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Thermal gelation properties and quality characteristics of duck surimi-like material *(duckrimi)* as affected by the selected washing processes

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Abstract: The effects of washing treatments and washing cycles on the thermal gelation properties and quality characteristics of *duckrimi* (duck-base surimi-like material) were evaluated. Minced spent layer duck (4.5 mm orifice diameter) were washed by using either tap water, 0.1M NaCl, 0.5% $NaHCO_3$ and 0.04M sodium phosphate in one, two or three washing cycles, respectively. Washing with 0.04M sodium phosphate in three washing cycles significantly increased ($P<0.05$) moisture, protein, ash, myofibrillar and stromal protein but decreased fat and sarcoplasmic protein content compared to unwashed MDDM (mechanically deboned duck meat). The interaction between washing treatments and the number of washing cycles significantly affected ($P<0.05$) washing yield, pH, water holding capacity, expressible moisture, gel strength and whiteness of MDDM. There was no significant interaction ($P>0.05$) between the two mentioned factors was observed in cooking yield and folding test. Increasing number of washing cycles significantly increased ($P<0.05$) pH, water holding capacity, gel strength and whiteness but decreased washing yield and expressible moisture of MDDM. Cooking yield and folding test had no significant difference ($P>0.05$) with the number of washing cycles. The increase in pH led to increased water holding capacity and whiteness intensity. It is suggested that washing with 0.04M sodium phosphate with three washing cycles was the best treatment to improve the quality of *duckrimi*. In summary, spent layer duck is another potential alternative raw material for the production of surimi-like material based products.

Keywords: Spent layer duck, *duckrimi*, surimi-like material, thermal gelation, washing treatments

Introduction

The production of surimi in Malaysia is a burgeoning business, as evident by its increase in production from 1,105.08 metric tons in year 2000 to 1,410 metric tons in year 2006 (Department of Fisheries, 2010). Based on this statistics there were huge demand on the processed surimi-based products consumed by Malaysians. Various surimi-based products like fish ball, octopus ball, crab-flavoured claw, shrimp chips and cuttlefish ball can be produced by using surimi as raw materials. Gna and Babji (1991) have pioneered the investigation of poultry as the raw material for the production of surimi. One decade later, Nowsad *et al*. (2000) conducted several studies related to the thermal gelation characteristics of surimi made from spent hens and broilers. These researches have prompted an interest in the usage of duck (a kind of poultry) as the raw material for the production of surimi-like material as an alternative for raw materials to be used in the production of surimi-based products. Spent layer duck is normally underutilized; hence, it is a cheap source of raw material in the production of surimi-like material. The formation of a high amount of heat stable collagen in spent layer ducks makes the muscles of the ducks objectionably tough, thus rendering spent layer ducks unsuitable to be served as whole meat food. Therefore, spent layer duck meat can be processed into value-added products like duck meatballs, which can be consumed as an alternative protein source.

Leaching (washing) is an important step in the production of surimi. Several washing treatments that are available as indicated in previous researches on the surimi processing of mechanically deboned poultry meat or MDPM are: tap water (Ball and Montejano, 1984); phosphate buffer solution with pH 5.8 to 8.0 (Hernandez *et al*., 1986; Elkhalifa *et al*., 1988); 0.1M NaCl (Froning and Niemann, 1988) and 0.5% $NaHCO_3$ (Ball and Montejano, 1984; Dawson *et al*., 1989). Yang and Froning (1990) found that all selected washing treatments were effective for the removal of heme pigments. Although there are various studies related to the usage of different types of washing treatments in the surimi processing of MDPM, but there is still much uncertainty about the combined effects of using disparate types of washing treatments in different numbers of washing cycles on spent layer duck (Khaki Campbell).

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Hence, the objectives of this study are to discover the effects of the number of washing cycles and different washing treatments on the thermal gelation properties and quality characteristics of '*duckrimi*'.

Materials and Methods

Source of duck meat

Mechanically deboned duck meat or MDDM of spent layer duck (Khaki Campbell) with an average age of 20 months old was obtained from CKL Marketing Sdn. Bhd., Bukit Mertajam, Penang. The MDDM was immediately kept frozen at -18 to -21ºC prior washing treatment.

Washing procedures

The washing solutions used were: tap water, 0.1M NaCl, 0.5% $NaHCO_3$ and 0.04M sodium phosphate buffer at pH=8.0 (0.04M SPB (pH=8.0)). 0.04M SPF (pH=8.0) was prepared from analytical grade of NaH_2PO_4 and Na_2HPO_4 according to the procedures established by Gomori (1955). The solutions were then stored at 5ºC before further used. The washing procedure was performed according to Riebroy *et al*. (2007) with a modification of the orifice diameter used. The MDDM was cut into rectangular blocks by using the meat bone saw (Model P79-SS, Norwalk CT, USA). The rectangular blocks (10 cm x 3 cm) of MDDM were minced by using mechanical mincer (Model EVE/ALL-12, Rheninghaus, Torino, Italy) with an orifice diameter of 4.5 mm. The minced MDDM was washed with the solutions (5ºC) using a water/mince ratio of 3:1 (v/w). The mixture was stirred (washed) for 5 minutes by using the universal mixer (Model B10-3, China) and then filtered with a commercial sieve. The number of washing replicates (one, two or three) of each solution was done separately. After the final wash of every treatment, the washed minced MDDM was allowed to settle for 20 minutes and the floated fat was skimmed off. Finally, it was filtered with a commercial sieve, followed by centrifugation at 5000 g for 20 minutes at 4ºC by using the refrigerated centrifuge (Model Union 5KR, Korea).

Preparation of Duckrimi *gels*

The preparation of *duckrimi* gels was done according to the method developed by Babji and Gna (1994). The centrifuged washed minced MDDM was mixed with 3% salt and blended for 2 minutes in a chopper mixer (Robot Coupe®, Model Blixer® 3B, France) and stuffed into a cellulose casing of 25 mm diameter. The stuffed samples were then cooked in warm water (36ºC) for 30 minutes for low temperature setting, followed by high temperature setting at 90ºC for another 10 minutes in two separate water baths (Model WB-22, Korea). After completion, the gels were immediately covered with ice in a plastic basin for 15 minutes for slow cooling. The unwashed MDDM sample was similarly prepared for control analysis.

Proximate analyses

The unwashed MDDM or control and the washed mince from the third washing cycle of 0.04M SPB (pH=8.0) (best solution for leaching, which was deemed to produced '*duckrimi*' with excellent quality characteristics), were analyzed for moisture, protein, fat and ash by the standard procedures of AOAC (2000).

Separation of sarcoplasmic, myofibrillar and stromal proteins

Sarcoplasmic, myofibrillar and stromal proteins of unwashed MDDM or control and the washed mince from the third washing cycle of 0.04M SPB (pH=8.0) were analyzed according to the method of Hashimoto *et al*. (1979). About 20 g of the sample was homogenized at 1800 rpm for 2-3 minutes by using the homogeniser (IKA® T25 Digital Ultra-Turrax, Model T 25D, Germany) in 200 mL of phosphate buffer (15.6 mM Na_2HPO_4, 3.5 mM KH_2PO_4) at pH 7.5. The homogenate was centrifuged at 5000 g for 15 minutes at 4ºC by using the refrigerated centrifuge (Model Union 5KR, Korea). The supernatant was kept and the residue was added with 200 mL of the same buffer, homogenized and centrifuged. Both of the centrifuged homogenates were combined and added with trichloroacetic acid to obtain a final concentration of 5%. The solution was then filtered to get the precipitate material, known as sarcoplasmic protein fraction.

Phosphate buffer (15.6 mM Na_2HPO_4, 3.5 mM KH_2PO_4) containing 0.45M KCl at pH 7.5 was added to the residue obtained from the second centrifugation process earlier, with the phosphate buffer/residue ratio of 10:1 (v/w). The mixture was homogenized and centrifuged at 5000 g for 15 minutes at 4ºC. The same process was repeated. The combined supernatants from both the supernatants were the myofibrillar protein fraction.

The residue obtained was mixed with 5 volumes of 0.1N NaOH and stirred for 12 hours at 4ºC. The mixture was then centrifuged at 5000 g for 15 minutes at 4ºC. The final residue was used as the stromal fraction. Each fraction was then subjected to the protein analysis by using the Micro Kjeldahl method (AOAC, 2000).

Washing yield

The washing yield was calculated according to the method of Jin *et al*. (2007).

$$\text{Washing yield (\%)} = \frac{\text{Weight of washed mince (g)}}{\text{Weight of raw material (g)}} \times 100$$

pH value

pH was measured according to the method of Lanier (1992) with slight modification, in which 5 g of washed mince and 45 mL of distilled water was used but the washed mince to distilled water ratio was still the same.

Water holding capacity (WHC)

The WHC of the washed mince was determined by using the modified method of Huda *et al*. (2001). Instead of 1 g of sample used, 10 g of sample was added to 40 mL of distilled water in a 50 mL centrifugal tube and homogenised by using the homogeniser (IKA® T25 Digital Ultra-Turrax, Model T 25D, Germany) at 1800 rpm for 2-3 minutes.

Cooking yield (CY)

Cooking yield was calculated from the percentage of the weight of cooked and uncooked samples (Serdaroğlu, 2006).

$$\text{Cooking yield (\%)} = (\text{weight of cooked samples/weight of uncooked samples}) \times 100$$

Whiteness intensities

The colour properties of cooked duckrimi gels were determined by using the Minolta Spectrophotometer (CM-3500d, Japan). CIE (International Commission on Illumination) L* (lightness), a* (redness) and b* (yellowness) were measured with measurements standardized with respect to the white calibration plate. Whiteness was calculated as described by Lanier *et al*. (1991).

Gel strength (GS)

Textural analysis of gels was done by using a computer-assisted TA.XT Plus (Stable Micro Systems, Godalming, UK) according to the method of Benjakul and Visessanguan (2003). The cooked gels were equilibrated and tested at room temperature. The samples were cut into cylindrical shapes with 2.5 cm in length. The breaking force (g) and deformation (mm) were measured by using the texture analyzer equipped with a spherical plunger with a diameter of 0.25 in. The probe (P/0.25S) was pressed into the cut surface of a gel specimen perpendicularly at a constant speed of 1 mm/sec for a distance of 11mm. The trigger force used was 5 g, with 1 mm/sec of pre-test speed and 10 mm/sec of post-test speed. The load cell capacity of the texture analyzer was 5 kg and the return distance was 35 mm. Gel strengh of the gels was the product of the breaking force and deformation.

$$\text{Gel Strengh} = \text{Breaking force (g)} \times \text{Deformation (mm)}.$$

Expressible moisture (EM)

EM was measured according to the method of Benjakul *et al*. (2001). Gel samples were cut into a thickness of 5 mm, weighed and placed between three pieces of Whatman paper No. 41 at the bottom and two pieces on top of the sample. The standard weight (5 kg) was placed on top and held for 2 minutes. The samples were then weighed again after 2 minutes.

$$\text{EM (\%)} = \frac{\text{Weight of pre-pressed sample (g)} - \text{Weight of pressed sample (g)}}{\text{Weight of pre-pressed sample (g)}} \times 100$$

Folding test (FT)

Folding test was done according to the procedures of Lanier (1992). Cooked samples were cut into three-millimeter thick portions. The slices were held between the thumb and the forefinger and folded to observe the way that they broke. The scale used was as follows: (1 = breaks by finger pressure, 2 = cracks immediately when folded in half, 3 = cracks gradually when folded in half, 4 = no cracks showing after folding in half, and 5 = no cracks showing after folding.

Statistical analysis

Data were subjected to analysis of variance (ANOVA). Comparison of means was carried out by using the Duncan's multiple-range tests of the SPSS (Statistical Package for Social Science) package (SPSS 17.0 for Windows, SPSS Incorporated, Chicago, Illinois, USA). A two-way ANOVA analysis was carried out to determine the significance of the interaction between the two factors (washing treatment and the number of washing cycles) involved. Any value of $P<0.05$ was considered to be significantly different. Analyses were run in duplicate (from any two blocks of the MDDM), each with three repeated measurements (triplicate).

Results and Discussions

Proximate and protein compositions

The proximate and protein compositions of unwashed MDDM and MDDM washed with 0.04M SPB (pH=8.0) in three washing cycles are presented in Table 1 and Table 2, respectively. The MDDM washed with 0.04M SPB (pH=8.0) in three washing cycles was chosen for proximate and protein compositions analyses because this treatment combination was deemed to be the best treatment for the production

of '*duckrimi*'.

Table 1. Proximate compositions[1] of MDDM

Treatments	Moisture (%)	Protein [c] (%)	Fat [d] (%)	Ash (%)
Unwashed MDDM	63.72 ± 0.67[b]	11.39 ± 0.14[a]	20.88 ± 0.01[a]	1.58 ± .02[b]
Washed MDDM[e]	76.10 ± 0.42[a]	8.66 ± 0.24[b]	4.90 ± 0.22[b]	1.73 ± .07[a]

[1] Mean of six individual measurements.
[ab] Means within columns having different superscripts are significantly different (P<0.05).
[c] Calculated on dry weight basis.
[d] Calculated on wet weight basis.
[e] 0.04M SPB (pH=8.0) in three washing cycles.

Table 2. Protein compositions[1] of MDDM

Treatments	Sarcoplasmic protein (%)	Myofibrillar protein (%)	Stromal protein (%)
Unwashed MDDM	7.41 ± 0.21[a] (65.06)	3.64 ± 0.68[b] (31.96)	0.34 ± 0.06[b] (2.98)
Washed MDDM[c]	2.17 ± 0.55[b] (25.06)	5.53 ± 0.22[a] (63.86)	0.96 ± 0.01[a] (11.08)

[1] Mean of six individual measurements.
Value in parenthesis ( ) is expressed as a percentage of total proteins.
[ab] Different letters in the same column indicate significant differences (P<0.05).
[c] 0.04M SPB (pH=8.0) in three washing cycles.

The protein content (dry weight basis) of MDDM washed with 0.04M SPB (pH=8.0) in three washing cycles was significantly lower (P<0.05) than unwashed MDDM (control). The results of protein content were similar with the previous work done by Dawson *et al*. (1988) and Elkhalifa *et al*. (1988), which showed that the protein of washed mince was lower than unwashed mince. The lower protein content in washed mince was mainly due to the removal of sarcoplasmic proteins (Lee, 1984), which are water-soluble fractions (Elkhalifa *et al*., 1988) from muscle tissues and its removal was enhanced when alkaline washing conditions were employed (Yang and Froning, 1990). As shown in Table 2, the sarcoplasmic protein content of MDDM washed with 0.04M SPB (pH=8.0) in three washing cycles was 70.71% lower than that of the unwashed MDDM. Hence, washing MDDM with 0.04M SPB (pH=8.0) in three washing cycles could effectively remove sarcoplasmic proteins from MDDM.

An effective washing process must be able to remove the undesirable sarcoplasmic proteins because sarcoplasmic proteins decrease gelation by obstructing the process of actomyosin cross-linkages (Okada, 1964; Babji and Gna, 1994). Small quantities of sarcoplasmic proteins can also have a detrimental effect on the strength and deformability of the myofibril protein gels (Haard *et al*., 1994; Hultin and Kelleher, 2000). Since sarcoplasmic proteins contribute to the odour of washed mince, their effective removal can reduce the odour of the final washed mince. Elkhalifa *et al*. (1988) and Babji and Gna (1994) stated that washing led to decreased sarcoplasmic proteins and increased salt soluble protein (myofibrillar proteins). A greater reduction in sarcoplasmic proteins was further observed in the leaching of meat by buffer solutions (Elkhalifa *et al*., 1988).

The washing of MDDM by 0.04M SPB (pH=8.0) in three washing cycles resulted in 51.92% increase in the myofibrillar protein content of MDDM. Myofibrillar proteins (myosin and actomyosin) are responsible for the gel strength (Babji and Gna, 1994) of '*duckrimi*'. Since they are salt soluble, the leaching process will remove sarcoplasmic proteins to a great extent, thereby increasing the myofibrillar protein content (Chaijan *et al*., 2004).

The stromal protein content in the unwashed MDDM was significantly higher (P<0.05) than that in the MDDM washed with 0.04M SPB (pH=8.0) in three washing cycles. Nowsad *et al*. (2000) suggested that washing significantly increased (P<0.05) the stromal protein content of spent hen. The stromal proteins remained in washed mince because of their insolubility in water (Elkhalifa *et al*., 1988). The presence of some stromal proteins is crucial to obtain a gel that is not too soft (Babji and Gna, 1994).

Moisture and ash content of MDDM washed with 0.04M SPB (pH=8.0) in three washing cycles were significantly higher (P<0.05) than unwashed MDDM (control) whereas the fat content on a wet weight basis was significantly lower (P<0.05) in MDDM washed with 0.04M SPB (pH=8.0) in three washing cycles compared to unwashed MDDM.

Hernandez *et al*. (1986), Elkhalifa *et al*. (1988) and Shahidi *et al*. (1992) reported that washing procedures significantly increased the moisture content of washed mince. Karthikeyan *et al*. (2004) reasoned that the increase in moisture content after washing was mainly due to the absorption of water by hydrophilic residues of myofibrillar proteins. The final moisture obtained in this study was quite close to the standard moisture content of surimi (78%), which was proposed by Uddin *et al*. (2006).

Owing to the differences in density and polarity between the fat and the washing treatments (Yang and Froning, 1992), parts of the fat were floated off during the leaching process. This caused a 76.53% reduction in the fat content of the washed mince as shown in Table 1. The removal of fat is essential during the washing process of surimi production because fat in surimi adversely affect its quality as a result of the interaction between the oxidised fats and proteins, causing denaturation, polymerization and changes in functional properties (Smith, 1987).

The ash content of the treatment was significantly higher (P<0.05) than the unwashed MDDM. This result is consistent with the work of Nowsad *et al*.

(2000). Washing changes the mineral composition of the washed mice. Since MDDM was washed with 0.04M SPB (pH=8.0) in three washing cycles, there was probably an increase in minerals such as phosphorus and sodium.

Washing yield

The interaction between the washing treatments and the number of washing cycles significantly affected ($P<0.05$) the washing yield of washed mince. In terms of washing cycles (excluding control), washing with tap water in a single washing cycle showed the highest washing yield whereas washing with 0.5% $NaHCO_3$ in three washing cycles showed the lowest washing yield (Table 3). Among all the number of washing cycles, washing in tap water gave the highest washing yield, followed by 0.04M SPB (pH=8.0), 0.1M NaCl and 0.5% $NaHCO_3$.

It can be observed that washing yield decreased significantly ($P<0.05$) with the increasing number of washing cycles for all types of washing treatments. Washing results in the weight loss of washed mince because fat and other components that are soluble in water are removed. Hence as the number of washing cycles increases, more undesirable substances such as pigments, blood and fat are removed (Lin and Chen, 1989), resulting in the weight loss of washed mince.

Washing with tap water in a single washing cycle showed the highest washing yield because this type of washing probably could not effectively remove the undesirable substances from the washed mince. Therefore, washing with 0.5% $NaHCO_3$ in three washing cycles was probably the most effective washing treatment in removing the undesirable substances from the washed mince, given its lowest washing yield. Washing treatments with higher pH resulted in lower washing yields (Shahidi *et al*., 1992). Since the pH of washed mince treated by 0.5% $NaHCO_3$ was always the highest among all types of washing treatments, it is justifiable that it gave the lowest washing yield (Figure 1). This is because the highest pH means that the pH is the farthest from the isoelectric point of the washed mince, which will in turn increase the solubility of MDDM proteins and give the lowest washing yield (Shahidi *et al*., 1992).

pH value

The interaction between the washing treatments and the number of washing cycles significantly affected ($P<0.05$) the pH of washed mince. The highest pH was observed in washed mince (MDDM) that was treated with 0.5% $NaHCO_3$ in three washing cycles whereas the lowest pH was unwashed MDDM. In terms of washing treatments, washing with tap water in one washing cycle gave the lowest pH. Regardless of the washing cycles, the pH value for washed mince was always the highest for 0.5% $NaHCO_3$, followed by 0.04M SPB (pH=8.0). However, there was no significant difference ($P>0.05$) in the pH value between MDDM that was treated with 0.1M NaCl and tap water in all of the washing cycles. This can be due to the almost similar pH of the two washing treatments, assuming that all the other factors are constant. As shown in Figure 1, pH increased with the increasing number of washing cycles (Nowsad *et al*., 2000; Barrero and Bello, 2000) as a result of the removal of free nitrogen, free fatty acids, free amino acids or other water-soluble acidic compounds during the washing process (Karthikeyan *et al*., 2004).

Table 3. Washing yields[1] of washed mince and Cooking Yield[1] and Folding Test[1] of cooked gels

Treatments	Number of washing cycles	Yield (%)	Cooking Yield (%)	Folding Test
Tap water	0	100.00^{A}	75.86 ± 1.44^{B}	4.0 ± 0.00^{B}
	1	62.40 ± 0.86^{aB}	91.86 ± 0.61^{aA}	5.0 ± 0.00^{aA}
	2	41.37 ± 0.81^{aC}	90.17 ± 1.39^{aA}	5.0 ± 0.00^{aA}
	3	28.89 ± 1.74^{aD}	89.74 ± 0.79^{aA}	5.0 ± 0.00^{aA}
0.1M NaCl	0	100.00^{A}	75.86 ± 1.44^{C}	4.0 ± 0.00^{B}
	1	47.07 ± 1.81^{cB}	90.16 ± 0.71^{abA}	5.0 ± 0.00^{aA}
	2	32.42 ± 1.26^{cC}	89.57 ± 0.47^{abA}	5.0 ± 0.00^{aA}
	3	24.42 ± 1.35^{bD}	87.03 ± 0.52^{bB}	5.0 ± 0.00^{aA}
0.04M SPB (pH=8.0)	0	100.00^{A}	75.86 ± 1.44^{C}	4.0 ± 0.00^{B}
	1	51.93 ± 1.57^{bB}	91.51 ± 1.35^{abA}	5.0 ± 0.00^{aA}
	2	36.50 ± 0.79^{bC}	89.77 ± 1.61^{abAB}	5.0 ± 0.00^{aA}
	3	26.69 ± 1.34^{abD}	87.78 ± 1.46^{bB}	5.0 ± 0.00^{aA}
0.5% $NaHCO_3$	0	100.00^{A}	75.86 ± 1.44^{C}	4.0 ± 0.00^{B}
	1	40.58 ± 0.71^{dB}	89.58 ± 1.15^{bA}	5.0 ± 0.00^{aA}
	2	22.82 ± 1.47^{dC}	87.33 ± 1.43^{bA}	5.0 ± 0.00^{aA}
	3	17.54 ± 1.31^{cD}	84.31 ± 0.62^{cB}	5.0 ± 0.00^{aA}

[1] Mean of six individual measurements.
[abcd] Different letters in the same column within the same number of washing cycles indicate significant differences ($P<0.05$).
[ABCD] Different capital letters in the same column within the same treatment indicate significant differences ($P<0.05$).

Cooking yield (CY), water holding capacity (WHC) and expressible moisture (EM)

The interaction between the washing treatments and the number of washing cycles did not significantly (P>0.05) affect the CY of MDDM gels. Since washing removes fat in MDDM, an insufficient fat-protein emulsion will be formed, resulting in a decreased CY. However, the decrease in CY wasn't observed between unwashed and washed MDDM. The decrease in CY was only observed when one to three washing cycles of all types of washing treatments were employed. The CY of washed MDDM gels was higher than unwashed MDDM (Yang and Froning, 1992). This may probably due to the increased myofibrillar protein concentration in the washed mince (Yang and Froning, 1992). The highest CY was observed in washed mince that was washed with tap water in a single washing cycle whereas the lowest CY was the unwashed MDDM (Table 3). In terms of washing treatments, washing with 0.5% $NaHCO_3$ in three washing cycles gave the lowest CY. CY depends on emulsion stability of the meat. Emulsion stability indicates the ability of the emulsion to hold water and it is also influenced by the fat content of the emulsion (Romans *et al*., 1985; Bhattacharyya *et al*., 2007). Although increased pH in a meat system may enhance water retention, the water is loosely bound (Siegel and Schmidt, 1979). Hence, washing with 0.5% $NaHCO_3$ in three washing cycles gave poor emulsion stability because of its highest pH (high pH causes water to be loosely bound) and therefore the lowest CY. Washing with tap water in a single washing cycle gave the highest CY because this treatment probably retained most of the fat among all the other washing treatments. As a result, a good emulsion was formed, which culminated in the highest CY.

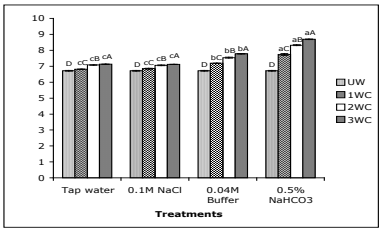

Figure 1. pH of washed mince from different washing treatments (Tap water; 0.1M NaCl; 0.5% $NaHCO_3$; 0.04M SPB (pH=8.0)). UW= unwashed MDDM; 1WC= one washing cycle; 2WC= two washing cycles; 3WC= three washing cycles. [abc] Different letters on the bars within the same number of washing cycles indicate significant differences (P<0.05). [ABCD] Different capital letters on the bars within the same treatment indicate significant differences (P<0.05). The pH values are means of six individual measurements

The interaction between the washing treatments and the number of washing cycles significantly affected (P<0.05) the WHC of washed mince. WHC of washed mince was significantly higher (P<0.05) than that of unwashed MDDM (Yang and Froning, 1992; Karthikeyan *et al*., 2004; Baxter and Skonberg, 2008). As washing removes components like fat and sarcoplasmic proteins that may interfere with the stability of the protein network, increased washing results in gels with higher WHC (Baxter and Skonberg, 2008). Since WHC is directly correlated to the myofibrillar protein content (Smith, 1991), WHC increased with increasing number of washing cycles for all types of washing treatments (Figure 2) because washing has shown to increase the myofibrillar content of washed MDDM in this study. The higher WHC in washed mince was also due to the addition of polar residues on the protein molecules of the washed mince (Karthikeyan *et al*., 2004). The highest WHC was observed in washed mince (MDDM) that was treated with 0.04M SPB (pH=8.0) in three washing cycles whereas the lowest WHC was the unwashed MDDM. In terms of washing treatments, washing with tap water in a single washing cycle gave the lowest WHC because this treatment was not able to considerably remove sarcoplasmic proteins that would otherwise decrease the WHC of the myofibrils (Wilson and Laack, 1999). Increased pH improves WHC (Hamm, 1986) and a positive correlation between pH and WHC has been found by Regenstein *et al*. (1984) and Martinez (1989). However, pH that is too high will cause the water to be loosely bound and caused the 'gained' water to be lost. Hence, pH 7.78 of the washed mince treated by 0.04M SPB (pH=8.0) in three washing cycles is the optimum pH to achieve the highest WHC in MDDM.

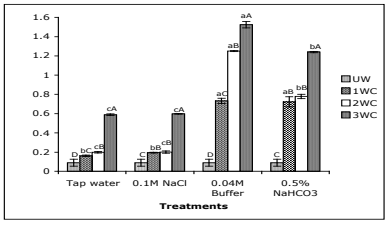

Figure 2. Water Holding Capacity of washed mince from different washing treatments (Tap water; 0.1M NaCl; 0.5% $NaHCO_3$; 0.04M SPB (pH=8.0)). UW= unwashed MDDM; 1WC= one washing cycle; 2WC= two washing cycles; 3WC= three washing cycles. [abc] Different letters on the bars within the same number of washing cycles indicate significant differences (P<0.05). [ABCD] Different capital letters on the bars within the same treatment indicate significant differences (P<0.05). The WHC values are means of six individual measurements

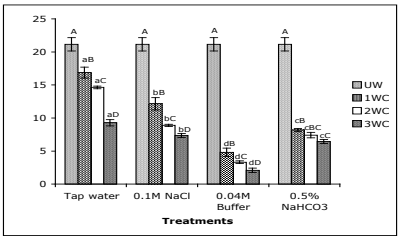

Figure 3. Expressible Moisture of cooked gels from different washing treatments (Tap water; 0.1M NaCl; 0.5% $NaHCO_3$; 0.04M SPB (pH=8.0)). UW= unwashed MDDM; 1WC= one washing cycle; 2WC= two washing cycles; 3WC= three washing cycles. [abcd] Different letters on the bars within the same number of washing cycles indicate significant differences (P<0.05). [ABCD] Different capital letters on the bars within the same treatment indicate significant differences (P<0.05). The EM values are means of six individual measurements

The interaction between the washing treatments and the number of washing cycles significantly

affected (P<0.05) the EM of washed mince. EM was significantly lower (P<0.05) in gels for washed mince that were treated with all types of washing treatments, compared with unwashed MDDM (Nowsad *et al*., 2000; Chaijan *et al*., 2004; Balange and Benjakul, 2009). As washing cycle for all types of washing treatments increased, EM of gels decreased significantly (P<0.05) (Figure 3). This trend is exactly opposite to the results of WHC, which suggests that EM is inversely related to WHC (Niwa, 1992). Ramirez *et al.* (2007) reported that EM increased as the amount of entrapped water decreased. As WHC has shown to increase with the increasing number of washing cycles, water held in the myofibrillar protein network was strong enough not to get released upon the application of pressure, thus rendering a decrease in EM (Mathew *et al*., 2002). The highest EM was observed in unwashed MDDM whereas the lowest EM was MDDM washed with 0.04M SPB (pH=8.0) in three washing cycles. The high EM in gels of unwashed MDDM was probably due to the poor gel forming ability of its proteins (Karthikeyan *et al*., 2004), because the strength of the protein network formed is related to the retention of water inside the gels. Increased pH due to washing, coupled with the high concentration of myofibrillar proteins at the end of the third washing cycle enhanced the water retention in MDDM treated by 0.04M SPB (pH=8.0). In terms of washing treatments, washing with tap water in a single washing cycle gave the highest EM. However, this treatment proved to give the lowest WHC in terms of washing treatments. Thus, this study has further proved that EM is inversely correlated to WHC.

Textural properties

The interaction between the washing treatments and the number of washing cycles significantly affected (P<0.05) the gel strength or GS of cooked gels. GS increased significantly (P<0.05) with the number of washing cycles for all types of washing treatments (Figure 4). Previous researchers have found a positive correlation (P<0.05) between the number of washing cycles and GS (Yang and Froning, 1992; Nowsad *et al*., 2000; Mathew *et al*., 2002; Karthikeyan *et al*., 2004). There is also a profound increase in GS of cooked gels that were treated with washing treatments as compared to unwashed mince, which is similar to the results of those researchers. The increase in GS with the number of washing cycles is due the stronger protein network (Chen *et al*., 1997) as a result of an increased myofibrillar protein content, which play an essential role in gel formation; and decreased sarcoplasmic protein content (Mathew *et al*., 2002). Sarcoplasmic proteins hinder the gelling ability of myofibrillar proteins and thus have an adverse effect on the strength and deformability of the myofibril protein gels (Haard *et al*., 1994; Hultin and Kelleher, 2000). The highest GS was observed in MDDM washed with tap water in three washing cycles whereas the lowest GS was the unwashed MDDM. In terms of washing treatments, washing with 0.5% $NaHCO_3$ in a single washing cycle gave the lowest GS. According to Lanier (1986), gel forming ability depends on pH, ionic strength, the amount of myofibrillar proteins and protein solubility. Martinez (1989) found that there was a negative correlation between GS and pH. According to Babji *et al*. (1995), the higher pH tends to give softer gels for MDCM, which explained the lowest GS in the treatment of 0.5% $NaHCO_3$ for all washing cycles. Since 0.5% $NaHCO_3$ is a reducing agent, it interferes with the –SH bonds of meat proteins to weaken the strength of the protein gels (Niwa and Musato, 1971). Washing with tap water in three washing cycles gave the highest GS because of the concentration of myofibrillar protein content as a result of the increasing washing cycles and the non-alkaline washing solution employed. Besides, GS was found to have an inverse relationship with the EM of the cooked gels. This is consistent with the findings of Mathew *et al*. (2002), Karthikeyan *et al*. (2004) and Balange and Benjakul (2009). According to Karthikeyan *et al*. (2004), the retention of water inside gels is related to the strength of the network formed; so the high EM in gels is the indication of the poor gel forming ability of the proteins from MDDM. Since EM was the highest for unwashed MDDM, it has poor gel forming ability, which contributed to its lowest GS.

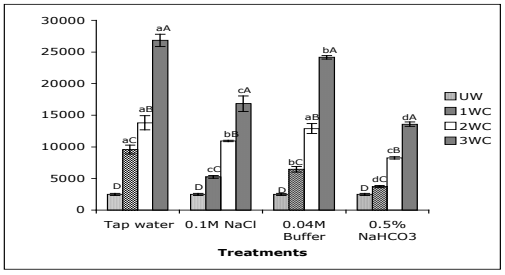

Figure 4. Gel Strenght of cooked gels from different washing treatments (Tap water; 0.1M NaCl; 0.5% NaHCO3; 0.04M SPB (pH=8.0)). UW= unwashed MDDM; 1WC= one washing cycle; 2WC= two washing cycles; 3WC= three washing cycles. [abcd] Different letters on the bars within the same number of washing cycles indicate significant differences (P<0.05). [ABCD] Different capital letters on the bars within the same treatment indicate significant differences (P<0.05). The GS values are means of six individual measurements

Folding test or FT is a quick and simple method to measure the quality of gel springiness (Nowsad *et al*., 2000). The interaction between the washing treatments and the number of washing cycles did not significantly affect (P>0.05) the FT of cooked gels. The first washing cycle of all types of washing

treatments only significantly increased (P<0.05) the score of FT (Table 3). It is interesting to note that although GS may increase with the increasing washing cycles, there is no relationship between GS and the score for FT. Therefore, a cooked gel can have a high GS but its FT can still be the same as the cooked gel with a lower GS. The range of GS that corresponds to the AA grade or 5 for the FT in this study is from 3753.52 to 26843.07 g/mm. This shows that FT is very subjective and is only used to distinguish between high and low quality surimi but lacks the sensitivity to discriminate between surimi samples having different functional properties such as GS (Reppond *et al*., 1987).

Whiteness intensity

The interaction between the washing treatments and the number of washing cycles significantly affected (P<0.05) the whiteness of cooked gels. Whiteness of gels increased (P<0.05) as the number of washing cycles for all types of washing treatments increased (Figure 5) (Miyauchi *et al*., 1973; Kim *et al*., 1996; Nowsad *et al*., 2000; Chaijan *et al*., 2004). The unwashed MDDM had the lowest whiteness index compared to all the washed mince, in which the results are consistent with the work of Yang and Froning (1992) and Balange and Benjakul (2009). The pigments responsible for the colour of MDDM are myoglobin and hemoglobin (Froning, 1976). Unwashed MDDM might have contained a higher amount of dark muscles, which contributed to its lowest whiteness. Ochiai *et al*. (2001) suggested that high-quality surimi with higher whiteness can be obtained when considerable amount of dark muscle is removed. Since MDDM was used, mechanical deboning has been found to release heme protein and lipid components from the bone marrow and this may increase the content of hemoprotein pigments in MDDM compared to manually deboned meats (Froning and Johnson, 1973).

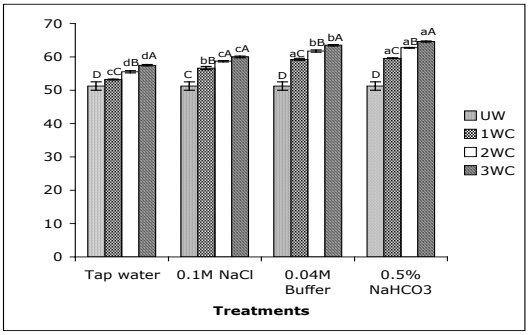

Figure 5. Whiteness of cooked gels from different washing treatments (Tap water; 0.1M NaCl; 0.5% NaHCO3; 0.04M SPB (pH = 8.0)). [abcd] Different letters on the bars within the same number of washing cycles indicate significant differences (P<0.05). [ABCD] Different capital letters on the bars within the same treatment indicate significant differences (P<0.05). The whiteness values are means of six individual measurements

Okada and Noguchi (1974) proposed that washing removes blood, fat, pigments, soluble proteins, myoglobin and other nitrogenous compounds, which improves the whiteness of cooked gels. Babji *et al*. (1995) have highlighted that the optimal goal of washing treatment for poultry was the effective extraction of heme pigments. The treatment of 0.5% $NaHCO_3$ in three washing cycles produced cooked gels with the highest whiteness whereas in terms of all washing treatments, washing with tap water in a single washing cycle gave the lowest whiteness (Figure 5). In each washing cycle, 0.5% $NaHCO_3$ had the highest whiteness followed by 0.04M SPB (pH=8.0), 0.1M NaCl and tap water. Previous researchers have established that the higher pH of the extracting medium (washing solution) increased whiteness of the resulting washed meat (Hernandez *et al*., 1986; Dawson *et al*., 1989; Kristinsson and Liang, 2006). Since the treatment of 0.5% $NaHCO_3$ in three washing cycles gave the highest pH in this study, it can probably remove the undesirable components, especially myoglobin, that can affect the whiteness of the cooked gels. Similar results were also obtained by Dawson *et al*. (1988). They observed that washing MDCM with 0.5% $NaHCO_3$ improved the whiteness of the product compared to washing with water. Poe1 (1949) and Fleming *et al*. (1960) reported that tap water was not very effective in extracting heme pigments from meat, which is consistent with the results of this study.

Conclusions

Various washing treatments affect the quality characteristics of *duckrimi* in comparison with unwashed duck meat. Improvement of the thermal gelation properties and quality characteristics of duckrimi were successfully attained from the different washing treatments in increasing number of washing cycles. Washing in an alkaline solution offered several advantages over tap water in improving the quality of *duckrimi*. Washing is of utmost importance to remove fat and sarcoplasmic proteins that have deleterious effect on the quality characteristics of *duckrimi* while concentrating the myofibrillar protein content that improved the functionality of *duckrimi*. The treatment combination of 0.04M sodium phosphate in three washing cycles was the best treatment combination to produce a high quality *duckrimi*. Albeit it is evident that MDDM from spent layer duck can be a viable alternative source for the production of surimi-based products.

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