrose and sorbitol was in the range 0.8-1.3 during 180 days frozen storage, which is higher than the results in this study. The decrease in springiness was significantly different ($P<0.05$) among the samples during six months of frozen storage.

Sorbitol exhibited the highest springiness value but also had the highest percentage decrease (56.68%). Sucrose and palatinit showed the lowest percentage decrease among the other samples: 46.16% and 47.40%, respectively. The highest percentage decrease was exhibited by sorbitol. Raw surimi had the lowest value starting from zero months of frozen storage until six months of frozen storage. Tabilo-Munizaga and Barbosa-Cánovas (2004) reported that springiness is a typical characteristic of viscoelastic materials. Chung *et al*. (2010) suggested that the raw material of fish meat, the condition of the preparation of the surimi gel and the formation of the net structure affect the springiness. The integrity of myosin is of great importance for gelation (An *et al*., 1996). The degradation of myosin results in inferior gel network formation, producing a poor water-holding capacity in a gel matrix with a lower elasticity (Benjakul *et al*.,

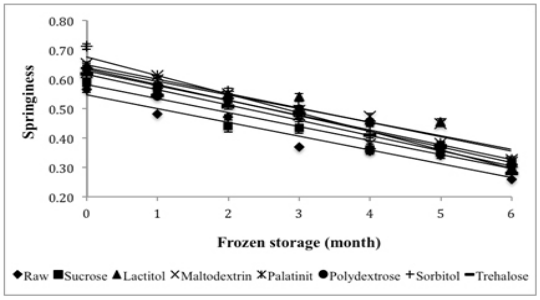

Figure 7. Changes in springiness of surimi gel with different cryoprotectants during six months of frozen storage. Values shown are averages of triplicate analyses of duplicate surimi blocks. Data are shown as the mean ± SD

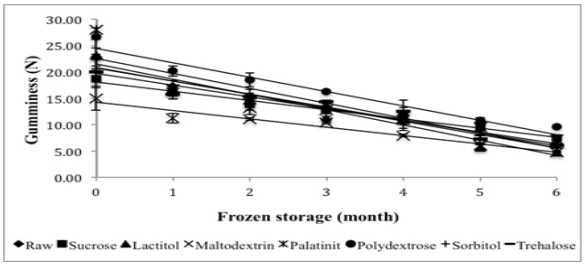

Figure 8. Changes in gumminess of surimi gel with different cryoprotectants during six months of frozen storage. Values shown are averages of triplicate analyses of duplicate surimi blocks. Data are shown as the mean ± SD

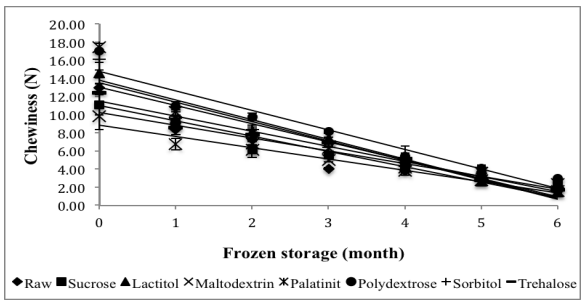

Figure 9. Changes in chewiness of surimi gel with different cryoprotectants during six months of frozen storage. Values shown are averages of triplicate analyses of duplicate surimi blocks. Data are shown as the mean ± SD

2003). The result shows palatinit-treated sample was able to maintain its springiness value after six months of frozen storage in comparison with sucrose.

The gumminess of all the samples is shown in Figure 8. The gumminess values were in the range 4.81 – 27.96 N and were significantly different ($P<0.05$) among the samples. Dey and Dora (2010) reported that the gumminess value of surimi gel prepared from croaker fish mixed with sucrose and sorbitol was in the range 2.94-16.67 N during 180 days frozen storage, which is lower than the results in this study. The decreasing values of gumminess were also significantly different after six months of frozen storage. Palatinit exhibited the highest gumminess value at 0 months of frozen storage, followed by polydextrose. Maltodextrin showed the lowest value in gumminess. Gumminess is a complementary parameter of hardness (Tabilo-Munizaga and Barbosa-Cánovas, 2004). It is suggested that polydextrose can be a potential cryoprotectant that can maintain the highest gumminess over six months of frozen storage.

Chewiness is defined as the energy required to chew surimi until it is ready to swallow (Luo *et al*., 2010). The chewiness values of all the samples are shown in Figure 9. The chewiness values of all the samples were in the range 1.45 – 17.40 N during six months of frozen storage and were generally significantly different ($P<0.05$) from each other. Dey and Dora (2010) reported that the chewiness value surimi gel prepared from croaker fish mixed with sucrose and sorbitol was in the range 1.96-22.56 N during 180 days frozen storage, slightly higher than the results in this study. The decreasing value of chewiness was also significantly different ($P<0.05$) after six months of frozen storage.

Palatinit exhibited the highest chewiness at zero months of frozen storage, followed by polydextrose. Maltodextrin showed the lowest value in chewiness. Cardoso *et al*. (2009) reported that chewiness is a parameter that provides a global assessment of textural quality. Chewiness is also a complementary parameter of hardness. According to this study, polydextrose can retain excellent chewiness after six months of frozen storage.

Conclusion

Generally, surimi treated with a cryoprotectant exhibits better physicochemical properties compared with raw surimi. Polydextrose was able to maintain better physicochemical properties than the other low-sweetness sugars and sucrose during six months of frozen storage.

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