Effects of water, oil, starch, calcium carbonate and titanium dioxide on the colour and texture of threadfin and hairtail surimi gels

Cheng-Kuang Hsu[1] & Been-Huang Chiang[2]*

1 Food Industry Research and Development Institute, Hsinchu 300, Taiwan
2 Graduate Institute of Food Science and Technology, National Taiwan University, 59, Lane 144, Keelung Road., Sec. 4, Taipei, Taiwan

(Received 16 August 2000; Accepted in revised form 4 April 2001)

Summary The effects of moisture, oil, starch, calcium carbonate and titanium dioxide on the colour and texture properties of surimi gels were studied. Increasing the moisture or oil contents raised the L^* values but reduced the b^* values. Calcium carbonate and titanium dioxide increased the L^* values, while potato starch decreased the b^* values. The addition of oil up to the 8% level affected textural properties, but increasing the oil content while maintaining final moisture content constant could significantly decrease the hardness of surimi gels.

Keywords Colour, surimi, texture.

Introduction

Colour and texture properties are important sensory attributes affecting the market acceptance of surimi products. Much research has focused on the development of new processing techniques to produce surimi seafood with unique texture functionality (Lanier, 1986; Hamann *et al.*, 1990; Hsu, 1995). For example, the addition of gel-enhancers or enzyme inhibitors such as whey protein, soybean protein, egg white, and beef plasma protein, have been used to improve the texture properties of surimi products (Chang-Lee *et al.*, 1990; Hamann *et al.*, 1990; Chen *et al.*, 1993; Park, 1994; Morrissey *et al.*, 1995). However, the use of fatty and dark-fleshed fish species such as herring, sardine and mackerel for surimi, is still a challenge mainly because of the dark appearance and undesirable flavour (Shimizu *et al.*, 1992; Reppond *et al.*, 1995) of the product. Methods to improve the colour and flavour properties of surimi made from dark-fleshed species have been to leach the mince with solutions of NaCl and $NaHCO_3$ and to separate dark meat from light meat. However, the heme pigments are much less easily extracted from dark-fleshed species because the dark muscle structure is much more tough and rigid than white muscle (Shimizu *et al.*, 1992). The separation of dark muscle by deep skinning of the fish using a skinning machine, or by applying high pressure water jets has been proposed, but they are not free of problems (Shimizu *et al.*, 1992). The addition of protein additives to improve the textural properties of dark-fleshed fish species could further worsen their colour properties, for example, the use of whey protein, beef plasma protein and soybean protein could increase the yellowness of the final products (Park, 1994; Hsu *et al.*, 1997). The use of food grade colour modifiers is the potential alternative to improve the colour properties of dark fleshed species. However, the addition of colour modifier to the fish mince may also alter the texture of the surimi product. Therefore, the objectives of this study were to test the hypothesis that water, oil, starch, calcium carbonate and titanium dioxide could be

*Correspondent: Fax: +886-2-2362-0849;
e-mail: bhchiang@ccms.ntu.edu.tw

used to alter the colour and textural properties of surimi gels.

Materials and methods

Materials

Frozen high grade Alaska pollock (*Theragra chalcogramma*) surimi, golden threadfin bream (*Nemipterus virgatus*) surimi, and low grade hairtail (*Trichiurus lepturus*) surimi were purchased from Kasei Frozen Foods Works Co., Ltd, Taiwan. These surimi were stored at −20 °C until use. Modified potato starch was purchased from Societa Piemontese Amidi e Derivati, Italy. Titanium dioxide and calcium carbonate were purchased from Warner Jenkinson Co., Louis, MO. Soybean oil was purchased from a local grocery store.

Surimi gel preparation

The frozen surimi was partially thawed at room temperature for approximately 2 h to prevent the rapid increase of sample temperature during the subsequent blending procedures. Approximately 600 g of surimi was blended with 2% NaCl (weight ratio to the surimi) in a mixer (Model WTI-168DX, Wang-Den Inc., Taiwan) for 4 min with the addition of ice/water to adjust the final moisture content to 78% while maintaining a temperature in the range of 5–10 °C. Predetermined amounts of oil, potato starch, calcium carbonate and titanium dioxide were added during mixing to modify the colour and textural properties of surimi gels. Predetermined amounts of ice/water were added to adjust the final moisture content of the surimi gels in the set of experiments that were aimed to determine the effect of the moisture level on the colour and textural properties. The mixture was extruded into stainless steel cooking tubes (inside diameter 3.0 cm, length 15 cm), and surimi gels were then produced by heating in a 90 °C water bath for 20 min, followed by cooling in ice water at 1 ± 0.5 °C for 10 min. Surimi gels were stored in ziplock bags and refrigerated at about 5 °C. The gels were removed from refrigerated storage within 48 h, left at room temperature for 1 h, and then cut into small sections (diameter 3.0 cm, length 3.0 cm) for colour and texture measurements.

Colour measurement

The colour of the surimi gels was measured using a colorimeter (Model TC-1500 DX, Tokyo Denshoku Co., Ltd, Japan). The L^*, a^*, and b^* values were recorded, with L^* denoting lightness on a 0–100 scale from black to white; a^*, red (+) or green (−); and b^*, yellow (+) or blue (−). A 'whiteness' index for overall colour evaluation of surimi was also used and calculated as: $L^* - 3b^*$ (Park, 1994).

Gel strength measurement

The gel properties were measured by a rheometer (Model CR-200D, Sun Scientific Co., Ltd, Japan) using a ball plunger with a diameter of 5 mm, and the results expressed as breaking force (g) and deformation (mm) representing the hardness and cohesiveness of the surimi gels, respectively.

Statistical analysis

One-way analysis of variance (one-way ANOVA) was conducted using an SAS package (SAS Institute Inc., Cary, NC, USA). Duncan's multiple ranges test was used to determine the significant difference between different treatments.

Results and discussion

Effect of moisture content

Surimi is typically made from lean fish species such as Alaska pollock, which have white flesh. Generally the demand is for surimi gels with high L^*, low b^* and high $L^* - 3b^*$ value indicating high lightness, low yellowness, and high whiteness, respectively. Compared with pollock surimi, golden threadfin bream surimi shows a slightly higher yellow value. Our data indicated that gels (containing 78% water) made from golden threadfin bream had 2 units more in the b^* value and thus equivalent to 6 units less in the whiteness value than pollock surimi gels (the L^*, b^*, and whiteness were 86.6, 5.43, and 70.3, respectively) having the same moisture content. Thus, golden threadfin bream surimi was selected in this study to determine whether adding water, oil, starch, calcium carbonate, or titanium dioxide can increase the whiteness value of the surimi gels to a level close to that of pollock surimi gels. Table 1 shows the effect of moisture content on the colour and texture properties of golden threadfin bream surimi gels. Significant changes in the L^* value were found when the moisture content increased from 74.3 to 79.5%, but no significant differences was obtained as the moisture content increased further. The b^* value decreased with the increase of the moisture content, but no significant changes were observed in the a^* value. The results indicated that the higher the moisture content, the whiter and the less yellow was the colour. Raising the moisture content of golden threadfin bream surimi gels from 74.3 to 82.5% resulted in 3 units more in the L^* values (from ~85 to ~88) and 2.9 units less in the b^* values (from ~8.7 to ~5.8). Reppond & Babbitt (1997) stated that L^* value increased but b^* value decreased linearly with the increase of the moisture content in pollock surimi. When adjusting moisture content from 73.6 to 81.1% in whiting and pollock surimi gels, Park (1995) also reported 3 units increase in the L^* values for both whiting (from ~76 to ~79) and pollock (from ~80 to ~83) and 2 and 1.5 units decrease in the b^* values for whiting (from ~7.5 to ~5.5) and pollock (from ~6 to ~4.5), respectively. This suggested that the increase in the L^* value was not species dependent, while the decrease in the b^* value tended to be species dependent. It was noted that the original b^* values followed the order: golden threadfin-bream surimi (8.7) > whiting surimi (7.5) > pollock surimi (6) [the b^* values of whiting and pollock were based on the value reported by Park (1995)], and the magnitude of the reduction in the b^* values also followed the same order. Therefore, it was suspected that the magnitude of the reduction in the b^* values by adding water depended on the original b^* values of the surimi gels. As expected, the breaking force decreased rapidly with the increase in the moisture levels (Table 1). When the moisture level increased from 74.3 to 78%, no significant change in the deformation was found, however, as moisture level further increased, the deformation started to decrease. Therefore, the deformation was less sensitive to the moisture levels of surimi gels. This result agreed with the report by Hamann & Lanier (1986). It was found that 4.5 units increase in the percentage of the moisture content was required to increase the whiteness of golden threadfin bream surimi gels to the level close to that of pollock surimi gels. However, raising water content by 4.5% units may not be feasible as a result of the loss in the breaking force. As moisture content showed significant influence on both the colour and texture characteristics, it is important to compare these properties of surimi gels at the same moisture level. Therefore, the final moisture levels of surimi gels were maintained at constant level of 78% in the subsequent experiments for testing the effects of various food additives.

Effect of soybean oil

The effect of soybean oil on the colour and textural properties of golden threadfin bream surimi gels is shown in Tables 2 and 3. The addition of oil significantly increased the L^* values and the whiteness values, and decreased the b^* values (Table 2). At the 6% oil level, increases of 5.8 units in the L^* values and 9.8 units in the whiteness values, and a decrease of 1.3 units in the b^* values were observed. When 4% oil were added, the whiteness value of gels made from golden threadfin bream surimi was close to that of

Table 1 The effect of final moisture content on the colour and textural properties of golden threadfin bream surimi[1]

% Water	L^*	a^*	b^*	L^*-3b^*	Force (g)	Deformation (mm)
74.3	85.0 ± 0.4^a	-1.14 ± 0.46 [2]	8.7 ± 0.4^a	58.8 ± 0.9^a	669 ± 17^a	12.3 ± 0.4^a
78.0	87.1 ± 0.3^b	-0.57 ± 0.41	7.5 ± 0.3^b	64.7 ± 0.9^b	351 ± 36^b	12.2 ± 0.7^a
79.5	87.5 ± 0.2^{bc}	-1.09 ± 0.13	7.1 ± 0.1^{bc}	66.2 ± 0.3^c	278 ± 18^c	11.3 ± 0.5^b
81.0	88.0 ± 0.3^d	-0.97 ± 0.16	6.8 ± 0.1^c	67.6 ± 0.3^d	165 ± 19^d	10.2 ± 0.3^c
82.5	87.8 ± 0.3^d	-0.39 ± 1.23	5.8 ± 0.7^d	70.4 ± 2.1^e	82 ± 13^e	9.6 ± 0.3^d

[1] Values are mean ± standard deviations.
[2] Values in same column are not significantly different ($P > 0.05$).
Values in same column with different letters are significantly different ($P < 0.05$).

Table 2 The effect of oil on the colour and textural properties of golden threadfin bream surimi

% Oil	L^*	a^*	b^*	$L^* - 3b^*$	Force (g)	Deformation (mm)
0	87.1 ± 0.3[a]	−0.57 ± 0.41[a]	7.5 ± 0.3[a]	64.7 ± 0.9[a]	351 ± 36[a]	12.2 ± 0.7[a]
2	89.6 ± 0.2[b]	0.09 ± 0.25[b]	7.1 ± 0.2[b]	68.2 ± 0.3[b]	295 ± 31[b]	12.1 ± 0.6[a]
4	91.2 ± 0.1[c]	0.24 ± 0.14[b]	6.9 ± 0.2[b]	70.4 ± 0.5[c]	187 ± 14[c]	11.0 ± 0.6[b]
6	92.9 ± 0.1[d]	0.01 ± 0.59[b]	6.2 ± 0.5[c]	74.5 ± 1.3[d]	102 ± 13[d]	11.2 ± 0.3[b]

Values in same column with different letters are significantly different ($P < 0.05$).

Table 3 The effect of oil on the colour and textural properties of golden threadfin bream surimi (without controlling the final moisture content to 78%)

% Oil	% Water	L^*	a^*	b^*	$L^* - 3b^*$	Force (g)	Deformation (mm)
0	74.3	85.0 ± 0.4[a]	−1.14 ± 0.46 [a]	8.7 ± 0.4[ab]	58.8 ± 0.9[a]	669 ± 17[ab]	12.3 ± 0.4[a]
1	73.6	86.8 ± 0.2[b]	−0.43 ± 0.20[b]	9.1 ± 0.2[c]	59.5 ± 0.5[a]	608 ± 68[ac]	11.2 ± 0.6[bc]
2	72.8	88.3 ± 0.4[c]	−0.38 ± 0.12[b]	8.9 ± 0.2[ac]	61.5 ± 0.6[b]	603 ± 51[c]	11.0 ± 0.7[bc]
4	71.4	89.3 ± 0.3[d]	−0.13 ± 0.29[bc]	8.7 ± 0.2[ab]	63.3 ± 0.7[c]	563 ± 65[c]	11.5 ± 0.8[b]
6	70.1	89.5 ± 0.5[d]	0.68 ± 0.90[d]	8.4 ± 0.2[b]	64.1 ± 0.6[d]	667 ± 49[ab]	10.0 ± 0.7[d]
8	68.8	90.7 ± 0.1[e]	0.16 ± 0.16[c]	8.7 ± 0.1[ab]	64.5 ± 0.3[d]	676 ± 39[b]	10.4 ± 0.3[cd]
10	67.5	84.8 ± 0.2[a]	−0.64 ± 0.06[b]	8.6 ± 0.1[b]	59.0 ± 0.3[a]	400 ± 53[d]	7.1 ± 1.0[e]

Values in same column with different letters are significantly different ($P < 0.05$).

pollock surimi gels. Therefore, adding oil was considered as an effective way to whiten the colour of surimi gels. The whitening effect of oil was believed to be the result of the light scattering effect of oil droplets in the product (Lee *et al.*, 1992). However, increasing oil content while maintaining constant moisture level (78%) would cause significant changes in the texture properties of surimi gels. Most significant would be a reduction in the breaking force, although deformation was less sensitive to the increase of oil concentration (Table 2). At 4% oil content, 50% reduction in the breaking force value was obtained. Hastings & Currall (1989) reported that corn oil showed a softening effect on cod surimi gels measured by instrumental means, but a reduction of the strength of the gels were not discerned in sensory tests. Another set of experiment was conducted by adding various amounts of oil to golden threadfin bream surimi without adjusting the final moisture content; the results are shown in Table 3. It was found that breaking force also decreased as the oil content increased from 0 to 4%. However, adding 6 to 8% of oil did not affect the breaking force, but a significant decrease was observed at 10% oil content. This was explained by the fact that adding oil would decrease the moisture content of the gels therefore the softening effect caused by adding oil was overcome by the hardening effect resulting from the reduction of moisture level. The L^* and whiteness value increased with the increase in oil content, about 5.7 units increase in the L^* and whiteness values was obtained when 8% oil was added. However, no significant improvement in the b^* values was found because the whitening effect given by adding oil was counteracted by the decline in the moisture levels. It was noted that at a 10% level, the surimi gels no longer had the ability to hold water and/or oil inside the gel matrix, thus, causing a dramatic decrease in the breaking force, L^*, and whiteness values. Our results suggested that a proper selection of the water/oil ratio was very important when oil was used to whiten the colour of surimi gels.

Effect of potato starch

Table 4 shows the effect of potato starch on the colour and texture properties of surimi gels made from golden threadfin bream. The addition of 2% potato starch did not cause any change in all the colour parameters. As the level further increased, potato starch significantly reduced the b^* values, but no improvement was found in the L^* value. When 6% of potato starch was used, 1.4 units

Table 4 The effect of potato starch on the colour and textural properties of golden threadfin bream surimi

% Starch	L^*	a^*	b^*	$L^* - 3b^*$	Force (g)	Deformation (mm)
0	87.1 ± 0.3[a]	−0.57 ± 0.41[a]	7.5 ± 0.3′[a]	64.7 ± 0.9[a]	351 ± 36[a]	12.2 ± 0.7[a]
2	86.9 ± 0.5[a]	−0.25 ± 0.28[a]	7.7 ± 0.1[a]	63.9 ± 0.6[a]	271 ± 22[bc]	10.7 ± 0.6[b]
4	86.5 ± 0.3[b]	−1.16 ± 0.33[b]	6.7 ± 0.2[b]	66.5 ± 0.4[b]	291 ± 28[b]	11.6 ± 1.0[a]
6	86.3 ± 0.4[b]	−1.08 ± 0.36[b]	6.1 ± 0.2[c]	67.9 ± 0.6[c]	252 ± 18[c]	10.7 ± 0.3[b]

Values in same column with different letters are significantly different ($P < 0.05$).

reduction in the b^* values and 3.2 units increase in whiteness resulted. As the whiteness of golden threadfin bream surimi gels was about 6 units less than that of pollock surimi gels, our data indicated that potato starch alone could not whiten the colour of golden threadfin bream surimi gels to the levels close to that of pollock surimi gels. The gel texture was also affected by the addition of potato starch. The breaking force tended to decrease with the increase in the concentration of potato starch but the deformation did not show significant changes caused by adding potato starch.

Effect of calcium carbonate

In the range of 0–2%, calcium carbonate showed no significant influence on the b^* values, but 3 units increase in both the L^* and whiteness values was observed (Table 5). Lee *et al.* (1992) stated that calcium carbonate would not dissolve at neutral pH in the analogue products. The undissolved particles of calcium carbonate are believed to bring about a light scattering effect, thus making products appear whiter. The use of calcium carbonate in foods is constrained in the range of 0.5–1.5% (Lee *et al.*, 1992). Our results indicated that adding calcium carbonate in the range could not whiten the colour of golden threadfin bream surimi gels to the levels close to that of pollock surimi. The breaking force significantly decreased with the addition of calcium carbonate, but no significant changes were found in the deformation (Table 5).

Effect of titanium dioxide

Titanium dioxide has been suggested a useful whitener for improving the acceptability of fish mince coloration (Meacock *et al.*, 1997). The addition of titanium dioxide in the range of 0–0.16% significantly increased the L^* and whiteness values of golden threadfin bream surimi gels, but not the b^* values (Table 6). The whiteness of golden threadfin bream surimi was close to that of pollock surimi when the concentration of titanium dioxide was more than 0.16%. As the amount of titanium dioxide used in the formulation was quite small, titanium dioxide could be considered as an effective colour modifier for surimi seafoods. No significant changes were observed in either the breaking force or the deformation values by adding titanium dioxide.

Effect of titanium dioxide and soybean oil on the colour of surimi gels made from hairtail

The results shown above indicated that titanium dioxide and soybean oil may be used as the whitening agents for surimi seafoods. The effects of titanium dioxide and oil on the colour of gels made from hairtail surimi were further

Table 5 The effect of calcium carbonate on the colour and textural properties of golden threadfin bream surimi

% $CaCO_3$	L^*	a^*	b^*	$L^* -3b^*$	Force (g)	Deformation (mm)
0	87.1 ± 0.3[a]	−0.57 ± 0.41 [1]	7.5 ± 0.3[a]	64.7 ± 0.9[a]	351 ± 36[a]	12.2 ± 0.7[a]
0.5	87.9 ± 0.3[b]	−0.39 ± 0.08	7.8 ± 0.1[ab]	64.6 ± 0.4[a]	265 ± 20[b]	1.0 ± 0.7[b]
1	88.9 ± 0.2[c]	−0.36 ± 0.14	7.9 ± 0.1[b]	65.2 ± 0.4[a]	307 ± 28[c]	12.1 ± 0.5[a]
2	90.2 ± 0.2[d]	−0.49 ± 0.16	7.7 ± 0.1[ab]	67.2 ± 0.3[b]	209 ± 24[d]	12.1 ± 1.0[a]

[1] Values in same column are not significantly different ($P > 0.05$).

Values in same column with different letters are significantly different ($P < 0.05$).

Table 6 The effect of titanium dioxide on the colour and textural properties of golden threadfin bream surimi

% TiO_2	L^*	a^*	b^*	$L^* - 3b^*$	Force (g)	Deformation (mm)
0	87.1 ± 0.3^a	-0.57 ± 0.41^a	7.5 ± 0.3^a	64.7 ± 0.9^a	351 ± 36^1	12.2 ± 0.7^1
0.02	87.8 ± 0.3^b	-0.69 ± 0.27^a	7.5 ± 0.2^a	65.2 ± 0.7^{ab}	329 ± 46	11.4 ± 0.8
0.04	89.0 ± 0.2^c	-0.14 ± 0.36^{bc}	7.7 ± 0.7^a	66.0 ± 2.3^{ab}	344 ± 32	12.2 ± 0.7
0.08	90.5 ± 0.5^d	-0.31 ± 0.18^{ab}	8.1 ± 0.2^b	66.1 ± 0.7^b	291 ± 56	1.5 ± 1.3
0.12	91.7 ± 0.1^e	0.12 ± 0.39^{cd}	7.7 ± 0.3^{ab}	68.5 ± 0.9^c	347 ± 33	12.0 ± 0.8
0.16	92.6 ± 0.2^f	0.22 ± 0.25^d	7.5 ± 0.2^a	70.1 ± 0.7^c	340 ± 39	12.2 ± 0.6

[1] Values in same column are not significantly different ($P > 0.05$).
Values in same column with different letters are significantly different ($P < 0.05$).

investigated to determine their ability in modifying the colour of gels made from fatty and dark species. The L^* value of hairtail surimi gels was ~7 units less than that of both pollock and golden threadfin bream surimi gels, and the b^* values were ~5.5 and ~3.5 units less than that of pollock and gold threadfin bream surimi, respectively. Table 7 shows the effect of titanium dioxide on hairtail surimi gels of the same moisture content of 78%. Again, the L^* values increased with the concentration of titanium dioxide while no significant changes ($P > 0.05$) on the b^* values was found up to the 0.4% level. At the 0.8% level, it was noted that a significant decrease in the b^* value was found. Furthermore, with the addition of 0.8% titanium dioxide, hairtail surimi gels had the same whiteness value as that of surimi gels made from golden threadfin bream indicating that titanium dioxide had great ability to whiten the colour of protein gels. Another advantage of using titanium dioxide was that in the concentration range tested it did not change the gel texture (both the breaking force and the deformation) (Table 7).

Table 8 shows the effect of soybean oil on the colour and texture properties of hairtail surimi gels without adjusting the final moisture content to the constant level of 78%. Because the hairtail surimi showed a very poor gel-forming ability, the addition of oil while maintaining the final moisture content at 78% was not feasible. In the range of

Table 7 The effect of titanium dioxide on the colour and textural properties of hairtail surimi

% TiO_2	L^*	a^*	b^*	$L^* - 3b^*$	Force (g)	Deformation (mm)
0	80.2 ± 0.2^a	0.60 ± 0.61^1	11.1 ± 1.9^a	46.9 ± 5.6^a	59 ± 8^1	3.9 ± 0.4^1
0.2	84.8 ± 0.2^b	0.87 ± 0.85	11.0 ± 0.6^a	51.8 ± 1.7^b	53 ± 6	4.0 ± 0.3
0.4	87.3 ± 0.2^c	0.54 ± 0.15	10.3 ± 0.1^a	56.3 ± 0.3^c	48 ± 5	3.8 ± 0.3
0.8	89.8 ± 1.2^d	1.23 ± 0.91	8.4 ± 1.0^b	64.8 ± 1.8^d	47 ± 8	4.1 ± 0.7

[1] Values in same column are not significantly different ($P > 0.05$).
Values in same column with different letters are significantly different ($P < 0.05$).

Table 8 The effect of oil on the colour and textural properties of hairtail surimi (without controlling the final moisture content to 78%)

% Oil	% Water	L^*	a^*	b^*	$L^* - 3b^*$	Force (g)	Deformation (mm)
0	76.0	79.0 ± 0.4^a	0.41 ± 0.15^{ab}	13.0 ± 0.1^a	40.1 ± 0.4^a	89 ± 6^a	4.3 ± 0.2^{ab}
1	75.2	80.3 ± 0.2^b	0.37 ± 0.31^{ab}	12.1 ± 0.2^b	43.9 ± 0.5^b	83 ± 2^a	4.5 ± 0.6^a
2	74.5	80.6 ± 0.4^{bc}	0.23 ± 0.30^a	11.9 ± 0.2^{bc}	45.0 ± 0.6^{bc}	73 ± 5^b	4.3 ± 0.3^{ab}
4	73.1	81.3 ± 0.6^{cd}	0.37 ± 0.17^{ab}	12.0 ± 0.2^b	45.3 ± 1.2^{bc}	72 ± 9^b	4.2 ± 0.5^{ab}
6	71.7	82.1 ± 1.8^{de}	0.23 ± 0.20^a	12.0 ± 0.7^b	46.2 ± 3.9^c	72 ± 4^b	3.9 ± 0.2^{bc}
8	70.4	83.1 ± 0.3^f	0.62 ± 0.11^{bc}	11.6 ± 0.2^c	48.4 ± 0.8^d	108 ± 5^c	3.6 ± 0.3^c
10	69.1	83.0 ± 0.8^{ef}	0.81 ± 0.33^c	11.6 ± 0.2^c	48.2 ± 1.3^d	98 ± 9^d	4.0 ± 0.2^{bc}

Values in same column with different letters are significantly different ($P < 0.05$).

0–8% oil content, the L^* values increased with oil content, but further increase of the oil level to 10% showed no significant effect. Adding oil was less effective in modifying the b^* value except at extremely high oil contents ($>8\%$). The addition of oil without controlling the final moisture content did not affect either the breaking force or the deformation of hairtail surimi gels (Table 8). A similar effect of oil concentration on the gel texture of golden threadfin bream and hairtail was observed (Tables 3 and 8). However, at 10% oil level, the changes in the colour or texture properties of the golden threadfin bream gels were not observed in the gels made from hairtail. The difference may be because the moisture content of hairtail surimi gels (76%) was higher than that of golden threadfin bream surimi gels (74.3%). It was suspected that at the high oil content, the fish protein gels lost the abilities to hold water and/or oil inside the gel matrix and the water and oil holding abilities may depend on the ratio of water/oil.

Conclusions

Raising the moisture or oil content of the threafin and hairtail surimis significantly increased the L^* values and decreased the b^* values of the gels. Potato starch decreased the b^* value, but not the L^* value. Calcium carbonate and titanium dioxide increased the L^* value, but not the b^* value. Adding water, oil, or titanium dioxide was considered as an effective way to whiten the colour of surimi gels. The addition of titanium dioxide did not have significant effects on the textural properties of surimi gels. The addition of oil content up to the 8% level had minor effects on the textural properties but raising oil content while maintaining constant final moisture content significantly decreased the breaking force of the surimi gels. Thus, proper selection of the oil/moisture ratio is very important when oil is used to modify the colour and textural properties of surimi gels. The effects of combined ingredients on the colour and textural properties of surimi gels require further study.

References

Chang-Lee, M.V., Lampila, L.E. & Crawford, D.L. (1990). Yield and composition of surimi from Pacific whiting (*Merluccius productus*) and the effects of various protein additives on gel strength. *Journal of Food Science*, **55**, 83–86.

Chen, J.S., Lee, C.M. & Crapo, C. (1993). Linear programming and response surface methodology to optimize surimi gel texture. *Journal of Food Science*, **58**, 535–538.

Hamann, D.D., Amato, P.M., Mu, M.C. & Foegeding, E.A. (1990). Inhibition of modori (gel weakening) in surimi by plasma hydrolysate and egg white. *Journal of Food Science*, **55,** 665–669, 795.

Hamann, D.D. & Lanier, T.C. (1986). Instrumental methods for predicting seafood sensory texture quality. In: *Seafood Quality Determination* (edited by D.E. Kramer & J. Liston). P. 123. Amsterdam: Elsevier Science.

Hastings, R.J. & Currall, J.E.P. (1989). Effects of water, oil, egg white and starch on the texture of cod surimi gels by response surface methodology. *Journal of Texture Studies*, **19**, 431–451.

Hsu, S.Y. (1995). Optimization of the surimi processing system with a central composite design method. *Journal of Food Engineering*, **24**, 101–111.

Hsu, C.K., Kolbe, E. & English, M. (1997). A nonlinear programming technique to develop least cost formulations of surimi products. *Journal of Food Process Engineering*, **20**, 179–196.

Lanier, T.C. (1986). Functional properties of surimi. *Food Technology*, **40**, 107–115.

Lee, C.M., Wu, M.C. & Okada, M. (1992). Ingredient and formulation technology for surimi-based products. In: *Surimi Technology* (edited by T.C. Lanier & C.M. Lee). P. 273. New York: Marcel Dekker.

Meacock, G., Taylor, K.D.A., Knowles, M.J. & Himonides, A. (1997). The improved Whitening of minced cod flesh using dispersed titanium dioxide. *Journal of the Science of Food and Agriculture*, **73**, 221–225.

Morrissey, M.T., Hartley, P.S. & An, H. (1995). Proteolytic activity in Pacific whiting and effects of surimi processing. *Journal of Aquatic Food Product Technology*, **4**, 5–18.

Park, J.W. (1994). Functional protein additives in surimi gels. *Journal of Food Science*, **59**, 525–527.

Park, J.W. (1995). Surimi gel colours as affected by moisture content and physical conditions. *Journal of Food Science*, **60**, 15–18.

Reppond, K.D. & Babbitt, J.K. (1997). Gel properties of surimi from various fish species as affected by moisture content. *Journal of Food Science*, **62**, 33–36.

Reppond, K.D., Babbitt, J.K., Berntsen, S. & Tsuruta, M. (1995). Gel properties of surimi from Pacific Herring. *Journal of Food Science*, **60,** 707–710, 714.

Shimizu, Y., Toyohara, H. & Lanier, T.C. (1992). Surimi production from fatty and dark-fleshed fish species. In: *Surimi Technology* (edited by T.C. Lanier & C.M. Lee). P. 181. New York: Marcel Dekker.

