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ORIGINAL ARTICLE

Optimization of parameters for obtaining surimi-like material from mechanically separated chicken meat using response surface methodology

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Abstract Surimi is a semi-processed washed fish mince protein concentrate mixed with cryoprotectants for frozen storage, which is the primary constituent of processed foods. Mechanically separated chicken meat (MSCM) is a common ingredient of comminuted sausages mainly due to its low price. The present work aimed to define the adequate parameters to obtain surimi-like material from MSCM using response surface methodology, and to characterize the chemical and textural properties of this product. The MSCM was utilized in the elaboration of surimi-like material using the bleaching method with sodium bicarbonate and sodium chloride solutions. For this purpose, the effect of process parameters viz: temperature (T=2, 7, and 12 °C), time (t=5, 10, and 15 min/cycles) and washing solution:MSCM ratio (R=2:1, 4:1, and 6:1 w/w) were evaluated using response surface methodology. The highest composite design averages obtained were 10.7 % for protein content, 1,003.4 g for breaking force, 645.8 g.cm for gel strength, 9.0 N for cutting strength, and 24.1 N.s for work of shearing at the optimum combination of processing conditions of 7 °C, 10 min and 4:1 washing solution:MSCM ratio, corresponding to the central points of the proposed experimental design. The obtained models had high determination coefficients, explaining 95.85, 98.23, 98.41, and 96.08 % of total variability in protein content, cutting strength, breaking force, and work of shearing variabilities, respectively. According to the folding test the surimi-like material presented the same characteristics of a high quality surimi (FT=5).

Keywords Chicken · Mechanically separated meat · Surimi-like material · Textural properties · Characterization

Introduction

Mechanical deboning is a procedure which salvages much of the meat remaining on bones after removal of the meat by skilled meat cutters, providing a source of underutilized animal proteins, the mechanically separated chicken meat (MSCM). In chicken, meat can be reclaimed mainly from neck, frame and back bones, which can be used as raw material for processed meat products due to its low price. However, the high content of heme pigments, connective tissue, calcium and fat still represent a bottleneck for a greater application of MDCM in foods (Cortez-Vega et al. 2013).

Surimi is a semi-processed, wet, frozen, washed fish myofibrillar protein concentrate (Lanier 1986). It presents unique textural properties and high nutritional value (Park and Morrissey 2000). In recent years, there has been considerable interest in manufacturing surimi-like materials from the muscle of animal species other than fish (Desmond and Kenny 1998). The characteristics of surimi-like material from poultry meat (Jin et al. 2007) and also from meat by-products, as MSCM (Smyth and O'Neill 1997; Perlo et al. 2006; Cortez-Vega et al. 2012) have been studied. The

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process used for the production of surimi-like material involves repeated washing of minced meat with aqueous solution to remove fat, pigments, and other water soluble substances and to produce a crude myosin extract (Antonomanolaki et al. 1999).

Surimi is desired as a food component because it has both excellent gel formation and binding properties (Dreyfuss et al. 1997). Improvement of surimi gel quality (gel strength) has been one of the major thrusts in surimi gel products. Gel forming ability of surimi depends on both intrinsic and extrinsic factors, including species (Lee 1984), physic and chemical properties of muscle proteins (Benjakul et al. 2001), the presence of endogenous enzymes, e.g. proteinases and transglutaminase (An et al. 1996), and the conditions used in processing (Benjakul et al. 2003). It is induced by the denaturation of protein and the subsequent aggregation of the denatured protein (Chan et al. 1992), which is reflected in the rheological properties (An et al. 1996; Ahmad et al. 2007).

The washing procedure is an important step in producing high-quality surimi (Benjakul et al. 1997; Medina and Garrote 2001; Ramadhan et al. 2012). Washing removes compounds such as sarcoplasmic proteins, inorganic salts, low-molecular weight substances, lipids, and blood components (Benjakul et al. 1998; DeWitt and Morrissey 2002), concentrating myofibrillar proteins, which play an essential role in gel formation, improving gel-forming ability and decreasing protein denaturation during frozen storage (Lee 1984; Lanier 1986; Scott et al. 1988), and enhances color and flavor of products (Toyoda et al. 1992). A substantial amount of muscle proteinases are also removed during the washing process in surimi production (Morrissey et al. 1995; Benjakul et al. 1998), resulting in less activity in surimi (An et al. 1994; Benjakul et al. 1997).

The application of the surimi technology in the production of a surimi-like material from MSCM could provide a new approach towards increasing its value and utilization. The objectives of this study were to optimize parameters (temperature, time and ratio) for the production of a surimi-like material from MSCM and to determine the effects of washing on the composition and functional properties of the surimi-like material.

Material and methods

Mechanically separated chicken meat (MSCM)

Fresh MSCM was supplied from a local poultry processing plant and transported under refrigerated conditions to our laboratory. It was produced in 3 mm particle size using a Baader separator (Baader model 694, Lübeck, Germany), operating at inlet 6 °C and outlet 10 °C, from broiler's necks, frames, backs and injured thighs, 24 h after the slaughtering.

Surimi-like material and surimi-like material gel

MSCM was washed in 3 cycles utilizing in each cycle a washing solution:MSCM ratio of 2:1, 4:1 or 6:1 (*w/w*), temperature of 2, 7 or 12 °C, for 5, 10 or 15 min. In each washing cycle, the stirring was kept constant at 220 rpm using a mechanical agitator (Marconi model MA-259, Piracicaba, Brazil). It was utilized 0.5 % $NaHCO_3$ solution for the first and second washings and 0.3 % NaCl solution for the last one. After each washing cycle, samples were centrifuged at 7 °C (Sigma model 6–15, Osterode, Germany). The first and second centrifugations were carried out at 3,000×*g* for 15 min, while the third one at 7,000×*g* for 25 min. The supernatant containing fat and water-soluble proteins was discarded. The final slurry was sieved through a 1 mm-mesh metal screen to remove connective tissues, blended with 4 % sucrose, 4 % sorbitol and 0.2 % Na-tripolyphosphate, packaged in 5-layer nylon propylene bags, and stored at −18 °C until analysis.

To prepare the gel, MSCM surimi-like material was added of 2.5 % salt. The mixture was chopped for 5 min at 4 °C to obtain the homogenous sol. The sol was then stuffed into stainless steel cylinders (30 mm diameter, 30 mm height) and both ends of casing were sealed tightly. Two-step heated gels were prepared by setting the sol at 40 °C for 30 min, followed by heating at 90 °C for 20 min. The gels were then cooled in iced water and stored for 24 h at 4 °C prior to analysis.

Proximate composition

Moisture, crude protein, crude fat and crude ash contents were determined in triplicate according to the methods described by AOAC (1995). Moisture was determined by the oven drying method at 105 °C until constant weight (method 950.46), protein by the Kjeldhal method (method 928.08), fat by the Soxhlet method (method 960.39) and ash by using the muffle oven technique (method 920.153). Carbohydrates were calculated by difference.

Yield

Yield was calculated from the difference between the weight of whole muscle and ending mass of MSCM surimi-like material. Yield % = (whole muscle weight−surimi-like material weight)/(whole muscle weight)−100 (Jin et al. 2007).

pH

pH was measured in triplicate using a digital pH meter (Marconi model PA 200, Piracicaba, Brazil) About 10 g of sample (MSCM or MSCM surimi-like material) was cut into small pieces to which 50 ml of distilled water was added and slurry was made using a blender and the pH was recorded (Smyth and O'Neill 1997).

Table 1 Values of independent variables and different levels of the experimental design applied to the process of MSCM surimi-like material production

Independent variable	Symbol	Level		
		−1	0	+1
Temperature (°C)	T	2	7	12
Time (min)	t	5	10	15
Ratio[a] (*w*/*w*)	R	2:1	4:1	6:1

T washing temperature; *t* wash-cycle time; *R* washing solution:MSCM ratio; *MSCM* mechanically separated chicken meat

[a] Washing solution:MSCM ratio

Gel properties

Texture analysis of MSCM surimi-like material gel was carried out using a texture analyzer model TA-XT2 plus (Stable Micro Systems, Surrey, England). Gels kept at 4 °C were equilibrated at room temperature (28–30 °C) before analysis. Cylindrical samples, 2.5×3.0 cm, were prepared and placed in the texture analyzer equipped with a spherical plunger (5 mm diameter; 60 mm/min depression speed) (Benjakul et al. 2000). Analyses were performed at least in triplicate. The results were expressed as breaking force (g) and deformation or distance to rupture (mm), representing the hardness and cohesiveness of the surimi gels, respectively. Gel strength (g.cm) was expressed as the product of breaking force and deformation. Analogously, samples were submitted to a cutting/shearing test using a knife blade. The cutting strength (N) is correlated to the firmness of the sample, and the work of shearing (N.s) indicated the total energy (work) required to shear (Bourne 2002). Pre-test and post-test speeds were the same of the force-distance tests.

Folding test

Folding test was performed in triplicate using gel slices (30 mm diameter, 3 mm thickness, 20±1 °C) according to the method of Tanikawa et al. (1985). The maximum score (FT=5) indicated no cracks were observed when the slice was folded twice without breaking. The minimum score (FT=1) was assigned if the slice broke into fragments when folded in half.

Factorial design and statistical analysis

A central composite design with central points was used to find the effects of three different process parameters (temperature (°C), time (min) and washing solution:MSCM ratio) on the responses protein, cutting strength, work of shearing, breaking force and gel strength. In Table 1 is shown the experimental setup of the independent variables. The statistical analysis of the experimental data was performed using the software Statistica 6.0.

The statistical significance ($p<0.05$) of the 2nd order model equations was evaluated by the analysis of variance. The response surface plots were represented a function of two independent variables while keeping the other independent variable constant at the optimum level.

Table 2 Experimental design and the pH, yield and proximal results for surimi-like material from mechanically separated chicken meat

Variable				Proximal composition					Yield (%)	pH
No	*T* (°C)	*t* (min)	*R* (*w*/*w*)	Moisture (%)	Protein (%)	Crude fat (%)	Ash (%)	Total (%)		
1	12	10	6:1	89.2±0.3	10.0±0.1	1.6±0.0	0.49±0.02	101.4	56.7	7.26±0.02
2	12	10	2:1	89.9±0.0	10.2±0.0	1.5±0.1	0.40±0.03	102.0	63.0	7.27±0.01
3	2	10	6:1	89.9±0.1	10.2±0.2	1.5±0.0	0.34±0.00	102.1	66.2	7.30±0.02
4	2	10	2:1	86.4±0.6	10.5±0.0	2.2±0.1	0.64±0.05	99.8	57.3	7.28±0.01
5	12	15	4:1	88.9±0.5	8.9±0.0	1.5±0.0	0.69±0.14	100.0	62.3	7.26±0.02
6	12	5	4:1	90.2±0.3	9.1±0.0	2.3±0.1	0.50±0.00	102.1	63.9	7.27±0.01
7	2	15	4:1	89.5±0.5	8.5±0.3	3.3±0.1	0.49±0.07	101.8	60.6	7.26±0.02
8	2	5	4:1	89.8±0.3	8.8±0.2	1.3±0.0	0.52±0.06	100.4	59.1	7.29±0.01
9	7	15	6:1	88.8±0.4	9.2±0.2	1.6±0.3	0.55±0.21	100.1	62.8	7.29±0.01
10	7	5	6:1	89.3±0.3	9.0±0.2	2.1±0.8	0.54±0.00	100.9	61.9	7.30±0.02
11	7	15	2:1	87.4±0.1	9.6±0.1	1.9±0.1	0.29±0.02	99.2	57.0	7.27±0.03
12	7	5	2:1	89.2±0.1	10.1±0.3	1.8±0.2	0.45±0.05	101.5	50.5	7.26±0.02
13	7	10	4:1	89.1±0.4	10.7±0.1	1.5±0.0	0.53±0.06	101.9	60.0	7.28±0.01
14	7	10	4:1	89.2±0.6	10.7±0.3	1.5±0.0	0.54±0.02	102.0	61.1	7.26±0.02
15	7	10	4:1	89.0±0.4	10.7±0.1	1.5±0.0	0.53±0.01	101.8	60.3	7.26±0.01

T washing temperature; *t* wash-cycle time; *R* washing solution:MSCM ratio; *MSCM* mechanically separated chicken meat; Experimental runs were performed in a random order

Table 3 Experimental design and the rheological results for surimi-like material from mechanically separated chicken meat

No	Variable			Knife blade		Spherical probe		
	T (°C)	t (min)	R (*w/w*)	Cutting strength (N)	Work of shearing (N.s)	Breaking force (g)	Deformation (mm)	Gel strength (g.cm)
1	12	10	6:1	6.2±0.3	7.6±0.0	519.4±11.6	6.1±0.0	314.7±5.1
2	12	10	2:1	6.7±0.2	10.0±0.2	675.1±18.2	6.3±0.1	427.3±11.1
3	2	10	6:1	7.1±0.4	17.6±0.1	370.4±7.8	6.3±0.1	231.8±4.0
4	2	10	2:1	6.8±0.6	17.7±0.4	676.9±22.6	6.4±0.0	432.5±9.8
5	12	15	4:1	7.2±0.5	13.5±0.3	672.0±17.1	6.4±0.0	428.1±7.3
6	12	5	4:1	7.4±0.6	16.4±0.5	647.8±20.4	6.3±0.0	407.4±9.1
7	2	15	4:1	6.4±0.4	18.2±0.5	652.8±12.1	6.3±0.0	410.6±5.7
8	2	5	4:1	7.9±0.5	21.0±0.2	348.9±19.4	6.4±0.0	223.0±8.3
9	7	15	6:1	6.9±0.2	9.2±0.3	828.6±22.5	6.4±0.0	527.0±9.7
10	7	5	6:1	6.7±0.4	13.5±0.3	672.0±24.2	6.3±0.0	424.0±11.8
11	7	15	2:1	6.3±0.6	10.1±0.3	946.1±13.4	6.4±0.0	601.7±6.3
12	7	5	2:1	7.6±0.3	18.7±0.1	792.6±15.2	6.4±0.0	507.3±7.1
13	7	10	4:1	9.0±0.3	24.2±0.3	1,002.9±15.8	6.4±0.0	645.9±7.2
14	7	10	4:1	9.1±0.5	24.2±0.5	1,004.3±12.9	6.4±0.0	647.8±6.1
15	7	10	4:1	8.9±0.51	24.0±0.4	1,002.9±15.5	6.4±0.0	646.9±7.0

T washing temperature; *t* wash-cycle time; *R* washing solution:MSCM ratio; *MSCM* mechanically separated chicken meat; experimental runs were performed in a random order

Gel strength = breaking force × distance to rupture

Results and discussion

Analysis of the effects and statistical models

In this work an experimental design was performed in order to determine optimal process conditions (time, temperature, and washing solution:MSCM ratio) for MSCM surimi-like material production. Table 2 shows the central composite and the observed responses on protein content (%), and Table 3 on cutting strength (N), work of shearing (N.s), breaking force (g), and gel strength (g.cm) for MSCM surimi-like material. The averages for the highest protein content (10.7 %), cutting strength (9.0 N), work of shearing (24.1 N.s), breaking force (1,003.4 g), and gel strength (645.8 g.cm) were obtained at the processing conditions of 7 °C, 10 min and 4:1 washing solution:MSCM ratio, that

Table 4 Main effects and second order interaction effects of the variables (*T*, *t* and *R*) on protein content (%), cutting strength (N), breaking force (g) and work of shearing (N.s) for the obtained MSCM surimi-like material

Variables	Estimated effects on responses				
	Protein content (%)	Cutting strength (N)	Work of shearing (N.s)	Breaking force (g)	Gel strength (g.cm)
Average	10.7[a]±0.1	9.0[a]±0.1	24.1[a]±1.1	1,003.4[a]±25.8	646.8[a]±18.2
T (L)	0.03±0.19	−0.20±0.15	−6.7[a]±1.3	116.3[a]±31.6	69.9[a]±22.3
T (Q)	−1.1[a]±0.3	−2.0[a]±0.2	−6.5[a]±1.9	−672.4[a]±46.5	−443.0[a]±32.8
t (L)	−0.52[a]±0.19	−0.10±0.15	−2.2±1.3	−175.1[a]±31.6	−117.8[a]±22.3
t (Q)	0.14±0.28	−2.6[a]±0.2	−15.3[a]±1.9	−213.5[a]±46.5	−147.5[a]±32.8
R (L)	−0.20±0.19	−0.73[a]±0.15	−4.7[a]±1.3	159.6[a]±31.6	101.4[a]±22.3
R (Q)	−2.7[a]±0.3	−1.6[a]±0.2	−7.2[a]±1.9	−173.6[a]±46.5	−116.2[a]±32.8
T × *t*	0.07±0.27	−0.42±0.22	−1.1±1.8	75.4±44.6	44.0±31.5
T × *R*	−0.01±0.27	0.67[a]±0.22	−0.03±1.85	−139.8[a]±44.6	−83.5[a]±31.5
t × *R*	0.34±0.27	0.75[a]±0.22	2.1±1.8	1.6±44.6	4.2±31.5

T washing temperature; *t* wash-cycle time; *R* washing solution:MSCM ratio; *MSCM* mechanically separated chicken meat; *L* linear; *Q* quadratic

[a] Significant effect within a 95 % confidence interval (ANOVA)

Table 5 ANOVA of the protein content (%), cutting strength (N), work of shearing (N.s), breaking force (g) and gel strength (g.cm) for the obtained MSCM surimi-like material

Response	Variation source	Degrees of freedom	Sum of squares	Mean squares	*F*-value calculated
Protein content (%)	Regression	9	8.3	0.92	12.8
	Residues	5	0.36	0.07	
	Total	14	8.7		
Cutting strength (N)	Regression	9	13.1	1.5	30.4
	Residues	5	0.24	0.05	
	Total	14	13.4		
Work of shearing (N.s)	Regression	9	420.0	46.7	13.6
	Residues	5	17.1	3.4	
	Total	14	437.1		
Breaking force (g)	Regression	9	617,574. 6	68,619.4	34.4
	Residues	5	9,965.8	1,993.2	
	Total	14	627,540.4		
Gel strength (g.cm)	Regression	9	265,238	29,470.9	29.7
	Residues	5	4,959.3	991.9	
	Total	14	270,197.3		

F-value listed = 4.77

represent the central point of the experimental design (Exp 13–15).

Through statistical analysis, the main effect of each variable on the responses was evaluated. Table 4 presents the main effects of the independent variables (time, temperature, and washing solution:MSCM ratio) on the responses (protein content, cutting strength, work of shearing, breaking force, and gel strength), the calculated average of the experimental responses, as well as their interaction effects. In this table, it could be noticed that time had the higher effect on cutting strength and work of shearing; temperature had the higher effect on breaking force; and washing solution:MSCM ratio had the higher effect on protein content. In all cases the effect was negative. Significant two factor interaction effects were observed for cutting strength and breaking force.

Analysis of variance (ANOVA) was performed and each response variable and effect of each process variable was compared (Table 5). Models generated for each response are represented by equations (Table 6). The second order response surface model was fitted well to the experimental data and the regression coefficients were statistically significant within 95 % confidence interval. The models presented high determination coefficients, explaining 95.85 %, 98.23 %, 98.41 %, and 96.08 % of the protein content, cutting strength, breaking force, and work of shearing variabilities, respectively (Table 6). According to Table 5, the calculated *F*-value was at least 5 times larger than the listed value ($P>0.05$) for cutting strength and breaking force, which showed a very high significance of the models (Barros Neto et al. 1996). However, the models for protein content and work of shearing, despite statistically significant, were unable to predict response variabilities.

The response surface plot each response variable was generated using predictive linear models (descriptive and/or predictive). The best response surfaces for protein content (Fig. 1a), cutting strength (Fig. 1b), work of shearing (Fig. 1c), breaking force (Fig. 1d), and gel strength (Fig. 1e) were determined. According to these figures, the best responses were observed in the central points of the response surfaces, and these values might be employed for a MSCM surimi-like material production process.

Compositional properties of MSCM and MSCM surimi-like material

The MSCM varies in its proximal composition due to the diverse factors as age, meat:bone ratio, skin content, cutting method, mechanical deboning processes, denaturation of protein, and amount of heme pigments (Perlo et al. 2006). The results of the proximate composition of the MSCM obtained in this study were compared with data previously reported by other authors (Grunden et al. 1972; Essary 1979; Froning 1981; Mott et al. 1982; Hamm and Young 1983; Smyth and O'Neill 1997; Rivera et al. 2000; Perlo et al. 2006).

It was observed that the MSCM composition varies significantly in function of the raw material utilized. The lipid content of the MSCM from the whole chicken, for instance, was reported on the 14.5–26.2 % range (18.5 % in this study).

Table 6 Second-order polynomial models for MSCM surimi-like material production based on various experimental responses: protein content (%), cutting strength (N), breaking force (g) and work of shearing (N.s)

Response	Second-order polynomial model	R^2
Protein content (%)	$=6.0247+0.3014\ T+0.0221\ T^2+0.9875\ R+0.0537\ R^2$	0.9585
Cutting strength (N)	$=0.4785\ T-0.0392\ T^2+2.3747\ t-0.3282\ t^2+0.3308\ R-0.0323\ R^2\ 0.0134\ T\ R+0.0372\ t\ R$	0.9823
Work of shearing (N.s)	$=-0.1304\ T^2+14.0703\ t-1.9097\ t^2-0.1446\ R^2$	0.9608
Breaking force (g)	$=-582.75+212.80\ T-13.45\ T^2+142.56\ t-26.69\ t^2+104.66\ R-3.47\ R^2-2.80\ T\ R$	0.9841
Gel strength (g.cm)	$=-393.92+138.92\ T-8.86\ T^2+100.51\ t-18.44\ t^2+67.45\ R-2.32\ R^2-1.67\ T\ R$	0.9816

T washing temperature; *t* wash-cycle time; *R* washing solution:MSCM ratio; *MSCM* mechanically separated chicken meat

Considering that the lipid content of the species influences the shelf-life of the products, the consumer's acceptance, and the method for surimi obtaining (Maza 2001), it is important to reduce this content by sequential washings to avoid adverse effects on the surimi quality, once that the oxidized lipids interact with proteins, causing denaturation, polymerization and changes in functional properties (Jin et al. 2007).

The compositional properties of the MSCM surimi-like material from the present study are shown in Table 2. The lipid content was quite low while moisture, inversely related to the lipid content, was quite high. Due the high lipid content of MSCM, adequate washing is required to prepare high quality surimi. However, the several washings resulted in high hydration of mince, which made the subsequent dehydration process more difficult (Bentis et al. 2005), producing a surimi-like material with a high moisture content, varying from 86.40 to 89.95 % (Table 2), despite the gel forming ability has not be repressed. However excessive successive washings may reduce chemical compositions of samples, e.g. after quadruple washing (Ismail et al. 2010) and may led to a decrease in myofibrillar proteins responsible for gelation (Babji and Kee 1994) forming a poorer gel matrix (Rawdkuen et al. 2009).

The water-holding capacity of the surimi gels varies greatly among the different species utilized; however different values for moisture content were reported for MSCM surimi-like material (Smyth and O'Neill 1997; Perlo et al. 2006) obtained at similar processing conditions (Smyth and O'Neill 1997; Nowsad et al. 2000; Perlo et al. 2006; Jin et al. 2007; Cortez-Vega et al. 2013). Actually, the higher pH resulted from the sequential washings with sodium bicarbonate solutions, in addition to the higher concentration of myofibrillar proteins, accounted for its higher moisture content (Smyth and O'Neill 1997). The mechanism of gelation of muscle mince starts with the formation of aggregates of myosin molecules, which are bound by various kinds of interactions according to the species in use (Ortiz and Aguilera 2004).

In the preparation of surimi-like material products, pH and the nature of the buffering agents of the washing media play important roles not only with regard to the stability of the product but also from a technological point of view. In the traditional surimi making process, water, instead of a buffered solution, is usually used (Srinivasan et al. 1996). Using 0.1 M sodium chloride solution for washing, a lipid removing of only 36.6 % was obtained from MSCM (Perlo et al. 2006), while using 0.1 % sodium chloride solution, lipids removing of 76.7 and 78.7 % were obtained from broiler and spent hen, respectively (Nowsad et al. 2000). Nevertheless, the utilization of 0.5 % sodium bicarbonate solution removed 98.1 % of lipids from MSCM (Smyth and O'Neill 1997) and 91.7 % of lipids in this work. It seems that the washing agent contributed more to the lipid removing than the washing cycles or ratio (Jin et al. 2007). More important than the reduction of the lipid content to less than 2.0 % by washing, the utilization of wash-water containing 0.5 % sodium bicarbonate was important due the more effective extraction of fats from MSCM (more than 90 % from the total).

The 0.5 % sodium bicarbonate washing solution provides better heme pigment extraction due to the solubilization of the muscle sarcoplasmic proteins (Yang and Froning 1992, 1994; Maza 2001; Ensoy et al. 2004), but may adversely affect functionality of myofibrillar proteins (Yang and Froning 1994). Addition of 0.5 % sodium bicarbonate solution resulted in a product with the highest pH, lowest fat and lowest pigment concentration, all of which are favorable characteristics in the manufacturing of further processed products (Ismail et al. 2011).

It was observed from Table 2 that proteins were maintained at significantly high levels (10.74±0.19 %) at the central point, after washings, indicating a non-significant loss of proteins (12.9±0.24 % for MSCM on a dry weight basis), which was probably due to some loss of the sarcoplasmic fraction (Bentis et al. 2005). It was also observed that proteins exhibited high functionality since they retained a significant amount of water (Zorba and Kurt 2006).

Effect of process variables on the protein content of MSCM surimi-like material

The pH increased from 6.27 (MCMS) to a maximum of 7.30 (MSCM surimi-like material) due to the utilization of 0.5 % sodium bicarbonate solution. This result was similar to the one reported by Hamada et al. (2004) when analyzing the effects of sodium carbonate in the properties of surimi from different species. This pH increase favors the gel strength due to the dissolution of the sarcoplasmatic proteins (Maza 2001; Jin et al. 2008; Luo et al. 2010). Apparently, there was no effect of pH on the protein content of MSCM surimi-like material, as shown in Table 2. The final pH varied in the small range of 7.26–7.30, while the protein contents in this region varied from 8.80 % to 10.75 % (Table 2).

The protein content of the MSCM surimi-like material is shown in Table 2. The time significantly influenced the amount of protein extracted (Table 3). In this case, the increase in washing time per cycle presented a negative effect on the protein content. In a general way, it means that the increase in time from 5 to 15 min diminishes the protein content. However, according to the best response surface generated for protein (Fig. 1a), the central value (10 °C) is the most appropriate for the process. From Fig. 1a, it can be seen that there is a protein increase from 5 to 10 min, and decrease from 10 to 15 min (or a decrease from 5 to 15 min, as indicated above). This behaviour was observed in all the situations where the best response was the central point.

The effect of temperature on the protein content is given in Table 2. The protein content decreased with temperature in the range studied (2–12 °C). However, according to the best

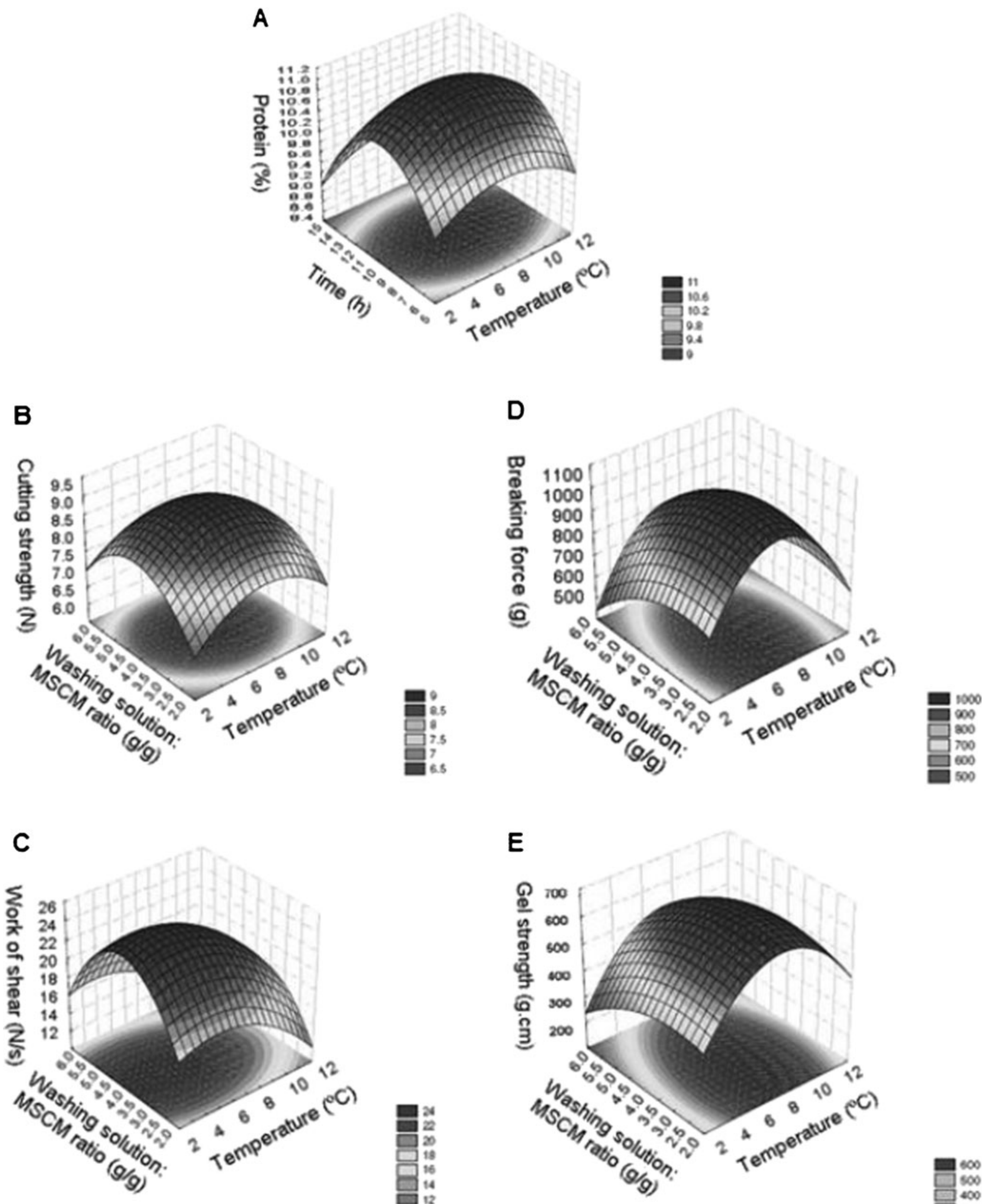

Fig. 1 Response surface of the **a** protein content (%), **b** cutting strength (N), **c** work of shearing (N.s), **d** breaking force (g) and **e** gel strength (g.cm) in function of the temperature (°C) and time (min) (for **a**) and temperature (°C) and washing solution:MSCM (for **b**, **c**, **d** and **e**). Washing solution:MSCM ratio was fixed in 2:1 for **a**. Time was fixed in 10 min. for **b**, **c**, **d** and **e**. MSCM: mechanically separated chicken meat

response surface generated for protein (Fig. 1a), the central value (7 °C) is the most adequate for the process. Batista (1999) reported an increase in the protein extract with increase in temperature. He pointed out that the increase was more significant in the extraction with calcium hydroxide.

The data presented in Table 4 show that the extraction yields decreased with an increase in the washing solution:MSCM ratio, when varying from 2:1 to 6:1. This behaviour is clear according to the best response surface generated for protein (Fig. 1a), where we can observe that the ratio of 2:1 was fixed as the most suitable to obtain a higher protein content during the process, despite that the ratio of 4:1 presented also a good response.

Effect of process variables on the rheological properties of MSCM surimi-like material

The rheological properties (cutting strength, work of shearing, breaking 1 force, and gel strength) of the MSCM surimi-like material are shown in Table 3. All variables (linear and quadratic) significantly influenced the breaking force and gel strength, being that the quadratic effect of washing temperature presented the highest significative effect on these responses (Table 4). In the same way, most of the variables influenced the responses cutting strength and work of shearing; however the quadratic effect of washing cycle time presented the highest significative effect for these responses (Table 4). In their work, Medina and Garrote (2001) reported that the three independent variables have a significant effect on gel strength, and the more relevant ones were the water-mince ratio and the washing cycle time for suribí surimi. Cutting strength and work of shearing can be used to study the mechanical properties of surimi gels.

Cutting strength determines the firmness of the gel and work of shearing indicated the energy necessary to shearing the gel. In both cases, the highest values for these responses were obtained at the central point (Fig. 1b, c) that corresponds to 7 °C, 10 min/cycle and 4:1 washing ratio. The higher force necessary for cutting (Fig. 1b) is in agreement with the higher protein content at this point (Fig. 1) because the force at cutting depends not only on the firmness but also on proper gelling (Yuste et al. 1999). The cutting strength values obtained in the present study are quite similar to those reported for chicken meat gels (Trespalacios and Pla 2007). In the same way, the larger work required to shear the gels at the central point (Fig. 1c) is also due to the role in formation of the crosslinked protein network after the thermal treatment (Kamath et al. 1992).

It is known that the textural properties of protein gels depend on their protein content. In general, the hardness of the protein gels tends to increase with increasing protein concentration. Here breaking force was used to indicate the hardness of the MSCM surimi-like material. Thus, higher breaking force values were expected for the surimi obtained according to the processing conditions in the central point of the response surface, as observed for the protein content (Fig. 1a), which was confirmed by the same behaviour verified for the breaking force (Fig. 1d). Concerning the gel strength (Fig. 1e), it was obtained by the product of breaking force and deformation and it is the main determinant for surimi quality (An et al. 1996). Considering that the deformation did not vary much for the different processing conditions employed (Table 3), the behaviour of this response was similar to that observed for the breaking force.

Many studies attempt to evaluate and compare surimi quality in terms of breaking force, deformation, and gel strength for different species. Our values for breaking force were much superior to that reported for chicken breast surimi-like material at similar processing conditions; however their obtained gel strength was higher (Jin et al. 2007). The breaking force of MSCM surimi-like material was also higher than results obtained for croaker, lizardfish, threadfin bream and bigeye snapper fish surimi (Benjakul et al. 2005). However their superior deformation equalized the gel strength (= breaking force × deformation) of fish and MSCM surimi-like material. The same behaviour was observed if compared to spent hen surimi-like material (Nowsad et al. 2000).

It was reported that the nature of the cross-links rather than concentration of the protein influences the textural properties (Hamann and MacDonald 1992). The alkaline saline washing played a role in improvement of gel strength due to the formation of a gel network which could form to a higher extent during thermal gelation of alkaline-treated protein, resulting in the enhanced gel strength associated with the decrease of lipid, which may interfere with myosin cross-linking during gel matrix formation because they do not form gels and have poor water holding capacity (Chaijan et al. 2010; Luo et al. 2010). Here it was observed that the protein concentration was the key parameter on the gel properties, being the best conditions of temperature, time, and washing ratio obtained at the central point of the proposed experimental design. The reduction of the textural properties after this point might be explained by the combined effect of temperature, time and washing ratio in excess, which contribute to the mislay of protein content and, consequently, gel quality.

Folding test

All MSCM surimi-like material obtained in the present study showed the maximum score FT=5 in the folding test. This result was obtained in triplicate for each one of the surimi batches. According to the experimental design presented in Table 2, the surimi had very strong gel-forming ability and extremely elastic characteristics. This high quality might be related to the utilization of sodium bicarbonate during washing (Hamada et al. 2004), which improves the gelling properties of the MSCM (Smyth and O'Neill 1997) and increases the extraction of sarcoplasmatic protein in relation to the pure water (Maldonado 1994).

Conclusion

The chemical and textural properties of MSCM surimi-like material were affected by the temperature, time and washing solution:MSCM ratio. The chemical compositions of samples showed a decrease in fat content and an increase in moisture content after washings. Temperature had the higher effect on breaking force; time had the higher effect on cutting strength and work of shearing, and washing solution:MSCM ratio had the higher effect on protein content. The application of the response surface methodology indicated that highest protein content, cutting strength, work of shearing, breaking force, and gel strength were obtained at the central point of the proposed experimental design, corresponding to the processing conditions of 7 °C, 10 min and 4:1 washing solution:MSCM ratio. The MSCM surimi-like material obtained at these conditions presented the same characteristics of a high quality MSCM surimi-like material, i.e., high gel strength and the maximum score in the folding test. The reduction of the textural properties after this point are due to the combined effect of temperature, time and washing ratio in excess, which contribute to the mislay of protein content and, consequently, gel quality. The obtained process conditions and surimi-like material represent a viable alternative source for the production of surimi-based products.

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