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Relationship between the Physical Properties and Perceived Saltiness of Various Surimi Gels Prepared by Different Setting Conditions

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Abstract

Salt intake is an important concern for health reasons and saltiness is affected not only by content of food, but also by the texture. Surimi-based products, such as kamaboko, are elastic gels with approximately 2% NaCl; despite recent concerns among Japanese consumers regarding high-salt foods, little is known about the relationship between saltiness and texture in these products. This study was aimed to clarify the relationship between saltiness and texture using heat-induced surimi gels as a model of surimi-based product. Various types of heat-induced gels with different physical properties were prepared from surimi and washed surimi by two-step heating with different setting (preheating) times at 30°C. Washed surimi was prepared to remove the additives, because the additives were thought to affect the taste of surimi gel. The physical properties of heat-induced gels were characterized by puncture breaking strength and expressible water. The perceived saltiness of the heat-induced surimi gels was evaluated with fixed number of chewing. Next, to improve the demerit of this method, the perceived saltiness of the washed surimi gels was evaluated by free chewing conditions. The perceived saltiness after fixed number of chewing and the maximum saltiness intensity during free chewing was evaluated using sensory tests by comparisons with salt solutions of known concentrations. The physical properties of heat-induced gels differed considerably depending on the salt content and heating conditions. A longer setting time was associated with a higher breaking force and lower expressible water, regardless of salt content. On the other hand, perceived saltiness depended on the NaCl concentration, but not greatly influenced by the physical properties of the gels prepared from both surimi and washed surimi. The perceived saltiness of all gels tested was less than 1/3 of solution with the same NaCl concentration. The maximum saltiness intensity did not correlate with breaking force, breaking strain and expressible water of heat-induced gels. From these results, it was suggested that the difference in physical properties derived by setting did not affect the relative saltiness intensity of gels to NaCl solution during consumption of surimi gels.

Keywords: Surimi-based products; Saltiness; Physical property; Setting; Heating condition; Sensory evaluation

Introduction

Demand for reduced-salt food products by health-conscious consumers has recently increased owing to associations between excessive salt intake and a range of diseases, e.g., hypertension and kidney diseases [1-3]. According to guidelines established by the WHO, the recommended salt intake is less than 5 g per day [4]. The United State recommends a salt intake of 3.75-5.75 g per day [5], the other countries set higher values of 6 g in the United Kingdom [6], 6 g in Australia [7], and 8 g for men and 7 g for woman is recommended in Japan [8]. Japanese recommendation is relatively higher than other countries, because many Japanese food are based on salty taste, and the actual salt intake per day is higher than those recommended.

On the other hand, approximately 1.5-2.5% NaCl is added to surimi for the production of surimi-based products, such as kamaboko [9], to solubilize the myofibrillar protein of fish meat and promote gelation to obtain the special elastic texture. Despite this, it is said that consumers do not perceive high saltiness in these products and therefore may unintentionally consume excess salt.

In general, flavor intensity is thought to be affected not only by the content of ingredients, but also by the texture of food. Sensory tests of various food gels, including egg whites [10,11], agar [12-14], and gelatin [15] at various concentrations, have suggested that sweetness is relatively weak in hard gels and strong in soft gels. It is possible that surimi-based products exhibit a similar texture-dependent pattern. However, little is known about the relationship between the saltiness and physical properties of these products. For these reasons, not only the salt concentration contained in the surimi-based products but also the factors which affect the perceived saltiness should be considered for properly controlling the salt intake of consumers and for manufacturing of reduced salt products.

The physical properties of surimi gels are affected by the heating conditions, such as temperature, time, and the combination of heating at different temperatures [16,17]. The phenomenon of setting (suwari) in the manufacturing process of surimi-based products is well known. Setting is a gelation of myofibrillar protein mainly based on enzymatic crosslinking reaction caused by heating salt-ground fish meat at a relatively low temperature (around 30°C), and the intensity of the reaction varies with temperature and time. By subsequently heating at high temperature around 90°C, a higher gel strength is obtained than when directly heated without setting. For this reason, a two-steps heating method is widely used for manufacturing of surimi-based products.

In previous studies on the relationship between texture and taste of foods concentrations of texture modifier such as agar, starch, etc. were changed in order to control the texture [10-15]. On the other hand, in the case of surimi gel, various types of heat-induced gels with different textures can be obtained from the same material, without additives. Therefore, surimi gel was thought to be suitable for investigations of the relationship between texture and taste.

Accordingly, in this study, the relationship between the physical properties and saltiness was examined using heat-induced surimi gels prepared by different setting (preheating at 30°C) times from the same materials. As materials, both surimi and washed surimi were used. Surimi generally contains 5-8% of saccharide such as sucrose and/or sorbitol, and 0.2-0.3% polyphosphate, which are used to prevent protein denaturation during frozen storage. In this study, washed surimi was prepared to remove the additives, because the additives were thought to affect to the taste of surimi gel. Further, to evaluate the perceived saltiness, the heat-induced surimi gels was evaluated with fixed number of chewing, and next, to improve the demerit of this method, the saltiness efficiency of the washed surimi gels was evaluated by free chewing conditions.

Materials and Methods

Preparation of heat-induced surimi gels

Frozen Alaska pollock surimi (FA grade, Maruha Nichiro Corporation, Tokyo, Japan) blocks (10 kg) were cut into portions of approximately 500 g, vacuum packed, and kept at -30°C until use.

Frozen surimi was thawed overnight, cut into small pieces, and chopped with 20% (w/w) ion exchanged water and NaCl (1%, 2%, and 3% w/w) until it became a viscous paste using a refrigerated cutter (Model UMC 5E; Stephan Machinery Co., Hameln, Germany) under vacuum conditions. The temperature was maintained at below 10°C. Surimi paste was stuffed into a polyvinylidene chloride casing tube (30 cm in length and 23 mm in diameter; Kureha Chemical Industry Co., Ltd., Nishiki, Japan) and incubated in water baths for setting at 30°C for 0-240 min, followed by a second heating at 90°C for 30 min. After heating, the gel was cooled immediately in ice water overnight, and physical properties were measured and a sensory evaluation was performed at 25°C.

Preparation of heat-induced gels from washed surimi

Frozen Alaska pollock surimi was thawed overnight, cut into small pieces (about 1 × 1 × 1 cm^3), chopped using a refrigerated cutter (Model UMC 5E) and stirred with 10 volumes of cold 0.4% NaCl solution (4.5°C) for 10 min. After it was maintained at 4.5°C for 30 min, the mixture was centrifuged at 12,000 × *g* for 15 min at 0°C and the precipitate was collected. This procedure was repeated twice. The precipitate was collected, the water content was adjusted to 87% (w/w), and NaCl was added (1%, 2%, and 3% (w/w) final concentrations) in a refrigerated vacuum cutter operated at 300 rpm for 4 min. The temperature was maintained below 10°C. The heat-induced gel from the salt-ground paste was prepared following the same procedure used for the heat-induced surimi gel.

Proximate composition

Moisture and crude ash contents were analyzed according to the methods of AOAC [18]. Total nitrogen content was determined by the Kjeldahl method [19] and a nitrogen conversion factor of 6.25 was used for calculating the protein content. Crude lipid was extracted according to the method of Folch et al. [20]. The crude carbohydrate content was obtained by subtracting the total composition ratios (%) of other chemical components from 100%. Sucrose and sorbitol in washed surimi were determined by UV method and colorimetric method, respectively [21,22].

Puncture test

Heat-induced gel samples with 23 mm-diameter were cut into cylinders of 25 mm-height. A center part of the cylindrical gels were compressed with a spherical plunger (5 mm-diameter) at a constant rate of 1 mm/s at 25°C until breaking using a rheometer (Rheoner II, RE2-33005B; Yamaden Co., Ltd, Tokyo, Japan). Breaking force (g) and breaking strain (mm) were determined. Ten replicate measurements were conducted and the highest and lowest values were omitted [17,23,24].

Measurement of water holding capacity

The water holding capacity of the gel was determined by the amount of expressible water. Cylindrical surimi gels were cut into thin slices weighing approximately 1 g (1.000 ± 0.025 g; 23 mm in diameter and about 0.25 mm in thickness). The slices were placed between two types of filter papers (No. 4A and No. 2A; Whatman International Ltd., Maidstone, UK) both above and below the sample (No. 4A on the inner side, No. 2A on the outer side). The samples were pressed under a fixed pressure (9.8 × 10^5 Pa) for 20 s. Expressible water was calculated according to the following formula [17].

$$Expressible\ \ water\ \ (\%) = \frac{pre{-}pressed\ weight\ (\mathrm{g}) - after{-}pressed\ weight\ (\mathrm{g})}{pre{-}pressed\ weight\ (\mathrm{g})} \times 100$$

and, the average value of four replicate measurements was obtained.

Sensory evaluation

Sensory analyses of gels were conducted by students from the Food Processing Laboratory of TUMSAT. Twenty panelists were selected and trained according to ISO 8586-2012 [25]. The sensory evaluation was performed in individual places in test room at 20 ± 2°C. Gel samples were cut into fixed sizes and presented a piece in a random order to every panelist. Reference solutions with different NaCl concentrations were prepared. The panelists evaluated the perceived saltiness of samples compared to that of reference solution and assigned scores after chewing the samples as described below. The saltiness efficiency of the surimi gels were evaluated by "Evaluation 1" with fixed number of chewing. Next, to improve the demerit of this method, the saltiness efficiency of the washed surimi gels were evaluated by "Evaluation 2" under free chewing conditions.

Evaluation 1 (Fixed number of chewing): Each panelist evaluated the perceived saltiness of a about 4 g sample (23 mm in diameter and 10 mm in height) with three-digit codes without information about the sample) after fixed number of chews (10 or 20 times) and compared it

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with the saltiness of 10 reference solutions (0.220-0.519% (w/w), 0.350-0.825% (w/w), and 0.450-1.061% (w/w) NaCl solutions for the evaluation of surimi gels with 1%, 2%, and 3% NaCl, respectively). Four samples were evaluated in a session and one session lasted for about 15 min. The saltiness efficiency ratio was calculated as the ratio of the concentration of salt solution perceived as having an equivalent saltiness to that of the sample gel divided by the real salt concentration of the sample (1, 2 or 3% (w/w)).

Evaluation 2 (Free chewing): Gel samples from washed surimi were cut into 1.00 ± 0.05 g (23 mm in diameter and 10 mm in height, divided into 4 small pieces). Samples with three-digit codes without information about the sample were presented in a random order with 2 replicates to every panelist. Each panelist was asked to insert a sample in the mouth and evaluated the maximum saltiness of every sample after chewing in a normal manner without indicating number of chews using a ten-point scale. Three reference solutions were used for evaluation of gels (Table 1). Four samples were evaluated in a session and the same evaluation was performed on another day (2-replicates). One session lasted for about 15 min. A sufficiently long interval (>120 s) was set between each trial of sensory evaluation.

For evaluation of surimi gel	Score 0	Score 5	Score 10
	Reference NaCl solutions (% w/w)		
1% (w/w)	0	0.322	0.519
2% (w/w)	0	0.512	0.825
3% (w/w)	0	0.659	1.061

Table 1: Reference NaCl solutions for the evaluation of perceived saltiness of heat-induced surimi gels containing 1, 2 and 3% (w/w) NaCl.

The saltiness efficiency is the salt concentration of salt solution perceived as equivalent saltiness as a sample divided by the real salt concentration contained in the sample.

Statistical analysis

All instrumental determinations were performed in quadruplicate, at minimum. Data are expressed as means ± standard deviations. Analyses of variance (ANOVA) were performed using SPSS software (SPSS 16.0 for Windows). Differences among the mean values of various treatments were measured by Duncan's multiple range test ($p<0.05$). The sensory evaluation data were analyzed using PanelCheck V.1.4.0 [26].

Results and Discussion

Evaluation of perceived saltiness of heat-induced surimi gel

Determination of heating condition of surimi gels: Prior to the experiment, the heating conditions to obtain surimi gels with "strong" and "weak" breaking properties were determined. Two-step heated gels with different breaking properties were prepared by the combination of setting at 30°C for 0-240 min and a second heating at 90°C for 30 min. The breaking force of these gels is shown in Figure 1. The gel strength increased as the increase of setting time for both the setting gel and 2-step heated gel. The breaking force of the 2-step heating gel with setting more than 20 min became greater than 500 g. For the preparation of a "strong gel (A)" and "weak gel (B)" for subsequent analyses, two heating conditions were selected: (A) setting at 30°C for 60 min followed by 90°C for 30 min and (B) 90°C for 30 min.

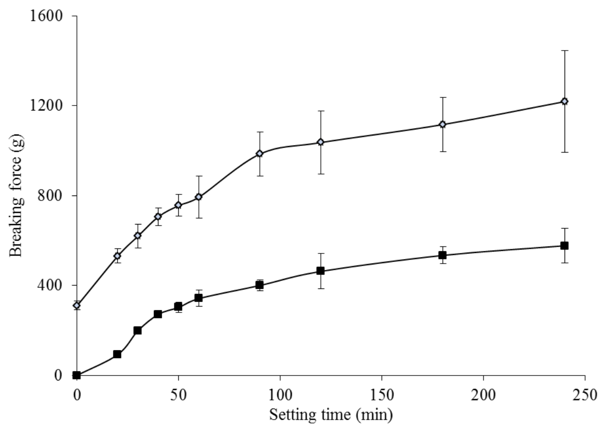

Figure 1: Temperature effects on gelation curves of heat-induced surimi gels (added 3% (w/w) NaCl) by setting at 30°C and followed by second heating at 90°C. Means and the standard deviations of eight measurements determined below 10°C. Closed squares: setting at 30°C, open diamonds: Two-steps heated gel (setting at 30°C for 0-240 min, followed by second heating at 90°C for 30 min).

Physical properties of heat-induced surimi gels: The physical properties of heat-induced surimi gels (A and B) with different NaCl concentrations are summarized in Table 2. The breaking force and breaking strain drastically increased by setting prior to heating at 90°C, regardless of the NaCl content in the gels. These results close to other researches, the breaking force of Alaska Pollock surimi at 30°C for 30 min incubation was significantly higher ($p<0.05$) than that of no incubation (direct heating at 85°C for 30 min). This indicates that the 'suwari' (gel setting) is strongest when incubated at 30°C for surimi from Alaska Pollock [17]. Similar phenomena have been observed in other studies [27,28]. The unique texture obtained by setting is thought to mainly result from the enzymatically catalyzed formation of non-disulfide covalent bonds between protein molecules [17]. For the surimi gel, salt must be added to solubilize the myofibrillar protein to form actomyosin, which form the network structure of the heat-induced gel and contribute the elastic texture [17,29]. In general, gels prepared by 2-step heating have higher breaking force than directly heated gels [30,31].

NaCl		1%	2%	3%
Breaking force (g)	A	1048 ± 61^{a}	1292 ± 86^{c}	1313 ± 74^{e}
	B	251 ± 14^{b}	271 ± 22^{d}	310 ± 19^{f}
Breaking strain (mm)	A	15.2 ± 0.4^{a}	17.9 ± 0.2^{c}	18.6 ± 0.2^{e}
	B	7.4 ± 0.3^{b}	9.6 ± 0.4^{d}	11.7 ± 0.2^{f}

Table 2: Breaking properties of heat-induced surimi gels prepared by different setting time and NaCl addition. (A) and (B): Refer to the footnote in Figure 2. Data are expressed as mean ± standard deviation (n=8). Different alphabetical letters within a column indicate statistical differences ($p<0.05$).

Perceived saltiness and saltiness efficiency ratio of heat-induced surimi gels: With respect to the sensory evaluation, it was necessary to determine the number of chews for each gel because perceived saltiness may be affected by chewing conditions. A preliminary test revealed that the gel with a higher breaking force (A with 3% NaCl) needed higher number of chews of 25.1 ± 3.5, which was longer than that of the gel with a weaker breaking force (B with 3% NaCl) (17.1 ± 2.7). Other study suggests that chewing force and chewing movements may be strongly influenced by the texture of food [32]. Therefore, in this sensory test, the saltiness levels after chewing 10 and 20 times were assumed to indicate the saltiness at the "early stage of mastication" and later stage at the "just before swallowing," respectively.

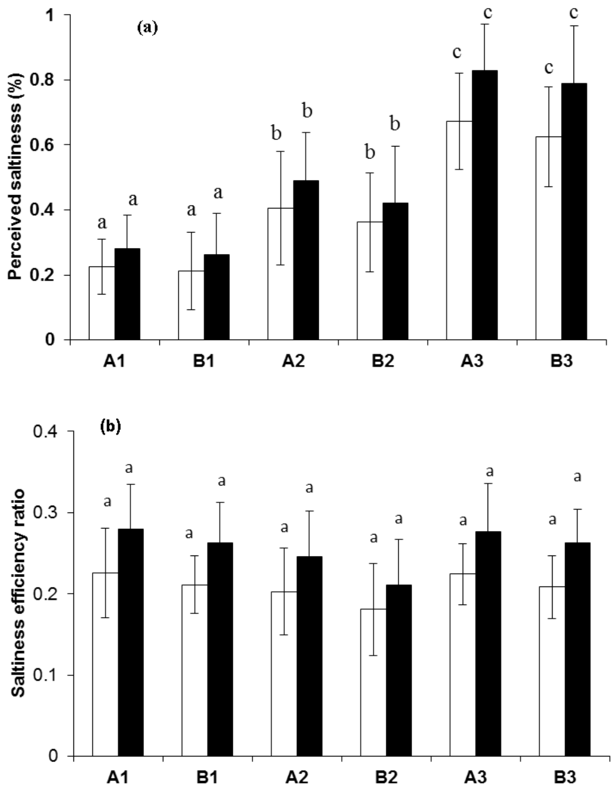

Figure 2: Perceived saltiness score (a) and saltiness efficiency ratio (b) of gel samples evaluated after chew for 10 and 20 times. Perceived saltiness is expressed as NaCl concentration in solution that sensed equivalent saltiness with sample gels. (A): setting at 30°C for 60 min followed by 90 for 30 min for "strong gel", (B) heating at 90°C for 30 min for "weak gel" and 1, 2, 3 are NaCl added into the sample in % (w/w). Open bars, closed bars: number of chews 10 and 20, respectively. Bars with the same alphabetical letter are not significantly different (p>0.05).

The perceived saltiness and saltiness efficiency ratio of heat-induced surimi gels prepared using different heating conditions (A and B) and 1, 2 and 3% (w/w) NaCl concentrations were evaluated after chewing 10 and 20 times (Figure 2). The perceived saltiness expressed NaCl concentration that was sensed as the equivalent saltiness with the sample gel was clearly different depending on the NaCl content.

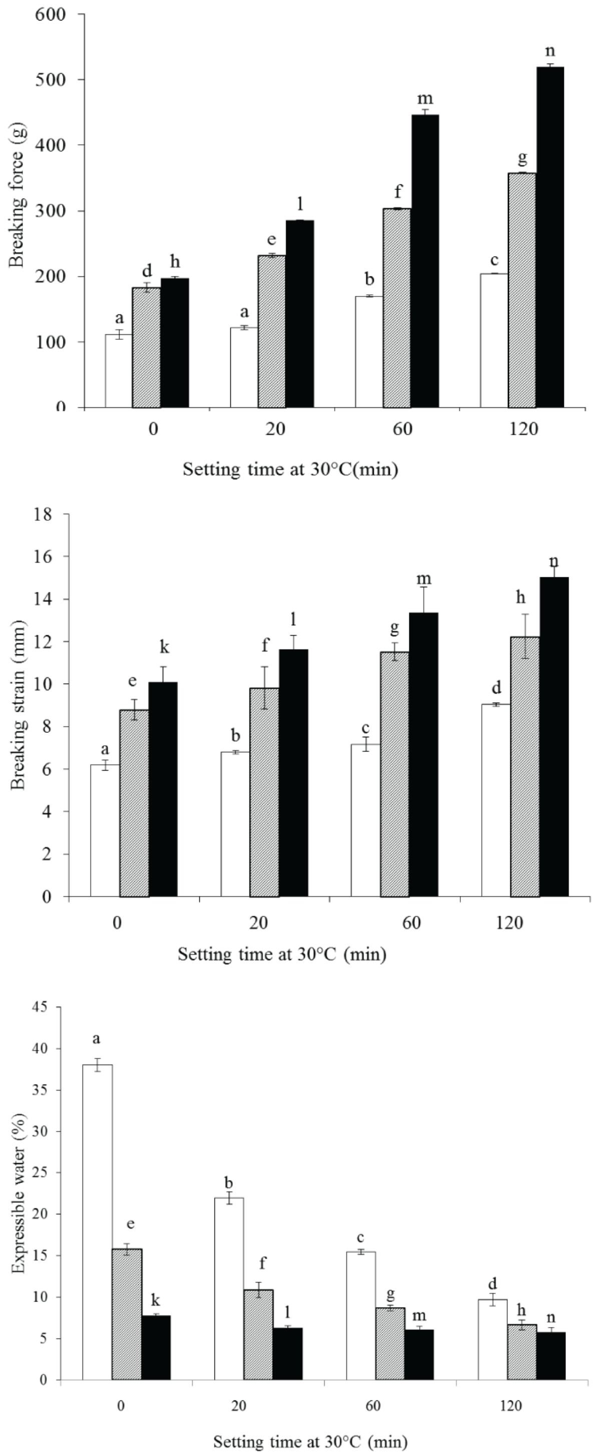

Figure 3: Physical properties and expressible water of 2-steps heated gels from washed surimi prepared with different setting time and NaCl addition. Mean and standard deviation of more than three measurements. Bars with the same alphabetical letter are not significantly different (p>0.05). Open, diagonal, and closed bars: 2-steps heated gels from washed surimi with 1, 2 and 3% (w/w) NaCl, respectively.

However, there were not significant differences in perceived saltiness (p>0.05) between A1 and B1, A2 and B2, A3 and B3 gels. The perceived saltiness was from 0.21 to 0.82% while salt content in sample was 1-3%. Data shows that the perceived saltiness level of surimi gels was very lower than actual salt content in surimi gel samples. This result was similar to the result of perceived sweetness of solid food. Shimada et al. [12] found that the perceived sweetness level of solid sweets was much lower than that of sucrose solutions. The sucrose content of each sample was from 7.8 to 80%, while the perceived sweetness in terms of the sucrose solution was from 6.7 to 25.7%. The overall correlation between the sucrose content and sweetness was 0.73 [12].

In this study, the average saltiness efficiency ratio was 0.19-0.26. This means that the differences in the perceived saltiness of gels were relatively difficult to detect and were 1/4 to 1/5 of the actual NaCl content. These results suggested that the saltiness of heat-induced surimi gels was not affected by the gel strength (derived from different setting conditions).

Generally speaking, foods containing low taste materials exhibit high taste efficiency ratio and the ratio show high dependency on physical properties. [12,33-37]. Difficulties were salt in surimi gels as well as sucrose in gel-type confectionaries influence not only taste but also physical properties. Previous studies about sweetness of gel foods reported different phenomena. The sweetness of samples swallowed without chewing was greatly affected by the sucrose content, and the other samples were affected by such factors as hardness [12]. The sucrose released from agar gels was reported to decrease with increasing fracture stress and strain [38-40] and these observations were consistent with sensory perceived sweetness [33]. Unfortunately, it could not dissolve these complex relationships between saltiness, salt content, and physical properties of surimi gels.

On the other hand, the perceived saltiness was slightly higher after chewing 20 times than after chewing 10 times, although this difference was not significant. This result means that the evaluation with fixed number of chewing have some inconvenience, because the number of chews required for the evaluation of heat-induced gels differed depending on textural differences. It was assumed that the fixed number of chew is not appropriate method for the determination of the perceived saltiness differences in the gels having different texture. Accordingly, in the next step, the evaluation was conducted under free chewing conditions.

Evaluation of perceived saltiness of washed surimi gel

Although above-mentioned results suggested that the difference in gel strength of heat-induced surimi gels prepared with/without setting did not affect perceived saltiness, surimi additives such as sucrose, sorbitol, and polyphosphate were thought to influence the taste of heat-induced surimi gels. The proximate composition of frozen surimi was as follows: moisture 73.6% (w/w), crude protein 19.8% (w/w), crude lipid 0.5% (w/w), crude ash 0.6% (w/w), and crude carbohydrate 5.5% (w/w). It was thought that the crude carbohydrate included sucrose and sorbitol. Therefore, in the next step, heat-induced gels were prepared with washed surimi to eliminate the effect of additives. After repeating of washing surimi, the residual content of sorbitol and sucrose became less than 0.4%.

Furthermore, it was thought that an improved method for perceived saltiness evaluation was necessary. The amount of mastication required before swallowing differed depending on the texture of the samples, making it difficult to compare the perceived saltiness of samples using fixed number of chews. Unlike natural mastication, where more number of chews and longer duration were required for harder gels, the panelists were asked fixed numbers of chews in this study. They may control the chewing force; weak force per chew for weaker gels and stronger force for harder gels. Therefore, the evaluation was performed under free chewing conditions.

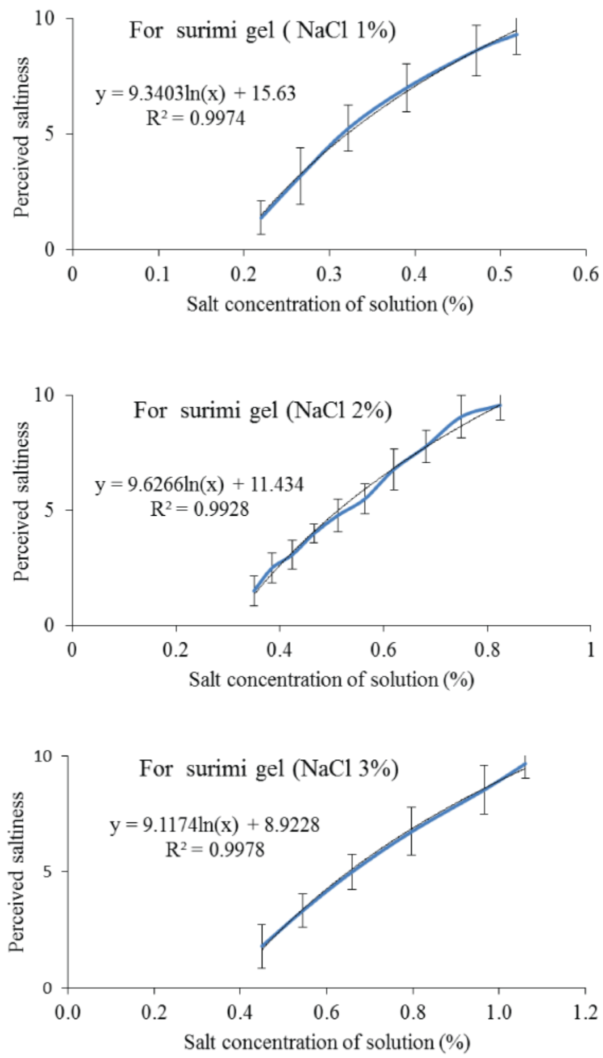

Figure 4: Perceived saltiness score of salt solution by trained panelists. Mean and standard deviation of 18 panelists. Equation in each graph is best fit curve of a logarithmic regression model with the regression coefficient.

Physical properties of washed surimi gels: The breaking properties and expressible water of washed surimi gels are shown in Figure 3. The physical properties of heat-induced gels differed considerably depending on the salt content and setting time. With an increase in the setting time, the breaking force increased especially in the case of the gel with 3% NaCl. The decrease in expressible drip accompanied by setting was remarkable especially in gels with low salt concentration (1%). Maximum gel strength can be attained from a given surimi by allowing for sufficient solubilization through proper comminution at an optimum salt concentration [41], and the gel strength increases depending on the salt content in the range of 0-3% [42]. Additionally, the gel strength and water holding capacity are almost corresponding in the range of this NaCl concentration [43].

The results obtained were almost matched to these studies. Consequently, it was shown that heat-induced gels with a variety of breaking properties and water holding capacity could be obtained by addition of 1-3% NaCl and setting for 0-120 min.

NaCl	Saltiness Parameter	Setting time at 30°C (min)			
		0	20	60	120
1%	I_{max}	0.29[a]	0.30[a]	0.27[a]	0.30[a]
	SER	0.29[d]	0.30[d]	0.27[d]	0.30[d]
2%	I_{max}	0.56[b]	0.58[b]	0.57[b]	0.54[b]
	SER	0.28[d]	0.29[d]	0.29[d]	0.27[d]
3%	I_{max}	0.66[c]	0.71[c]	0.73[c]	0.67[c]
	SER	0.22[d]	0.24[d]	0.24[d]	0.22[d]

Table 3: Maximum saltiness intensity (I_{max}) and saltiness efficiency ratio (SER) of 2-steps heated gels prepared from washed surimi with various setting time at 30°C. Values are average of 9 trained panelists with 2 repetitions. Value followed by different alphabetical letters within a row indicate significant differences (p<0.05).

Maximum saltiness intensity of washed surimi gel	Breaking force	Breaking strain	Expressible water
1% (w/w) NaCl	0.01	0.08	0.01
2% (w/w) NaCl	0.03	0.24	0.11
3% (w/w) NaCl	0.03	0.03	0.26

Table 4: Correlation coefficient (r) between maximum saltiness intensity of washed surimi gel and breaking force, breaking strain, and expressible water.

Sensory evaluation of washed surimi gels: Figure 4 shows the perceived saltiness of salt solution. A good logarithmic relationship was obtained between salt content in solution and perceived saltiness by panelists. Using those regression models, the saltiness score evaluated by free chewing was converted to NaCl concentration of NaCl solution sensed equivalent saltiness. Table 3 shows the maximum saltiness intensity (I_{max}) of heat-induced gels from washed surimi, which were prepared with different setting times (0, 20, 60, 120 min) and NaCl contents (1%, 2% and 3%). The perceived saltiness was different depending on the NaCl content, but not on the setting time. I_{max} were approximately the same to saltiness of 0.25%, 0.5% and 0.7% NaCl solutions for gels including 1%, 2% and 3% NaCl, respectively. The saltiness efficiency ratios (SER) calculated from I_{max} were 0.22-0.30 for all gels. These results were consistent with the previous results obtained using heat-induced surimi gels. The linear correlation coefficient (r) between I_{max} and breaking force, breaking strain, and expressible water of washed surimi gels were shown in Table 4. It was clearly presented that all r values were low. It means that there are no significant relationship between I_{max} and breaking force, breaking strain, and expressible water of washed surimi gels prepared with different setting times. The sensory evaluation results obtained during free mastication revealed that the differences in physical properties derived from the setting time had minimal effects on the perceived saltiness during gel consumption.

Conclusions

In both the case of heat-induced gels prepared from surimi and washed surimi by various setting time, the physical properties were very different depending on the heating conditions. On the other hand, the differences of physical properties did not affect the saltiness efficiency ratio of the gels. This phenomenon may be influenced by not only the characteristics of the texture derived by setting but also the salt concentration in the gels. For this reason, it should be carefully judged whether the texture will affect the saltiness efficiency of the surimi products. Therefore, further studies are required to clarify what kind of physical factors affect the taste of surimi-based products.

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