

Physicochemical Properties of Japanese Scad (Decapterus Maruadsi) Surimi Prepared using the Acid and Alkaline Solubilization Methods

Nur Syamimi Fatin, Nurul Huda, Wahyudi David

Abstract— The physicochemical properties of Japanese scad (*Decapterus maruadsi*) surimi prepared using the acid solubilization method (ACS), alkaline solubilization method (ALS), and conventional method (CON) were investigated and compared. In CON, the fish was mechanically deboned, washed, screw pressed, treated by adding cryoprotectants, and frozen. For ACS and ALS, the minced meat was homogenized, solubilized with acid pH 3 or alkaline pH 12, respectively, and centrifuged to separate insoluble materials from soluble protein. The soluble protein was collected and adjusted to the isoelectric point of proteins (5.4), and the precipitated proteins then were centrifuged to collect the protein isolate. Cryoprotectants were added and the product was frozen. ACS yielded the highest protein recovery, ALS yielded the highest lipid reduction, and CON yielded the lowest protein recovery and lipid reduction. ACS and ALS generated products with higher protein and lower fat contents compared with CON, whereas CON produced a product with higher moisture and ash contents than ACS and ALS. Quantitative descriptive analysis revealed that the surimi produced by CON had a strong fishy odor and a rancid odor. Results shows that compared to CON, ACS and ALS methods increase the protein recovery, lipid reduction and gel quality of Japanese scad surimi.

Index Terms— Acid solubilization, Alkaline solubilization, Fish, Protein solubilization, Surimi

1 INTRODUCTION

Surimi is a Japanese term for an intermediate fish product that is used primarily to prepare a traditional gel food called kamaboko. Surimi is defined as a fish protein product prepared by washing mechanically deboned fish to remove blood, lipids, enzymes, and sarcoplasmic proteins and as minced and washed fish flesh that has cryoprotectants added for stabilization [1]. Surimi originated in Japan, and it is commonly produced from Alaskan pollack or whiting [2]. It is perceived to have wholesome and nutritious attributes [3] which have contributed to the increasing worldwide consumption of surimi-based products.

The demand for fish is increasing, but its availability is decreasing. Surimi provides opportunities to use different sources of protein in its production, such as underutilized species with little or no commercial value [4]. However, the surimi industry's demand for white fleshed fish is higher than its demand for other types, mainly because its whiteness and textural properties result in a product with the desired properties (e.g., it produces a good gel) [5,6]. Dark flesh also can be used, but it requires a different processing method.

The acid solubilization (ACS) and alkaline solubilization (ALS) methods may prove to be efficient techniques to process underutilized protein resources as well as dark fleshed fish. In these processes, the fish protein is homogenized and solubilized at either high or low pH. The solubilization of proteins enables removal of unwanted high-density components, such

as bones, scales, connective tissues, and cell membranes, and low-density components, such as neutral lipids, by centrifugation. The advantage of this process is that the recovery rate is high and the protein isolate may have improved functions and shelf-life compared to protein hydrolysates and surimi produced by the conventional (CON) method [7-10].

Japanese scad (*Decapterus maruadsi*) is a fish from the Carangidae family that inhabits the Eastern Indian Ocean and the Western Central Pacific Ocean throughout most warm coastal waters. Its local names are basung, curut, sadin, selar, selayang, and selayang mata besar. In Malaysia it is called selayang, corot, or sadin. According to the Annual Fisheries Statistics of Malaysia for the year 2012, Japanese scad production was 102,790 tonnes, which represents 6.98% of the total 1,472,240 tonnes of fish landed in Malaysia. Due to the availability of Japanese scad and its low price (RM 4.15 for the average ex-vessel price per kilogram in Malaysia), it has the potential to become a raw material for surimi production [11,12].

However, little is known about the production of Japanese scad surimi using the ACS or ALS methods. Therefore, the objectives of this study were to evaluate the suitability (protein recovery, lipid reduction and sensory evaluation) of Japanese scad as a raw material for surimi production and to measure the physicochemical properties (gel strength, texture profile analysis, expressible moisture, and water holding capacity) of Japanese scad surimi prepared using the CON, ACS, and ALS methods.

2 MATERIAL AND METHODS

Japanese scad between 13 and 20 cm long were manually beheaded and gutted and then mechanically deboned. This fish meat mince without further treatment served as the untreated control in this study. HCl and NaOH were used to adjust the

- Nur Syamimi Fatin is a student at Universiti Sains Malaysia, 11800, Penang, Malaysia
- Nurul Huda is associate professor at Universiti Sains Malaysia, 11800, Penang, Malaysia. Email: nrlhd@usm.my
- Wahyudi David is lecturer at Universitas Bakrie, Jakarta, Indonesia. Email: wahyudi.david@bakrie.ac.id

pH of samples for the ACS and ALS methods. All chemical reagents used for the experiments were of analytical grade. Cryoprotectants used were sucrose, sorbitol, and sodium tripolyphosphate.

2.1 Preparation of Surimi using the Conventional Method

Surimi prepared using the CON method was processed following Lanier (1992) with slight modifications [13]. Raw Japanese scad were beheaded, gutted, and the backbone was removed to eliminate viscera and impurities prior to deboning [14]. A fish bone separator machine was used to separate the fish flesh from unwanted substances such as bones and skin. The fish meat was pressed between a travelling belt and a steel drum with perforation size of 5 mm diameter. The minced fish meat then was washed three times by diluting in cold water (4°C) using 1:3 ratio (fish:water) for 2 minutes, followed by settling for 10 minutes. The water layer was removed using a commercial sieve, and the water remaining in the washed product was removed using a screw press. The raw surimi was then mixed with cryoprotectants (3% sucrose, 3% sorbitol, and 0.3% sodium tripolyphosphate) using a cutter mixer. The surimi was packed and frozen in an air blast freezer at -18°C. The frozen surimi was stored at -18°C until used.

2.2 Preparation of Surimi using the Acid and Alkaline Solubilization Methods

Surimi samples prepared using the ACS and ALS methods were produced according to Hultin and Kelleher (2000) [15]. After deboning, the minced Japanese scad meat was washed three times in cold water (4°C) using a 1:9 ratio and homogenized for 1 minute. Next, the homogenized mince was divided into two equal parts: one part was solubilized in an acid solution at pH 3, and the other was solubilized in an alkaline solution at pH 12. The homogenates were centrifuged at 10000 g for 20 minutes at 4°C to separate the undissolved proteins from the dissolved proteins. After centrifugation, the sample consisted of three layers: lipid, supernatant (solubilized proteins), and sediment. The sediment layer, which consisted of skin, bones, cartilage, and impurities, was removed. The solubilized protein layer was retained and adjusted to the isoelectric point of proteins (pH 5.4). The recovered proteins were collected by centrifugation at 10000 g for 20 minutes at 4°C, which resulted in a sediment layer and a supernatant layer. The pH of the supernatant layer was adjusted to pH 7 before the acid or alkaline solubilized precipitate was mixed well with cryoprotectants (3% sucrose, 3% sorbitol, and 0.3% of sodium tripolyphosphate). The samples were frozen using an air blast freezer, and the frozen samples were kept at -18°C until used.

2.3 Proximate Analysis

Proximate analysis (moisture, protein, fat, and ash content) of the surimi samples was carried out following AOAC methods [16]. Moisture content was determined by the oven drying method, protein by the Kjeldahl method, fat content by Soxhlet extraction, and ash content by the dry ashing method.

2.4 Protein Recovery

The protein recoveries of the CON, ACS, and ALS methods were calculated according to Kristinsson and Liang (2006) by recording the weight of the starting material and the final isolate and the protein content of each. The total protein (g) was calculated for each fraction. Recovery was calculated by dividing total protein content in the recovered protein isolates by the total protein content in the corresponding starting materials. The protein content in each fraction was assayed in triplicate using the Kjeldahl method [10,16].

2.5 Lipid Reduction

Lipid reduction was calculated as the amount of total lipids in the protein isolates and the amount of total lipids in the corresponding starting materials. The lipid content in the fractions was determined using the Soxhlet method [16].

2.6 Gel Preparation

Surimi gels were prepared following Rawdkuen et al. (2009) with slight modifications. The frozen surimi was thawed at 4°C overnight and the moisture content was adjusted to 80% by adding ice. The sample then was mixed with 3% NaCl and blended for 2 minutes using a high-speed cutter mixer to obtain homogeneous surimi. The surimi homogenate was stuffed into a 2.5 cm diameter casing, and both ends were bound tightly. The product was heated for 30 minutes in hot water (36°C) and then cooked in hotter water (90°C) for 10 minutes. After cooking, all surimi gels were immediately cooled in iced water for 30 minutes and stored at 4°C overnight prior to analysis [17].

2.7 Color

A Minolta colorimeter (CM3500d, Osaka, Japan) was used to determine the lightness (L*), redness (a*), and yellowness (b*) of the raw material, isolated protein, and surimi gels following Nolsøe et al. (2011). The raw material and isolated protein samples were placed in plastic containers and five readings of the surface of each sample were made. Surimi gels were cut into slices, and five readings of the surface of five different slices of each sample were made. Whiteness was calculated as $100 - [(100 - L^*)^2 + a^{*2} + b^{*2}]^{1/2}$ [18].

2.8 Impurities

The impurities test was conducted out by compressing 10.0 g of surimi to 1.0 mm thickness or less. Objects present in the material were counted and measured. Those > 2.0 mm in diameter counted as one, whereas those < 2.0 mm in diameter counted as one-half. Any objects < 1.0 mm were disregarded. Measurements were made on two or more samples, and the result was expressed as the average value. Table 1 lists the scores for the number of impurities present.

S Table 1: Scores for number of impurities

Score	Impurities	Score	Impurities
10	0	5	12-15
9	1-2	4	16-19
8	3-4	3	20-25

7	5-7	2	26-30
6	8-11	1	Over 31

2.9 Gel Strength

Gel strength was measured using a Texture Analyzer TA-XT2 (Stable Micro System, Surrey, UK) following Rawdkuen et al. (2009) with slight modifications. Gels were equilibrated at room temperature for 30 minutes before analysis. Five cylindrical samples 2.5 cm in length and 2.5 cm in diameter were prepared and tested. Gel strength was measured by the texture analyzer, which was equipped with a spherical plunger (5 mm diameter) with a depression speed of 60 mm min. Gel strength of the surimi gels was calculated as follows [17]:

$$\text{Gel strength} = \text{Force (g)} \times [(\text{Distance 1} - \text{Distance 2})] \quad (1)$$

2.10 Texture Profile Analysis

The Texture Analyzer TA-XT2 with a 75 mm compression platen and a 25 kg load cell also was used to analyze the texture profile of the samples. Each sample was placed under the probe, which moved downward at a constant speed of 3.0 mm/s, test speed of 1.0 mm/s, post-test speed of 3.0 mm/s, and prefixed strain of 75%. The trigger force used was 10 g. After the first compression, the probe was returned to the initial position and stopped for 2 s before the second compression started [19].

2.11 Expressible Moisture

Expressible moisture (EM) was measured following Ng (1987). A gel sample with a thickness of 5 mm was weighed and placed between two pieces of Whatman filter paper No. 1 at the top and three pieces of the same type of filter paper at the bottom. The standard weight (5 kg) pressure equipment was placed on top of the sample and maintained for 2 min. The sample was removed and weighed again. EM was calculated and expressed as percentage of sample weight [20].

2.12 Water Holding Capacity (WHC)

WHC was determined following Jin et al. (2007). The WHC of each sample was calculated by adding 5 g of surimi to a centrifugation tube and centrifuging it at 50 °C at 1000 g for 15 minutes. After centrifugation, the sediment was decanted and the sample was weighed again. The WHC (i.e., liquid loss) was expressed as percentage of weight of liquid release to original weight of sample [21].

2.13 Statistical Analysis

SPSS software (SPSS 17.0 Statistical Package for Social Science) was used to evaluate the chemical analysis, physical analysis, and sensory analysis data. Comparison of means among the different types of Japanese Scad Surimi produced by untreated, CON, ACS, and ALS was conducted using Duncan's multiple range tests.

3 RESULT AND DISCUSSION

3.1 Proximate Analysis

Table 2 shows the proximate composition of untreated Japa-

nese scad and surimi prepared using the CON, ACS, and ALS methods. Moisture contents of the samples were significantly higher in the untreated and CON samples compared to the ACS and ALS samples. The higher moisture in CON was probably due to the additional water obtained during the triplicate washing step. The moisture contents of the ACS and ALS samples did not differ much, as they were prepared using the same method. Protein contents in the untreated, ACS, and ALS samples were significantly higher than that in the CON sample. This difference was due to the first centrifugation step in the ACS and ALS methods, which removed lipids, impurities, bones, and scales. In addition, myofibrillar proteins and sarcoplasmic proteins were recovered in the ACS and ALS processes [10].

Fat contents of the ACS and ALS samples were significantly lower than those of the CON and untreated samples. This difference was due to the centrifugation step in the ACS and ALS processes that removed neutral and membrane lipids efficiently [22]. Fish bones and scales contribute to the mineral content of fish, and ash content was used as an indicator of how well these undesirable substances were removed from the proteins. The untreated sample contained a higher ash content compared to the CON, ACS, and ALS samples, and the ash contents in the ACS and ALS samples were slightly lower than that of the CON sample. During the ALS process, insoluble solids were separated during the first centrifugation step when the soluble proteins were recovered in the supernatant. The insoluble solids formed a sediment layer at the bottom of the container due to high speed centrifugation and difference in density [23].

The carbohydrate content in fish muscle usually is less than 1%, but the value in dark fish muscle may occasionally reach 2% [22]. The carbohydrate contents in the CON, ACS, and ALS samples higher than 5% and were significantly higher than that in the untreated sample. The carbohydrates came from the cryoprotectants added to the raw surimi after the dewatering step.

3.2 Protein Recovery and Lipid Reduction

Table 3 shows the protein recoveries and lipid reduction values for Japanese scad surimi produced using different processes. The ACS and ALS methods yielded higher protein recoveries compared with the CON process. This finding agrees with results of other studies that applied these methods to muscle from other fish species, such as mullet [8], Pacific whiting [24], tilapia [17], and herring [7]. Kristinsson et al. (2006) investigated channel catfish muscle and reported protein recoveries of 71.5%, 70.3%, and 62.3% for the ACS, ALS, and CON methods, respectively [25].

Most of the water-soluble sarcoplasmic proteins and possibly part of the myofibrillar proteins were washed away and removed during the washing steps of the CON process, which explains the lower protein recovery for this method compared to the ACS and ALS methods [15,26,27]. In contrast, both myofibrillar protein and sarcoplasmic protein were not removed completely in the first centrifugation step of the ACS and ALS processes (Kristinsson and Liang, 2006). Rawdkuen et al. (2009) also found higher protein recoveries from tilapia for the

ACS (81.4%) and ALS (71.5%) methods compared to the CON method (67.9%). Kristinsson and Demir (2003) measured the protein recovery for catfish, Spanish mackerel, mullet, and croaker and reported that the ACS process resulted in the highest protein recovery (71–81%), followed by the ALS (65–70%) and then the CON (54–62%) methods. Kristinsson and Liang (2006) also reported that the ACS method yielded higher protein recoveries than the ALS method for Atlantic croaker muscle proteins.

Studies of catfish and tilapia demonstrated a significantly higher amount of soluble proteins left in the supernatant after the second centrifugation for the ALS method, whereas more sarcoplasmic proteins were recovered when using the ACS method; these results explain the higher recovery for the ACS process compared to the ALS process. In addition, the ALS process causes less protein denaturation, thus less coaggregation of proteins occurs as proteins are readjusted to pH 5.4 compared to the ACS process, which could be responsible for less overall recovery for the ALS process [10].

Lower lipid content minimizes lipid oxidation and makes surimi more stable [4]. The ALS process resulted in the greatest lipid reduction, followed by the ACS and CON processes (Table 3). Kristinsson and Demir (2003) also reported greater lipid reduction for the ALS process followed by the ACS and CON methods for the four different fish species they studied. Hultin and Kelleher (2003) suggested that the greater lipid removal in the ALS method may be due to the greater emulsification ability of the proteins at alkaline pH values. The CON process had lower lipid reduction because membrane lipids were retained and a portion of the storage lipids coaggregated with the proteins during the washing process. At low and high pH, the solubilized proteins were separated from the storage lipids and membrane phospholipids [28].

3.3 Color of Surimi

Color is a very important aspect for surimi. Generally, the whiter the surimi the higher the market interest. Discoloration problems generally arise due to the presence of melanin from the eyes and skin and hemoglobin and myoglobin from blood and dark muscle (Nolsøe et al., 2011). Japanese scad surimi produced using the ACS method had the highest lightness (L^*) and whiteness values, followed by CON, ALS, and untreated mince (Table 4). The ACS and ALS samples also had lower redness (a^*) values than untreated and CON-process samples. Kristinsson and Liang (2006) also reported higher redness values in untreated and CON samples of Atlantic croaker. Higher redness values likely were due to greater retention of the native heme protein in Japanese scad raw surimi. The untreated Japanese scad mince had the highest redness value due to the presence of myoglobin in the muscle and possible contamination by hemoglobin and skin pigments (Nolsøe and Underland, 2008). The ACS and ALS samples had higher yellowness (b^*) values than CON samples, probably due to higher levels of denatured and oxidized heme proteins in the former [25].

3.4 Impurities Test

The impurities test was conducted to test the quality of the surimi prepared using different processes. Untreated mince-

meat contained the highest number of impurities, followed by CON samples (Table 5). The conventional washing process removed undesirable substances, but most of the solids were collected in the end. However, the first centrifugation in the ACS and ALS methods separated the impurities efficiently [23]. The ACS and ALS samples both had scores of 10, which means that almost no impurities were present (Table 5). Good quality surimi does not have a score lower than 7 [2].

3.5 Gel Strength and Textural Profile Analysis

The most important characteristics of surimi are its gel strength and textural profile. It is one of the criteria for deciding the frozen surimi grade of quality [29]. Sarcoplasmic proteins can be removed with appropriate washing steps, resulting in the presence of concentrated myofibrillar proteins, which play an important role in gel formation [22]. The ACS-processed surimi gel had significantly higher gel strength than the ALS- and CON-processed surimi gels (Table 6). ACS-processed surimi also had the highest values for hardness, springiness, cohesiveness, and chewiness, followed by ALS- and CON-processed surimi gels (Table 6). However, the textural properties did not differ much among the ACS and ALS samples. The ACS samples had the highest hardness values compared to the CON and ALS samples, possibly due to the excess protein-protein interactions present in the ACS samples. These interactions may have resulted in a hard and inelastic gel, whereas an excess of protein-water interactions in the ALS and CON samples may have resulted in softer and more fragile gels [22].

The ACS-processed surimi had better gel forming ability compared to the other gels, maybe due to its high protein recovery and lipid reduction. Gel quality of surimi is influenced by the properties of myofibrillar proteins, which are affected by the interactions of emulsified fat globules with protein [30]. However, the fat content in seafood products may lead to lipid oxidation, which is an important cause of quality deterioration. Lipid oxidation can lead to undesirable appearance, odor, and taste as well as possible textural problems due to interaction of oxidation products with proteins. This is a real problem in fish because of their high content of highly polyunsaturated fatty acids (Hultin, 1994). Thus, lowering the lipid content in surimi gels may reduce the risk of formation of oxidized lipids, which negatively impact gelation of muscle protein [31].

According to Rawdkuen et al. (2009), gels prepared from conventionally processed tilapia surimi have better gel strength (breaking force) than gels prepared from ACS- and ALS-processed surimi. Kristinsson and Liang (2006) reported similar findings for Atlantic croaker, and Chaijian et al. (2004) reported that CON-processed surimi gels made from mackerel species had higher gel strength than those produced using the ALS method. Clearly, the type of fish used affects gel quality has been reported.

3.6 Expressible Moisture (EM) and Water Holding Capacity (WHC)

Japanese scad surimi produced using the CON process had the highest EM, followed by those produced by ALS and ACS

(Table 7). The gel produced by the ACS process had the lowest EM, which indicates that the protein network of these gels had greater WHC [17].

The sequence for WHC from greatest to least was the same as that for EM, which was ACS > ALS > CON (Table 7). The low liquid loss from the ACS-produced gel could be because the protein gel was able to retain more water. WHC and EM usu-

ally reflect the extent of denaturation of the protein and water content. A poor gel network with low protein integrity cannot imbibe water, which leads to greater water release and low WHC [32]. The ACS process produced gels with high gel-forming ability, as they were able to hold water better and had the lowest EM and highest WHC values.

Table 2: Proximate composition (%) of Japanese scad mince (untreated) and surimi produced using conventional (CON), acid solubilization (ACS), and alkaline solubilization (ALS) methods

Proximate Composition (%)	Untreated	CON	ACS	ALS
Moisture	75.73 ± 0.41 ^c	74.74 ± 0.44 ^b	74.48 ± 0.28 ^b	72.67 ± 0.13 ^a
Protein	21.25 ± 0.80 ^b	15.67 ± 1.99 ^a	18.96 ± 2.25 ^b	18.20 ± 0.45 ^{ab}
Fat	1.55 ± 0.03 ^c	1.42 ± 0.14 ^c	0.49 ± 0.06 ^b	0.12 ± 0.02 ^a
Ash	1.25 ± 0.06 ^c	0.88 ± 0.07 ^b	0.71 ± 0.02 ^a	0.72 ± 0.02 ^a
Carbohydrate	0.22 ± 0.16 ^b	7.29 ± 0.12 ^a	5.36 ± 0.11 ^b	8.29 ± 1.54 ^a

Means in each row with different superscript letters are significantly different (P < 0.05).

Table 3: Protein recoveries and lipid reduction values for Japanese scad surimi prepared using conventional (CON), acid solubilization (ACS) and alkaline solubilization (ALS) processes

Method	Protein recovery (%)	Lipid reduction (%)
CON	55.97 ± 0.4 ^a	58.02 ± 0.03 ^a
ACS	78.40 ± 0.55 ^c	70.53 ± 1.34 ^b
ALS	70.34 ± 0.64 ^b	86.02 ± 0.37 ^c

Means in each row with different superscript letters are significantly different (P < 0.05).

Table 4: L* (lightness), a* (redness), b*(yellowness), and whiteness values of untreated Japanese scad mince and surimi prepared using conventional (CON), acid solubilization (ACS), and alkaline solubilization (ALS) methods

Method	L*	a*	b*	Whiteness
Untreated	38.13 ± 0.01 ^a	6.96 ± 0.11 ^d	12.44 ± 0.04 ^d	36.51 ± 0.17 ^a
CON	46.91 ± 0.02 ^b	5.11 ± 1.12 ^c	12.59 ± 0.04 ^a	45.28 ± 0.02 ^c
ACS	48.66 ± 0.05 ^d	2.08 ± 0.02 ^b	15.75 ± 0.09 ^b	46.26 ± 0.05 ^d
ALS	47.12 ± 0.13 ^c	1.50 ± 0.15 ^a	15.77 ± 0.45 ^b	44.79 ± 0.06 ^b

Means in each row with different superscript letters are significantly different (P < 0.05).

Table 5: Results of the impurities test of untreated Japanese scad mince and surimi produced using conventional (CON), acid solubilization (ACS), and alkaline solubilization (ALS) processes

Method	Untreated	CON	ACS	ALS
No. impurities	51	25	0	0
Score	1	3	10	10

Table 6: Gel strength and textural properties of Japanese scad surimi gels prepared using conventional (CON), acid solubilization (ACS), and alkaline solubilization (ALS) processes

Textural Properties	CON	ACS	ALS
Gel strength (g.mm)	222.60 ± 53.96 ^a	1255.11 ± 118.51 ^c	927.38 ± 228.35 ^b
Hardness (g)	786.26 ± 53.17 ^a	3902.22 ± 185.12 ^b	3761.90 ± 73.10 ^b
Springiness (mm)	0.69 ± 0.03 ^a	0.87 ± 0.01 ^c	0.85 ± 0.00 ^b
Cohesiveness (ratio)	0.31 ± 0.05 ^a	0.70 ± 0.03 ^b	0.70 ± 0.01 ^b
Chewiness (g.mm)	168.50 ± 31.69 ^a	2241.18 ± 244.81 ^b	2231.00 ± 54.73 ^b

Means in each row with different superscript letters are significantly different (P < 0.05).

Table 7: Expressible Moisture (EM) and Water Holding Capacity (WHC) of Japanese scad surimi gel prepared using conventional (CON), acid solubilization (ACS), and alkaline solubilization (ALS) processes

Method	CON	ACS	ALS
Expressible moisture (%)	34.51 ± 0.90 ^c	4.35 ± 1.63 ^a	23.48 ± 2.60 ^b
Water holding capacity (%)	36.60 ± 5.41 ^a	48.05 ± 0.05 ^b	45.38 ± 5.13 ^b

Means in each column with different superscript letters are significantly different (P < 0.05).

4 CONCLUSION

The results of this study show that the ACS and ALS samples had significantly higher protein content and lower fat content compared with untreated and CON samples. The CON samples had the highest moisture and ash content among all sample types. In addition, the ACS process had the highest protein recovery and the ALS method had the highest lipid reduction among the methods tested. The ACS and ALS samples also scored 10 on the impurities test, which means that no impurities were present. The ACS-produced gels had the greatest gel strength, best textural profile, and greatest WHC. However, the CON-produced gels had the highest whiteness values. Overall, the ACS and ALS methods exhibited efficient protein recovery and lipid reduction and resulted in products with good gel strength and WHC and better textural properties than those of the CON samples.

ACKNOWLEDGMENT

The authors acknowledge with gratitude the support given by Universiti Sains Malaysia (USM Fellowship) and a research grant from the Malayan Sugar Manufacturing Company, Berhad.

REFERENCES

[1] Vilhelmsson, O. The state of enzyme biotechnology in the fish processing industry. *Trends in Food Science and Technology*. 1997, 8, 266-270.
[2] Sonu, S. C. Surimi. National Oceanic and Atmospheric Administration, Technical Memorandum, National Marine Fisheries Service,

South West Region (1986).
[3] Guennegues, P. and Morrissey, M.T. Surimi resources. In Park, J.W. (Ed.). *Surimi and Surimi Seafood*, 2nd edition. (2005) p. 3-32, Boca Raton, FL: CRC Press. <http://dx.doi.org/10.1201/9781420028041.pt1>
[4] Martin-Sanchez, A.M., Navarro, C., Perez-Alvarez, J.A. and Kuri, V. Alternatives for efficient and sustainable production of surimi: a review. *Comprehensive Reviews in Food Science and Food Safety* 2009, 8: 359-374. <http://dx.doi.org/10.1111/j.1541-4337.2009.00087.x>
[5] Venugopal, V., Doke, S.N. and Thomas, R. Thermostable water dispersion of shark meat and its application to prepare protein powder. *Journal of Aquatic Food Product Technology* 1997, 63:53-67. http://dx.doi.org/10.1300/J030v06n03_04
[6] Venugopal, V. and Shahidi, F. Traditional methods to process underutilized fish species for human consumption. *Food Review International* 1998, 14: 35-97. <http://dx.doi.org/10.1080/87559129809541149>
[7] Undeland, I., Kelleher, S. D. and Hultin, H. O. Recovery of functional proteins from herring (*Clupea harengus*) light muscle by an acid or alkaline solubilization process. *Journal of Agricultural and Food Chemistry* 2002, 50 (25): 7371-7379. <http://dx.doi.org/10.1021/jf020199u>
[8] Kristinsson, H.G. and Demir, N. Functional protein isolates from underutilized tropical and subtropical fish species and byproducts. In Bechtel, P. (Ed.). *Advances in seafood byproducts*. (2003) p 277-98. Anchorage, Alaska : Univ. of Alaska Press.
[9] Kristinsson, H. G., Theodore, A. E., Demir, N. and Ingadottir, B. A Comparative Study between Acid-and Alkali-aided Processing and Surimi Processing for the Recovery of Proteins from Channel Catfish Muscle. *Journal of Food Science* 2005, 70: C298-C306. <http://dx.doi.org/10.1111/j.1365-2621.2005.tb07177.x>
[10] Kristinsson, H. G. and Liang, Y. Effect of pH-Shift Processing and Surimi Processing on Atlantic Croaker (*Micropogonias undulatus*) Muscle Proteins. *Journal of Food Science* 2006, 71(5): C304-C312. <http://dx.doi.org/10.1111/j.1750-3841.2006.00046.x>

- [11] Department of Fisheries Malaysia. Fisheries Statistics of Malaysia. Department of Fisheries Malaysia (2013), Available from <http://www.dof.gov.my>
- [12] Food and Agriculture Organization of the United Nations. Fisheries Statistics [Internet], (2013) Available from <http://www.fao.org>.
- [13] Lanier, T. C. Measurement of surimi composition and functional properties. In Lanier, T. C. and Lee, C. M. (Eds.). *Surimi Technology*, (1992) p. 123-166. New York: Marcel Dekker, Inc.
- [14] Martin-Sanchez, A.M., and Navarro, C. Alternatives for efficient and sustainable production of surimi: A Review. *Comprehensive Reviews in Food Science and Food Safety* 2009, 8: 359-374. <http://dx.doi.org/10.1111/j.1541-4337.2009.00087.x>
- [15] Hultin, H.O., and Kelleher, S.D. *Surimi Processing from dark muscle fish*. In Park, J.W. (Ed.). *Surimi and Surimi Seafood*, 2nd edition. (2000) p. 59-77, Boca Raton, FL: CRC Press.
- [16] AOAC. *Official Methods of Analysis*, in Association of Official Analytical Chemists, 17th edition, Washington, DC. (2000)
- [17] Rawdkuen, S., Sai-Ut, S., Khamsorn, S., Chaijan, M. and Benjakul, S. Biochemical and gelling properties of tilapia surimi and protein recovered using an acid-alkaline process. *Food Chemistry* 2009, 112 (1): 112-119.
- [18] Nolsøe, H., Marmon, S. K. and Undeland, I. Application of Filtration to Recover Solubilized Proteins During pH-Shift Processing of Blue Whiting (*Micromesistius poutassou*); Effects on Protein Yield and Qualities of Protein Isolates, (2011) 1-9.
- [19] Nurkhoeriyati, T., Huda, N. and Ahmad, R. Gelation properties of spent duck meat surimi-like material produced using acid-alkaline solubilization methods. *Journal of Food Science* 2011, 76 (1): S48-S55. <http://dx.doi.org/10.1111/j.1750-3841.2010.01963.x>.
- [20] Ng, C. S. Measurement of free and expressible drips. In H. Hasegawa (Ed), *Laboratorium Manual on Analytical Methods and Procedure for Fish and Fish Product*, 1987, 1-2.
- [21] Jin, S.K., Kim, I.S., Kim, S.J., Jeong, K.J., Choi, Y.J. and Hur, S.J. Effect of muscle type and washing times on physico-chemical characteristics and qualities of surimi. *Journal of Food Engineering* 2007, 81(3): 618-623.
- [22] Nolsøe, H. and Undeland, I. The Acid and Alkaline Solubilization Process for the Isolation of Muscle Proteins: State of the Art. *Food and Bioprocess Technology*, 2008, 2 (1), 1-27. <http://dx.doi.org/10.1007/s11947-008-0088-4>
- [23] Chen, Y.C. and Jaczynski, J. Protein recovery from rainbow trout (*Oncorhynchus mykiss*) processing byproducts via isoelectric solubilization/precipitation and its gelation properties as affected by functional additives. *Journal of Agricultural and Food Chemistry* 2007, 55 (22): 9079-9088.
- [24] Choi, Y.J. Park, J.W. Acid-aided protein recovery from enzyme-rich pacific whiting. *Journal of Food Science* 2002, 67:2962-967. <http://dx.doi.org/10.1111/j.1365-2621.2002.tb08846.x>
- [25] Kristinsson, H. G., Theodore, A. E., Demir, N., and Ingadottir, B. A Comparative Study between Acid-and Alkali-aided Processing and Surimi Processing for the Recovery of Proteins from Channel Catfish Muscle. *Journal of Food Science* 2006, 70 (4): C298-C306. <http://dx.doi.org/10.1111/j.1365-2621.2005.tb07177.x>
- [26] Xiong, Y. O. L. Thermally Induced Interactions and Gelation of Combined Myofibrillar Protein from White and Red Broiler Muscles. *Journal of Food Science* 1992, 57(3): 581-585. <http://dx.doi.org/10.1111/j.1365-2621.1992.tb08047.x>
- [27] Lin, T. M., and Park, J. W. Extraction Of Proteins From Pacific Whiting Mince At Various Washing Conditions. *Journal of Food Science* 1996, 61(2): 432-438. <http://dx.doi.org/10.1111/j.1365-2621.1996.tb14210.x>
- [28] Kristinsson, H.G. and Hultin, H.O. The effect of acid and alkali unfolding and subsequent refolding on the pro-oxidative activity of trout hemoglobin. *Journal of Agriculture Food Chemistry*. 2004, 52: 5482-5490.
- [29] Suzuki, T. *Fish and Krill Protein: Processing Technology*. London: Appl. Sci. Publ. Ltd. (1981)
- [30] Hultin, H.O. *Seafoods: Chemistry, Processing Technology and Quality*. In Shahidi, F. and Botta, J. R. (Eds.). Boston, MA: (1994).Springer. <http://dx.doi.org/10.1007/978-1-4615-2181-5>
- [31] Murakawa, Y., Benjakul, S., Visessanguan, W. and Tanaka, M. Inhibitory effect of oxidized lipid on the thermal gelation of Alaska pollack (*Theragra chalcogramma*) surimi. *Food Chemistry* 2003, 82: 455-463.
- [32] Chaijan, M., Benjakul, S., Visessanguan, W. and Faustman, C. Characteristics and gel properties of muscles from sardine (*Sardinella gibbosa*) and mackerel (*Rastrelliger kanagurta*) caught in Thailand. *Food Research International*. 2004, 37 (10): 1021-1030. <http://dx.doi.org/10.1016/j.foodres.2004.06.012>
- [33] Chaijan, M., Benjakul, S., Visessanguan, W. and Faustman, C. Physicochemical properties, gel-forming ability and myoglobin content of sardine (*Sardinella gibbosa*) and mackerel (*Rastrelliger kanagurta*) surimi produced by conventional method and alkaline solubilisation process. *European Food Research and Technology*. 2005, 222(1-2): 58-63. <http://dx.doi.org/10.1007/s00217-005-0091-1>