

# Effect of Tofu Powder and Carrageenan on Functionality and Physical Characteristics of Surimi Emulsion Gel

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## ABSTRACT

The effect of tofu powder and carrageenan on the functionality, textural parameters and microstructure of surimi emulsion gel were studied. Tofu powder (20, 40, 60 and 80%) was used as a replacement for surimi as a pre-emulsion in the formulation of the emulsion gel. The tofu powder increased the emulsion stability, water holding capacity (WHC) and hardness of the gels. Microstructural observation supported the texture profile analysis (TPA) and functionality results. Evaluation was carried out on the addition of carrageenan at various concentrations (0.25, 0.5 and 0.75%) to the gel that replaced 80% of the surimi with tofu powder. Increasing carrageenan also improved the stability of the emulsion, WHC and hardness of the gels. Microstructural observation showed that the addition of carrageenan resulted in a smoother and more compact gel network.

**Keywords:** tofu powder, carrageenan, meat emulsion, surimi, microstructure

## INTRODUCTION

Meat emulsions are comminuted meat mixtures of water, protein, fat and other ingredients. In the meat industry, meat emulsion products are used to balance quality and quantity considerations associated with functionality, nutritional value and cost. The texture and appearance of meat emulsion products depend on the structure of the matrix formed by the protein gel and the moisture content. A successful gel has a balance between protein-water and protein-protein (Flores *et al.*, 2007).

Surimi is the concentrate of the myofibrillar proteins of fish muscle. It is a fish protein product prepared by mincing fish flesh and washing it in water. It is the primary raw material of the important Asian food products called

kamaboko, chikuwa and crab stick. Surimi has important functional properties, such as forming a three-dimensional gel, binding water and forming strong membranes on the surface of fat globules in emulsion systems, which are major factor contributing to the quality of processed meat (Zayas, 1997).

Soy protein is commonly used as a food ingredient in meat emulsion products in order to improve the functional characteristics of the system, such as water binding, textural properties and to reduce the cost and the fat content (Lecomte *et al.*, 1993; Ho *et al.*, 1997; Ramezani *et al.*, 2003). However, soy protein is imported from overseas and its manufacturing process is complicated and costly. Tofu powder is produced from ground dried tofu, which can be used as the main ingredient in processed meat products

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(Panyathitipong and Puechkamut, 2002). Tofu powder has high solubility and good emulsion properties (Panyathitipong and Puechkamut, 2008). Tofu powder was added to frankfurters, to decrease the fat content and to increase the protein and moisture contents, with no difference in sensory attributes reported compared to the controls (Ho *et al.*, 1997).

Soy proteins and hydrocolloids have been used in meat emulsion products. Hydrocolloids, especially carrageenans, have been utilized often in modifying both the textural and sensory attributes of meat products (Flores *et al.*, 2007). Carrageenans were considered beneficial with regard to the processing and quality characteristics of meat emulsion products, where carrageenan was combined with other ingredients, including soy proteins (Ortiz *et al.*, 2004; Verbeken *et al.*, 2005).

Therefore, the objective of this research was to study the relationship between the structural changes and properties of surimi emulsion gel due to the presence of tofu powder and carrageenan.

## MATERIALS AND METHODS

### Materials

Soybean (CM 60) with a moisture content of 9-10% that had been cultivated during summer in 2007 was obtained from the Chiang Mai Field Crops Research Center. It was stored at 15°C before being used in the tofu processing. The coagulant ( $MgSO_4$ ) used to prepare the tofu powder was food grade reagent and other reagents were analytical grade. Surimi AA grade was obtained from Pacific Marine Food Co. Ltd. Mixed carrageenan (Aquagel SGE) was obtained from Burapaheep Co. Ltd.

### Surimi emulsion gel preparation

Frozen surimi was ground in a commercial food processor for 1 min at low speed. Salt (2.25% weight of surimi = WS) and soybean

oil (12% WS) were slowly added to the ground surimi. Then, ice (22.5% WS) was incorporated and ground for 1 min. Sugar (5% WS) was slowly added and then ice (22.5% WS) was incorporated for 2 min at high speed. The batter was stuffed in a stainless mold and heated in a temperature-controlled water bath maintained at 40°C for 20 min and 90°C for 20 min. Then, samples were cooled immediately in cool water.

The tofu powder was prepared from the curd of the soymilk, which was coagulated using  $MgSO_4$  and dried as described in the method of Panyathitipong and Puechkamut (2008). Tofu powder was prepared to be used in pre-emulsion as a replacement for surimi in the surimi-emulsion gel process. The pre-emulsion mixture was made by mixing tofu powder with water and oil. Water was added to adjust the moisture content of the tofu powder to that of surimi and the amount of oil was equal to the added oil of the formulation.

### Water holding capacity (WHC) analysis

The water holding capacity of surimi emulsion gel samples was analyzed by the modified method of Hughes *et al.* (1997), with 10 g batter samples placed in centrifuge tubes and heated for 15 min in a water bath at 90°C. After heating, the samples were cooled to room temperature, and centrifuged at 9,000 rpm for 20 min. The supernatant was eliminated and the WHC of the remaining pellets was calculated using Equation 1:

$$WHC (\%) = \left( \frac{1 - (\text{weight of sample before heating} - \text{weight of sample after centrifugation}) \times 100}{\text{total water content in the sample}} \right) \quad (1)$$

### Emulsion stability analysis

The emulsion stability was analyzed by the modified method of Hughes *et al.* (1997), with 25 g batter samples placed in centrifuge tubes and centrifuged at 4,000 rpm for 1 min. The samples were heated in a water bath at 70°C for 30 min. After heating, the samples were centrifuged at

4,000 rpm for 3 min. The pellets samples were removed and weighed. The supernatants were poured into pre-weighed crucibles and dried overnight at 100°C. The volume of total expressible fluid (TEF) and the percentage fat were calculated using Equations 2 and 3:

$$\% \text{TEF} = \frac{\text{weight of sample} - \text{weight of pellet}}{\text{sample weight}} \times 100 \quad (2)$$

$$\% \text{ fat} = \frac{\text{dried supermatant}}{\text{TEF}} \times 100 \quad (3)$$

### Texture profile analysis (TPA)

Texture profile analysis was performed using a texture analyzer (TA-XT2i, Stable Micro Systems). Each gel sample was cut and compressed twice to 30% of its original height with an aluminum platen having a diameter of 75 mm. The conditions of texture analysis were: pre-test speed 1 mm/s, test speed 1 mm/s and post-test speed 1 mm/s. Values for hardness and springiness were recorded

### Scanning electron microscopy

Small pieces of emulsion gel samples were fixed overnight in 2.5% glutaraldehyde in a 0.1 phosphate buffer at pH 7.2, then rinsed twice in a phosphate buffer for 30 min each time, followed by rinsing in distilled water for 30 min. The samples were dehydrated using a gradual series of ethanol (30, 50, 70 and 90%, with 1 hr at each level and then in absolute ethanol three times,

for 1 hr each time). The samples were mounted on aluminum stubs and coated with a layer of gold under vacuum, for surface and cross section visualization. Micrographs of the samples were obtained with a scanning electron microscope (JEOL, model JSM-5410LV).

### Statistical analysis

A completely randomized design was used and differences among group means were analyzed by Duncan's new multiple range test ( $p \leq 0.05$ ). All the measurements were carried out in triplicate, except for TPA, which was replicated 10 times.

## RESULTS AND DISCUSSION

### Effect of tofu powder on functionality of surimi emulsion gel

Water holding capacity (WHC) is one important attribute of a meat emulsion product. Values for WHC of the emulsion gels formulated with the addition of tofu powder in a pre-emulsion to replace surimi are shown in Table 1. Increasing the amount of tofu powder caused a significant ( $p \leq 0.05$ ) increase in WHC. Replacement of meat protein with soy protein increased WHC by reducing expressible water (Lecomte *et al.*, 1993; Chin *et al.*, 1999), because it absorbed water immediately and later formed a heat-stable gel (Chin *et al.*, 1998).

Emulsion stability in samples formulated with different amounts of tofu powder was

**Table 1** Effect of tofu powder on functionality of surimi emulsion gels.

Tofu powder (%)	Water holding capacity (%)	Emulsion stability	
		TEF (%)	Fat (%)
Control (0)	90.90 <sup>c</sup> ±8.10	1.12 <sup>a</sup> ±0.03	1.18 <sup>a</sup> ±0.02
20	92.01 <sup>b</sup> ±5.80	1.16 <sup>a</sup> ±0.02	1.06 <sup>b</sup> ±0.05
40	92.38 <sup>b</sup> ±5.02	0.97 <sup>b</sup> ±0.07	0.97 <sup>c</sup> ±0.01
60	93.40 <sup>a</sup> ±7.11	0.86 <sup>c</sup> ±0.07	0.65 <sup>d</sup> ±0.02
80	93.68 <sup>a</sup> ±1.50	0.69 <sup>d</sup> ±0.05	0.33 <sup>e</sup> ±0.03

<sup>a-e</sup> = Values followed by different letters within a column are significantly different ( $p \leq 0.05$ ).

significant different ( $p \leq 0.05$ ) (Table 1). The fat loss of the control was significantly ( $p \leq 0.05$ ) higher than for other treatments, indicating that protein participates in some fat emulsification. The result was similar to that of Barbut (2006), who reported adding non meat protein as dairy protein decreased fat loss in chicken meat batters. The control and the treatment with 20% tofu powder added resulted in high total expressible fluid (TEF), thus decreasing the stability of the emulsion. The TEF of the surimi emulsion decreased when the amount of tofu powder increased, due to the WHC and moisture absorption of the tofu powder. Water holding capacity is dependent on both the fat and moisture content and is very important to maintain emulsion stability in the meat emulsion product (Choi *et al.*, 2009). Many proteins are used as emulsifiers, due to their hydrophilic and hydrophobic side chains. The characteristics of these proteins may be attributed to their particular properties, which influence their adsorption capacity at the oil and water interface (Ayadi *et al.*, 2009).

#### Effect of tofu powder on texture of surimi emulsion gels

Soy protein is often incorporated in meat products to improve their processing and final product properties, especially the textural characteristics. The effect of tofu powder on the textural properties of the emulsion gel, when used as a replacement for surimi is shown in Table 2. The control had the lowest hardness ( $p \leq 0.05$ ) and the hardness of the emulsion gel gradually

increased with the increased addition of tofu powder. The results indicated that the inclusion of tofu powder increased the hardness compared to the control, through moisture retention and increased structural stability of the gel matrix (Chin *et al.*, 1998). The results were similar to those of Hung and Zayas (1992), Su *et al.* (2000) and Barbut (2006), who reported that the addition of non meat proteins in meat emulsion products significantly increased hardness compared to the control. Addition of tofu powder did not significantly affect springiness. This result was similar to Shand (2000), who reported that the springiness values following treatment with soy protein concentrate in low fat meat batters were generally similar to the control, indicating that the addition of soy protein concentrate had minor effects on springiness.

#### Effect of tofu powder on microstructure of surimi emulsion gel

The 3-dimensional network structure of gel is an important determinant of texture and functional properties, such as water and fat holding capacity (Chen *et al.*, 2007). Scanning electron microscopy (SEM) was used to show differences in the 3-dimensional microstructure of the surimi emulsion gel formulated with tofu powder (Figure 1)

The meat emulsion gel showed a granular aggregated structure consisting of large open spaces within the matrix (Figure 1A). Increasing the tofu powder concentration resulted in a denser and rougher structure. These microstructural

**Table 2** Effect of tofu powder on texture of surimi emulsion gel.

Tofu powder (%)	Hardness (g.force)	Springiness
Control (0)	2274.44 <sup>e</sup> ±143.96	0.925 <sup>a</sup> ±0.05
20	3675.23 <sup>d</sup> ±219.81	0.932 <sup>a</sup> ±0.01
40	4908.85 <sup>c</sup> ±441.63	0.906 <sup>a</sup> ±0.06
60	6350.90 <sup>b</sup> ±393.79	0.901 <sup>a</sup> ±0.04
80	7100.82 <sup>a</sup> ±598.53	0.942 <sup>a</sup> ±0.02

<sup>a-e</sup> = Values followed by different letters within a column are significantly different ( $p < 0.05$ ).

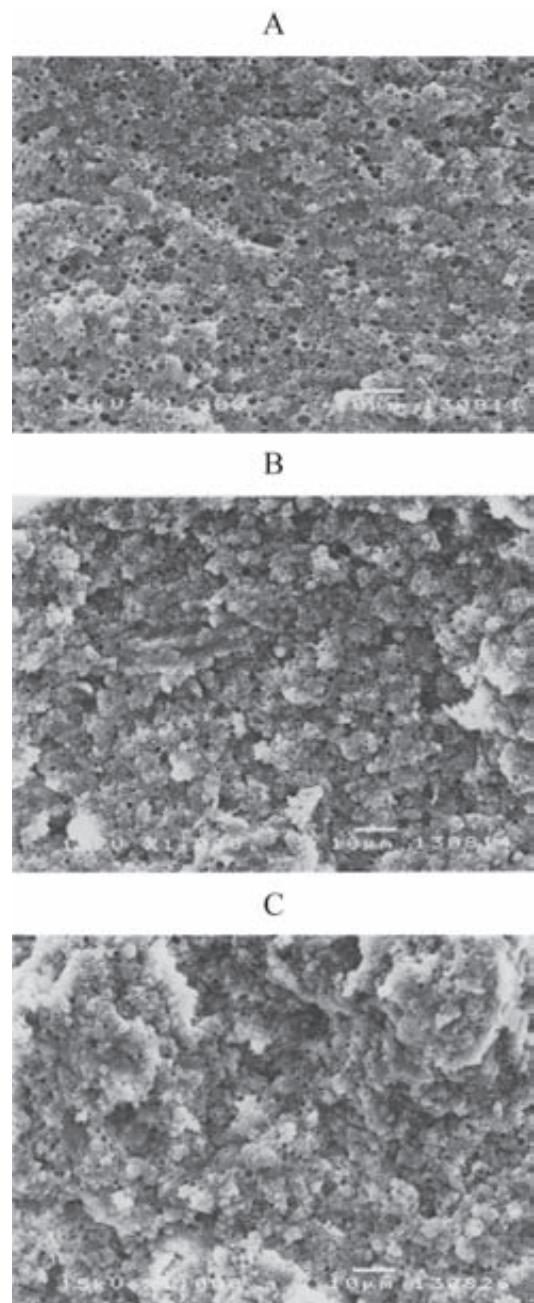
investigations supported the texture profile analysis (TPA) observations that indicated that the products containing tofu powder were firmer than the control. The micrograph of the emulsion gel (Figures 1B and 1C) showed a dense structured matrix that may cause more resistance to applied stress and greater water holding capacity. These microstructural changes helped to explain the functionality differences among the gels. A uniform structure with numerous small pores would probably result in more absorptive capacity and better retention of fat and water compared to a structure with large pores. (Chen *et al.*, 2007).

Investigation of the effects of the replacement of meat protein with high levels of tofu powder was an objective of the current research, so 80% tofu powder was selected for further experimentation.

#### **Effect of carrageenan and tofu powder on functionality of surimi emulsion gel**

Carrageenan is a sulphate polysaccharide extracted from red algae. It is widely used in the food industry, because of its water binding, thickening and gelling properties. Carrageenan at various concentrations (0.25, 0.50 and 0.75 % weight of surimi) were mixed with sugar and added to the gel in which 80% of the surimi had been replaced with tofu powder. The effect of carrageenan on the water holding capacity of the gels is shown in Table 3. The results showed that increasing the carrageenan concentration caused an increase in WHC ( $p \leq 0.05$ ) that was consistent with Verbeken *et al.* (2005), who reported that increasing the carrageenan concentration in gel meat products increased gel strength and WHC.

There were significant ( $p \leq 0.05$ ) differences in the stability of the surimi tofu powder (Table 3). The gels without carrageenan resulted in the highest TEF and fat, thus decreasing the stability of the emulsion. Luruena-Martinez *et al.* (2004) reported similar results for frankfurters made with the addition of locust bean gum and



**Figure 1** Scanning electron micrographs of surimi emulsion gel formulated with different levels of tofu powder added: (A) 0% (Control), (B) 40% and (C) 80% tofu power.

xanthan gum. Protein-hydrocolloid interactions also play a significant role in the structure and stability of many processed foods. Proteins and hydrocolloids can form hybrid complexes with enhanced functional properties in comparison with the protein or hydrocolloid alone. Electrostatic complexation of oppositely charged proteins and hydrocolloids allows better anchoring of the newly formed macromolecular amphiphile onto the oil-water interface (Andres *et al.*, 2006).

### Effect of carrageenan and tofu powder on texture and microstructure of surimi emulsion gel

The emulsion gels prepared by replacing 80% of the surimi with tofu powder and adding carrageenan at various concentrations were compressed and evaluated for their hardness and springiness (Table 4). When carrageenan was added, a significant ( $p \leq 0.05$ ) increase in the emulsion gel hardness and a decrease in springiness were observed. This result was similar to Ruusunen *et al.* (2003), Garcia-Garcia and Totosaus (2007) and Ayadi *et al.* (2009), who

reported that the addition of carrageenan leads to increased hardness in low fat sausage products. The textural changes can be explained in terms of the influence of the presence of carrageenan on the gelling process of the protein. The carrageenan-protein interaction leads to a compact network resulting in a hard gel (Figure 2). The structure of the gel at 0% carrageenan showed a gel network that looked dense and rough (Figure 2A). Increasing the carrageenan concentration resulted in a smoother gel matrix and increased the compactness of the protein gel network, which had a less aerated structure that might cause a reduction in springiness (Figure 2B-D). Moreover, the significant increase in the gel hardness that was observed at high levels of carrageenan could have been the result of the formation of an additional carrageenan gel network (Ayadi *et al.*, 2009). The evolution of the microstructure can explain not only textural properties, but also the change in the WHC. The compactness of the protein gel network allowed more binding of water, therefore, with an increase in the carrageenan concentration, the WHC increased (Ayadi *et al.*, 2009).

**Table 3** Effect of carrageenan on functionality of the gel that replaced 80% of surimi with tofu powder.

Carrageenan (%)	Water holding capacity (%)	Emulsion stability	
		TEF (%)	Fat (%)
0	93.68 <sup>c</sup> ±1.10	0.69 <sup>a</sup> ±0.03	0.33 <sup>a</sup> ±0.03
0.25	93.62 <sup>c</sup> ±2.70	0.52 <sup>b</sup> ±0.04	0.30 <sup>a</sup> ±0.01
0.50	94.38 <sup>b</sup> ±1.40	0.38 <sup>c</sup> ±0.03	0.22 <sup>b</sup> ±0.01
0.75	95.47 <sup>a</sup> ±2.30	0.29 <sup>d</sup> ±0.05	0.19 <sup>b</sup> ±0.03

<sup>a-c</sup> = Values followed by different letters within a column are significantly different ( $p < 0.05$ ).

**Table 4** Effect of carrageenan on texture of the gel that replaced 80% of surimi with tofu powder.

Carrageenan (%)	Hardness (g.force)	Springiness
0	7113.56 <sup>c</sup> ±537.00	0.940 <sup>a</sup> ±0.016
0.25	8298.01 <sup>b</sup> ±414.41	0.908 <sup>b</sup> ±0.022
0.50	8313.36 <sup>b</sup> ±350.80	0.915 <sup>b</sup> ±0.025
0.75	8841.38 <sup>a</sup> ±414.75	0.907 <sup>b</sup> ±0.016

<sup>a-c</sup> = Values followed by different letters within a column are significantly different ( $p \leq 0.05$ ).

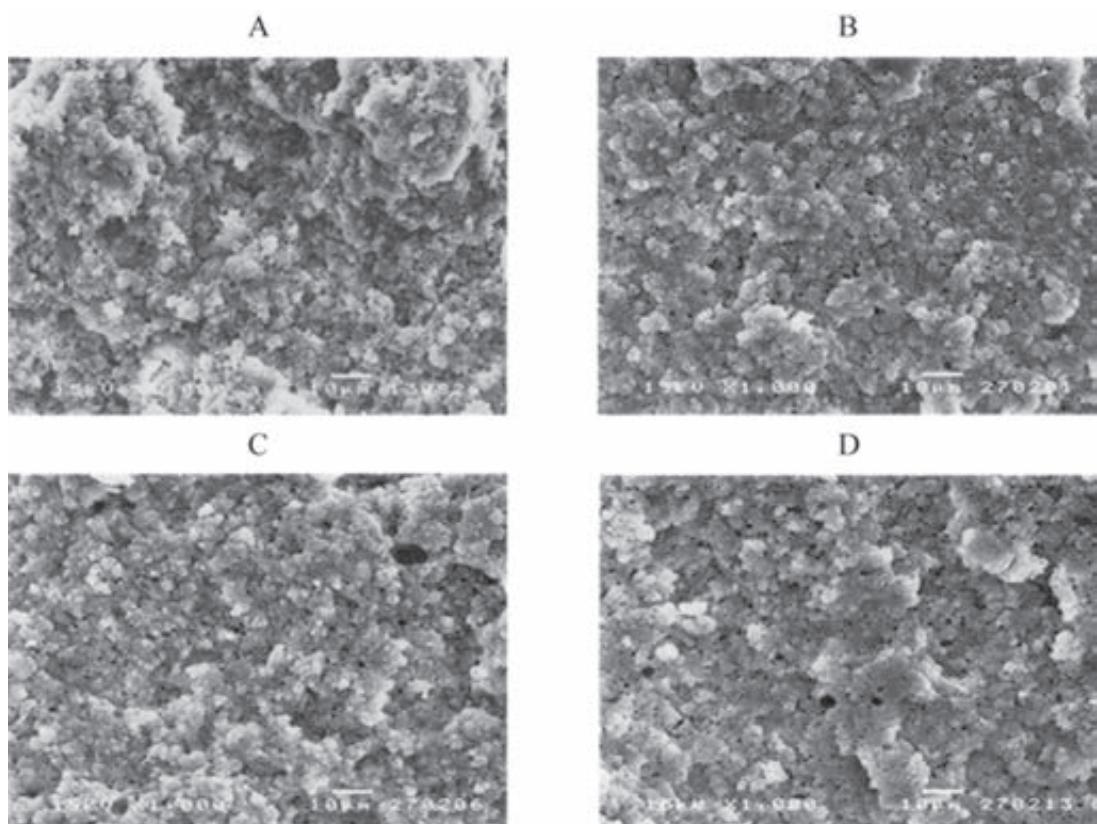
## CONCLUSION

The influence of the addition of tofu powder and carrageenan affected the functionality, textural properties and microstructure of surimi emulsion gel. The WHC, stability and hardness of the emulsion gel increased with increasing amounts of tofu powder ( $p \leq 0.05$ ). Microstructural observation supported the TPA and functionality results. Moreover, the addition of carrageenan caused a significant change in the gel ( $p \leq 0.05$ ). Increasing the carrageenan concentration resulted in greater WHC, emulsion stability and hardness. Microstructural observation showed that increasing carrageenan levels resulted in a

smoother, more compact gel matrix. The experiment indicated that tofu powder substitution at 80% was appropriate for the meat emulsion product. However, further study on product development, including flavor improvement and sensory evaluation should be undertaken.

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**Figure 2** Scanning electron micrographs of surimi emulsion gel formulated with 80% tofu powder and different levels of added carrageenan: (A) 0%, (B) 0.25%, (C) 0.5% and (D) 0.75%.

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