To be submitted to

J of Food Science and Biotechnology

Rice Flour – A functional ingredient for premium crabstick

Sungik Hur[1)], Dong-Soo Kim *, Cho Seung-Mock, and Jae W. Park[1)]

Korea Food Research Institute, Sungnam, Gyeongi-do, South Korea

[1)] Oregon State University, Seafood Research and Education Center, 2001 Marine Drive,
Room 253, Astoria, OR 97103, USA

*** Corresponding author:**

Dr. Dong Soo Kim

Korea Food Research Institute, Sungnam, Gyeongi-do, South Korea

E-mail: dskim@kfri.re.kr

Abstract

Rice flour possesses functional properties in enhancing texture and whiteness. This study was carried out to evaluate rice flour as a functional ingredient for premium crabstick and develop a commercially viable recipe for premium crabstick. Physicochemical properties of crabstick pastes prepared with 42% surimi, various rice flour concentrations (0, 1, 3, and 5%), and other ingredients were evaluated. The physical properties were measured during refrigerated and frozen storage. Rice flour measured at various concentrations (5% to 40% in water) using differential scanning calorimetry (DSC) demonstrated similar patterns with an endothermic peak at around 63.5^{o}C. During refrigerated storage up to 21 days, the strength of gel increased gradually, while cohesiveness stayed mostly unchanged. At 1% rice flour addition, fracture gel properties during 21 days of refrigerated storage showed optimum results. During frozen storage, water retention ability (WRA) gradually decreased as freeze-thaw (F/T) cycle was extended. However, the reduction was minimized as rice flour concentration increased. Two different crabstick samples (control and 1% rice flour) demonstrated no difference in strength and cohesiveness of gels. Rice flour (1%) can be used to replace various starches as a functional ingredient in premium crabstick.

Keywords: rice flour, crabstick, gelation, texture, color

Introduction

Surimi-based crabstick has become the most popular surimi seafood outside Japan since its development by Sugino and Osaki independently in Japan in 1975 (1). Currently, approximately 35% of surimi produced globally is used for the production of crabstick, predominantly in the U.S.A. and Europe. Due to surimi price fluctuations during the last 20 years, however, the quality of some crabsticks has changed significantly. South Korea (Korea hereafter) also played an important role in developing the U.S. surimi seafood market during the mid 1980s. Korea is the second largest surimi seafood producing country (2). Korea uses about 15% of the total surimi produced in the world after Japan, which uses approximately 50%. Korea's traditional surimi seafood (*Ahmook*) makes up the majority of surimi seafood sales at 260 billion KRW (3).

Crabstick became popular in Korea when it was introduced in the late 1970s. It was predominantly used for Gimbap (Sea Vegetable Roll) as a meat ingredient. With the fluctuation of surimi price, Korea also experienced significant changes in crabstick quality. Crabstick quality began to suffer as manufacturers decreased the concentration of surimi in the final product or used lower quality surimi in an attempt to cut costs. Consumers started to show their displeasure with the low quality crabstick and the market became flat in the late 1990s and early 2000s. The market size of low quality crabstick is about 90 billion KRW. Hansung Enterprise (Seoul, Korea) introduced the first premium quality crabstick (Crami) in Korea in 2002 and it was joyously received by Korean markets. Other companies began to follow the lead of Hansung and together played a major role in revitalizing the Korean crabstick market. The premium crabstick market in Korea has grown by 60% over the last 4 years (3).

However, to prevent a cycle of quality reduction–market crash and to promote a positive perception of crabstick, it would be beneficial to research new functional and healthy ingredients to continue to add value to the crabstick product line. As in many Asian cultures, rice remains a major part of the daily diet of Koreans. Recently, it has received increased attention from Western consumers due to its healthy nutritional values. It is a great source of vitamins (thiamine, niacin, folic acid, pantothenic acid, and riboflavin) and minerals (magnesium, phosphorus, copper, manganese, selenium, calcium, and potassium) (4). Rice is also low in fat, but contains essential omega-3 and omega-6 fatty acids. Since rice is primarily consumed in its whole grain form, other uses for rice have not been evaluated as functional food ingredients (5). Currently there has been little research done in muscle foods using rice flour as a gel enhancing ingredient. Based on the textural properties of traditional foods made using rice (i.e., rice cake) in Korea and Japan, rice flour can be an effective functional ingredient in enhancing textural properties of crabstick. Unlike wheat flour, rice flour can provide white chalky color to crabstick, where white color is considered as premium quality. In addition, Korean rice, which is round and short grain, has lower amylose content (12 – 19%) compared to long grain rice containing 19 – 23% amylose (6). It means it contains higher (81 – 89%) amylopectin that can show better freeze-thaw stability or reduce the degree of retrogradation.

Our objectives were to evaluate rice flour as a functional ingredient for premium crabstick and further develop a commercially viable recipe for premium crabstick.

Materials and Methods

Materials

Two forms of rice flour were manufactured using medium grain rice by Daesun Flour Mills Inc. (Hampyeong, Korea). Rice flour (for cake) was ground using a roll mill and sieved using a 40-mesh screen. Rice flour (for noodle) was ground using a jet mill and sieved using a 180-mesh screen. Based on our preliminary evaluation of rice flour, rice flour (for cake) was eliminated due to its large particle size. Particles were too large to be uniformly mixed with surimi paste. Therefore fine rice flour (for noodle) was used for the entire study. Proximate analysis for rice flour was conducted in triplicate using the AOAC method (7). Moisture concentration was 12.64 ± 0.28%, protein concentration was 5.74 ± 0.03%, and pH was 6.29 ± 0.02.

Alaska pollock (*Theragra chalcogramma*) surimi (A grade) was obtained from American Seafoods (Seattle, WA, U.S.A.). The surimi was stored frozen at -18 °C until used in surimi crabstick paste preparation.

Paste preparation

Surimi crabstick pastes were made using four different rice flour concentrations (0, 1, 3, and 5%) while maintaining a final moisture concentration of approximately 76.5% as shown in Table 1. The crabstick paste of 0% rice flour concentration was used as the control sample. With our interest in finding a better utilization of rice flour, we attempted to replace various starches with rice flour while maintaining the content of surimi equal to the amount typically used for premium crabstick. Total addition of starch and rice flour was maintained at 8%. As rice flour replaced total starch concentration, a mixing ratio of starches was proportionally maintained as follows potato starch: wheat starch: modified starch at 3:4:1, respectively.

Surimi chopping and mixing were done according to the method of Park (8). The frozen surimi blocks were thawed at room temperature (≈ 23℃) for 1 h and cut into small pieces (2 to 3 cm cubes). The pieces were chopped at low speed (1,800 rpm) for 1 min in a vertical vacuum cutter (UM5, Stephan Machinery Corp., Columbus, OH, U.S.A.). Salt (2%) was then added and chopped at low speed for another 1 min. Then four different rice flour concentrations (0, 1, 3, or 5%) were appropriately sprinkled into the bowl. Additional ingredients, 5% liquid egg white, 2% sugar, 1% seasoning, and 40% ice/water, were added and then chopped on low speed for 1 min. The crabstick paste was then chopped at high speed (3,600 rpm) with a vacuum of 40 - 60 kPa for 3 min.

Gel preparation and storage

The paste was then packed into a polyethylene vacuum bag and subjected to a vacuum machine (Reiser VM-4142, Roescher Werke GMBH, Osnabrueck, Germany) to remove air pockets which might have been introduced while removing paste from the bowl and placing it into a bag.

Ohmic heating

The paste was stuffed into nylon tubes (inner diameter = 30mm, length = 220mm) using a sausage stuffer (Model 14208, The Sausage Maker, Buffalo, N.Y., U.S.A) and subjected to ohmic heating. This fast ohmic cooking was used to mimic the initial cooking of commercial crabstick, which is done fast in a thin sheet. Stuffed tubes were placed between two stainless steel electrodes (i.e. electrodes were inserted into each end of the tube) and tightened by the center tube aluminum clamp. The needle thermocouple (needle thermocouple 1.6 mm x 260 mm, Ecklund-Harrison Technologies, Inc., Fort Meyers, FL, U.S.A.) was then inserted into the nylon tube and used to control cooking time along with the temperature controller (Cni 3254-C24, Omega Engineering, Inc., Stamford, CT, U.S.A.). One of two electrodes was connected to an air cylinder (SR-242-Q, Bimba Manufacturing Company, Monee, IL, USA) providing 3.5 bar and the valve of the cylinder was then opened to provide solid contact between the electrodes and the sample paste. The sample was then heated using 250V. When the sample temperature reached 90℃, the sample was held for 1 min. Total cooking time was approximately 90 seconds.

Water bath heating

Ohmically cooked surimi seafood gels, which were rolled in a plastic bag and sealed, were heated at 90°C for 40 min. This water bath cooking was used to simulate the pasteurization of commercial crabstick products. Pasteurized samples were chilled in ice water for 15 min. The chilled gels were subjected to refrigerated (4 °C) and frozen (-18 °C) storage.

Gel storage

The quality of refrigerated samples was measured for texture, color, and water retention ability during refrigerated storage (4 °C) at Day 1, 7, 14, and 21. As for the measurement of frozen stability (-18°C), frozen samples were subjected to a number of freeze-thaw (F/T) cycles, which are commonly used to mimic long term frozen storage. Frozen samples were treated with freezing and thawing for 0, 3, 6, and 9 cycles. All samples were partially vacuum sealed to maintain the shape of samples and to minimize sample spoilage. One F/T cycle was defined from freezing samples at least 16 h in the freezer (-18 °C) to thawing at refrigerated condition (4 °C) for 7 h. The 0 cycle samples were measured before freezing.

Micro differential scanning calorimetry (DSC)

The thermal properties of rice flour were measured by DSC using six different rice flour paste (a mixture of flour to water at ratios of 5:95, 10:90, 15:95, 25:75, 40:60,and 55:45, respectively) and crabstick paste with four different rice flour concentrations (0, 1, 3, and 5%) prepared as described above. DSC was performed using a micro DSC III (Setaram, Inc., Lyon, France). The instrument was calibrated for temperature accuracy using naphthalene. Sample, accurately weighed around 500 ± 5 mg, was sealed in a hastelloy sample vessel. Another calibration with sample was performed along with an empty reference vessel to determine the amount of distilled, deionized (DDI) water required as a reference. Samples were scanned with a reference vessel containing DDI water at a heating rate of 1.0 °C/min over a temperature range of 20-90 °C. All of the samples were conducted at least in duplicate or until two uniform thermograms were consecutively obtained.

Oscillatory dynamic measurement

The six different rice flour slurries and four different crabstick pastes, both prepared above, were subjected to a dynamic rheometer (CVO-100, Malvern, Inc., Worcestershire, U.K.) to measure gel network development as a function of temperature. The samples were loaded between a cone and plate geometry (40 mm diameter, 4° angle) with a gap of 150 µm. A solvent trap with a moistened sponge inside was used to prevent moisture loss. The elastic modulus (G') of the rice flour was measured with a single frequency of 1.0 Hz under a constant shear stress of 10 Pa after determining the linear viscoelastic region at a heating rate of 1.0°C/min during the temperature sweep from 20 to 90°C. The crabstick paste was measured with 0.1 Hz frequency and shear stress of 40 Pa during the temperature sweep from 20 to 90°C. All of the samples were subjected to temperature sweep at least twice or until two uniform rheograms were consecutively obtained.

Fracture gel texture analysis

Gels cooled in ice/water and stored overnight in a refrigerated storage (4°C) were set at room temperature for 2h before subjecting to fracture textural properties (breaking force, g and deformation, mm) using a TA texture analyzer (TA-XT plus; Texture Technologies Corp., New York, USA) (9). Gels were cut into 30-mm long cylinders. A 5 mm diameter spherical probe was used with a crosshead speed set at 1 mm/sec. For each sample, 10 measurements were made.

Water retention ability (WRA)

Water retention ability (WRA) was measured according to the method developed by Kocher *et al.* (10). A microcentrifuge filtration unit consisting of a 1.5 mL filtrate receiver tube and a sample reservoir with an encapsulated membrane (0.45 µm) was used. Surimi gels, after cutting into fine particles, were weighed (0.4 ± 0.05 g) before being placed in the sample reservoir and the filtration unit was spun in a microcentrifuge (5415C, Eppendorf, Hamburg, Germany) at 5,500 rpm for 10 min. All of the samples were conducted in triplicate. WRA was determined as:

$$\text{WRA} = [\text{total water (g) in surimi gel} - \text{water (g) released}] / \text{total surimi gel (g)},$$

where, total water (g) = % moisture of surimi gel x surimi gel weight (g) and water (g) released = [(microcentrifuge tube weight (g) + water(g)]– microcentrifuge tube weight (g).

Color properties

Color properties (L*, a*, b*) of gels were measured in triplicate using a Minolta colorimeter (CR-310, Minolta Camera Co. Ltd., Osaka, Japan) before gels were used for fracture textural analysis. The instrument was standardized using a Minolta calibration plate and a Hunter Lab standard hitching tile according to the method of Park (11). The whiteness was calculated using the equation L*-3b*.

Crabstick paste preparation and evaluation

Based on texture and color evaluation of rice flour at various concentrations, 1% rice flour was determined as the best. Therefore, crabstick gels were prepared manually using a sheet mold and roller using two formulae (control and 1% rice flour). Crabstick paste (≈40 g) was placed inside the molding sheet frame (7.5 cm wide, 25.5 cm long, 0.15 cm thick) and the paste was evenly filled using a roller according to Poowakanjana and Park (12). Crabstick paste sheet (1.5 mm thick) on aluminum foil was cooked in steam (92 °C) for 1 min. Then this partially cooked sheet was manually rolled into a crabstick shape. Color paste, which was prepared by mixing 2% carmine and 98% surimi paste prepared above, was applied on the surface before cooking in steam (92 °C) for 1 min. Then the crabstick was wrapped using a plastic film and cooked in steam (92 °C) for 40 min to mimic the commercial pasteurization step, which also completed the gelation of egg white, starches, and rice flour. Crabsticks were then cooled in ice water for 30 min and equilibrated to room temperature (≈23℃) before texture measurement.

Gel texture of crabstick was measured using a wire cutter attached to a TA texture analyzer (TA-XT plus; Texture Technologies Corp., New York, USA). Gel breaking force (g) and deformation (mm) were reported. For each sample, 10 measurements were made.

Statistical Analysis

The results were presented as the average and standard deviation of each experiment conducted at least in triplicate and evaluated using SPSS (version 13) software package (SPSS Inc., Chicago, IL, USA). ANOVA with Tukey's test was used to determine statistical significance ($P<0.05$).

Results and Discussion

Effect of rice flour concentrations on micro DSC

Differential scanning calorimetric properties of rice flour slurry were evaluated using a concentration from 5% to 55% (Figure 1). At a concentration of 5% to 40%, similar DSC patterns were obtained with an endothermic peak at around 63.5 ± 0.2°C possibly due to the gelatinization of starch and gelation of albumin (water-soluble rice protein). According to Juliano (13), the four proteins from rice are albumin (water-soluble), globulin (salt-soluble), glutelin (alkali-soluble), and prolamin (alcohol-soluble). Enthalpy values increased as flour concentration increased. This indicated more thermal energy was required to swell rice starch in the presence of excessive water before aggregation as flour concentration increased (14, 15). Pan et al. (16) reported the gelatinization temperature of rice flour, when mixed in water, was 69.3°C (medium grain) and 78.7°C (long grain). At 55% flour concentration, two endothermic peaks were obtained at 62.8 °C and 78.0 °C. According to Tsutsui et al. (17), the gelatinization temperature of medium grain rice starch is 62°C when measured at 10% starch suspension. Therefore, the first peak (62.8°C) is possibly related to the melted starch crystallites with water and denaturation of rice protein (18, 19) and the second peak linked to the melting of remaining starch crystallites (14, 20).

When rice flour was mixed with surimi and other ingredients, two peaks were developed at around 36.5 °C and around 71-72 °C and the peak temperature was shifted to higher temperatures as the rice flour concentration increased from 0 to 5%, indicating gelation was slightly delayed (Figure 2). According to several reports, the Alaska pollock myosin and actin start unfolding and aggregate at around 30-35°C and 65-75°C, respectively (9, 21, 22).

Park (23) reported that starch gelatinization is delayed by the presence of myofibrillar proteins, salt, and sugar in the surimi-starch system. Potato starch, which has a gelatinization temperature around 60°C in water, is gelatinized at 70°C when combined with surimi. On the other hand, the gelatinization temperature of rice flour is 63°C in water (Figure 1), which further suggests that this rice flour possibly gelatinized at a higher temperature than 70°C. Therefore, Peak 2 was delayed as rice flour concentration increased.

Oscillatory dynamic measurement

Dynamic rheology is often used to measure gel formation and phase transition during temperature sweep from 20°C to 90°C. While fracture gel analysis measures the texture upon rupture of gels, dynamic rheology measures non-fracture gel properties through monitoring the development of heat-induced gelation. Dynamic rheogram for storage modulus (G'), denoting the nature of elastic properties for the four treatments, generally exhibited the same trend except between 45 – 85°C, where covalent bonds and hydrophobic interactions were completed for proteins (24, 25) and gelatinization of starch was completed (15, 26). The significant increase in G' of the four treatments is due to the formation of a 3-dimensional network from amylose. As amylose leaches out, swollen starch particles are reinforced to form strong interaction (27, 28). Once heating is completed, all showed equal G' and G", indicating the four treatments have the same elastic and viscous properties, respectively (Figure 3a). An increased G' peak at near 36°C (Figure 3c) was probably due to the formation of a semi-gel like structure of myosin tail. As heating continued, this semi-gel like structure ruptured and released some fluidity, resulting in a decrease of G’ (29).

Transition of phase angles for the four treatments was somewhat similar except between 20–32°C and 45–57°C (Figure 3b). A phase angle of 90° indicates perfe`ct viscous properties, while 0° denotes perfect elastic properties. The transition of the phase angle from 40° to 10° during temperature sweep explains that the sample paste was quite elastic (less viscous) at the beginning and became more elastic once heating was completed.

Fracture gel texture

Fracture properties of gel texture measured using a penetration probe is highly correlated with sensory evaluation (30). Breaking force (g) indicates the strength of gel, while deformation (mm) denotes the cohesive nature of the gel. Gel strength decreased significantly as rice flour concentration increased (Figure 4) indicating the reinforcing effect of rice flour on the strength of surimi gel was not as strong as that of starches. During refrigerated storage of 21 days, the strength of gel increased gradually, while cohesiveness stayed unchanged. Among several major forces that stabilize protein-starch gels, hydrogen bonds become stronger as temperature decreases (24). According to Lanier et al. (24) and Howe et al. (31), gel hardness is strongly influenced by hydrogen bonds during refrigerated temperatures and gel cohesiveness, which increases at elevated temperatures (up to 60^{o}C) by hydrophobic interactions, is not affected at refrigerated storage. In addition, 1% rice flour showed almost identical fracture gel properties compared to the control after 21 days of refrigerated storage (Figure 4). For the frozen storage effect, which was evaluated using freeze/thaw (F/T) cycles, the strength of gel increased somewhat significantly, while the cohesiveness of gel decreased significantly as F/T cycles were extended (Figure 5). These changes were minimized as the concentration of rice flour increased. A high concentration of amylopectin in Korean rice flour possibly minimized the changes of texture during frozen storages. On the other hand, the surimi-starch gels become brittle and rigid because high amylose starches undergo severe retrogradation during storages. (23). A treatment with 1% rice flour demonstrated similar gel strength and cohesiveness compared to the control after 9 F/T cycles.

Water retention ability (WRA)

Water molecules behave as either free water or bound water in the gel matrix. As external force is given to the gel matrix, free water is released while bound water is retained in the gel matrix. WRA measures how much water is retained as bound water in the gel matrix. WRA during refrigerated storage for 21 days did not show a visual difference while a statistical difference was noted (Figure 6). However, there was an interesting trend that overall WRA increased as the concentration of rice flour increased possibly due to high amylopection content in Korean rice flour. During frozen storage, it was noted that WRA gradually decreased as F/T cycles were extended. However, the reduction was minimized as rice flour concentration increased. With regard to WRA, 5% rice flour gave the best performance. Starch retrogradation and ice recrystallization affected the deterioration of the frozen paste during storage (32) and high-amylose starches easily undergo retrogradation during frozen storage. In other words, high-amylopectin starch would release the least amount of free water during frozen storage (33).

Gel color

Appearance and color most affect decision making of consumers regarding purchase choice. Color of surimi gels is affected by color quality of surimi and the properties and concentration of starch used. Typically, the higher the L* value or the lighter a surimi gel is, the higher its color quality. When starch granules are fully swollen, translucent gels with lower L* values are obtained. Starch gels with larger granules (i.e., potato) exhibit more translucence while those with smaller granules (wheat, rice) are more opaque. For b* values, when starch granules are not fully swollen, the gels are more yellow in hue (higher b*) compared to when starch granules are fully swollen and are slightly blue in hue (negative b*) (23). Whiteness value increased as refrigerated storage extended (Figure 7). As rice flour concentration increased from 0 to 5%, the proportion of added starch content decreased and the proportion of rice protein increased. This proportional change significantly affected gel color from translucence to opaqueness during refrigerated storage. However, the whiteness of frozen samples decreased as F/T cycles were extended. Ice crystal formation during frozen storage and the possible growth of ice crystals with repeated F/T cycles probably derived water molecules out of gel matrices, resulting in reduced L* values. The highest whiteness after 9 F/T cycles was found with a gel made with 5% rice flour. For both cases, the change was minimized as the concentration of rice flour increased. Among three samples containing rice flour, 1% treatment showed the closest whiteness compared to the control.

Crabstick preparation and texture evaluation

Based on the results above, a formula containing 1% rice flour demonstrated comparable texture and color of the control. Two different crabstick samples (control and 1% rice flour) were prepared for textural analysis (Table 1). Two crabstick samples demonstrated 259.35 g and 277.64 g for breaking force as well as 8.06 mm and 8.90 mm for deformation, respectively. They were not statistically different. This result indicates 1% rice flour can replace various starches without affecting texture quality (23, 34).

Conclusion

Rice flour was evaluated as a functional ingredient for premium crabstick. With our interest in premium crabstick, formulation development was not intended to reduce surimi concentration but to replace various starches with rice flour. Total concentration of starches and rice flour remained equal at 8% in four different test formulae. Dynamic rheology and micro differential scanning calorimetry were not able to differentiate the viscoelastic properties and thermal properties as affected by rice flour addition (15). However, fracture gel analysis demonstrated the textural changes of gels containing various rice flour concentrations during refrigerated and frozen storage. The difference in observed results was probably because of two different thermal treatments used during testing: dynamic rheology was done using a continuous temperature sweep from 20-90^{o}C while fracture gels were prepared using a 2-step heating process (fast ohmic heating followed by slow steam heating). Considering texture, whiteness, and water retention ability results of surimi gels as well as prepared crabstick samples, 1% rice flour can be functionally used for the production of premium crabstick. Rice flour at 3% and 5% addition showed slightly reduced gel texture. However, if the addition of 3-5% rice flour is desired, verification with sensory panel should be conducted to determine the appropriate level of consumer acceptance.

Acknowledgments

This work was financially supported by Korea Food Research Institute, Korea.

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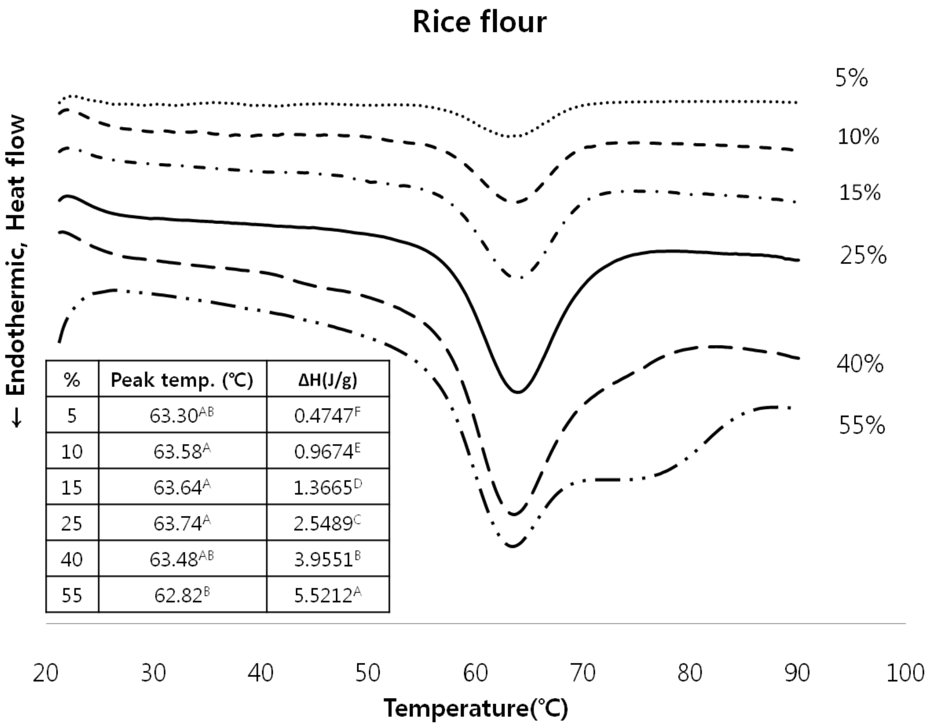
Table 1 - Formulation for crabstick paste prepared with different amounts of starches and rice flour

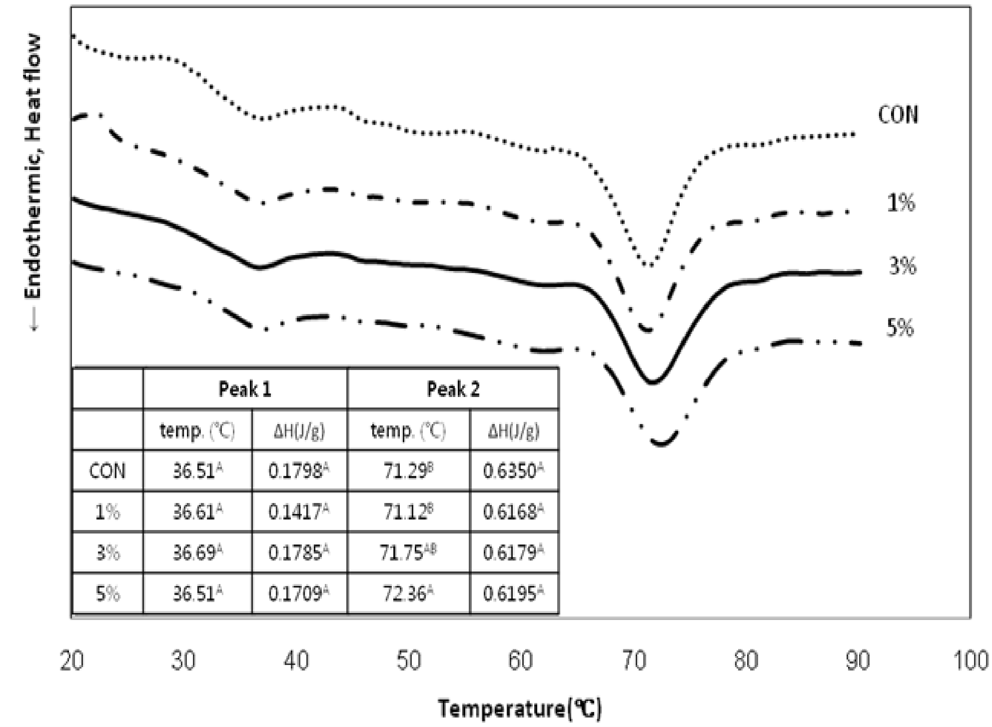
	CON	1%	3%	5%
Surimi	42	42	42	42
Water	40	40	40	40
Salt	2	2	2	2
LEW	5	5	5	5
P starch	3	2.6	1.9	1.1
W starch	4	3.5	2.5	1.5
M starch	1	0.9	0.6	0.4
Sugar	2	2	2	2
Seasonings	1	1	1	1
Rice Flour	0	1	3	5
Total (%)	100	100	100	100
Moisture (%)	76.4	76.4	76.6	76.8

LEW = Liquid egg white, P = potato, W = wheat, M = modified.



%	Peak temp. (℃)	ΔH(J/g)
5	63.30^{AB}	0.4747^{F}
10	63.58^{A}	0.9674^{E}
15	63.64^{A}	1.3665^{D}
25	63.74^{A}	2.5489^{C}
40	63.48^{AB}	3.9551^{B}
55	62.82^{B}	5.5212^{A}

Figure 1 - Differential scanning calorimetry for rice flour paste. Different superscript letters in the same column of the table denote significant ($P<0.05$) differences.



	Peak 1		Peak 2	
	temp. (℃)	ΔH(J/g)	temp. (℃)	ΔH(J/g)
CON	36.51^{A}	0.1798^{A}	71.29^{B}	0.6350^{A}
1%	36.61^{A}	0.1417^{A}	71.12^{B}	0.6168^{A}
3%	36.69^{A}	0.1785^{A}	71.75^{AB}	0.6179^{A}
5%	36.51^{A}	0.1709^{A}	72.36^{A}	0.6195^{A}

Figure 2 - Differential scanning calorimetry of surimi gels as affected by rice flour Different superscript letters in the same column of the table denote significant ($P<0.05$) differences.

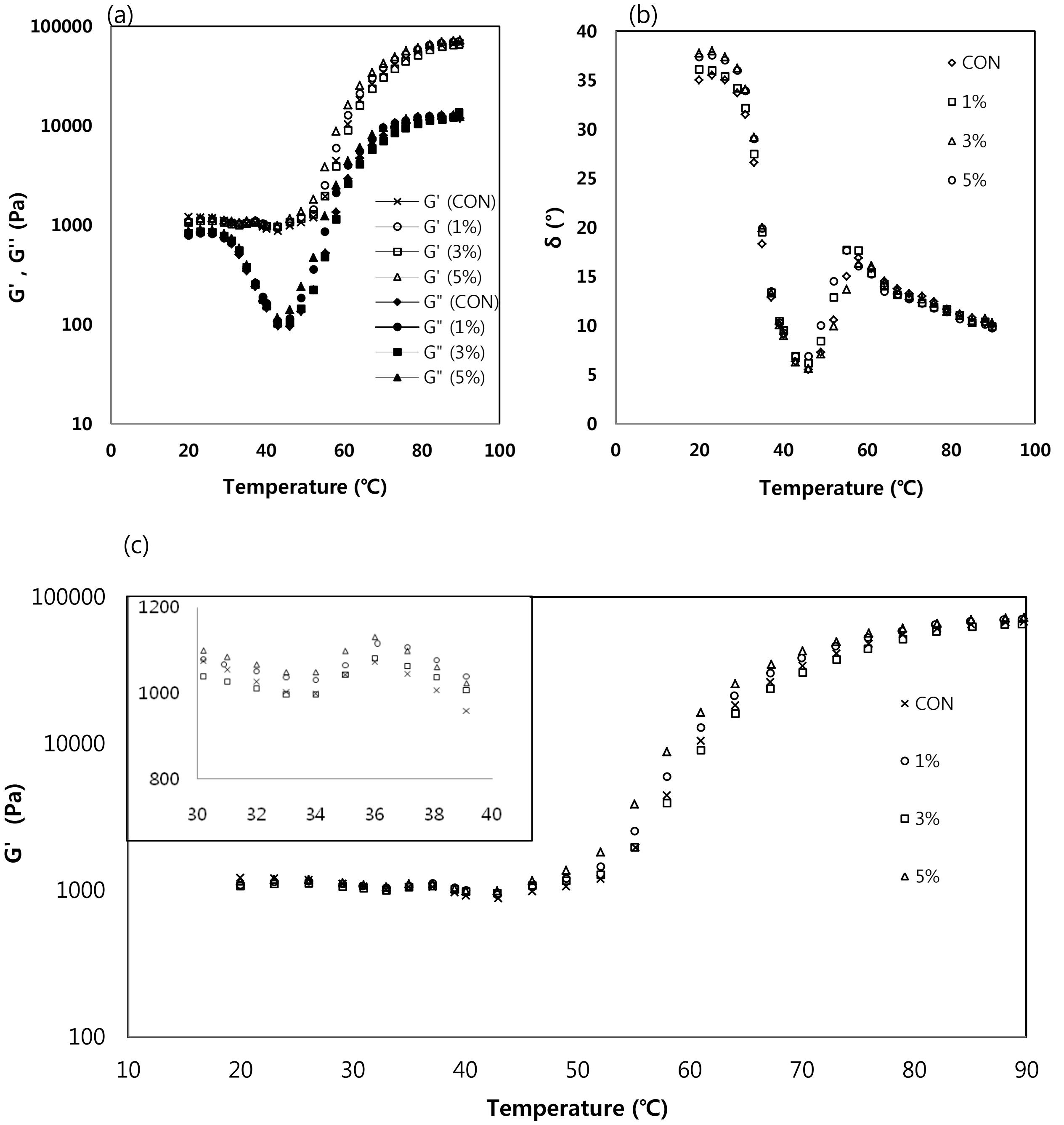


Figure 3 - Effect of rice flour on the thermal gelation of surimi paste. (a) Storage modulus (G’) and loss modulus (G”) of surimi paste during temperature sweep. (b) Phase angle (δ) of surimi paste during temperature sweep. (c) G’ of surimi paste during temperature sweep.

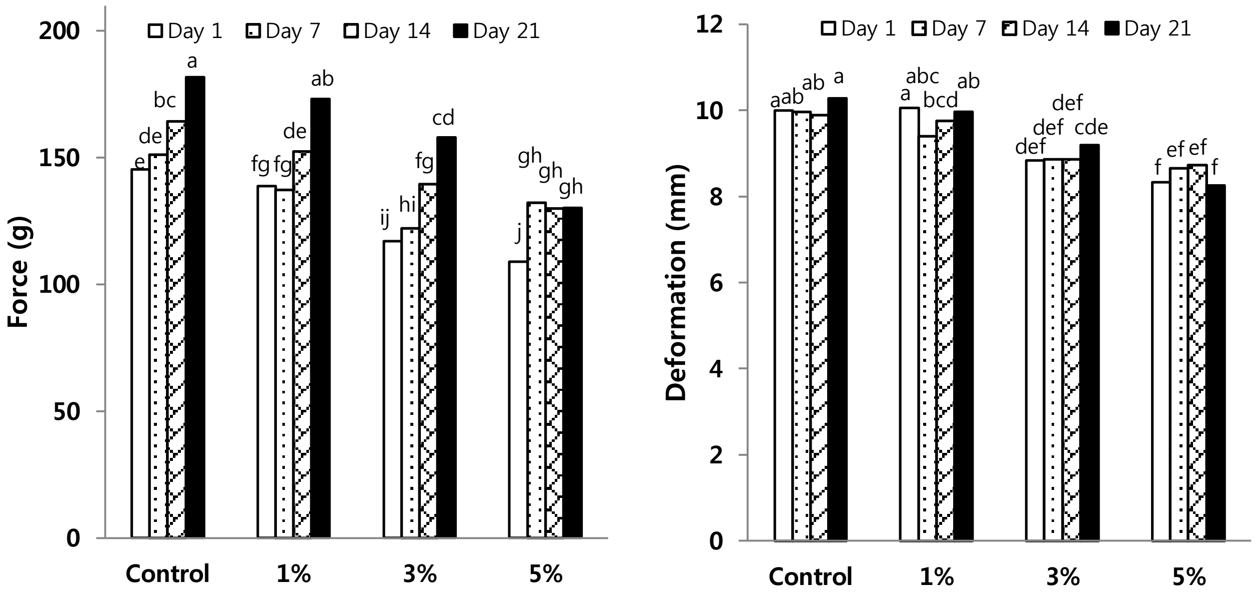


Figure 4 - Breaking force and deformation of various surimi gels during refrigerated storage. Different letters denote significant ($P<0.05$) differences.

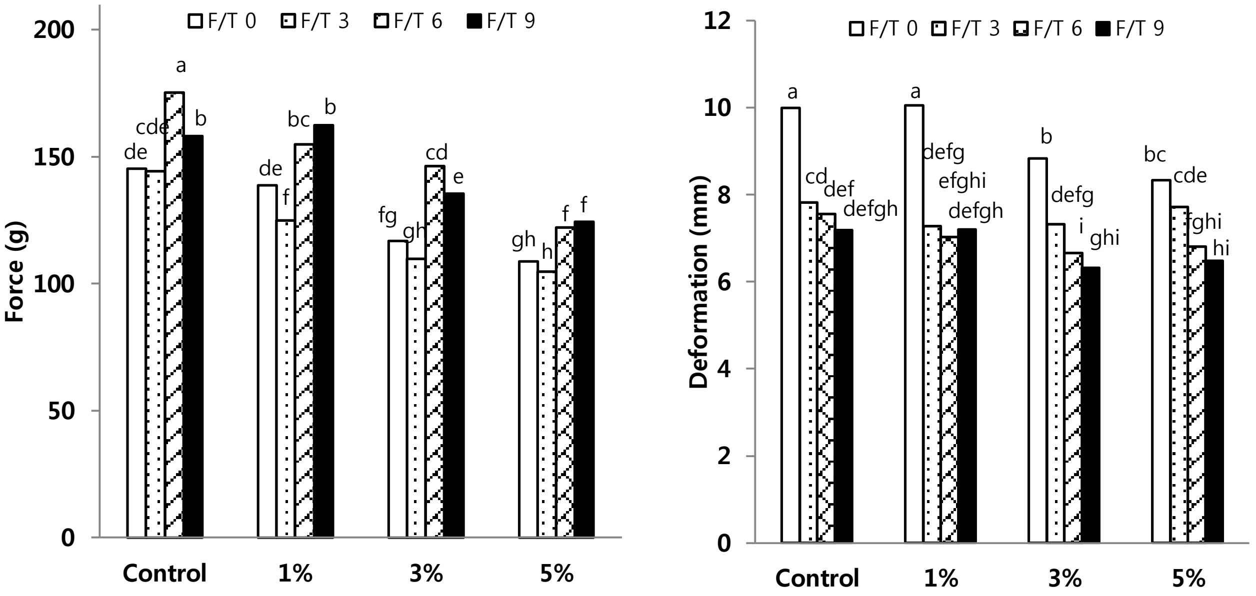


Figure 5 - Breaking force and deformation of various surimi gels during freeze/thaw cycles. Different letters denote significant ($P<0.05$) differences.

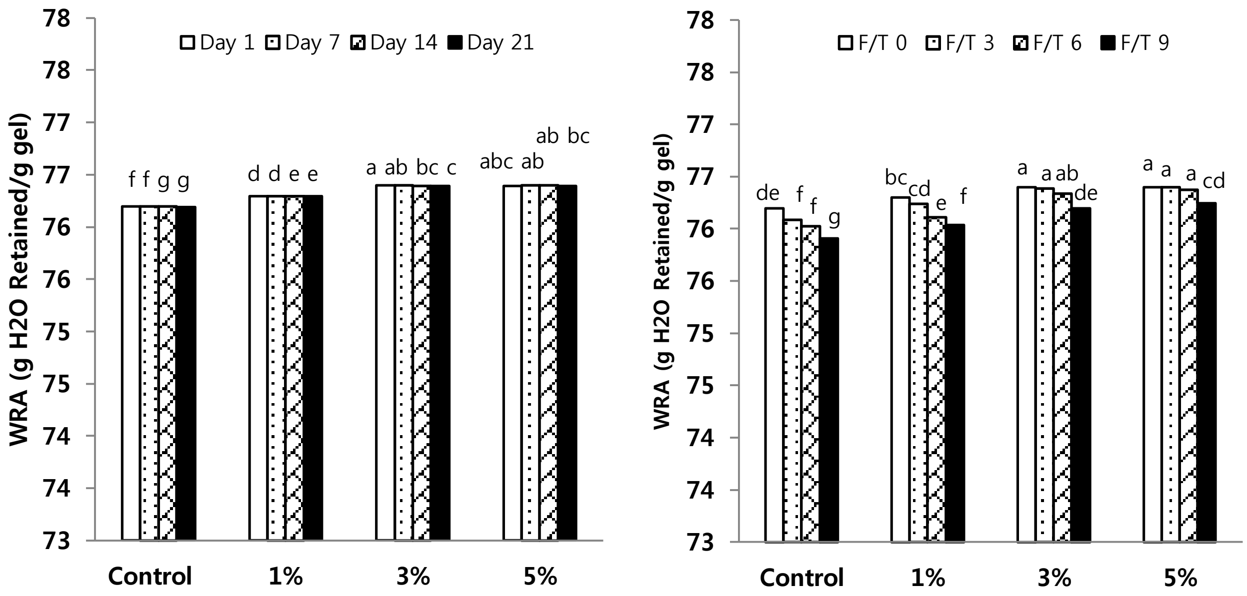


Figure 6 - Water retention ability (WRA) of various gels during refrigerated (left) and freeze/thaw cycles (right). Different letters denote significant ($P<0.05$) differences.

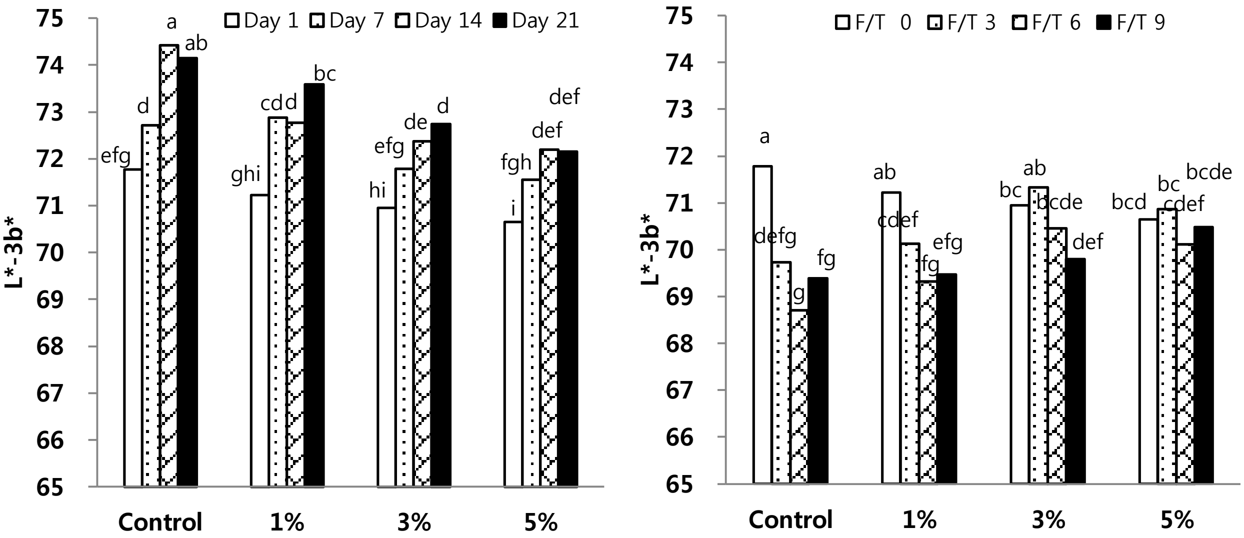


Figure 7 - Whiteness values of various crabstick gels during refrigerated (left) and freeze/thaw cycles (right). Different letters denote significant (P<0.05) differences.