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Effect of oxidized phenolic-containing plant extracts on gel properties of goatfish surimi

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Abstract

The effect was studied of oxidized phenolic-containing plant extracts from Vietnamese coriander and holy basil at 0.1–0.4% protein content on the gel properties of goatfish (*Mulloidichthys martinicus*) surimi. The lowest expressible moisture content and the highest breaking force, deformation, gel strength and texture profile (hardness, gumminess, chewiness) were observed in surimi gel with 0.1% oxidized phenolic-containing plant extracts from Vietnamese coriander. The trichloroacetic acid-soluble peptide content decreased as the concentration of extract increased. Analysis of protein subunits using sodium dodecyl sulfate-polyacrylamide gel electrophoresis demonstrated that as the concentration of extract increased the intensity of the myosin heavy chain band decreased, whereas that of the polymerized protein band increased. Compared to the control, the microstructure of surimi gel with 0.1% oxidized phenolic-containing plant extracts from Vietnamese coriander was denser, more ordered and had a more uniform protein network. Compared to the control, sensory evaluation resulted in higher liking scores for surimi gel with 0.1% oxidized phenolic-containing plant extracts from Vietnamese coriander with regard to springiness, texture and overall liking. Therefore, the addition of 0.1% oxidized phenolic-containing plant extracts from Vietnamese coriander could improve the gel-forming ability of goatfish surimi without having any adverse effects on the sensory properties.

Introduction

Surimi is a minced fish that has been washed and treated with cryoprotectants to prevent denaturation of the protein. Surimi is used in many food products such as kamaboko, fish sausage, fish ball and crab stick (Chaijan et al., 2010). Recently, surimi-based products have become popular worldwide and the quality of materials and the manufacturing efficiency are important for the finished product (Bashir et al., 2017).

Gel-forming ability is one of the important properties of minced fish and surimi, being influenced by internal and external factors such as the type of fish, freshness, endogenous enzymes, food additives, and the manufacturing process (Park, 2005; Hossain et al., 2011). Myofibrillar proteins are the main components responsible for gel-forming ability (Lanier et al., 2013). At 40°C, myofibrillar proteins can form a network through intracellular and intercellular crosslinking and this is caused by endogenous transglutaminase (TGase), which induces non-disulfide covalent bonds, increasing the gel strength (Thongraung, 2011). Many food ingredients have been used to increase the gel strength of surimi, such as protein additives, though some food additives have adverse effects on surimi gel (Akazawa et al., 1994; Rawdkuen et al., 2004; Rawdkuen et al., 2008; Balange and Benjakul, 2010; Jafarpour et al., 2012). The addition of egg white affects both the color and odor, the addition of whey protein concentrate, is expensive and the addition of blood plasma increases the risk of mad cow disease (Balange and Benjakul, 2010). Therefore, food additives that are cheap, and that can improve the quality of surimi gel, are still being investigated (Balange and Benjakul, 2009a; 2009b; 2009c).

Phenolic compounds are abundant in plant tissues, such as coffee beans, tea leaves, tubers, and the cell walls of fruit (Shahidi and Naczk, 2004). Interactions between phenolic compounds and protein play an important role in the manufacturing process of some foods. For example, Balange and Benjakul (2009a; 2009b; 2009c) have studied the addition of oxidized phenolic compounds to mackerel and bigeye snapper surimi. They showed that oxidized

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phenolic compounds can interact with protein by crosslinking and thus strengthening the surimi gel. In addition, gel with added oxidized tannic acid (OTA) has the highest gel properties at the appropriate level (Balange and Benjakul, 2009c). However, they only investigated the interaction between protein and commercial phenolic compounds, whereas many researchers are studying the phenolic content and antioxidant activities of plant leaves such as Vietnamese coriander, Chinese chives, ivy gourd, Yanang, Thai basil, and holy basil. Some plants in Thailand have high phenolic content and are available at low cost (Wongsa et al., 2012). However, information regarding the effect of phenolic-containing plant extracts on the gel properties of surimi is still scarce. Thus, the aim of this study was to investigate the effect of oxidized phenolic-containing plant extracts from Vietnamese coriander and holy basil on the gel properties, texture profiles and sensory evaluation of goatfish surimi.

Materials and Methods

Materials

Frozen goatfish surimi (*Mulloidichthys martinicus*) grade A was purchased from Andaman Surimi Industries Co., Ltd Samut Sakhon province, Thailand. Vietnamese coriander and holy basil leaves were purchased from the local market in Talad Thai, Pathum Thani, Thailand.

Sodium hydroxide (NaOH) and copper sulphate ($CuSO_4$) were obtained from Qrec (Auckland, New Zealand). Hydrochloric acid (HCl) and Folin-Ciocalteu reagent were procured from RCI Labscan (Bangkok, Thailand) and Merck (Darmstadt, Germany), respectively. Sodium dodecyl sulfate (SDS), *N, N, N′, N′*-tetramethyl ethylene diamine (TEMED) and all chemicals for electrophoresis were purchased from Bio-Rad Laboratories (Hercules, CA, USA).

Preparations of plant leaves

The leaves were washed and dried at room temperature, then were dried in a hot-air oven at 50°C for 8–10 hr. Prepared leaves were subjected to grinding (HR- 2021; Philips; Shanghai, China) and passed through a 35-mesh sieve. Sample powders were collected in laminated aluminum foil and vacuum sealed. The packed samples were stored in a desiccator at room temperature (30 ± 2°C) under dark conditions until further analysis (Wongsa et al., 2012).

Extraction of phenolic-containing plant extracts

Powdered Vietnamese coriander and holy basil leaves powder (5 g) were mixed with 100 ml of 70% ethanol, following the method of Ismail et al. (2004) with slight modifications. Then, the mixtures were shaken at 200 rpm/min for 1 hr at 25 ± 2°C. The samples were filtered through Whatman filter paper No.1 (Whatman Schleicher & Schuell; Maidstone, UK). The filtrates were evaporated under vacuum conditions until the ethanol was almost removed, producing final samples of less than 30 mL.

Preparation of oxidized phenolic-containing plant extracts

The phenolic-containing plant extracts were oxidized following the method of Strauss and Gibson (2004) with slight modifications. The samples were diluted with distilled water to 100 mL, and adjusted to pH 8 using 6 M NaOH or 6 M HCl, then placed in a water bath at 40°C. Oxygen gas was flushed into the mixtures for 30 min, to completely oxidize the phenolic compounds. After oxygenation, the solutions were neutralized and transferred to a freeze drier. The dried samples were collected in laminated aluminum foil, vacuum sealed, and stored at -18 ± 2°C until used.

Preparation of goatfish surimi gel

Surimi gel was prepared following the method of Sutloet and Sompongse (2013), with slight modifications. The frozen surimi was thawed in a chilled room (4 ± 2°C) for 3–4 hr until the core temperature rose to 0°C. Then, the surimi was cut into small pieces, minced (MCM64060; Bosch; Ljubljana, Slovenia), and ground with 2.5% salt. The moisture content was adjusted to 80% by the addition of iced oxidized phenolic-containing plant extract phenolic solution from the leaves at different concentrations (0%, 0.1%, 0.2% or 0.4% by protein content in fish meat) during the grinding of the mixture. Then, the batter was stuffed into cellulose casing (2.5 cm diameter) and tightly sealed at both ends. The temperature of the batter was maintained below 12°C throughout the process. The batter was then heated at 40°C for 30 min followed by heating at 90°C for 20 min. All gels were then immediately cooled in iced water until the core temperature of the samples fell below 10°C. The samples were stored overnight at 4 ± 2°C prior to further analysis.

Determination of surimi gel

Textural properties

The textural properties of the gel samples (breaking force (in grams) and deformation (in centimeters) were determined using a penetration test with a texture analyzer (TA-XTPlus; Stable Micro Systems; Goldalming, UK) with a spherical probe (5 mm diameter; 60 mm/min test speed). Gels were tempered and tested at room temperature. Seven cylinder-shaped samples 2.5 cm in length were prepared from each gel. The gel strength (in grams centimeters) was expressed as the breaking force multiplied by the breaking distance. Texture profile analysis (TPA), consisting of hardness, springiness, cohesiveness and chewiness, was conducted using the texture analyzer with a cylindrical probe (50 mm diameter; 5 mm/s test speed).

Whiteness

The gel samples were cut to a 5 mm thickness, and the whiteness was determined using a HunterLab instrument (ColorFlex CX2687; Reston, VA, USA). D65 illuminant was used as the light source. CIE L^*, a^* and b^* values were measured. Whiteness was calculated as described by the method of Lanier et al. (1991) using Equation 1:

$$\text{Whiteness} = 100 - [(100 - L^*)^2 + a^{*2} + b^{*2}]^{1/2} \quad (1)$$

Expressible moisture content

The expressible moisture content was measured by the method of Chaijan et al. (2010). The gel samples were cut to a thickness of 5 mm and then, the samples were weighed (X) and placed between pieces of Whatman No.4 filter paper (three pieces at the bottom and two pieces on the top). A standard weight (5 kg) was placed on top of the sample and held for 2 min. The sample was removed from the papers and weighed again (Y). The expressible moisture content was calculated using Equation 2:

$$\text{Expressible moisture content (\%)} = 100 - [(X - Y)/X] \quad (2)$$

Trichloroacetic acid-soluble peptide content

The trichloroacetic acid (TCA)-soluble peptide content was analyzed using the method of Balange and Benjakul (2009c). A minced sample (2 g) was mixed with 18 mL of 5% TCA (cold solution) and homogenized at 11,000 rpm for 2 min using a homogenizer (Z1110-series, EYELA; Tokyo, Japan). The homogeneous sample was incubated at 4°C for 1 hr and then centrifuged at 8,000×g for 5 min. The TCA-soluble peptide content in the supernatant was analyzed using the method of Lowry et al. (1951) and expressed in micromoles tyrosine/g sample.

Sodium dodecyl sulfate poly-acrylamide gel electrophoresis (SDS–PAGE)

Protein patterns of samples were analyzed following the method of Laemmli (1970), using reduced and unreduced conditions. For the unreduced samples, an extract solution (20 mL) contianing 2% (w/v) sodium dodecyl sulfate (SDS), 0.1 M dithiothreitol (DTT) in 60 mM Tris-HCl pH 7.5 was added to the sample (0.5 g) and the mixture was left to stand for 24 hr. The sample was then homogenized and boiled at 97C for 5 min and then mixed with sample buffer (distilled water 1.9 mL, 10% SDS 0.8 mL, glycerol 0.4 mL, 0.5 M Tris-HCl (pH 6.8) 0.5 mL and 1% (weight per volume; w/v) bromophenol blue 0.2 mL). For the reduced samples, instead of DTT, 10% β-mercaptoethanol was added to destroy the disulfide bonds, while distilled water was added at the same volume as in the unreduced condition. The prepared samples were loaded into a polyacrylamide gel composed of 10% running gel and 4% stacking gel. Electrophoresis was conducted at a constant current of 20 mA per gel, using a Mini Protein II unit (Bio-Rad; Richmond, CA, USA). After separation, the proteins were stained with 0.02% (w/v) Coomassie Brilliant Blue R-250 in 50% (volume per volume; v/v) methanol and 7.5% (v/v) acetic acid, and destained with 50% ethanol (v/v) and 7.5% (v/v) acetic acid, followed by 5% ethanol (v/v) and 7.5% (v/v) acetic acid.

Scanning electron microscopy

The microstructure of the gels was determined using a scanning electron microscope (SEM), following the method of Sutloet and Sompongse (2013). The specimens were examined on an SEM (JSM-6610LV; JEOL; Tokyo, Japan) operated at up to 15 kV.

Sensory evaluation

Surimi gel samples with and without 0.1% oxidized phenolic-containing plant extracts from Vietnamese coriander leaves were heated at 75°C for 5 min. After that, the casing was removed and each gel was cut into 1 cm lengths. Thirty untrained panelists evaluated the gels on a 9-point hedonic scale (9 = like extremely, 5 = neither like nor dislike and 1 = dislike extremely) for appearance, color, odor, flavor, springiness, texture and overall liking, according to the method of Oujifard et al. (2012).

Statistical analysis

The experiment was designed using a completely randomized design. Data were subjected to analysis of variance. Duncan's new multiple range test was used to determine the differences among sample means at $p = 0.05$. All experiments were done in triplicate, except for the sensory evaluation, which was run in duplicate.

Results and Discussion

Effect of oxidized phenolic-containing plant extracts on the properties of surimi gels

Gels from goatfish surimi with oxidized phenolic-containing plant extracts at different concentrations had different breaking forces, deformations and gel strengths (Table 1). The results indicated that gels with oxidized phenolic-containing plant extracts at 0.1% and 0.2% had significantly higher breaking forces and gel strengths than the control gel. However, when the concentration was increased further, up to 0.4%, the breaking force, deformation, and gel strength fell. This suggested that the addition of oxidized phenolic-containing plant extracts at appropriate concentrations improved the gel forming properties of the surimi. These results were in agreement with Yasin et al. (2017), who studied modification of chicken feet gelatin using aqueous sweet basil and lemongrass extract, where the gel strength of the gelatin increased up to the addition of plant extracts at 2 mL/100 g dry gelatin, and then decreased after the addition of the extracts at 2.5–3.0 mL/100 g dry gelatin. They suggested that the excessive amount of plant extracts negatively affected the gel strength of the chicken feet gelatin (Yasin et al., 2017). Phenolic compounds can interact with protein in two ways: irreversibly via covalent bonds or reversibly via non-covalent bonds (Balange and Benjakul, 2009b). The protein structure was denser and stronger because of the crosslinking between the phenolic compounds and protein. Quinone, which is generated by the oxidation of phenolic compounds, is electrophilic, and can react with amino or sulfhydryl groups on the molecular chain of the protein to form C-N or C-S covalent bonds with phenolic aromatic rings (Rawel et al., 2002; Strauss and Gibson, 2004). Moreover, phenolic compounds can expose the sulfhydryl groups left inside the protein structure to oxidation, forming disulfide bonds that strengthen the network of the protein gel (Balange and Benjakul, 2009a).

Higher concentrations of phenolic-containing plant extracts had an adverse effect on the surimi gel structure, decreasing the breaking force, deformation and gel strength. This occurred at a concentration of 0.4%. Higher concentrations may increase the crosslinking of protein to a point at which an orderly network cannot form. Balange and Benjakul (2009b) reported that the addition of high concentrations of phenolic compounds may affect their self-aggregation, leading to a loss of protein crosslinking. The addition of oxidized ferulic acid and oxidized caffeic acid at 0.2% and 0.15% to surimi gel from bigeye snapper resulted in a decrease in the breaking force and deformation. Moreover, as some types of phenolic compound have large molecules, self-aggregation might interfere with the interaction with myofibrillar protein. This is suggested by the reported decrease in the breaking force and deformation of mackerel surimi gel with the addition of 0.75% OTA (Balange and Benjakul, 2009c).

The texture measurements using the TPA of surimi gels with added oxidized phenolic-containing plant extracts from Vietnamese coriander and holy basil is shown in Table 2. Gel surimi with added extract from Vietnamese coriander at 0.1% had the highest hardness, gumminess and chewiness. Increasing the concentration decreased all of these values, which was associated with a decrease in the gel strength (Table 1). A strong gel network made the gel harder and more resistant to the interacting forces. However, there was no significant change in springiness or cohesiveness (data not shown).

Table 1 Breaking force, deformation and gel strength of surimi gels with and without oxidized phenolic-containing plant extracts from Vietnamese coriander and holy basil

Sample	Concentration (%)	Breaking force (g)	Deformation (cm)	Gel strength (g.cm)
Control	-	138.47 ± 14.16^{b}	0.53 ± 0.06^{bc}	73.48 ± 15.42^{b}
Vietnamese coriander	0.1	158.73 ± 9.86^{a}	0.55 ± 0.05^{a}	88.38 ± 13.63^{a}
	0.2	154.46 ± 12.76^{a}	0.54 ± 0.07^{ab}	83.80 ± 17.58^{a}
	0.4	135.05 ± 29.09^{b}	0.53 ± 0.07^{ab}	73.52 ± 24.73^{b}
Holy basil	0.1	152.12 ± 10.48^{a}	0.54 ± 0.05^{ab}	82.78 ± 12.62^{a}
	0.2	148.92 ± 13.30^{a}	0.54 ± 0.07^{ab}	80.59 ± 16.90^{ab}
	0.4	124.93 ± 20.26^{c}	0.51 ± 0.05^{c}	64.74 ± 16.25^{c}

Control = without the extract

Values indicate mean ± SD (n = 5)

Means with different lowercase superscript letters in the same column are significantly different ($p < 0.05$).

233.13^{bc}

Table 2 Texture profile of surimi gels with and without oxidized phenolic-containing plant extracts from Vietnamese coriander and holy basil

Sample	Concentration (%)	Hardness (g)	Gumminess (g)	Chewiness (g)
Control	-	2154.47 ± 133.48^{c}	1579.81 ± 84.01^{c}	1461.63 ± 80.25^{c}
Vietnamese coriander	0.1	2470.82 ± 95.64^{a}	1811.18 ± 47.70^{a}	1661.91 ± 51.74^{a}
	0.2	2289.62 ± 126.43^{bc}	1675.63 ± 55.00^{bc}	1539.21 ± 65.07^{bc}
	0.4	2212.56 ± 265.65^{bc}	1608.59 ± 233.13^{bc}	1473.86 ± 218.51^{c}
Holy basil	0.1	2358.07 ± 156.29^{ab}	1722.16 ± 93.01^{ab}	1595.92 ± 96.14^{ab}
	0.2	2358.33 ± 192.69^{ab}	1720.15 ±119.80^{ab}	1580.29 ± 100.40^{ab}
	0.4	1958.63 ± 128.05^{d}	1423.99 ± 100.94^{d}	1322.92 ± 84.91^{d}

Control = without the extract

Values indicate mean ± SD (n = 5)

Means with different lowercase superscript letters in the same column are significantly different ($p < 0.05$)

Effect of oxidized phenolic-containing plant extracts on the whiteness of surimi gels

The whiteness of all surimi gels, with and without oxidized phenolic-containing plant extracts from both Vietnamese coriander and holy basil, at different concentrations decreased significantly as the concentration increased (Table 3) compared to control gel.

The oxidized phenolic-containing plant extracts had a dark color, so that adding the extract to surimi gels made the whiteness decrease.

Balange and Benjakul (2009b) reported that the addition of oxidized phenolic compounds decreased the whiteness of surimi gel from bigeye snapper. Surimi gel with added plant extract also had a low whiteness. Shitole et al. (2014) reported that the addition of seaweed extract (*Sargassum tenerrimum)* to surimi gels from lesser sardine decreased the whiteness due to darkening after evaporation. The result was in line with a reported decrease in L^* and a^* values of surimi gel from goatfish and threadfin beam with added seaweed extract *(Gracilaria fisheri)* and in surimi gel from sardine with extract at high concentrations (Buamard and Benjakul, 2015).

Effect of oxidized phenolic-containing plant extracts on expressible moisture content of surimi gels

The expressible moisture content of surimi gels with and without oxidized *phenolic-containing plant extracts* from Vietnamese coriander and holy basil at different concentrations are shown in Table 3. Surimi gels with added the extracts had significantly lower expressible moisture content than the control gel except for the gel with 0.4% holy basil extract. The gels added with extracts with 0.1% and 0.2% had the lowest expressible moisture content. As the concentration of oxidized phenolic-containing plant extracts increased, the expressible moisture content tended to increase. A decrease in the expressible moisture content was associated with an increase in the gel strength (Table 1). When the phenolic compounds and protein are crosslinked, the protein network becomes denser and stronger leading to an increase in the water holding capacity and a decrease in the expressible moisture content. Quinone generated under base conditions can crosslink with proteins or amino acids, strengthening the gel network and increasing the water holding capacity.

Table 3 Whiteness, expressible moisture content and TCA-soluble peptide content of surimi gels with and without oxidized phenolic-containing plant extracts from Vietnamese coriander and holy basil

Sample	Concentration (%)	Whiteness	Expressible content (%)	TCA-soluble peptide content (μmole tyrosine/g)
Control	-	70.96 ± 2.44[a]	15.44 ± 1.46[a]	1.65 ± 0.14[ab]
Vietnamese coriander	0.1	69.77 ± 1.86[b]	10.53 ± 1.02[b]	1.61 ± 0.27[ab]
	0.2	68.12 ± 1.94[c]	11.97 ± 1.91[b]	1.33 ± 0.08[c]
	0.4	66.06 ± 2.03[d]	11.87 ± 3.07[b]	1.12 ± 0.07[d]
Holy basil	0.1	70.73 ± 2.47[a]	10.80 ± 0.38[b]	1.72 ± 0.02[a]
	0.2	69.52 ± 1.74[b]	12.38 ± 0.76[b]	1.54 ± 0.07[b]
	0.4	68.47 ± 2.06[c]	14.26 ± 1.12[a]	1.36 ± 0.04[c]

Control = without the extract

Values indicate mean ± SD (n = 5)

Means with different lowercase superscript letters in the same column are significantly different ($p < 0.05$)

Effect of oxidized phenolic-containing plant extracts plants on trichloroacetic acid-soluble peptide content of surimi gel

The TCA-soluble peptide content describes the degradation of protein by protease that occurs in setting and gel forming. The highest TCA-soluble peptide content was found in the control gel (Table 3), and when higher levels of oxidized phenolic-containing plant extracts were added, the TCA-soluble peptide content decreased significantly. This result suggested that phenolic-containing plant extracts can inhibit the degradation of protein by protease. Therefore, crosslinking of protein by the phenolic compounds led to the protein network becoming denser, and inhibiting enzyme attachment at active sites. The structure of the gel network resists the digestion of enzyme because many bonds are created between the phenolic compounds and protein, inducing covalent bonds, hydrogen bonds and hydrophobic interactions (Balange and Benjakul, 2009b).

The decrease in the TCA-soluble peptide content was similar to that reported in Buamard and Benjakul (2015), where the addition of coconut husk extract at higher concentrations in surimi gels decreased the TCA-soluble peptide content. Their report found a different mechanism whereby coconut husk extract reacted directly with protease, resulting in a loss of enzyme activity. The addition of kiam wood extract in gel surimi from mackerel reduced the protein solubility of the gel (Balange and Benjakul, 2011).

Effect of oxidized phenolic-containing plant extracts on protein pattern of surimi gel

The protein patterns of gels with different concentrations of oxidized phenolic-containing plant extracts from Vietnamese coriander and 0.1% holy basil are shown in Fig. 1. For the unreduced samples, (Fig. 1A) the MHC bands disappeared because of the polymerization of the protein during heating and enlargement of the protein structure. This result was observed from an increase in the intensity of the polymerized protein bands. The MHC bands and degradation bands almost disappeared in the gels with added compounds. However, these polymerized protein bands were more intense than in the control gel. These protein patterns showed the capacity of the phenolic-containing plant extracts to induce crosslinking. Slight differences in intensity were found in the actin bands due to partial crosslinking induced by the phenolic-containing plant extracts. MHC is crosslinked readily during setting (Benjakul and Visessanguan, 2003). Moreover, the gels with added oxidized phenolic-containing plant extracts showed lower intensity in the protein degradation bands than the control gel. After degradation, a low molecular weight protein band was observed. These results confirmed the decrease in the TCA-soluble peptide content of surimi gels reported in Table 4.

In addition, it was reported that OTA induced a conformation change in protein when the sulfhydryl groups were exposed, forming disulfide bonds by oxidation (Balange and Benjakul, 2010). This phenomenon was confirmed by the protein pattern under reducing conditions (Fig. 1B). The results showed that the intensity of the MHC bands was restored under reduction. This suggested that disulfide bonds were produced by crosslinking between the phenolic-containing plant extracts and the protein. Lower intensity MHC bands were found in gels with added oxidized phenolic-containing plant extracts than in the control gel. Gel with 0.1% Vietnamese coriander extract had the lowest MHC band intensity. These results suggested that both disulfide bonds and non-disulfide covalent bonds were important in the crosslinking of phenolic-containing plant extracts and protein. The latter are formed by the reaction between quinone and the amino acid or sulfhydryl group side chain of polypeptide, in which covalent bonds (C-N or C-S) with phenol rings are created. These results confirmed the protein pattern of surimi gel from mackerel with ethanolic kiam wood extract (EKWE) reported by Balange and Benjakul (2011). They found that gel with oxidized EWKE under base conditions had a lower intensity MHC band than the control gel. It has also been reported that the addition of coconut husk extract to surimi gel from sardine resulted in the disappearance of the MHC band (Buamard and Benjakul, 2015).

Effect of oxidized phenolic-containing plant extracts on the microstructure of surimi gel

The microstructures of surimi gels with added oxidized phenolic-containing plant extracts from Vietnamese coriander and 0.1% holy basil are shown in Fig. 2. The control gel had many voids inside the structure and an irregular network (Fig. 2A), whereas the gels with Vietnamese coriander extract had a finer and more continuous network structure (Fig. 2B). The results showed the efficiency of the phenolic-containing plant extracts in inducing crosslinking of the protein, resulting in the formation of a denser network structure.

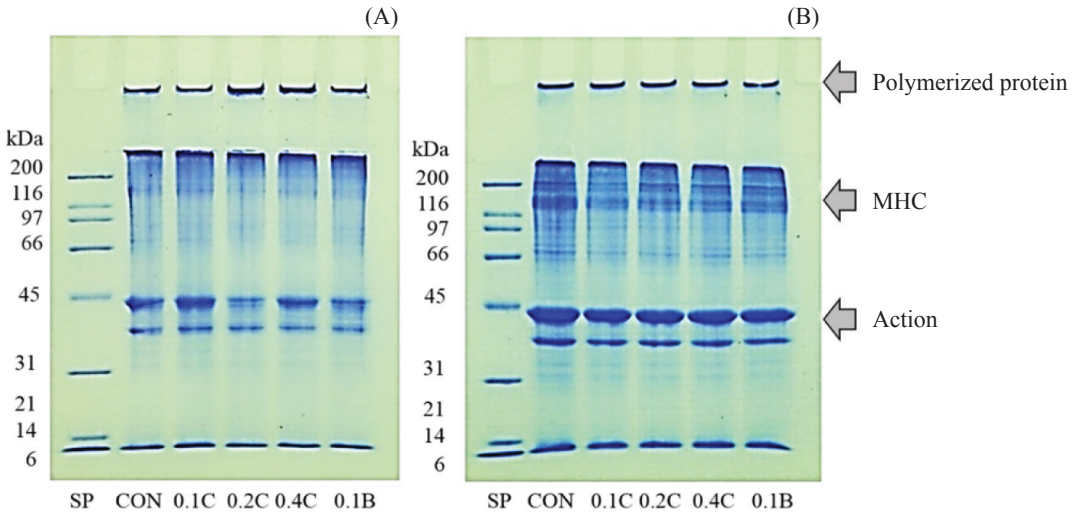

Fig. 1 Sodium dodecyl sulfate poly-acrylamide gel electrophoresis patterns of gels with oxidized phenolic-containing plant extracts from Vietnamese coriander (C in the x axis text) and holy basil (B in the x axis text): (A) unreduced sample; (B) reduced sample, where MHC= myosin heavy chain; SP = standard protein; CON = control and the number at the bottom of each lane expresses the concentration of extract (by % protein content in fish meat)

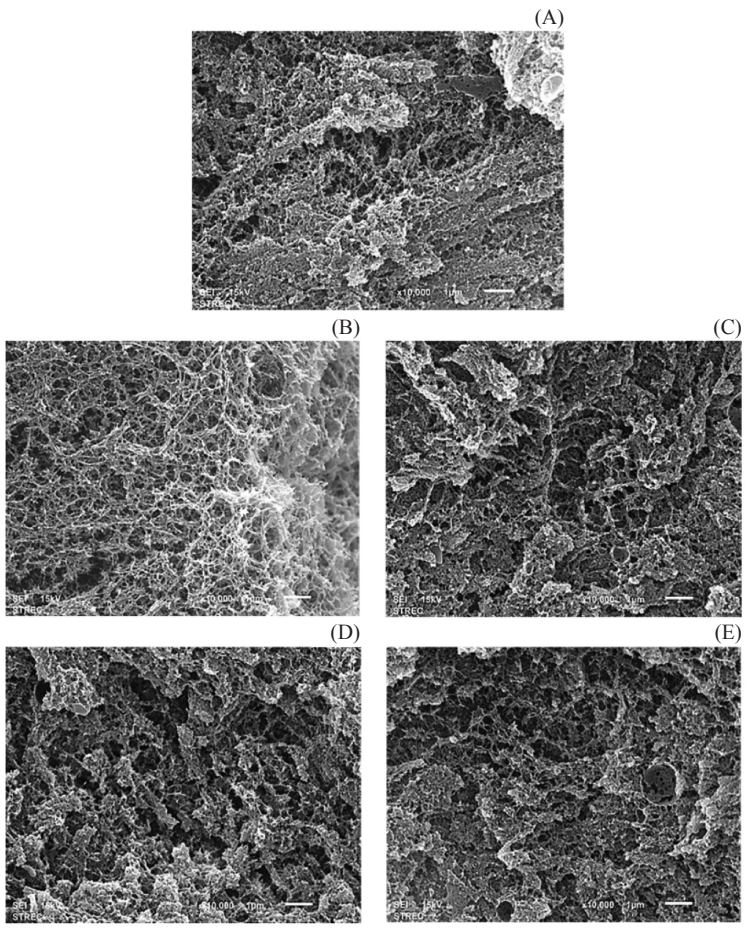

Fig. 2 Microstructure of gels with oxidized phenolic-containing plant extracts from Vietnamese coriander at: (A) 0%; (B) 0.1%; (C) 0.2%; (D) 0.4% Vietnamese; E 0.1% holy basil extract added, with all magnification at 10,000×

Table 4 Likeness scores of surimi gels with and without 0.1% oxidized phenolic-containing plant extracts from Vietnamese coriander

Attribute	Likeness score	
	Control	Vietnamese coriander
Springiness	5.70 ± 1.41[b]	6.50 ± 1.42[a]
Texture	5.83 ± 1.42[b]	6.78 ± 1.33[a]
Overall liking	6.40 ± 1.15[b]	7.12 ± 1.01[a]

Control = without the extract

Values indicate mean ± SD (n = 30)

Means with different lowercase superscript letters in the same column are significantly different ($p < 0.05$)

A denser network, smaller voids and a more ordered structure were found in the gel with 0.1% phenolic-containing plant extracts from Vietnamese coriander (Fig. 2B). This indicated a good water holding capacity, and was associated with the highest breaking force, and gel strength shown in Table 1, and the lowest expressible moisture content shown in Table 3. Increasing the concentration to 0.4% produced a lower continuous network and more aggregation in the gel (Fig. 2D). This was caused by the excessive phenolic-containing plant extracts inducing self-aggregation and interrupting the uniformity and order of the network.

The gel with 0.1% phenolic-containing plant extracts from holy basil (Fig. 2E) had a less fine, ordered and uniform network than the gel with the extract from Vietnamese coriander at the same concentration. The results agreed with the report by Balange and Benjakul (2009a), that gel with oxidized phenolic compounds at the appropriate concentration formed a finer and more uniform network structure than the control. The strong network of the protein structure might have been caused by the crosslinking of protein induced by the phenolic compounds. Buamard and Benjakul (2015) studied the addition of coconut husk extract to surimi gel from sardine. They found that, while the network structure of the control gel was coarse with many voids or large holes, the gel with coconut husk extract had a dense protein network and more crosslinking within its structure.

Effect of oxidized phenolic-containing plant extracts on the sensory evaluation of surimi gel

Likeness scores for gels with and without 0.1% oxidized phenolic-containing plant extracts from Vietnamese coriander are shown in Table 4. The gel with 0.1% Vietnamese coriander received significantly higher likeness scores for springiness, texture and overall liking than the control. This coincided with its greater hardness, gumminess and chewiness than the control (Table 2). The likeness scores for appearance, color, odor and flavor were not significantly different from the control.

Phenolic compounds play an important role in the sensory attributes of many food products (O'Connell and Fox, 2001). For example, phenolic-containing grape seed extracts have been used to add phenolic compounds to dried sausage, while seaweed extract has been used to add them to sardine surimi, without negatively affecting the sensory properties (Lorenzo et al., 2013; Shitole et al., 2014). The addition of 0.125% coconut husk extract to surimi from sardine increased the likeness scores for texture and overall liking compared with the control gel (Buamard and Benjakul, 2015). The current results suggested that the addition of oxidized phenolic-containing plant extracts from Vietnamese coriander both improved the gel forming ability of the surimi and increased the likeness scores.

The addition of oxidized phenolic-containing plant extracts at the optimum level enhanced the interaction between myofibrillar protein, increasing the gel strength and water holding capacity of the gel. This was due to the formation of an ordered, dense gel microstructure with finer strands. It was concluded that the addition of oxidized phenolic-containing plant extracts from Vietnamese coriander could improve the gel forming ability of goatfish surimi, without having any adverse effects on the sensory properties.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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