The Effects of Mechanically Deboned Chicken Hydrolysates on the Characteristics of Imitation Crab Stick

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Abstract

The effects of adding mechanically deboned chicken (MDC) hydrolysates on the quality characteristics of imitation crab stick (ICS) during storage were investigated. ICS was prepared from Alaska Pollack, chicken breast surimi, and protein hydrolysates enzymatically extracted from MDC. ICS samples were divided into 4 groups: without protein hydrolysate (control), added with 0.5% protein hydrolysate (T1), added with 1.0% protein hydrolysate (T2), and added with 1.5% protein hydrolysate (T3). Results showed that crude protein content did not differ significantly among the ICS samples (p>0.05). ICS sample added with MDC hydrolysates had higher crude fat and ash content but lower moisture content than the control (p<0.05). Lightness was significantly lower in T2 and T3 than in the other groups at 0 and 4 wk of storage. Also, whiteness decreased in the groups contained MDC hydrolysates. Breaking force and jelly strength were higher in samples containing MDC hydrolysates compared to control samples (p<0.05). Additionally, saturated fatty acid contents were lower in the groups containing MDC hydrolysates than in control sample groups (p<0.05). Polyunsaturated fatty acid (PUFA) and essential fatty acids (EFA) were significantly higher in T2 and T3 than the control samples. In particular, all samples containing MDC hydrolysates had reduced thiobarbituric acid-reactive substances (TBARS) values at 4 wk. Free radical scavenging activity also was increased with addition of MDC hydrolysates.

Key words: imitation crab stick, surimi, mechanically deboned chicken hydrolysates, quality properties

Introduction

The primary ingredient in fish paste or crab sticks is surimi, a stabilized myofibrillar protein prepared from fish protein by mincing and washing of mechanically deboned fish to remove blood, lipids, enzymes, and sarcoplasmic proteins (Vilhelmsson, 1997). Surimi is light in color, bland in odor, low in fat, and extremely functional due to the unique gelling properties of the myofibrillar proteins, which make it a robust functional ingredient in the manufacture of new food products (Lanier, 2000).

Numerous studies have been conducted on surimi containing fish meat. In addition, the application of surimi technology in the production of surimi-based products from other species could provide a new approach for increasing its utilization and functional properties.

Animal meat is of much interest in the development of surimi-based products made from beef, pork and chicken (Jung et al., 2004; Park et al., 1996). Pork meat has been reported to have high myofibrillar protein content allowing increased gel forming capacity in surimi. Also, chicken breast could be used to produce many refined products, such as fish protein with different textures. Therefore, the addition of myofibrillar proteins from spent laying hens to surimi-based ICS holds promise in promoting the utilization of such products.

Protein hydrolysates, rich in low molecular weight peptides (di- and tri-peptides, with minimal free amino acids),
are a good dietary source due to their high nutritional value and therapeutic properties (Bhaskar et al., 2007). In recent years, research has focused on the generation of bioactive peptides from food sources including meat and meat by-products (Daoud et al., 2005; Jang and Lee, 2005; Li et al., 2007). Some peptides possess antihypertensive activity through their ability to inhibit Angiotensin I-converting enzyme (Arihara et al., 2001; Saiga et al., 2003a). Protein hydrolysates of animal muscles, and their by-products, also possess antioxidant activity and improved functional properties (Liu et al., 2010; Saiga et al., 2003b; Sakanaka and Tachibana, 2006). Also, enzymatic hydrolysates have been shown to enhance the emulsifying and foaming properties of fish protein (Shahidi et al., 1995).

Mechanically deboned chicken (MDC) is one of the most common raw materials in processed poultry products, which along with other meat by-products, could provide economical bioactive peptides in the form of hydrolysates. Thus, its use in protein hydrolysis could be used to produce value-added surimi-based products. However, there is little information relating to the functional peptides generated in meat-based products such as ICS. Therefore, the aim of the present study was to investigate the effects of MDC protein hydrolysates on the quality and characteristics of ICS during storage at 5°C.

**Materials and Methods**

**Sample preparation and protein hydrolysate**

Alaska Pollack was purchased from Han-sung Food Co. Ltd. (Korea) and stored at -20°C until use. Chicken breast meat was obtained from a commercial slaughter house. To make surimi, the external fat, bone, and skin were removed and the lean muscle was cut into approximately 3.0 × 3.0 × 2.0 cm³ cubes and ground through a 3 mm diameter hole using a mincer. Minced samples were homogenized using a Polytron homogenizer (T25-B, IKA Sdn. Bhd., Malaysia) with distilled water at 15,000 rpm for 30 s. The homogenate was filtered through a 1 mm mesh metal screen to remove connective tissue. The filtrate was centrifuged at 10,000 g for 25 min and the supernatant containing fat and water-soluble proteins was discarded. The resulting sediment was used for ICS manufacture.

In this study, one- and two-stage hydrolysis was employed. The nerves, skin, and visible fat were removed from the meat, which was then fragmented, ground, and homogenized with distilled water (meat:water ratio, 1:3 w/w). The homogenate was heated to 43°C and the pH was adjusted to 7.0 with 2 N NaOH. The enzyme used for protein hydrolysis was Protarimex (Novonordisk Bioindustrials, Inc., Denmark). Protarimex (5%) was added and the reaction pH was maintained by the addition of 2 N NaOH. The hydrolytic process was terminated by heating the mixture to 85°C for 20 min, ensuring inactivation of the enzyme. The resulting slurry was centrifuged (Union 5KR, Hanil, Korea) at 8,000 rpm for 10 min to remove insoluble fractions. The hydrolysate slurry was then heated to 50°C and the pH was adjusted to 7.0 with 2 N NaOH. Bromelain (1%) was added to the mixture and the reaction pH was maintained by the addition of 2 N NaOH. After heating at 90°C for 15 min to inactivate the enzyme, the hydrolysate was centrifuged at 8,000 rpm for 20 min to remove insoluble fractions. The degree of hydrolysis (DH) was determined using the 20% (w/v) trichloroacetic acid (TCA) method, as described in the semi-micro Kjeldahl procedure. DH was defined as the percentage ratio of the total nitrogen in two-stage hydrolysate (A) to the total nitrogen in one-stage hydrolysate (B), and calculated as [(A − B) / B] × 100 (4.64% crude protein and 25.2% DH). The composition of the crab stick is detailed in Table 1, while the flow diagram of its preparation is shown in Fig. 1.

**Proximate composition**

The proximate composition analysis of ICS including moisture, crude protein, crude fat and crude ash, was performed according to AOAC methods 950.46, 992.15, 985.15, and 920.153 for ICS (AOAC, 2000).

**Color**

Color (CIE L*, a*, b*) was measured using a Minolta colorimeter (CR-400, Japan), which was standardized using a white plate. Five readings were taken from the surface of the samples. Whiteness was determined using

| Table 1. The basic formulation of imitation crab stick |
|-----------------------------------------------|
| Ingredients (%) | Control | T1 | T2 | T3 |
|-----------------|---------|----|----|----|
| Alaska pollack surimi | 30.48 | 30.48 | 30.48 | 30.48 |
| Chicken breast surimi | 7.62 | 7.62 | 7.62 | 7.62 |
| MDC hydrolysates | - | 0.50 | 1.00 | 1.50 |
| Wheat starch | 18.75 | 18.75 | 18.75 | 18.75 |
| Distilled water | 35.76 | 35.76 | 35.26 | 34.76 |
| Mixed ingredients | 6.89 | 6.89 | 6.89 | 6.89 |
| **Total** | 100.0 | 100.0 | 100.0 | 100.0 |

1Mechanically deboned chicken
2Mixed ingredients: salt 1.37, sugar 0.88, crab extract 0.63, gluten 0.32, soy protein isolate 0.53, egg albumen liquid 0.18, carrageenan 0.16, calcium carbonate 0.41, soybean oil 0.53, monosodium L-glutamate 0.44, glycine 0.16, phosphate 0.19, red color DW 0.09, mixed seasoning 1.00
The following formula: L*−3b* (Park et al., 1996).

**Gel characteristics**

The gel characteristics were determined according to the method described by Phatcharat et al. (2006). Five cylindrical pieces 3.5 cm wide and 3 cm thick were stored at 20°C prior to determination. The breaking force, deformation, jelly strength, and gel strength were measured using a texture analyzer (EZ-test, Shimadzu, Japan) equipped with a cylindrical plunger (diameter 5 mm, depression speed 80 mm/min).

**Fatty acid composition**

Lipid extraction was performed as described by Folch et al. (1957). Samples (5 g) were homogenized in 30 mL of chloroform-methanol solution (2:1, v/v), after which 10 mL of 0.88% NaCl was added and the mixture incubated for 2 h to allow phase separation. The chloroform-methanol extract was evaporated in a water heating block at 40°C. The lipid extracts were then converted to fatty acid methyl esters using a 14% boron-trifluoride methylation solution. The resultant fatty acid methyl esters were separated and analyzed by gas chromatography (Agilent, 6890N GC system, USA). A fused Supelco™ capillary column of 60 m × 0.32 mm × 0.25 μM (Supelco, USA) was used. The gas chromatography oven temperature was 180°C, which increased at a rate of 5°C/min to a final temperature of 240°C. The temperatures of the injector port and the detector were set at 250°C. Fatty acid methyl ester was injected into the split injection port (10:1 split ratio). The flow rate for the N₂ carrier gas was 20 cm/sec.

**Lipid oxidation**

Lipid oxidation was determined using the thiobarbituric acid reactive substances (TBARS) method (Buege and Aust, 1978). ICS sample (5 g) was weighed into a 50 mL test tube and homogenized for 15 s with 15 mL of deionized distilled water using a Polytron homogenizer at the highest speed (T25basic, IKA, Malaysia). The homogenate (2 mL) was transferred to a disposable test tube (13×100 mm), and the butylated hydroxyanisole (10%, 50 μL) and thiobarbituric acid/trichloroacetic acid (TBA/TCA) solution (4 mL) were added. Absorbance was determined at 531 nm against a blank containing 2 mL of deionized distilled water and 4 mL of TBA/TCA solution. The TBARS measure was expressed in mg of malondialdehyde (MDA) per kg of sample.

2,2-diphenyl-1-picrylhydrazla hydrate (DPPH) radical scavenging activity

The DPPH radical scavenging activity was determined according to the modified method of Brand-Williams et al. (1995). A solution of DPPH (6.5 μM) in methanol was prepared daily before measurement. ICS sample (2 mL) was mixed with 3 mL DPPH solution so that the final concentration of DPPH was 0.1 mM. Blank sample contained the same concentrations of methanol and DPPH. The reaction mixture was shaken vigorously and was incubated in the dark for 30 min, after which the absorbance of the solution was measured in triplicate at 517 nm. The radical scavenging activity was calculated using the formula:

\[ \text{DPPH inhibition} (%) = \left( \frac{A_B - A_A}{A_B} \right) \times 100 \]

\[ A_B = \text{absorption of blank sample}, \]
\[ A_A = \text{absorption of a tested sample}. \]

**Statistical analysis**

This study was designed as a 4×2 factorial experiment based on the parameters of treatment (control, T1, T2,
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Results and Discussion

Proximate composition

The results of the proximate composition analysis of ICS containing MDC hydrolysates are shown in Table 2. The carbohydrate content ranged from 19.3% to 20.9%, and there was no significant difference among the ICS samples (data not shown). The ICS also showed no significant difference in crude protein content when compared with the control group. However, all groups containing MDC hydrolysates showed reduced moisture content when compared to control \( p < 0.05 \). Rawdkuen et al. (2004) reported that the expressible moisture of surimi gels decreased when higher an amount of chicken plasma protein was added. Therefore, lower final moisture contents can be reached due to an increase in other chemical compositions. Crude fat content was significantly higher in the MDC hydrolysate containing samples than in the control samples. Also, the ash content was significantly higher in the samples with 1.0% and 1.5% MDC hydrolysates than in the control samples \( p < 0.05 \). The functional and textural properties of surimi or surimi-based products depend on many factors, including the content of various gelling and non-gelling ingredients (Nowasad et al., 2000). High protein, high myofibrillar protein, low crude fat, and adequate water are required for making high-quality surimi-based products (Jin et al., 2007). Lipids in surimi products may adversely affect quality as oxidized lipids interact with proteins, causing denaturation and alteration of functional properties (Smith, 1987).

Color

The color characteristics of ICS containing MDC hydrolysates are shown in Table 3. The light, red, and yellow values of the MDC hydrolysates were 48.8, 5.0 and 15.6, respectively. Lightness was significantly lower in T2 and T3 than in the other groups at 0 and 4 wk of storage \( p < 0.05 \). Redness was significantly higher in the groups containing MDC hydrolysates than in the control group at time 0 of storage. It also significantly increased with the storage periods in all treatments \( p < 0.05 \). Whiteness was lower in T2, but there were no significant differences among the groups. In addition, MDC hydrolysates had no

### Table 2. Proximate compositions (%) in imitation crab stick

| Items      | Control | T1        | T2        | T3        |
|------------|---------|-----------|-----------|-----------|
| Moisture   | 69.36±0.06\textsuperscript{A} | 68.38±0.05\textsuperscript{B} | 67.64±0.10\textsuperscript{C} | 67.55±0.06\textsuperscript{C} |
| Crude protein | 9.51±0.29     | 10.20±0.17     | 10.39±0.27     | 9.86±0.01     |
| Crude fat  | 1.08±0.05\textsuperscript{C} | 1.25±0.02\textsuperscript{AB} | 1.23±0.09\textsuperscript{B} | 1.36±0.06\textsuperscript{A} |
| Ash        | 1.54±0.13\textsuperscript{B} | 1.84±0.27\textsuperscript{AB} | 1.95±0.17\textsuperscript{A} | 1.96±0.05\textsuperscript{A} |

\textsuperscript{A-C} Means with different superscript in the same row significantly differ at \( p < 0.05 \).

\textsuperscript{1} Treatments are the same as in Table 1.

### Table 3. Color (CIE value) of imitation crab stick containing MDC hydrolysates during storage

| Items      | Storage wk | Control | T1        | T2        | T3        |
|------------|------------|---------|-----------|-----------|-----------|
| Lightness (\(L^*\)) | 0         | 81.19±0.62\textsuperscript{A} | 81.51±0.30\textsuperscript{AB} | 78.72±0.30\textsuperscript{B} | 81.16±1.02\textsuperscript{A} |
|            | 4         | 80.90±0.20\textsuperscript{B} | 80.23±0.22\textsuperscript{AB} | 80.40±0.47\textsuperscript{AB} | 79.72±0.53\textsuperscript{B} |
| Redness (\(a^*\)) | 0         | -1.67±0.03\textsuperscript{AB} | -1.54±0.19\textsuperscript{BC} | -1.03±0.06\textsuperscript{A} | -1.18±0.27\textsuperscript{AB} |
|            | 4         | -0.12±0.06\textsuperscript{A} | -0.59±0.13\textsuperscript{B} | -0.21±0.01\textsuperscript{A} | -0.10±0.06\textsuperscript{A} |
| Yellowness (\(b^*\)) | 0         | 6.38±0.02     | 6.80±0.09     | 6.31±0.31\textsuperscript{B} | 6.77±0.29     |
|            | 4         | 7.02±0.30     | 7.77±0.06     | 7.04±0.23\textsuperscript{B} | 6.67±0.38     |
| Whiteness (\(W^2\)) | 0         | 62.06±0.55\textsuperscript{A} | 61.11±0.05\textsuperscript{AB} | 59.78±1.06\textsuperscript{B} | 60.84±0.61\textsuperscript{AB} |
|            | 4         | 59.83±0.77\textsuperscript{B} | 59.93±0.35\textsuperscript{B} | 59.28±0.45     | 59.71±0.61     |

\textsuperscript{A-C} Means with different superscript in the same row significantly differ at \( p < 0.05 \).

\textsuperscript{ab} Means with different superscript in the same column significantly differ at \( p < 0.05 \).

\textsuperscript{1} Treatments are the same as in Table 1.

\textsuperscript{2} \( W = L^*–3b^* \)
effect on preservation of the whiteness. Given that white
ness is one of the most important factors in the perceived
quality of surimi (Chen, 2002), high quality surimi is
obtained when as much as possible of the dark muscle is
removed (Ochiai et al., 2001). Jin et al. (2009) reported
that ICS containing MDC surimi were less white and
more yellow. Thus, addition of MDC hydrolysates may
negatively influence the color of ICS.

**Gel characteristics**

The gel characteristics of ICS containing MDC hydro-
lysates are shown in Table 4. The breaking force values
increased with storage time for all samples, but were
higher in samples containing MDC hydrolysates com-
pared to control \((p<0.05)\). Deformation values were lower
in the 0.5% MDC hydrolysate group compared to the
control group at wk 0 \((p>0.05)\) and the T3 group had the
lowest deformation value at 4 wk. Jelly strength and gel
strength significantly increased with storage time for all
samples \((p<0.05)\). Jelly strength was greater in samples
containing MDC hydrolysates compared to the control
samples \((p<0.05)\). Also, the gel strength was greater in the
samples containing 1.0 and 1.5% MDC hydrolysates com-
pared to the control samples at wk 0 \((p>0.05)\). Reppond
and Babbitt (1997) reported that torsion stress and strain
decreased linearly with increased moisture content of su-
rimi, likely a result of lower myofibril protein concen-
tration and decreased cross-link density (Sylvia et al., 1994).
We found that the addition of MDC hydrolysates increased
the breaking force and gel strength values. Thus, it is indi-
cated that the physical strength of ICS may be increased
by the addition of MDC hydrolysates.

**Fatty acid composition**

The fatty acid composition of ICS containing MDC
hydrolysates is shown in Table 5. The saturated fatty acid
(SFA) content was significantly higher in the control sam-
ples compared to the other groups. Monounsaturated fatty
acid (MUFA) content was significantly lower in T2 and
T3 than the other groups \((p<0.05)\). However, the unsatu-
rated fatty acid (UFA) content was higher in MDC hydro-
lysate containing samples compared to the control sam-
ples \((p<0.05)\). Polyunsaturated fatty acid (PUFA) and es-
sential fatty acids (EFA) were also significantly higher in
T2 and T3 than in the other samples. Jin et al. (2009)
showed that crab sticks containing MDC had a higher
linoleic acid level. The increase in the UFA content, thou-
ght to have beneficial health properties (Belury, 2002),
was positively related to MDC hydrolysate content. Ac-
cording to Kris-Etherton et al. (2003), n-3 fatty acids such
as linolenic acid (C18:3, PUFA) are beneficial in reduc-
ing cardiovascular disease risk. Therefore, supplementa-
tion with MDC hydrolysates may have positive effects on
health. However, the fatty acid composition can influence
adipose tissue firmness; Wood et al. (2003) reported that
when SFAs increase in animal diets, the fat profile moves
towards a more stable composition. This may be partially
due to the fact that UFAs are more prone to oxidation
than SFAs (Du et al., 2001).

**Lipid oxidation and DPPH radical scavenging activity**

TBARS and DPPH values in ICS containing MDC hy-
drolysates are shown in Table 6. The TBARS values for
all groups increased with storage time \((p<0.05)\). In com-
parison to the control, all samples containing MDC hydro-
lysates had reduced TBARS values at 4 wk. Lipid oxid-
ation, measured as TBARS, is a major factor in reducing
the quality and acceptability of meat products; those with
a high degree of unsaturation and fat content are more
susceptible to lipid oxidation (Morrissey et al., 1998). However, the TBARS values were not influenced by lipid content or fatty acid composition in the present study. TBARS values were low in the treatment groups, as expected, due to the addition of MDC hydrolysates. Inhibition of the formation of TBARS in beef homogenate by egg-yolk protein hydrolysate was found to be dose-dependent (Sakanaka and Tachibana, 2006). In addition, hydrolysate concentrations ranging from 1 to 2% have previously been shown to retard lipid oxidation in pork patties (Penaramos and Xiong, 2003). In the current study, the TBARS values in ICS varied only minimally from 1.50 to 1.65, suggesting a non-significant effect of hydrolysate addition on this parameter.

In all treatment groups, DPPH radical scavenging activity decreased with storage time ($p<0.05$). Scavenging activity was greater in samples containing MDC hydrolysates compared to control samples and was also positively correlated with hydrolysate content. Reactive oxygen species are unstable and readily react with many other chemical groups and substances in the body (Halliwell and Gutteridge, 1990). Wu et al. (2004) found that porcine hemoglobin hydrolysates, prepared by enzyme hydrolysis, had high DPPH radical scavenging activity. Liu et al. (2010) also found that the antioxidant activity of porcine plasma protein hydrolysate increased in parallel with DH. We found that DPPH radical scavenging activity in the present study was similar to that reported by Chang et al. (2004).

### Table 5. Fatty acid compositions (%) of imitation crab stick containing MDC hydrolysates

| Fatty acids          | Control          | T1               | T2               | T3               |
|----------------------|------------------|------------------|------------------|------------------|
| Myristic acid (C14:0)| 0.78±0.01<sup>a</sup> | 0.72±0.01<sup>b</sup> | 0.66±0.01<sup>c</sup> | 0.63±0.01<sup>d</sup> |
| Palmitic acid (C16:0)| 16.54±0.12<sup>a</sup> | 16.39±0.05<sup>b</sup> | 16.27±0.05<sup>c</sup> | 16.13±0.01<sup>c</sup> |
| Palmitoleic acid (C16:1)| 2.06±0.90           | 1.48±0.01           | 1.16±0.01           | 1.20±0.01           |
| Magnaric acid (C17:0)| 0.38±0.01<sup>a</sup> | 0.35±0.01<sup>b</sup> | 0.34±0.00<sup>c</sup> | 0.34±0.00<sup>c</sup> |
| Magaoic acid (C17:1)| 0.17±0.00<sup>a</sup> | 0.16±0.00<sup>b</sup> | 0.15±0.00<sup>c</sup> | 0.15±0.00<sup>c</sup> |
| Stearic acid (C18:0)| 6.23±0.03<sup>a</sup> | 6.08±0.02<sup>b</sup> | 6.18±0.05<sup>c</sup> | 6.08±0.03<sup>b</sup> |
| Oleic acid (C18:1)| 21.44±0.20<sup>b</sup> | 21.78±0.02<sup>a</sup> | 20.94±0.12<sup>c</sup> | 21.09±0.09<sup>c</sup> |
| Linoleic acid (C18:2,n-6)| 44.76±0.48<sup>c</sup> | 45.35±0.07<sup>b</sup> | 46.26±0.18<sup>a</sup> | 46.43±0.13<sup>a</sup> |
| Linolenic acid (C18:3,n-3)| 5.18±0.06<sup>b</sup> | 5.21±0.01<sup>b</sup> | 5.46±0.02<sup>a</sup> | 5.43±0.02<sup>a</sup> |
| Arachidic acid (C20:0)| 0.40±0.01           | 0.40±0.00           | 0.41±0.01           | 0.40±0.01           |
| Eicosenoic acid (C20:1)| 0.42±0.10<sup>b</sup> | 0.51±0.01<sup>AB</sup> | 0.57±0.01<sup>a</sup> | 0.51±0.01<sup>AB</sup> |
| Eicosatrienoic acid (C20:4)| 1.58±0.02<sup>c</sup> | 1.50±0.01<sup>c</sup> | 1.54±0.02<sup>b</sup> | 1.58±0.01<sup>a</sup> |
| SFA<sup>1</sup> | 24.33±0.15<sup>a</sup> | 23.94±0.07<sup>b</sup> | 23.87±0.11<sup>b</sup> | 23.57±0.04<sup>c</sup> |
| UFA | 75.67±0.15<sup>c</sup> | 76.06±0.07<sup>b</sup> | 76.13±0.11<sup>a</sup> | 76.43±0.04<sup>b</sup> |
| MUFA | 24.08±0.66<sup>a</sup> | 23.93±0.02<sup>a</sup> | 22.82±0.12<sup>b</sup> | 22.95±0.11<sup>b</sup> |
| PUFA | 51.52±0.56<sup>b</sup> | 52.06±0.09<sup>b</sup> | 53.26±0.21<sup>a</sup> | 53.43±0.15<sup>a</sup> |
| EFA | 51.52±0.56<sup>b</sup> | 52.06±0.09<sup>b</sup> | 53.26±0.21<sup>a</sup> | 53.43±0.15<sup>a</sup> |

<sup>a</sup>-<sup>d</sup>Means with different superscript in the same row significantly differ at $p<0.05$.
<sup>1</sup>-<sup>3</sup>Treatments are the same as in Table 1.

### Table 6. TBARS and DPPH radical scavenging activity in imitation crab stick containing MDC hydrolysates during storage

| Items | Storage wk | Control | T1 | T2 | T3 |
|-------|------------|---------|----|----|----|
|       |            | 0       | 4  | 4  | 4  |
| TBARS (mg/100 g) | 0 | 0.57±0.03<sup>b</sup> | 0.55±0.09<sup>c</sup> | 0.63±0.12<sup>c</sup> | 0.56±0.03<sup>c</sup> |
| DPPH (%) | 0 | 17.10±0.36<sup>a</sup> | 19.00±0.60<sup>c</sup> | 19.67±0.67<sup>ab</sup> | 21.87±0.32<sup>ab</sup> |

<sup>A</sup>-<sup>D</sup>Means with different superscript in the same row significantly differ at $p<0.05$.
<sup>a</sup>-<sup>b</sup>Means with different superscript in the same column significantly differ at $p<0.05$.
<sup>1</sup>-<sup>3</sup>Treatments are the same as in Table 1.

**Conclusion**

This study was carried out to compare the physicochemical properties of ICS containing different levels of MDC...
hydrolysates. Addition of MDC hydrolysates resulted in a higher fat content and lower moisture content compared with control samples. Inclusion of MDC hydrolysates increased both the breaking force and jelly strength, and increased UFA content in a proportional manner. In particular, lipid oxidation was inhibited and free radical scavenging activity increased in the presence of the hydrolysates. This is novel data with regard to MDC hydrolysate peptides in ICS, but further research is needed to characterize the MDC hydrolysate peptides responsible for the antioxidant activity observed.

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