

Effects of washing step and salt-addition levels on textural and quality properties in the chicken-surimi products

Yi-Hsieng Samuel Wu ^{*,1} Yi-Ling Lin ^{*,1} Sheng-Yao Wang,^{*} Danqing Lin,^{*} Jr-Wei Chen,[†] and Yi-Chen Chen ^{*,2}

^{*}Department of Animal Science and Technology, National Taiwan University, Taipei 106, Taiwan; and [†]Poultry Industry Section, Department of Animal Industry, Council of Agriculture, Executive Yuan, Taipei 100, Taiwan

ABSTRACT The massive wastewater from surimi manufacture and salt addition is controversial. In our previous study, a chicken-surimi (CS) product can be successfully developed from the spent-hen breast via 3 times of washing steps and 2.5% salt addition in the recipe. Due to the characteristics of broiler breast (higher protein contents in muscle), this study was to optimize the washing step for CS batter recovered from broiler breast and the salt-addition level in the CS-product recipe. The step of washing once with 0.1% salt solution showed no ($P > 0.05$) differences in the texture profile and color parameters (except a* value) in CS batters

compared to initial washing steps (a 3-step washing procedure). The CS batter obtained by this washing step had higher amino-acid contents than boiler breast and large Grade A egg and even fit adults' daily essential amino-acid requirement. Besides, the lower ($P < 0.05$) water loss of cooked CS products during the storage (4° C) was shown beyond 2.0% salt addition in CS products. For efficient/ecofriendly extraction and sodium-content reduction, the washing once with a 0.1% salt solution and 2% salt addition in the recipe is recommended in the CS batter recovered from broiler breast and its products, respectively.

Keywords: chicken surimi, extraction step, salt reduction, processing properties, nutritional composition

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INTRODUCTION

Surimi is a unique functional food material made of myofibrillar protein in fish muscle or other animal-sourced meats, that is, chicken and pork (Kim and Park, 2008; Choi et al., 2012; Liu et al., 2014; Wang et al., 2016). Although this kind of meat product was commonly available in the Asian-Pacific markets, it had been developed on an industrial scale in Japan and named “surimi” several centuries ago. Surimi and surimi-based products, Kamaboko, are traditional Japanese products, which occupy an important position in the dietary culture in Japan. Due to their unique textural properties and high nutritional value, the surimi-based product has become more and more various and popular (Park and Morrissey, 2000; Pepe et al., 2007). The excellent quality of surimi is odorless and has a creamy white appearance with excellent gelling properties to

form into various shapes before cooking and setting (Morrissey et al., 2000). Park (2013) indicated that most retailed surimi-based products are a good source of magnesium, protein, vitamin B12, phosphorus, and selenium without saturated fat. Nowadays, surimi could even be included ω -3 rich oil, egg white, or dietary fiber (Pietrowski et al., 2011; Wang et al., 2016; Wu et al., 2021). Most myofibrillar protein (salt-soluble protein) is retained in the surimi manufacture. However, fat and sarcoplasmic protein (water-soluble protein, i.e., hemoglobin/myoglobin, nucleic acids, enzymes, etc.) can be removed through the washing steps (usually washed for 2–3 cycles) (Lee and Min, 2004; Wang et al., 2016). Due to the washing cycles, the massive wastewater increases the surimi production cost and causes environmental pollution.

The raw materials in the production of a surimi-based product can also result from other meats, such as chicken (Wang et al., 2016), pork (Choi et al., 2012), and beef (Ruiz et al., 1993). However, the surimi manufacture provides a new utilization to increase the added value (Martín-Sánchez et al., 2009; Wang et al., 2016; Wu et al., 2021). As we know, chicken meat has many desirable nutritional characteristics, such as low lipid content and a relatively high concentration of polyunsaturated fatty acids that can be further increased by

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¹These authors contributed equally as co-first authors.

²Corresponding author: ycpchen@ntu.edu.tw

specific dietary strategies. Recently, our team invested that CS batters extracted from spent hen breast can be fortified with flaxseed oil to increase its nutritional value (Wang et al., 2016), and the shelf-life of this flaxseed-oil fortified chicken surimi can be extended by adding a rosemary extract and dry ice in the manufacturing procedure (Wang et al., 2019). Moreover, our recent report indicated that this surimi product's flaxseed-oil addition and texture could be enhanced and improved by wheat fiber addition (dietary fiber), respectively (Wu et al., 2021). This CS product with some healthy claims could be a potential material to develop products for children and elders.

The salt (sodium chloride, **NaCl**) addition in the CS formula may cause another health concern for consumers. Salt is the most common additive and essential in meat processing for technical, antimicrobial, and sensory purposes (Nattress et al., 2001; Hutton, 2002). Moreover, salt plays a vital role in the solubilization of myofibrillar proteins. Salt gives the meat gel a good water-fat-retention and acceptable elasticity for subsequent processing. Besides, salt can solubilize myofibrillar proteins in meat, forming a gel and ideal texture (Puolanne et al., 2001). The major effect of NaCl on improving water-holding capacity (**WHC**) is by swelling myofibrillar proteins, which can swell to double the size depending on the concentration of NaCl (Siró et al., 2009). The NaCl effect on meat proteins is most probably caused by the fact that chloride ions (**Cl⁻**) are more strongly bound to the proteins than sodium (**Na⁺**), which increases the electrostatic repulsive force between myosin and actin filaments (Basso et al., 2013). The protein structure matrix unfolds, and then swelling occurs with increasing the repulsive forces, which causes an increased negative charge of proteins. The ion "cloud" from sodium was formed around the myofibrillar proteins (myofilaments), and the differences in local ion concentrations increased osmotic pressure within the myofibrils. Consequently, it caused the filament lattice to swell (Cheng and Sun, 2008). The swelling provides a higher number of protein side chains to bind water, which improves the WHC of meat (Fernández-Martín et al., 2002).

Nowadays, upon the development of society, more and more people tend to have a nutrient-balanced and healthy diet to improve or keep the life quality. Meat and meat products are an essential part of developed or even developing countries due to high consumption (Jiménez-Colmenero et al., 2001). On the other hand, there are controversies for meat products such as high calories, cholesterol, and sodium. In order to produce health-beneficial and high-quality meat products, it is necessary to avoid undesired compounds, such as saturated fatty acid and sodium, or reduce them to appropriate the limits (Jiménez-Colmenero, 2007). Arihara (2006) reveals that intervention during the preparation stages is one strategy that alters foods' composition. In this case, reformulation is useful and possible to develop a range of derivatives with custom-designed composition and properties.

As we know, through the washing process, sarcoplasmic proteins and other impurities can be removed, and then the shelf life of surimi-like products can be prolonged. According to our previous report (Wang et al., 2016), 0.1% (w/v) salt solution instead of distilled water in the last (the third) washing step for spent-hen breast during the surimi manufacture can reduce the loss of myofibrillar protein and moisture content in the final CS batter while CS product can be developed by 2.5% addition in the recipe. Due to more purity in broiler breast than that in spent-hen breast, this study would first dig into an optimal washing method on the efficacy of the CS-batter extraction from broiler breast and then investigate the suitable salt-addition level for the recipe of CS products. Finally, this study aims to develop the semi-manufactured CS batter based on ecofriendly manufacture, sodium reduction, cost-efficacy, and good physico-chemical properties.

MATERIALS AND METHODS

Preparation of Chicken-Surimi Batters

This study was to divide into 2 objectives:

- 1) Optimal washing steps of chicken-surimi-batter extraction: The broiler breast was purchased from a local meat packer (Ding Yao Food Co. Ltd., New Taipei City, Taiwan) and packaged in plastic bags (PE/nylon) and then transported to our lab under -20°C environment. Based on our previous study (Wang et al., 2016), a washing solution containing 0.1% (w/v) salt (Taiyen Co., Tainan, Taiwan) in the last (third) washing step could effectively reduce the loss of myofibrillar proteins in the extraction of proteins from a spend-hen-chicken breast. Hence, tap water with or without 0.1% (w/w) salt (Taiyen Co.) was used in this experiment. Different methods (Control: pure chicken breast; T1: washing once [0.1% salt solution]; T2: washing once [tap water]; T3: washing twice [tap water + 0.1% salt solution]; T4: washing three times [tap water + tap water + 0.1% salt solution]) were applied to prepare the CS batters. The CS batters were minced using a homogenizer (Model: RC-Blixer 4, 4.5L S/S bowl robot couple, South Melbourne, Australia). Each step of the washing process was followed by centrifugation at $8,000 \times g$ for 15 min at 4°C (Centrifuge 6500, Kubota Corp., Osaka, Japan) for dehydration. During each washing step, the minced broiler breast was blended with a 4°C washing solution in a ratio of 1:4 (w/w). About texture profile analyses, color properties, cooked CS-batter samples were prepared by mixing recovered chicken breast proteins extracted from different washing steps with 2.5% (w/w) salt (Taiyen Co.), 0.3% (w/w) polyphosphate (Chien-Yuan Inc., Taipei, Taiwan), a cryoprotectant mixture of 4.0% (w/w) trehalose (Hayashibara Shoji Inc., Okayama, Japan) and 4.0% (w/w) sorbitol (Roquette, Lestrem, France).

2) Optimal salt-addition level in the recipe of chicken-surimi products: The broiler breast was also purchased from a local meat packer (Ding Yao Food Co. Ltd., New Taipei City, Taiwan) and packaged in plastic bags (PE/nylon) and then transported to our lab under -20°C environment. First, CS-batter samples were obtained by mixing recovered chicken breast proteins with 0.3% (w/w) polyphosphate, cryoprotectant mixture [4.0% (w/w) trehalose and 4.0% (w/w) sorbitol], and then stored at -20°C . SiO_2 (Chien-Yuan Inc., Taipei, Taiwan) was added to CS batters as a food additive to the formula. The CS samples were thawed overnight in a refrigerator (4°C) before the experiment started. Then, those materials were divided into 6 parts, and different salt (Taiyen Co.) levels (0, 0.5, 1.0, 1.5, 2.0, and 2.5%) were incorporated into CS-batter samples (Supplementary Table 1). All CS samples were heated in a circulator water bath (GDB160, Genepure Technology Co., Ltd., Taichung, Taiwan) at 95°C for 15 min. The heat-set CS products were collected for subsequent analyses.

Textural and Nutritional Analyses

Moisture Content and Production Yield and of Raw Chicken-Surimi Batters. The moisture content of cooked CS products was determined using the oven-drying method (105°C for 24 h), and the measurement of production yield of raw CS batter referred to the method of Jin et al. (2007). The production yields of raw CS batters recovered from different washing methods were calculated as the following formula:

$$\begin{aligned} &\text{Production yield (\%)} \\ &= \frac{\text{weight of raw chicken - surimi batter}}{\text{weight of the raw chicken breast}} \\ &\quad \times 100 (\%) \end{aligned}$$

Color Parameter of Cooked Chicken-Surimi Products The color was determined using a color checker (Model NR-11, Nippon Denshoku, Bunkyo, Tokyo, Japan). The L^* (lightness), a^* (red to green), and b^* (yellow to blue) values show lightness, redness, and yellowness, respectively. Whiteness was calculated using the following equation (Ramadhan et al., 2012):

$$\text{Whiteness} = 100 - \sqrt{(100 - L^*)^2 + a^{*2} + b^{*2}}$$

One hundred grams of raw CS sample was vacuum packed by using a vacuum packaging machine (JV01, Jaw Feng Machinery Co., Ltd., Chiayi County, Taiwan) and heated for 15 min in the circulator water bath (GDB160, Genepure Technology Co., Ltd.) at a temperature of 95°C . The sample surfaced measured color parameter values (CIE L^* , a^* , and b^*) were measured on the sample surfaced. Then CS-batter samples were equilibrated to room temperature for approximately 2 h

before cooling to the color measurement at a core temperature of 25°C .

Texture Profile Analysis of Cooked Chicken-Surimi Products Texture profile analysis (TPA) is an empirical method to assess the textural characteristics of meat products (Wu et al., 2021). Six parameters were obtained in this study, that is, hardness (N), springiness, cohesiveness, gumminess (N), chewiness (N), and resilience. TPA has performed at least three replicates of each independent-batch sample. When CS samples were cooked and cooled as previously described, one cm^3 cubic sample was prepared. The textural properties of each cooked CS sample were measured by a cylinder probe P/50 (50-mm diameter cylinder aluminum, Stable Micro System Ltd., Godalming, UK) and a texture analyzer (TA.XT plus, Stable Micro System Ltd.). The samples were compressed to 60% of strain, and the test speed was 5 mm/s (Supplementary Table 2). Supplementary Figure 1 shows the schematic diagram of the correlation between force and time while chewing by texture profiler analyzer.

Sodium Dodecyl Sulfate-Polyacrylamide Gel Electrophoresis. The sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) analysis was referred to Wang et al.'s (2016) method with slight modifications. The raw CS batters and supernatants were obtained from different washing methods and collected from each washing process, respectively. About 0.2-g CS batter was added with 7.8 mL of phosphate buffer saline (PBS, pH 7.0) on ice and then centrifuged at $2,500 \times g$ for 10 min at 4°C . A 50 μL filtrate from the centrifuged tubes or 50 μL supernatants collected from each washing process of different washing methods was mixed with 5 μL of 5X loading dye [10% (w/v) sodium dodecyl sulfate (SDS, Bionovas Biotechnology Co., Ltd, Bremerton, WA), 0.05% (v/v) β -mercaptoethanol (Amreso, LLC., Cleveland, OH), 20% (v/v) glycerol (Sigma-Aldrich Co., LLC., St. Louis, MO), 0.2% (w/v) bromophenol blue (Sigma-Aldrich Co., LLC.) in 3M Tris-HCl (Bio basic inc., Markham ON, Canada) at pH 6.8] and heated in the circulators water bath (GDB160, Genepure Technology Co., Ltd.) at 95°C for 15 min. A 5 μL aliquot of sample was applied onto the polyacrylamide stacking gel (5%, w/v) and running gel (10%, w/v). The BlueRay Prestained protein ladder (Genedirex, Inc., Taoyuan City, Taiwan) was used as a molecular weight marker to identify the protein patterns. Electrophoresis was carried out in a Mini-PROTEAN Tetra Cell (Bio-Rad Laboratories Informatics Division, Philadelphia, PA) at 80V for approximately 30 min, and then changed to 120 V for approximately 90 min until the bromophenol blue marker reached the bottom of the gel. Gels were subsequently stained for 15 min in 0.06% (w/v) Coomassie Brilliant Blue G-250 (Sigma-Aldrich Co., LLC.) in 10% (v/v) acetic acid (Sigma-Aldrich Co., LLC.) and then de-stained in 7.5% (v/v) acetic acid and 5% (v/v) methanol for 4 h. Photomicrographs were obtained with an imaging system (MUV21-312, Major Science Co., Saratoga, CA).

Nutritional Analyses of Chicken-Surimi Products

Proximate Analyses of Cooked Chicken-Surimi Products. The proximate analyses of cooked chicken-surimi (CS) products (2.0 or 2.5% salt addition) were based on the methods from AOAC (1995). Briefly, the moisture content of cooked CS products was determined using the oven-drying method (105°C for 24 h), whereas the fat content in cooked CS products was determined according to the Soxhlet extraction method. Sample size and extraction time were 5 g and 16 h at a drip rate of approximately 10 mL/min, respectively, and extractions were performed with petroleum ether. Besides, crude protein was determined by the Kjeldahl assay. Last, ash content was performed by incinerating a sample in a muffle furnace at 550°C for 24 h. The following formulation obtained carbohydrate content in CS products: Carbohydrate = 100 - (Moisture + Fat + Protein + Ash). All of the results were expressed as g/100 g reported as the mean value of duplicates of each sample. A calculation obtained the calories of CS products as Calories (kcal/100 g) = Carbohydrate × 4 + Fat × 9 + Protein × 4.

Amino-Acid/Mineral Profile of Raw Chicken-Surimi Batter/Chicken Breast and Cooked Chicken-Surimi Products (2.0 and 2.5% Salt Addition) The amino-acid and mineral profiles of samples were analyzed at Experiment Station Chemical Laboratories of the National Animal Industry Foundation, Pingtung, Taiwan. The 1-gram sample was briefly added in 2 mL methane sulfonic acid solution (4N) and vacuumed. Amino acids in samples were identified and quantified using a high-performance liquid chromatography (HPLC) system (Agilent #1100; Agilent Technologies, Santa Clara, CA). The data were described as mg amino acid per gram CS batter and CS product, respectively. Regarding the mineral profile of samples, all glass containers were soaked in 10% (w/v) hydrochloric acid solution for 24 h to further experiments. First, the ashed sample was added with 2-mL nitric acid (70%). Acidized samples were diluted by double-distilled water (ddH₂O) filtered. The filtrate was diluted to a 50 mL volumetric bottle by ddH₂O. The mineral profile of samples was analyzed by an Inductively Coupled Plasma-Optical Emission Spectrometer (ELEMENT 2*ICP-MS, Thermo Fisher Scientific Inc., MA). The analysis includes lead (Pb), arsenic (As), manganese (Mn), selenium (Se), calcium (Ca), iron (Fe), magnesium (Mg), potassium (K), and sodium (Na).

Centrifugation and Purge Losses of Cooked Chicken-Surimi Products With Different Salt Added Levels During the Storage. According to previous methods with slight modifications, measurements of centrifugation and purge losses of cooked CS products with different salt added levels were made with a slight modification (Wu et al., 2021). Centrifugation and purge loss of cooked CS products was measured immediately after manufacture and in each 3-d interval of 12-d storage at

4°C. The samples were cut into approximately 1.0 to 1.5 cm long and 0.15 to 0.20 g. The samples were placed in 1.5-mL tubes with an ADVANTEC No. 1 filter paper (Toyo Roshi Kaisha, Ltd., Tokyo, Japan) in the bottom of tubes to separate the samples from the expelled liquid. The samples were then centrifuged at 100 *g* for one h at 4°C. After centrifuging, the samples were weighed again. Then the centrifugation loss was calculated as the difference in weight before and after centrifugation. Regarding the purge loss of samples during the storage, samples were dried with Kimwipes (Kimberly-Clark Global Sales, Inc., Roswell, GA) to remove excess surface moisture, weighed to determine the initial weight, and packaged with zipper storage bags. After the storage period, samples were removed from their storage bags, dried with Kimwipes, and weighed again. Purge loss was calculated as a percentage of the weight of each sample at each storage period (3, 6, 9, and 12th d) compared to their initial weights.

Statistical Analysis

The experiment was conducted using a completely randomized design (CRD). All analytical parameters were determined in 3 independent batches (at least 3 replications per batch). When a significant difference ($P < 0.05$) among groups was detected by using one-way ANOVA, differences between treatments were further distinguished by using the least significant difference (LSD) assay. Besides, the differences of 2.0 and 2.5% salt addition on nutritional composition and amino-acid/mineral profiles of CS products were distinguished by the Student *t*-test ($P < 0.05$). All statistical data analyses were conducted via SAS (SAS Institute Inc., Cary, NC, 2002).

RESULTS AND DISCUSSION

Determination of Optimal Washing Steps of Chicken-Surimi-Batter Extraction

Effects of Different Washing Steps on an Efficient Chicken-Surimi-Batter Extraction. As a result, it showed production yield and moisture content in raw CS batter (Table 1). With the increasing washing times, an increased ($P < 0.05$) production yields of CS batter were obtained, while a similar pattern on the moisture content of CS batters was also presented. The production yield of T1 treatment (83.96%) was the lowest ($P < 0.05$), and in comparison to other treatments, the highest ($P < 0.05$) production yield of T4 was up to 99.08%. However, the increased washing times also resulted in the higher ($P < 0.05$) moisture contents in the CS batters from 71.10% (pure chicken breast, Control) to 84.43% (T4 treatment). The recovered protein contents in the CS batters were decreased ($P < 0.05$) compared with the raw materials, chicken breast, while T4 treatment had the lowest ($P < 0.05$) recovered protein (15.420.30 g/100 CS batter). For the heat-set CS batter samples with 2.5% salt addition, hardness was

Table 1. Effects of different washing methods on production yield, moisture, and recovered protein of raw chicken-surimi batters and texture profile analysis and color properties of cooked chicken-surimi products with 2.5% salt addition.

Treatment ^A	Control	T1	T2	T3	T4
Production yield (g/100 breast)	100.00 ± 0.00 ^a	83.96 ± 0.87 ^d	87.44 ± 0.88 ^c	96.66 ± 0.56 ^b	99.08 ± 0.71 ^a
Moisture (g/100 g product)	71.10 ± 0.31 ^d	75.00 ± 0.36 ^c	77.57 ± 0.62 ^b	79.93 ± 1.13 ^b	84.43 ± 0.34 ^a
Recovered protein (g/100 product)	28.90 ± 0.31 ^a	20.98 ± 0.09 ^b	19.63 ± 0.74 ^b	19.40 ± 1.11 ^b	15.42 ± 0.30 ^c
			<i>Texture profile analyses</i>		
Hardness (N)	1.16 ± 0.02 ^a	1.11 ± 0.02 ^a	0.74 ± 0.01 ^b	0.68 ± 0.01 ^c	0.55 ± 0.03 ^d
Springiness	0.88 ± 0.01 ^a	0.88 ± 0.00 ^a	0.89 ± 0.01 ^a	0.90 ± 0.00 ^a	0.90 ± 0.01 ^a
Cohesiveness	0.65 ± 0.02 ^c	0.69 ± 0.01 ^b	0.71 ± 0.01 ^{ab}	0.72 ± 0.01 ^{ab}	0.75 ± 0.01 ^a
Gumminess (N)	0.75 ± 0.02 ^a	0.79 ± 0.01 ^a	0.52 ± 0.01 ^b	0.48 ± 0.01 ^b	0.41 ± 0.03 ^c
Chewiness (N)	0.66 ± 0.03 ^a	0.69 ± 0.01 ^a	0.46 ± 0.01 ^b	0.44 ± 0.01 ^b	0.37 ± 0.03 ^c
Resilience	0.29 ± 0.00 ^c	0.31 ± 0.01 ^{bc}	0.31 ± 0.00 ^{bc}	0.32 ± 0.01 ^{ab}	0.35 ± 0.01 ^a
			<i>Color properties</i>		
L*	81.66 ± 0.52 ^b	81.15 ± 0.19 ^b	81.14 ± 0.29 ^b	82.00 ± 0.76 ^b	83.43 ± 0.22 ^a
a*	1.03 ± 0.20 ^a	0.01 ± 0.03 ^b	-0.03 ± 0.04 ^b	-0.94 ± 0.26 ^c	-0.65 ± 0.23 ^c
b*	16.12 ± 0.60 ^a	16.35 ± 0.15 ^a	16.16 ± 0.48 ^a	17.70 ± 2.54 ^a	15.61 ± 0.88 ^a
Whiteness ^B	75.53 ± 0.04 ^a	75.04 ± 0.13 ^a	75.16 ± 0.29 ^a	74.67 ± 2.33 ^a	77.21 ± 0.76 ^a

^AControl: pure chicken breast; T1: chicken breast washed once (0.1% salt solution); T2: chicken breast washed once (tap water); T3: chicken breast washed twice (tap water+0.1% salt solution); T4: chicken breast washed three times (tap water + tap water+0.1% salt solution).

^BWhiteness = $100 - \sqrt{[(100-L)^2 + a^{*2} + b^{*2}]}$ (Ramadhan et al., 2021); Data are given as Mean ± SEM (n = 3).

^{a-d}Mean values without a common letter in each testing parameter are significantly different via the LSD test ($P < 0.05$).

significantly influenced ($P < 0.05$) upon the washing times. The lowest ($P < 0.05$) hardness was detected in the T4 treatment. CS batters obtained from T1 treatment demonstrated the highest ($P < 0.05$) hardness, which is similar to those from the pure chicken breast (Control) but higher than ones obtained from other treatments. There were no ($P > 0.05$) differences among pure chicken breast and treated groups about springiness. Cohesiveness values of heat-set CS obtained from T4 treatments were significantly higher ($P < 0.05$) than those obtained from T1 and pure chicken breast. The resilience among treatments illustrated a similar pattern as cohesiveness results. According to the results of color analyses of heat-set CS batter samples with 2.5% salt addition (Table 1), the redness (a^*) of the CS batter samples was decreased ($P < 0.05$) by washing methods. Moreover, CS batter obtained from the T4 treatment had the highest ($P < 0.05$) lightness (L^*) than those from other treatments and Control. In contrast, there were no ($P > 0.05$) differences in yellowness (b^*) and whiteness among treatments (Table 1). Besides, the protein patterns in the supernatant collected from each step of different washing steps and final CS batters from different washing steps were illustrated in Figures 1A and 1B, respectively. The amount of water-soluble protein (sarcolemmal protein, mainly some enzymes) from the T1 supernatant was more than the T2 treatment, while those of T3 and T4 were not different in the first regular water washing (Figure 1A). On the other hand, the salt-soluble protein (myosin and actin) in the CS batter decreased as the washing steps increased (Figure 1B).

The moistures of CS batters were increased, accompanied by washing times (Table 1). As we know, the high moisture in meat products affects the preservation of the product because high water activity promotes the growth of bacterial colonies. Besides, those results also agreed with results obtained by Jin et al. (2007), who reported that the increase of the washing cycle would decrease hardness. Based on the data of texture analysis profile of cooked CS batter samples from various

washing steps, T1 treatment had the highest ($P < 0.05$) hardness, gumminess, and chewiness but lower cohesiveness and resilience (Table 1). The texture characteristics among various CS washing treatments may echo that the higher moisture content in CS batters decreases the hardness, gumminess, and chewiness and increases cohesiveness and resilience. Therefore, more complicated washing steps may not be suitable for manufacturing broiler breast-based CS batter.

Regarding the appearance of surimi products, Ramadhan et al. (2012), Wang et al. (2016), and Wu et al. (2021) pointed out that color is one of the most critical factors in the quality of surimi and is affected by subsequent processing surimi. Chaijan et al. (2005) also reported that the washing process is necessary for color improvement and the gel strengthening of surimi products. The color of the surimi could be improved by increasing the washing times because the consumers preferred white fish-surimi products. Furthermore, they also reported that redness values are decreased mostly due to the decreased concentration of water-soluble proteins (mainly myoglobin and hemoglobin) in surimi processing. Ochiai et al. (2001) indicated that high-quality surimi with lower redness could be obtained when the myoglobin and hemoglobin in dark muscle are washed out as much as possible. However, the a^* values of T3 and T4 were decreased ($P < 0.05$), which may not influence the preferences (whiteness) due to the slight difference (Table 1). Besides, the results of SDS-PAGE indicated that most of the water-soluble proteins could be removed via the first washing (Figure 1A), and the result of 0.1% salt solution washing compared to other treatments could remove more impurities without enhancing the moisture in the CS batter (Table 1).

Meanwhile, an excessive washing step might lead to the dissolution of salt-soluble proteins. For further commercial-scale production, T1 treatment could solve massive wastewater and decrease the cost of sewage treatment equipment for the CS batter extracted from broiler breast. Thus, the T1 (washed once by using 0.1%

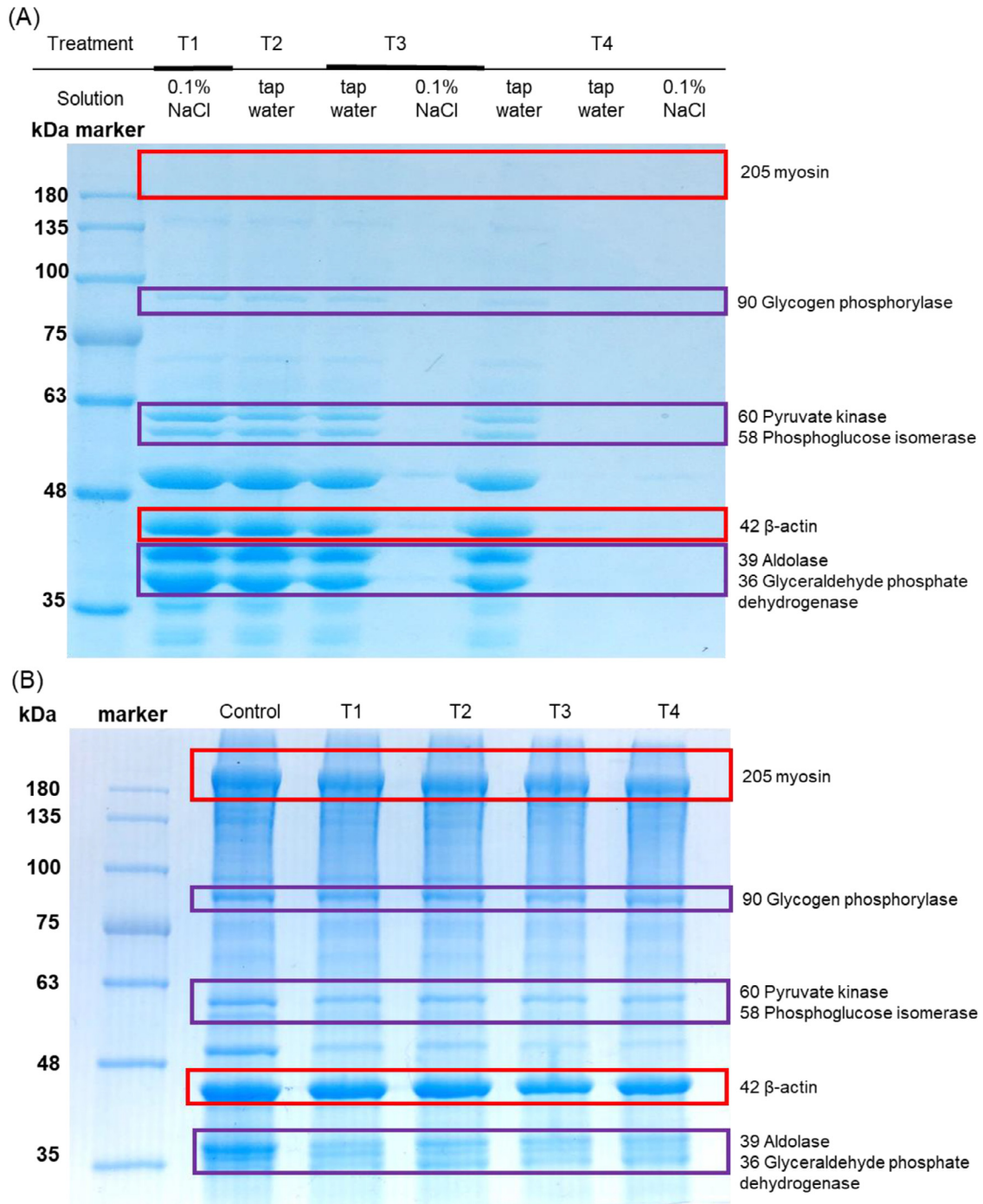


Figure 1. (A) SDS-PAGE of protein patterns in supernatants affected by different washing methods and (B) SDS-PAGE of protein patterns in the chicken-surimi batter affected by different washing methods. Control: pure chicken breast; T1: chicken breast is washed once (0.1% salt solution); T2: chicken breast washed once (tap water); T3: chicken breast is washed twice (tap water + 0.1% salt solution); T4: chicken breast is washed three times (tap water + tap water + 0.1% salt solution). Abbreviation: SDS-PAGE, sodium dodecyl sulfate-polyacrylamide gel electrophoresis.

salt solution) processing can be chosen as the optimal treatment for manufacturing CS batter from broilers because more complicated washing steps do not make better texture and attractive color but result in the higher water content, which causes difficult handling for the further processing. Moreover, the CS batter extraction using the T1 method could be more efficient and ecofriendly due to refining the washing method.

Amino-Acid Composition of Chicken-Surimi Batter Obtained From T1 Treatment The contents of both total essential amino acids (total EAA) and branched-

chain amino acids (BCAAs) in the CS batter obtained from T1 treatment were higher than those of broiler breast (Table 2). The proportions of lysine, threonine, histidine, methionine, leucine, and isoleucine accounted for 22.3, 15.1, 6.6, 19.6, and 14.5 mg/g CS batter, were higher than those of chicken breast. In comparison with the EAA profile of large whole eggs (Grade A), the CS batter had higher amino-acid content than the eggs, and the BCAA content even reached 1.875 and 1.3 folds of the whole large egg (24 mg/g egg) and the adult requirement (34 mg/g protein), respectively (Table 2).

Table 2. Total amino acid composition of raw chicken-surimi batter^A and broiler breast.

Amino acid	Chicken-surimi batter (mg/g batter)	Broiler breast (mg/g breast)	Whole egg* (mg/g egg)	Adults** (mg/Kg BW/day)
Lysine	22.3	18.2	8.32	12
Threonine	15.1	8.2	5.94	7
Histidine	6.6	6.0	2.83	8-12
Methionine	6.0	4.6	8.03 [#]	13 [#]
Phenylalanine	5.7	7.6	11.72 ^{##}	14 ^{##}
Tryptophan	1.5	1.7	1.66	3.5
Leucine	19.6	16.6	10.50	14
Isoleucine	14.5	10.3	6.16	10
Valine	10.9	11.2	7.34	10
Total EAA	102.2	84.4		
Total BCAA	45.0	38.1		
Glutamic acid	39.4	31.1		
Aspartic acid	24.6	19.5		
Alanine	12.2	12.1		
Tyrosine	8.1	5.7		
Serine	7.7	7.4		
Glycine	7.6	8.9		
Proline	6.0	4.7		
Cysteine	2.8	2.7		
Arginine	17.2	18.6		
Total NEAA	125.6	110.6		

^AChicken-surimi batters were obtained via T1 treatment.

*Composition of whole large egg (Grade A) from [USDA Research Service, Food Data Central \(2021\)](#).

**Values are based on people older than 12 years old from [FAO/WHO/UNU Expert Consultation \(1985\)](#).

[#]Methionine + cysteine.

^{##}Phenylalanine + tyrosine.

EAA: essential amino acid; BCAA: branched-chain amino acid; NEAA: non-essential amino acid.

Regarding the functionalities of most EAAs in CS batters, lysine could help calcium absorption and promote collagen formation ([Fini et al., 2001](#)). Threonine can maintain protein balance in the body and help to control epileptic seizures ([Chapman et al., 2008](#)). Besides, leucine, isoleucine, and valine belong to BCAAs that directly provide energy for skeletal muscle and help muscle protein synthesis ([Shimomura et al., 2004](#)). EAAs also promoted muscle health in elderly adults ([Volpi et al., 2003](#)); therefore, increasing the concentration of EAAs in the elderly food product. From the results, the CS batter obtained from T1 treatment (washed once by using 0.1% salt solution) could offer a more nutritious source of high-quality protein for human consumption, especially the elderly.

Determination of Optimal Salt-Addition Level for Chicken-Surimi Products

Effects of Different Salt-Addition Levels on Texture Profile and the Water Holding Capacities of Cooked Chicken-Surimi Batters. Table 3 shows the effects of different salt-addition levels on texture profiles of cooked CS products. Hardness, gumminess, and chewiness of CS products were increased ($P < 0.05$) when the salt was added to the recipe, but other parameters such as springiness, cohesiveness, and resilience generally decreased. The CS product with 2.0 and 2.5% salt addition had higher ($P < 0.05$) hardness values than those with other salt-addition levels. On the contrary, the CS products had lower ($P < 0.05$) springiness, cohesiveness, and resilience values when the salt was added beyond 2.0% salt

in the recipe. However, no ($P > 0.05$) differences between those with 2.0 and 2.5% salt additions were detected regarding the texture profile of CS products. Focusing on other important physical properties of cooked CS products, centrifugation and purge losses in a 3-d interval were used to evaluate the WHC of cooked CS products with different salt-addition levels within 12 d of storage at 4°C ([Figure 2](#)). CS products showed increasing ($P < 0.05$) centrifugation loss when the salt was added below 2.0% ([Figure 2A](#)). A similar pattern in the purge loss (%) of cooked CS products is in [Figure 2B](#). Meanwhile, there was no ($P > 0.05$) difference in centrifugation and purge losses of cooked CS products between the 2.0 and 2.5% salt additions.

[Kim and Park \(2008\)](#) indicated that salt addition is required to extract myofibrillar proteins and obtain the desired texture upon cooking in the surimi gelation. Almost all surimi seafood was manufactured with salt up to 2.5% to maintain taste, texture, and microbial safety ([Kim and Park, 2008](#); [Wang et al., 2016](#); [Wang et al., 2019](#)). The measurement of centrifugation loss is developed to assess a fast determination of WHC in meat products, and purge loss is to understand a loss from meat products influenced by the myofibrils' capacity that holds water in the meat products ([Kristensen and Purslow, 2001](#)). Based on our results, the lowest ($P < 0.05$) WHC performance in CS products was observed without salt addition ([Figure 2](#)). These 2 characteristics are applied to indicate the ability to retain water in meat upon storage. Overall, the cooked CS product showed the weakest gel without the salt addition, while a concentration beyond 2.0% salt added CS batters also demonstrate better texture and WHC

Table 3. Textural profile of cooked chicken-surimi products with different salt-addition levels.

Treatment (salt-addition level)	Hardness (N)	Springiness	Cohesiveness	Gumminess (N)	Chewiness (N)	Resilience
0.0%	0.06 ± 0.01 ^d	0.91 ± 0.00 ^a	0.69 ± 0.00 ^a	0.42 ± 0.01 ^c	0.38 ± 0.01 ^e	0.31 ± 0.01 ^{ab}
0.5%	0.65 ± 0.01 ^c	0.90 ± 0.02 ^a	0.68 ± 0.00 ^a	0.45 ± 0.01 ^c	0.40 ± 0.01 ^{de}	0.30 ± 0.01 ^{ab}
1.0%	0.68 ± 0.01 ^c	0.91 ± 0.01 ^a	0.66 ± 0.01 ^{ab}	0.45 ± 0.00 ^c	0.41 ± 0.01 ^{de}	0.28 ± 0.01 ^b
1.5%	0.82 ± 0.02 ^b	0.89 ± 0.02 ^{ab}	0.65 ± 0.01 ^{bc}	0.54 ± 0.02 ^b	0.48 ± 0.01 ^c	0.30 ± 0.01 ^{ab}
2.0%	1.05 ± 0.02 ^a	0.84 ± 0.01 ^{bc}	0.62 ± 0.01 ^{cd}	0.65 ± 0.01 ^a	0.55 ± 0.01 ^b	0.25 ± 0.01 ^c
2.5%	1.09 ± 0.02 ^a	0.86 ± 0.01 ^c	0.62 ± 0.02 ^d	0.68 ± 0.03 ^a	0.58 ± 0.03 ^a	0.25 ± 0.01 ^c

Data are given as Mean ± SEM (n = 3).

^{a-d}Mean values without a common letter in each testing parameter affected by different salt-addition levels are significantly different via the LSD test ($P < 0.05$).

upon the storage. Therefore, based on the results from this study, the 2% salt addition for the ideal textural development of CS batters was suggested.

Nutritional Composition and Amino-Acid/Mineral Profiles in Cooked Chicken-Surimi Products

The proximate analyses and amino-acid/mineral profiles of cooked CS products with 2.0 and 2.5% salt additions were demonstrated in Table 4. The calories and ash contents of the 2.5% salt added surimi product were higher ($P < 0.05$) than that of 2.0% salt added one (Table 4), whereas the moisture content decreased ($P < 0.05$) while the salt addition elevated from 2.0% to 2.5%.

There was only a tendency toward higher amino acid contents in 2.5% salt added surimi among all amino acids. Regarding the content of minerals in cooked CS products with both salt additions, the lead (Pb), arsenic (As), cadmium (Cd), manganese (Mn), and calcium (Ca) were detected in neither 2.0 nor 2.5% salt added CS products (Table 4). Selenium (Se), iron (Fe), and magnesium (Mg) were assayed in the cooked CS products, but no ($P > 0.05$) differences were observed. Last, the increased ($P < 0.05$) concentrations of potassium (K) and sodium (Na) were analyzed with the higher salt addition, but the iron was significantly decreased ($P < 0.05$). The higher calories and ash content are highly related to the lower moisture content (dehydration phenomenon) in the 2.5% salt added-surimi product. Regarding the regulatory levels of toxic mineral contents in food products (Food and Drug

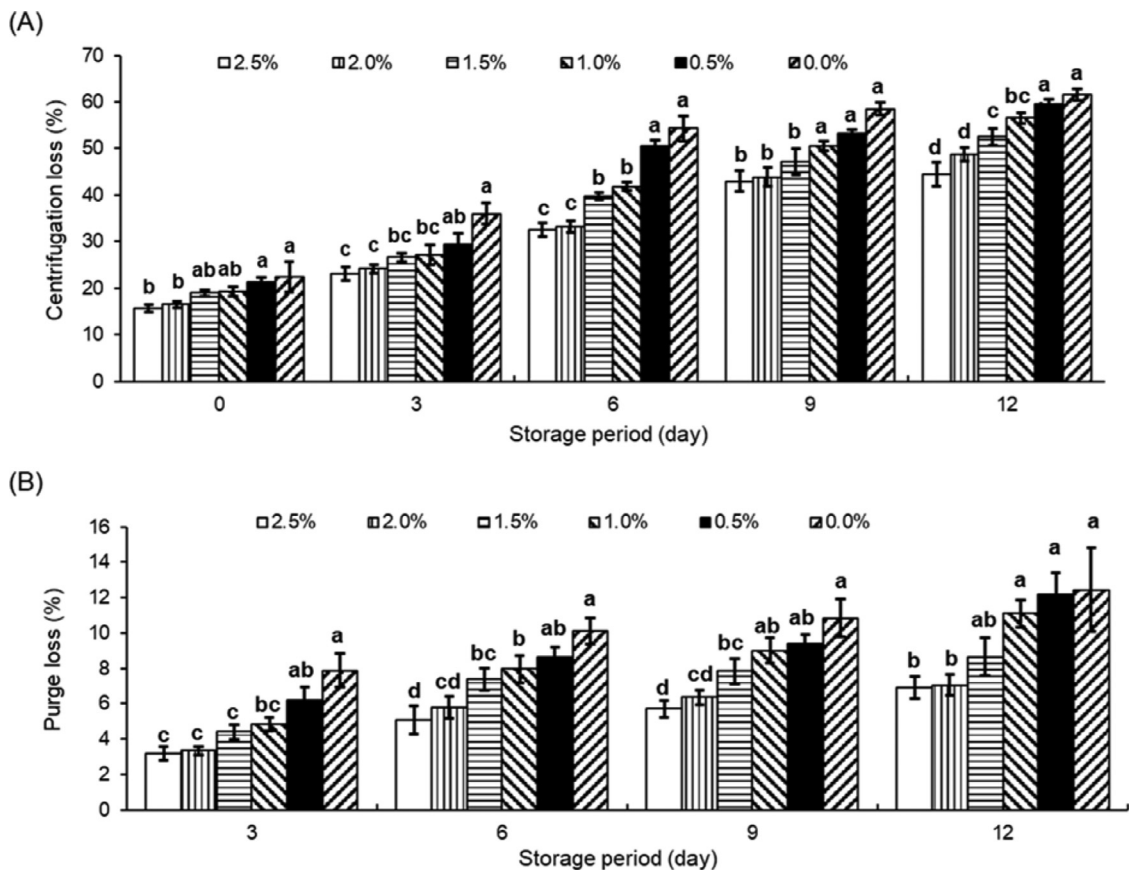


Figure 2. (A) Centrifugation loss (%) and (B) purge loss (%) of cooked chicken-surimi products with different salt-addition levels during 12 d of storage at 4°C. Data is given as Mean ± SEM (n = 3). ^{a-d}Data bars without a common letter in each storage period are significantly different via the LSD test ($P < 0.05$).

Table 4. Nutritional composition and amino-acid/mineral profiles of cooked chicken-surimi products with 2.0 and 2.5% salt-addition levels, respectively.

	2.0% salt	2.5% salt
Nutritional composition		
Calories (kcal/100 g)	113.6 ± 0.4	123.5 ± 0.7*
Moisture (g/100 g)	70.8 ± 0.1*	68.0 ± 0.2
Ash (g/100 g)	2.6 ± 0.0	3.0 ± 0.0*
Fat (g/100 g)	1.5 ± 0.1	1.5 ± 0.4
Carbohydrates (g/100 g)	6.0 ± 0.5	6.6 ± 0.3
Protein (g/100 g)	19.1 ± 6.4	21.0 ± 1.2
Amino-acid profile (mg/g)		
Lysine	17.5 ± 5.1	19.1 ± 4.3
Threonine	9.5 ± 1.8	9.6 ± 1.7
Histidine	5.0 ± 3.6	5.4 ± 1.1
Methionine	4.4 ± 3.6	4.1 ± 5.7
Phenylalanine	7.3 ± 0.9	7.6 ± 1.5
Tryptophan	2.3 ± 0.2	2.5 ± 0.1
Leucine	15.7 ± 4.0	16.5 ± 3.2
Isoleucine	11.2 ± 0.4	11.1 ± 1.6
Valine	9.4 ± 2.0	10.0 ± 2.1
Glutamic acid	29.9 ± 7.4	32.0 ± 8.3
Aspartic acid	18.9 ± 4.5	19.8 ± 4.8
Alanine	10.7 ± 3.6	11.5 ± 3.7
Tyrosine	6.0 ± 4.1	6.5 ± 0.7
Serine	6.7 ± 1.9	6.9 ± 1.9
Glycine	7.5 ± 1.8	7.9 ± 2.4
Proline	3.1 ± 7.5	2.6 ± 2.0
Cystine	1.9 ± 1.2	2.0 ± 0.5
Arginine	13.6 ± 4.2	14.5 ± 3.4
Mineral profile		
Lead, Pb (ppm)	N.D.	N.D.
Arsenic, As (ppm)	N.D.	N.D.
Cadmium, Cd (ppm)	N.D.	N.D.
Manganese, Mn (ppm)	N.D.	N.D.
Calcium, Ca (mg/100 g)	N.D.	N.D.
Selenium, Se (ppm)	0.1 ± 0.0	0.1 ± 0.0
Iron, Fe (mg/100 g)	0.32 ± 0.0	0.31 ± 0.0
Magnesium, Mg (mg/100 g)	9.1 ± 0.0	9.5 ± 0.1
Potassium, K (mg/100 g)	66.4 ± 0.6	73.4 ± 0.4*
Sodium, Na (mg/100 g)	807.2 ± 13.6	1061.0 ± 15.6*

Chicken-surimi batters were recovered via the T1 method.

Data are given as Mean ± SEM (n = 3).

*P < 0.05.

Administration, Department of Health and Welfare, Executive Yuan, Taiwan, 2018), the levels of Pb and Cd in poultry's edible muscle, and As in lipids are not allowed over than 0.1, 0.05, and 0.1 ppm, respectively. Hence, these 2 cooked CS products are safe for human consumption. Besides, the increased K and Na contents in cooked CS products upon the higher salt addition should be due to the by-product ingredient in the table salt used in this study. Furthermore, as we know, the lower Na intake could decrease chronic diseases, especially hypertension or coronary disease. Hence, reducing salt added to 2% on the recipe of CS products would not alter the physical properties and nutrition value.

CONCLUSIONS

Salt reduction in meat processing products has been advocated in these years, which indicates that manufacturing modulation for salt reduction and eco-friendly may provide a strategy in practice. CS batter can be obtained from broiler breast via washing once with 0.1% (w/v) salt solution, which has the most

efficacy and ideal physical characteristics. This CS batter extracted from broiler breast can be successfully obtained by washing once with a 0.1% salt solution based on the sodium reduction, efficient and eco-friendly manufacture, and physicochemical properties. CS batters obtained via this washing method contain higher EAAs and BCAAs than broiler breasts and benefit human consumption. Regarding the salt added in the recipe of CS products, the reduction of salt addition (2.0%) is suggested owing to health concerns of sodium consumption, and meanwhile, could contribute the better gel texture and less moisture loss during the storage. The 2.0% salt is suggested to be added to the recipe for other CS kind products.

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DISCLOSURES

The authors declare that no competing financial interests or personal relationships have influenced the work reported in this paper.

SUPPLEMENTARY MATERIALS

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