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Effect of red palm oil and extra virgin coconut oil on physicochemical and gelation properties of threadfin bream surimi

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Abstract

Appropriate addition of vegetable oil can improve the flavour, increase the nutritional composition, and modify the quality of surimi seafood products. In the present work, the effects of different levels (0 to 2%) of red palm oil (RPO) and extra virgin coconut oil (EVCO) on the properties of threadfin bream surimi were studied. Significant changes were observed in the contents of moisture and fat when the oils were incorporated ($p < 0.05$), while no differences in the contents of ash and protein were observed ($p > 0.05$). The incorporation of RPO significantly decreased whiteness as the oil level increased, and ranged from 54.44 to 57.59 from 65.20 in Control ($p < 0.05$). No significant change in whiteness among samples with EVCO was observed ($p > 0.05$), regardless of the levels. The pH and cooking yield of the samples increased, whereas water-holding capacity (WHC) decreased ($p < 0.05$). As the oil levels increased, the gel strength continuously decreased ($p < 0.05$), in which the highest decrease of 41% was observed in sample containing 2% RPO, compared to Control. Based on texture profile analysis (TPA), hardness displayed a significant increase with increasing oil levels, and ranged from 14 to 28 N ($p < 0.05$). Chewiness, springiness, and cohesiveness increased as incorporated oils increased ($p < 0.05$). Microstructure study revealed that the oil droplets were uniformly distributed on the gel surface. Higher storage modulus (G') of the samples was observed when the oils were incorporated, compared to Control. Nevertheless, there was no marked difference in the modulus among samples incorporated with the oils at the same level. The present work demonstrated that RPO and EVCO incorporation directly affected threadfin bream surimi's physicochemical and gelation properties.

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Introduction

Surimi is a concentrated myofibrillar protein obtained by washing fish mince with water (Eymard *et al.*, 2005). It is an increasingly popular functional ingredient for various seafood products due to its unique textural properties and high nutritional value. Fat is usually trimmed away in surimi processing to improve the myofibrillar protein concentration (Zhou *et al.*, 2017). However, removing fat from surimi may cause the products to have a rubbery and dry texture. Therefore, manufacturers typically add exogenous animal fat to control their quality and textural characteristics.

Owing to the health concerns associated with animal fat, which contains high cholesterol, most consumers prefer food products containing no animal fat. Therefore, different vegetable oils, such as peanuts and rapeseed, have been incorporated into seafood products to modify their properties (Shi *et al.*,

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2014). Chen *et al.* (2023) reported that supplementing surimi with peanut and sunflower oils improved whiteness, textural, rheological, and nutritional quality. Soybean and safflower seed oils can effectively improve the quality and flavour of surimi (Song *et al.*, 2022).

Different vegetable oils have different effects on the quality of surimi due to their fatty acid compositions (Liu *et al.*, 2014). Red palm oil (RPO) is a rich source of long-chain fatty acids, particularly palmitic acid (Mancini *et al.*, 2015). In contrast, extra virgin coconut oil (EVCO) is a rich source of medium-chain fatty acids, notably lauric acid (Marina *et al.*, 2009). Long-chain fatty acids increase the combination of oil droplets and protein hydrophobic points, and enhance the hydrophobic interaction between oil and protein (Chen *et al.*, 2021).

From a health perspective, both RPO and EVCO have attractive potential. The benefits of RPO to health include reducing the risk of arterial thrombosis, and inhibiting endogenous cholesterol biosynthesis (Oguntibeju *et al.*, 2009). Lauric acid in EVCO has antiviral and antibacterial activities (German and Dillard, 2004). Due to its health benefits, the incorporation of RPO and EVCO instead of other vegetable oils could be a means to prepare functional surimi gels. However, information regarding the impact of RPO and EVCO on the properties of surimi gel is scarce. Therefore, in the present work, RPO and EVCO were added to threadfin bream surimi. The effects of these oils on the physicochemical and gelation properties of the surimi were then studied.

Materials and methods

Materials

Fresh threadfin bream (*Nemipterus* spp.) was purchased from Taman Seri Serdang Public Market (Seri Kembangan, Selangor, Malaysia). RPO and EVCO were purchased from AEON MaxValu Prime Evo Bangi (Bandar Baru Bangi, Selangor, Malaysia).

Preparation of surimi paste

Fresh threadfin bream was beheaded, gutted, and washed before deboning. The flesh was separated from the bone using a fish deboning machine (Asasemarak (M) Sdn. Bhd., Wangsa Maju, Kuala Lumpur, Malaysia). The mince was washed once at a mince:water ratio of 1:3 (w/w) using a washing tank (Fish Leaching Tank, SWE-FLST 75, Safe World Enterprise, Klang, Selangor, Malaysia) for 5 min with constant agitation. Washing was done using iced water at 4°C.

The mince was dewatered using a decanter (Bean Severing Machine, Ban Hing Holding Sdn. Bhd., Kuala Lumpur, Malaysia) for 30 min. RPO and EVCO were added to the surimi paste following the experimental formulations in Table 1. Then, the paste was mixed in a silent bowl cutter (TQ5, Taat Bestari Sdn. Bhd., Ampang, Selangor, Malaysia) for 5 min. It was then stored in a freezer (BJY-CFSD600A, Aman Semesta Enterprise, Shah Alam, Selangor, Malaysia) at -18°C for 24 h before analysis. The surimi paste was used in the following analyses, and in developing heat-set surimi gel to determine their textural properties.

Table 1. Ingredients of different surimi formulations.

Ingredient (g)	Control	A	B	C	D
Surimi	820	820	820	820	820
Iced water	180	180	180	180	180
Red palm oil	0	10	20	0	0
Extra virgin coconut oil	0	0	0	10	20

Preparation of surimi gel

Approximately 820 g of surimi paste from each formulation was thawed in a 4°C refrigerator for 2 h. The paste was chopped in a silent bowl cutter (TQ5, Taat Bestari Sdn. Bhd., Ampang, Selangor, Malaysia) for 2 min before 1% (w/w) salt was added, and the chopping continued for another 3 min. The final moisture content of the paste was 82%. Then, the paste was extruded into a casing with a diameter of 25 mm, and the ends were tightly sealed before incubation in a water bath at 40°C for 30 min, followed by 90°C for 20 min (Benjakul *et al*., 2002). Heated surimi gel was quickly chilled with flowing tap water, and frozen at -18°C for 24 h before analysis.

Proximate composition

The moisture, ash, protein, and fat contents were determined for the surimi pastes. Moisture content was determined by the oven method. Ash content was determined by incineration in a muffle furnace (Carbolite, Saintifik Maju, Petaling Jaya, Selangor, Malaysia) at 550°C overnight (Method No. 942.05; AOAC, 2000). Protein content was determined by the micro Kjeldahl method (Method No. 981.10; AOAC, 1983), and fat content was determined by the Soxhlet extraction method (Method No. 930.09; AOAC, 2005).

Whiteness

Approximately 50 g of surimi gel was equilibrated at room temperature for 1 h (Zhou *et al*., 2017). The tristimulus colour values of the gel were determined using a colorimeter (Chroma Meter, CR-410, Konica Minolta, Inc., Chiyoda City, Tokyo, Japan). Lightness (L^*), redness (a^*), and yellowness (b^*) values were recorded to calculate the whiteness (W) of the gel using Eq. 1 (Yang *et al*., 2014):

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

where L^*, a^*, and b^* = coordinates in Hunter's L^*, a^*, b^* Colour Difference Equation.

pH

Approximately 50 g of frozen surimi paste was thawed at room temperature for 1 h before pH determination. Then, 25 mL of distilled water was added to 5 g of paste. The mixture was homogenised, and the pH was measured using a calibrated pH meter (PB-10, Sartorius, Göttingen, Germany).

Cooking yield

Water in a pot was heated to boil on a stove. Surimi gel was weighed using an analytical balance and put in the pot. The gel was cooked in boiling water for 10 min. Then, the cooked gel was separated from the cooking water, and cooled for 15 min. The weight of the cooked gel was measured after cooling. The cooking yield was calculated as the percentage of the surimi gel weight after cooking, divided by the surimi gel weight before cooking.

Water-holding capacity

The WHC of surimi gel was determined according to Gao *et al*. (2019). Approximately 2 g of the gel with a layer of Whatman filter paper no. 2 were placed in a 50 mL centrifuge tube, and centrifuged at 4,000 rpm for 10 min at 4°C. The WHC was calculated as the percentage of the surimi gel weight after centrifugation, divided by the surimi gel weight before centrifugation.

Microstructure

The microstructures of surimi gel were observed using a scanning electron microscopy (SEM). The surimi sample was dried at -45°C for 48 h using a freeze dryer (FreeZone 12 Litre, Labconco Corporation, Kansas City, Missouri, USA). The dried sample was then mounted on a bronze stub, and sputter-coated with a gold layer. The prepared sample was observed under the SEM (JSM-IT100 InTouchScope, JEOL, Ltd., Akishima, Tokyo, Japan) at an acceleration voltage of 15 kW.

Temperature sweep test

The gelation properties of surimi paste were determined using a dynamic controlled-stress rheometer (RS600, Thermo HAAKE, Waltham, Massachusetts, USA) (Collyer and Clegg, 1998) equipped with a 35 mm 2° cone-plate geometry, and a gap of 0.105 mm. The paste was defrosted at room temperature for 1 h before testing, and relaxed for 5 min after the measuring system reached the testing position. A temperature sweep test was performed from 10 to 90°C at a linear heating rate of 1°C per minute to determine the surimi paste's heat-induced gelation profile. The frequency was fixed at 1.0 Hz, and the stress was set at 100 Pa (Moreno *et al*., 2015). The changes in G' were then determined.

Puncture test

The puncture test was performed using a texture analyser (TA-XT2i, Stable Micro Systems, Godalming, Surrey, England) with a spherical-ended stainless steel probe (P/0.5s). The 25 mm diameter and height of cubic surimi gel were equilibrated at room temperature for 1 h before testing. The probe was pressed into the surface of the gel perpendicularly at a constant crosshead speed of 1 mm/sec. The gel strength (g.mm) was obtained by multiplying the breaking force (g) and the breaking deformation (mm).

Compression test

The TPA of surimi gel was carried out according to Buamard and Benjakul (2015). Surimi

gel cubes with a diameter and height of 25 mm were used for this analysis. A 10 mm cylindrical aluminium probe (P/10) was attached to a texture analyser. The sample was placed on the base, and subjected to two compression cycles. The TPA parameters were measured with the following testing conditions: crosshead speed of 0.5 mm/sec, 75% compression of the original sample height, and a time interval between the first and second compression of 10 s. Hardness (N), chewiness (N), springiness, and cohesiveness were then determined.

Statistical analysis

The data were subjected to a one-way analysis of variance (ANOVA). A comparison of means was carried out by Tukey's range test with a 95% confidence level. Statistical analysis was performed using the statistical software Minitab® Release 17. All the analyses were replicated at least three times.

Results and discussion

Proximate composition

Table 2 shows the proximate composition of different surimi paste formulations. Incorporating RPO and EVCO significantly ($p < 0.05$) decreased the moisture content. This was consistent with the significant ($p < 0.05$) increase in fat content due to the oils' fatty acids. Adding exogenous oil, such as camellia tea oil, significantly increased the fat content of surimi while decreasing the moisture content (Zhou *et al*., 2017). Table 2 also shows a clear trend of doubling fat content when the oil level was doubled, thus indicating the proportional relationship between oil concentration and surimi fat content.

The ash and protein contents were not significantly different ($p > 0.05$) between the samples. The oils mainly comprised fatty acids, and contained only traces of minerals and no protein. Alaska pollock surimi with or without oil showed no significant difference in the ash content values (Pietrowski *et al*., 2011). There was no significant difference between the protein levels of surimi with or without camellia tea oil (Zhou *et al*., 2017).

Whiteness

Table 2 shows the whiteness of different surimi gel formulations. The whiteness of C and D was significantly ($p < 0.05$) higher than A and B. EVCO resulted in whiter surimi due to minimal pigmentation in the oil. The emulsion created when the oil comminuted with fish muscle proteins and water resulted in a better light scattering effect attributed to increased whiteness (Park, 2005). However, the whiteness was not significantly different ($p > 0.05$) between Control, C, and D, thus indicating that a low concentration of EVCO was insufficient to significantly increase the whiteness of surimi. In contrast, RPO resulted in a significantly ($p < 0.05$) less white surimi due to the rich pigmentation in the oil. The significant differences can be explained by the prominent reddish colour of the oil resulting from dark red-orange antioxidants that are naturally present in it (Ma *et al*., 2017).

Table 2. Proximate composition and physicochemical properties of different surimi formulations.

Sample	Control	A	B	C	D
Proximate composition					
Moisture (%)	81.94 ± 0.35^{a}	78.20 ± 0.17^{b}	73.09 ± 0.26^{c}	78.38 ± 0.08^{b}	73.33 ± 0.39^{c}
Ash (%)	1.14 ± 0.05^{a}	1.15 ± 0.03^{a}	1.15 ± 0.01^{a}	1.13 ± 0.02^{a}	1.15 ± 0.00^{a}
Protein (%)	15.62 ± 0.39^{a}	15.55 ± 0.48^{a}	15.16 ± 0.17^{a}	15.46 ± 0.42^{a}	15.10 ± 0.53^{a}
Fat (%)	1.30 ± 0.04^{c}	5.10 ± 0.68^{b}	10.60 ± 2.35^{a}	5.03 ± 0.72^{b}	10.42 ± 1.64^{a}
Physicochemical property					
Whiteness	65.20 ± 0.05^{a}	57.59 ± 0.11^{b}	54.44 ± 0.44^{c}	66.34 ± 0.04^{a}	66.62 ± 0.30^{a}
pH	6.42 ± 0.02^{c}	6.54 ± 0.01^{b}	6.62 ± 0.02^{a}	6.52 ± 0.03^{b}	6.64 ± 0.00^{a}
Cooking yield (%)	92.50 ± 0.19^{b}	92.60 ± 0.66^{b}	96.60 ± 0.80^{a}	92.44 ± 0.88^{b}	95.23 ± 0.44^{a}
Water holding capacity (%)	71.67 ± 0.76^{a}	50.69 ± 0.78^{c}	42.33 ± 0.16^{d}	65.50 ± 0.50^{b}	52.33 ± 0.53^{c}

Data are mean ± standard deviation. Means followed by different lowercase superscripts in the same row are significantly different ($p < 0.05$).

pH

Table 2 shows that the pH of Control was 6.42. White-fleshed fish species like the threadfin bream usually have an initial pH above 6.6 (Hultin *et al*., 2005). In the present work, the lower pH was due to removing water-soluble elements during washing, thus leaving more concentrated acidic elements. A significant ($p < 0.05$) increase in pH due to RPO and EVCO was also recorded as the oils' neutral pH had shifted the samples' pH to a higher range. The present work also found that pH significantly increased ($p < 0.05$) by doubling the oil level. Nevertheless, the pH remained within the optimal range for surimi gelation process (Chang *et al*., 2001).

Cooking yield

Table 2 shows the effects of RPO and EVCO on the cooking yield of surimi gel. There was no significant ($p > 0.05$) difference in the cooking yield between Control, A, and C. In contrast, B and D containing 2% oil showed a higher ($p < 0.05$) cooking yield than the other formulations. When a meat-based product has high cooking yield, it means that it has high amount of fat (Purnomo and Rahardiyan, 2008). Therefore, when the manufacturers add higher oil concentration, more of the oil could be retained to produce surimi with significantly higher cooking yield, leading to lesser product loss due to the cooking process. Cheetangdee (2017) partially replaced porcine fat with soybean oil to modify the characteristics of sausages, and discovered that the oil successfully improved cooking yield relative to control.

Water-holding capacity

As shown in Table 2, the WHC of surimi gel significantly decreased ($p < 0.05$) by incorporating RPO and EVCO. These findings indicated a reduced gel network's capacity to hold water due to poor gel network formation (Wang *et al*., 2018). As oil was added to the gel, the large and unstable oil droplets were more likely to interfere with the gel matrix's protein-protein interaction (Gani and Benjakul, 2018). Eventually, the compactness of the three-dimensional gel network structure weakened, and caused the loss of free water trapped in the structure, thus resulting in decreased WHC (Chen *et al.*, 2023). The surimi gels with different vegetable oils, such as peanut and coconut oils, had lower WHC than the control (Song *et al.*, 2022).

Control with the highest moisture content could retain the moisture within the gel protein network, and yield the highest WHC. The absence of oil allowed the paste to form good gel network without oil droplets disturbing the protein-protein interaction. Hence, it resulted in a gel with good WHC. Varieties of vegetable oil also affected the WHC of surimi gel (Shi *et al*., 2014). The difference in the WHC between the samples with the same level of either RPO or EVCO was possibly related to their different fatty acid compositions. The present work also demonstrated that when vegetable oil content increased, the WHC of surimi gel significantly decreased ($p < 0.05$).

Microstructure

Based on Figure 1, a fibrous structure was observed in Control, and its protein surface was the smoothest as no oil was incorporated into the formulation. Conversely, oil droplets were observed to be embedded on the surface and in the matrix of the other samples. It was also noted that the number of oil droplets increased with increasing levels of oil incorporated. At higher oil levels, larger oil droplets were also observed. The oil droplets showed higher interfering effect on protein-protein interaction in the gel matrix by increasing the intermolecular distances between protein chains, thus lowering the strength, as evidenced by the decreased gel strength (Table 3). A lower proportion of myofibrillar proteins in the sample containing a higher amount of oil likely resulted in their decreased WHC (Gani *et al.*, 2018), as shown in Table 2.

Temperature sweep test

Figure 2 shows the different surimi gelation stages obtained in the present work. Various researchers also reported the same trends (Campo-Deano *et al*., 2009; Cando *et al*., 2016). The protein underwent different processes at each stage, from unfolding to aggregation. As the temperature increased from 10 to 90°C, the trend of all samples' G' curves was similar. The first drop in G' indicated protein unfolding attributed to the heating process that broke many hydrogen bonds within the folded protein structure (Liu *et al*., 1991). It was also possibly associated with actomyosin's unfolding, which caused significant structural change (Esturk, 2003). The dissociation of actin-myosin, which increases protein mobility, and breaks the protein

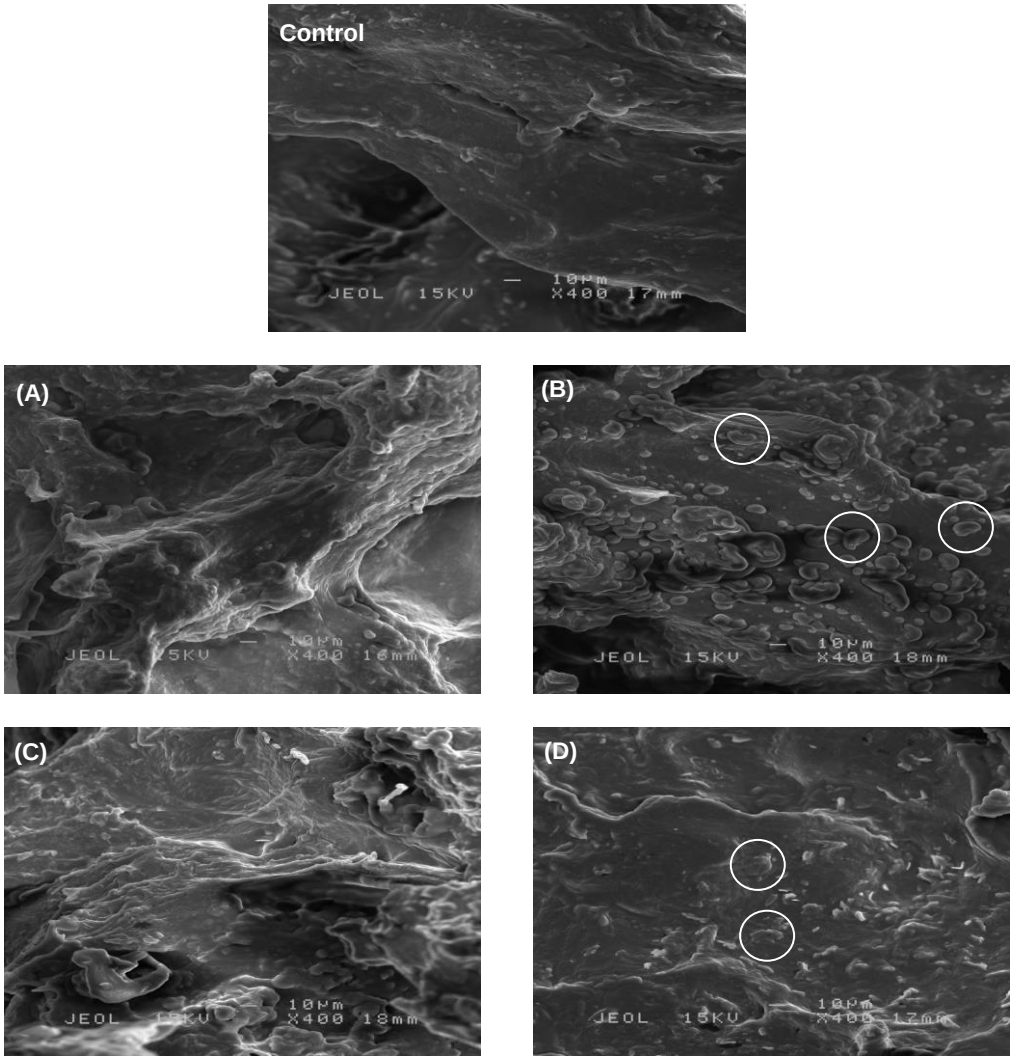

Figure 1. Electron micrographs of different surimi formulations. Circles indicate embedded oil droplets. Magnification: 400×.

Table 3. Texture profile of different surimi formulations.

Sample	Control	A	B	C	D
Gel strength (g.mm)	275.52 ± 0.69^{a}	203.53 ± 0.84^{c}	155.53 ± 0.85^{e}	241.45 ± 1.09^{b}	192.37 ± 0.74^{d}
Hardness (N)	14.71 ± 0.12^{c}	27.39 ± 0.17^{b}	28.59 ± 0.15^{a}	27.53 ± 0.14^{b}	28.68 ± 0.18^{a}
Chewiness (N)	3.92 ± 0.14^{c}	4.18 ± 0.18^{b}	4.29 ± 0.12^{a}	4.18 ± 0.14^{b}	4.30 ± 0.15^{a}
Springiness	0.62 ± 0.03^{c}	0.77 ± 0.03^{b}	0.84 ± 0.04^{bc}	0.77 ± 0.05^{b}	0.90 ± 0.01^{a}
Cohesiveness	0.24 ± 0.04^{b}	0.40 ± 0.04^{a}	0.37 ± 0.01^{a}	0.40 ± 0.04^{a}	0.37 ± 0.02^{a}

Data are mean ± standard deviation. Means followed by different lowercase superscripts in the same row are significantly different ($p < 0.05$).

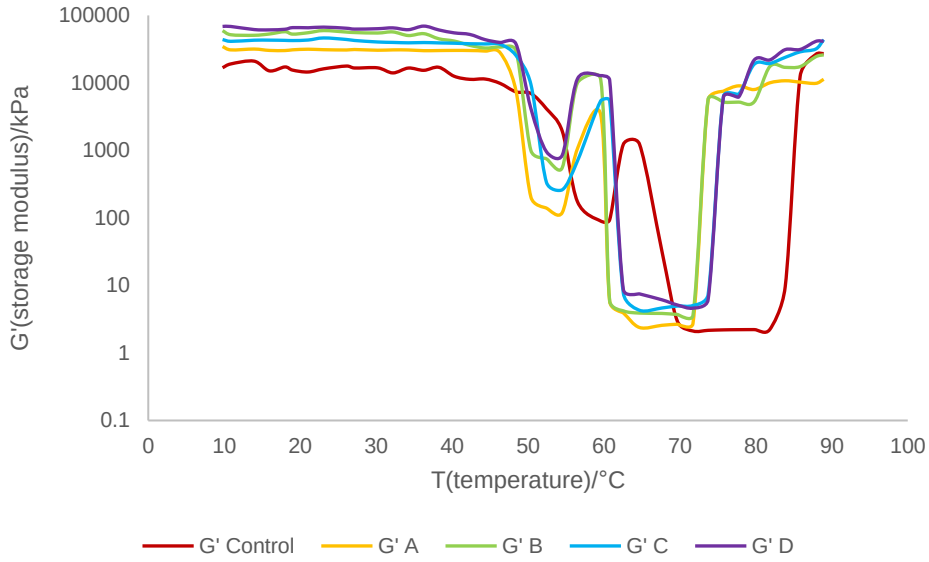

Figure 2. Gelation profiles of different surimi formulations obtained from temperature sweep test conducted over 10 to 90°C.

network (Shi *et al*., 2014), could also lead to decreased G'. In the present work, protein unfolding occurred at higher temperature range of 50 to 60°C. Due to its high thermal stability, processing at 25 to 30°C was insufficient to unfold threadfin bream surimi proteins (Poowakanjana *et al*., 2012).

After the first drop, G' increased back briefly. The increase could have been related to actomyosin molecular interactions and protein network structure formation *via* hydrogen bonds between protein molecules, thus forming a weak network (Zhang *et al*., 2013). At higher temperatures, the second drop of G' might have been caused by the destruction of a more significant number of hydrogen bonds, thus destabilising the protein aggregation previously formed (Liu *et al*., 1991), and causing a more intense decrease in G', as reflected by the more profound drop in the curve. Upon further heating, G' increased sharply and reached its peak at the end of the curve, which was caused by the formation of permanent, irreversible cross-linked myosin filament, and a stable three-dimensional gel structure due to continuous protein aggregation (Buamard and Benjakul, 2015). In the present work, the final increase in G', which marked the gelation completion, was from 79 to 85°C. The final stage of surimi thermal gelation was completed in a temperature range of 70 to 80°C (Ganesh *et al*., 2006).

Figure 2 also shows that the G' increased with the incorporation of RPO and EVCO. This reflected an increased resistance to shear forces in surimi with oil due to oil-protein interaction. The presence of oil could alter the molecular structure of proteins, and induce the exposure of hydrophobic groups (Meng *et al.*, 2005). There was a significant increase in hydrophobic interactions in surimi prepared with different concentrations of camellia tea oil (Zhou *et al.*, 2017). The changes in hydrophobic interactions might be related to the ability of the oil to affect protein-protein interactions, and change the protein environment of surimi gels.

Puncture test

For A, B, C, and D, the gel strength decreased significantly ($p < 0.05$) compared to Control (Table 3). Due to RPO and EVCO incorporation, the oil droplets in those formulations were more likely to interfere with protein-protein interaction in the gel matrix, thus lowering the gel strength (Gani and Benjakul, 2018). These results were consistent with the fact that the WHC also decreased with the incorporation of RPO and EVCO (Table 2). Jiao *et al.* (2019) reported that incorporating fish oil into surimi gel disrupted the protein matrix, and decreased gel strength. As the levels of virgin coconut oil increased, the gel strength continuously decreased (Gani *et al.*, 2018). The gel strength was also significantly ($p < 0.05$) lower when the oil level doubled. Shi *et al.* (2014) reported significant decrease in silver carp surimi gel strength when oil concentration increased.

Compression test

The compression test revealed significant ($p < 0.05$) differences between the textural properties of

different surimi gel formulations, as shown in Table 3. RPO and EVCO increased the gel's hardness, springiness, cohesiveness, and chewiness. Adding ω-3 oil increased the hardness of the surimi gel (Pietrowski *et al*., 2012). The exogenous oil had also possibly acted as a filler that occupied the empty spaces of the surimi gel matrix. This interaction changed the protein structure as the oil's insertion restrained the gel matrix against movement, thus increasing the surimi gel hardness (Zhou *et al*., 2017).

Conclusion

Incorporating RPO and EVCO significantly influenced threadfin bream surimi's physicochemical and gelation properties. Gel strength decreased as RPO and EVCO levels increased. However, the higher gel strength of surimi incorporated with EVCO compared to that with RPO indicated the possible functions of EVCO in gel-forming processes. The gel whiteness decreased with increasing RPO levels but remained unchanged with increasing EVCO levels. The viscoelastic study revealed that RPO and EVCO affected the storage modulus of the surimi paste. RPO and EVCO incorporation increased the fat content, pH level, cooking yield, hardness, chewiness, springiness, and cohesiveness, but did not impact the ash and protein contents.

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