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FUNCTIONAL CHARACTERISTICS AND QUALITY OF ULTRAVIOLET-IRRADIATED PARTIALLY INSOLUBLE FISH GELATIN AS SHARK FIN ANALOGS

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Key words: fish gelatin, shark fin analogs, tilapia, UV treatments.

ABSTRACT

Tilapia skin gelatin powder was used to parpare shark fin analogs. Experimental samples were exposed to ultraviolet (UV) irradiation at 612, 1224, 1836, 2448, 3060, and 3672 mJ/cm^2. Fish gelatin exposed to UV at 1836 mJ/cm^2 became partially insoluble. UV exposure reduced the transmittance of amide I at 1630 cm^{-1}, amide II at 1480-1575 cm^{-1}, and amide III at 1237 cm^{-1} in Fourier transform infrared spectra. UV treatment at 612 mJ/cm^2 significantly reduced the gel strength of fish gelatin, whereas higher UV exposure increased the gel strength. UV irradiation at up to 3060 mJ/cm^2 increased the b* value (yellowness) of gelatin powder, and UV irradiation at 3672 mJ/cm^2 reduced the gelatin particle size from a mean length of 0.43 mm and a mean width of 0.25 mm to 0.29 and 0.2 mm, respectively. Hence, UV irradiation of fish gelatin at 612 mJ/cm^2 can significantly prevent cooking loss by 32.6%. UV-irradiated fish gelatin can be applied as a structural ingredient for preparing shark fin analogs.

I. INTRODUCTION

Gelatin is commonly used as a foaming and gelling agent in biomedical, pharmaceutical, and food products such as jellied meats, candy, desserts, and bakery and ice cream products (Karim and Bhat, 2008; Wangtueai and Noomhorm, 2009). Gelatin is mostly derived from cattle hide, demineralized cattle bones, and pig skins (Montero and Gómez-Guillén, 2000; Patil et al., 2000). Fish gelatin is a potential alternative to porcine and bovine gelatins for kosher and halal markets (Jongjareonrak et al., 2010). However, the low gelling temperature and gel strength of fish gelatin prevents its extensive use in the food industry (Haug et al., 2004; Karim and Bhat, 2008).

Dried shark fin is a rather expensive ingredient used in gourmet cuisines. The demand for shark fins results in discarding live definned sharks, and this malpractice has severely endangered the sustainability of the shark population (Fong and Anderson, 2002). Hence, a high demand exists for preparing shark fin analogs from mammalian and fish gelatins. To prepare the traditional delicacy of shark fin soup by using shark fins, the dried fins are rehydrated by soaking in warm water at 50-60°C before cooking with other ingredients. Commercial shark fin analogs are prepared from sodium alginate and porcine gelatin with water. The high cooking loss and soft texture of shark fin analogs hinder the substitution of natural shark fin products. Ultraviolet (UV)-irradiated fish gelatin exhibits improved gel strength (Bhat and Karim, 2009), and the partial insolubility of fish gelatin can prevent the cooking loss of shark fin analogs (Sung and Chen, 2014).

The present study investigated the crosslinking ability, gel strength, and other functional properties of tilapia skin gelatins irradiated with UV. This study also evaluated the cooking properties of shark fin analogs made from UV-treated gelatins.

II. MATERIALS AND METHODS

Dried tilapia skin gelatin of 200 Bloom was purchased from Jellice Pioneer Provate Limited, Taiwan Branch (Pingtung, Taiwan). Sodium alginate (product name: Duck Algin Nspl) was supplied by Kikkoman Biochemifa Company (Tokyo, Japan). Moreover, 2.5% glutaraldehyde in 0.1 M sodium phosphate buffer was purchased from Electron Microscopy Sciences (Hatfield, PA, USA). Commercial shark fin analogs were purchased from Ju Chang Food Industrial Co., Ltd. (New Taipei City, Taiwan).

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1. Ultraviolet Irradiation

For UV irradiation, samples of 100 g gelatin powder were spread evenly on a stainless steel sheet (35 × 52 cm) in a biological laboratory fume hood. The samples were exposed to a UV-C light source (Philips TUV 15 w/G15 T8, Eindhoven, Holland) at a distance of 30 cm from the surface for 30, 60, 90, 120, 150, and 180 min. The intensity of UV-C light was measured using a UV light meter (model ST-512, Shenzhen Laesent Technology Co., Ltd., Taipei, Taiwan). The samples were exposed to UV-C irradiation at 612, 1224, 1836, 2448, 3060, and 3672 mJ/cm^2, transferred into 1-kg polyethylene (PE) bags, and stored in air at room temperature for further research.

2. Determination of the Color of Gelatin Powder and Gel

The gelatin powder and gel (6.67%) color was examined using a spectrocolorimeter (TC-1800 MK-II, Tokyo, Japan) with the L* (lightness), a* [redness (+)/greenness (−)], and b* [yellowness (+)/blueness (−)] color scale. The color difference (ΔE) was calculated using the following formula: $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$ (Goyeneche et al., 2014).

3. Determination of Bloom Gel Strength and Viscosity

The gel strength (Bloom) was measured using the British Standard 757:1975 method (BSI, 1975), with slight modification. Gelatin samples [6.67% (w/v)] were dissolved in Bloom jars (Lotun Science Corp., Taipei City, Taiwan) with distilled water at 60°C for 1 h to allow the gelatin to absorb water and swell. Subsequently, the jars were allowed to cool down to room temperature (25°C) for 15 min and transferred into a refrigerator at 7°C for 16-18 h before the measurement of the gel strength. The gel strength of gelatins was measured using a TA-XT2 texture analyzer (Stable Micro System, Haslemere, UK) with a load cell of 5 kg. The gel sample in the Bloom jar was tested using a flat-faced cylindrical Teflon plunger (diameter of 1.27 cm). Regarding the dimensions, the sample gel had a diameter of 5.2 cm and a height of 4.5 cm. The gel strength was expressed as the maximum force (g) of the plunger with a speed of 0.5 mm/s required to penetrate into the gel to a depth of 4 mm.

The viscosity of gelatin was measured using the method described by Ninan et al. (2011). The viscosities (cP) of gelatin solutions at 6.67% (w/v) were measured by dissolving the samples in distilled water and heating for 1 h at 60°C with stirring. A Brookfield digital viscometer (Model DV-II+, Brookfield Engineering Laboratories Inc., Middleboro, Massachusetts, USA) equipped with a No. 1 spindle at 60 rpm was used with a 40°C water bath. Five viscosity values were recorded for each sample.

4. Fourier Transform Infrared Spectra Analysis

The Fourier transform infrared (FTIR) spectra of gelatin samples were analyzed at 25 ± 2°C by using the method described by Benjakul et al. (2009). Each gelatin sample was loaded onto a crystal cell and clamped onto the mount of a Bruker tensor 27 FTIR spectrometer (Karlsruhe, Germany). The percentage of transmittance was recorded in the spectral range of 400-4000 cm^{-1}. Two measurements were taken for each sample.

5. Determination of Foaming Properties and Emulsifying Properties

The emulsion activity index (EAI), emulsion stability index (ESI), foam expansion (FE), and foam stability (FS) were determined according to the method of Jellouli et al. (2011), with slight modifications. Gelatin solution [20 mL, 1% (w/v)] was incubated at 60°C for 30 min. The solution was homogenized with a stirrer at a speed of 2500 rpm for 1 min at room temperature to incorporate air (DC-100R, Newlab Instruments Co., Ltd., Taipei, Taiwan). After homogenization, the whipped sample was transferred into a 100-mL cylinder. The volume of the whipped sample was recorded. The FE was calculated as follows:

$$\text{Foam expansion (\%)} = \frac{(\text{the total volume after homogenization} - \text{the total volume before homogenization})}{\text{the volume before homogenization}} \times 100\%$$

FS was expressed as the volume (mL) of foam at different time points.

$$\text{EAI (m}^2\text{/g)} = \frac{2 \times 2.303 \times A_0 \times N}{c \times \phi \times 10000}$$

where A_0 refers to the absorbance measured immediately (t = 0) after emulsion formation, N to a dilution factor, c to the weight of protein per unit volume (g/mL), and ϕ to the oil volumetric fraction (0.25).

$$\text{ESI (min)} = \frac{A_0 \times 10}{A_0 - A_{10}}$$

A_{10} is the absorbance recorded at 10 min (A_{10}) after emulsion formation (Pearce and Kinsella, 1978).

6. Stereo Microscopy and Scanning Electron Microscopy

The gelatin sample exposed to UV-C irradiation at 3672 mJ/cm^2 was observed under a stereo microscope (Olympus SZX 16, Pennsylvania, USA) according to the method of Pang et al. (2014), with slight modification. The gelatin gel at 6.67% (w/v) was cut with a razor blade into approximately 1 × 1 × 1-mm^3 cubes and soaked in 2.5% (v/v) glutaraldehyde in 0.1 M phosphate buffer (pH 7.2) for 12 h. The sample was rinsed with distilled water for 1 h and dehydrated in serial concentrations of 50, 75, 85, 95, and 100% (v/v) ethanol. The samples were mounted onto brass stubs by using double-sided carbon conductive adhesive tape (Electron Microscopy Sciences, Hatfield, Pennsylvania, USA). Gold coating was applied using an ion sputter coater (Hitachi E101, Tokyo, Japan). The samples were examined under a Hitachi S-2400 Scanning Electron Mi-

croscope (50, 100, 800, and 10,000X magnification) at 15 kV (Tokyo, Japan).

7. Shark Fin Analog Preparation and Cooking Loss Measurement

Gelatin (2.5, 5, 7.5, and 10%) and sodium alginate (2.5%) on a wet weight basis were mixed with 100 mL of distilled water in a water bath at 60°C for 1 h with stirring. Subsequently, the slurry was cooled down and filled into a plastic syringe with a 1.5-mm tip. The slurry was pressed into calcium chloride solution (2.5%) and soaked for 30 min to form shark fin analog threads that were rinsed with distilled water and their diameters measured as the initial wet product. Diameters of 15 sample threads in replicates were recorded using a vernier caliper. Subsequently, the weight of the shark fin analog was measured, and the shark fin analog was oven dried at 105°C until the weight remained constant (AOAC, 1995). The diameter of the dried shark fin analog was measured at initial drying (ID), and the dried shark fin analog was rehydrated in distilled water for 30 min at room temperature. Its diameter was measured after rehydration (AR). Subsequently, the rehydrated shark fin analog was cooked in boiling water for 1 h to record cooking loss after cooking (AC) (AACC, 2000). The rehydration ratio was calculated as the weight of rehydrated shark fin analogs divided by the weight of dried shark fin analogs.

The water content, rehydration ratio, and cooking loss of shark fin analogs made from UV-treated gelatin were measured as mentioned earlier.

8. Sensory Evaluation

The shark fin analog made from 612 mJ/cm^2 UV-irradiated gelatin, which showed the lowest cooking loss, was served to 40 untrained panelists at the Department of Food Science, National Taiwan Ocean University to evaluate color, aroma, texture, and overall scores. The panelists consisted of 20 male and 20 female students and faculty members aged between 18 and 52 years. The panelists evaluated each attribute using a 7-point hedonic scale ranging from 1 (*dislike extremely*) to 7 (*like extremely*). Samples were coded with randomized three digits.

9. Statistical Analyse

A completely randomized block design was used with three replications. Data were analyzed by analysis of variance programs using the SPSS 1.2 statistic program (1998). Differences in means were evaluated using Duncan's Multiple Ranges Test (Steel and Torrie, 1980). Data are expressed as mean ± standard deviation (SD), and $p < 0.05$ was considered significant.

III. RESULTS AND DISCUSSION

1. Effect of UV Irradiation on Color and Gel Strength of Gelatin

The tilapia skin gelatin powder color changed from milky white to pinkish yellow after UV irradiation at 3672 mJ/cm^2. Fish gelatin powder irradiated at 3060 mJ/cm^2 exhibited a significant increase ($p < 0.05$) in the value of b*, and the color difference (ΔE) value relative to that of control gelatin powder was higher than 2 (Table 1). The result indicated that the human eye could easily perceive the difference between the control and treated gelatin samples. The color value change also indicated the occurrence of carbonyl-amide reactions. The color of gelatin gel is a critical quality for the appearance of gelling products. Gelatin gel irradiated at 1224 mJ/cm^2 exhibited a significant reduction ($p < 0.05$) in the L* and b* values, compared with those of the control tilapia gelatin gel sample (Table 2).

The particle size of gelatin powder exposed to UV irradiation at 3672 mJ/cm^2 was smaller (mean length = 0.29 ± 0.11 mm and width = 0.2 ± 0.08 mm) than that of the control (mean length = 0.43 ± 0.09 mm and mean width = 0.25 ± 0.08 mm) (Fig. 1). The smaller particle size may be because the high UV dosage caused the dehydration of gelatin powder, which changed to pinkish yellow (Fig. 1). The observed effect might be attributed to the occurrence of carbonyl-amide reactions in gelatin powder. UV irradiation generated heat, leading to the

Table 1. The dose effect of ultraviolet irradiation on color of fish gelatin powder.

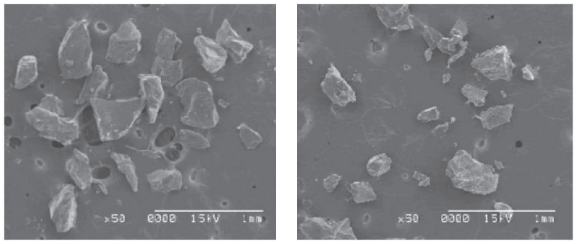
Dosage (mJ/cm^2)	Color of fish gelatin powder			
	L*	a*	b*	ΔE
0	96.59 ± 0.03^{ab}	-7.71 ± 0.24^{ab}	18.09 ± 0.73^{ab}	-
612	96.61 ± 0.02^{ab}	-7.78 ± 0.26^{ab}	18.48 ± 0.71^{ab}	0.40
1224	96.61 ± 0.02^{ab}	-7.77 ± 0.20^{ab}	18.23 ± 0.66^{ab}	0.16
1836	96.60 ± 0.04^{ab}	-7.86 ± 0.50^{ab}	18.59 ± 1.50^{ab}	0.52
2448	96.60 ± 0.04^{ab}	-7.97 ± 0.36^{ab}	18.92 ± 1.07^{ab}	0.87
3060	96.55 ± 0.02^{ba}	-8.37 ± 0.20^{ba}	20.18 ± 0.65^{ba}	2.19
3672	96.58 ± 0.02^{ab}	-8.16 ± 0.16^{ab}	19.32 ± 0.42^{ab}	1.31

Values are givens as mean ± SD from triplicate determinations.
[a-c] Means in the same column with different superscripts are significantly ($p < 0.05$) different.

Table 2. The dose effect of ultraviolet irradiation on color of fish gelatin gel.

Dosage (mJ/cm^2)	Color of fish gelatin gel			
	L*	a*	cb*	ΔE
0	10.56 ± 0.21^{a}	-7.63 ± 0.08^{ab}	16.21 ± 0.31^{aa}	-
612	10.55 ± 0.16^{ab}	-7.67 ± 0.05^{bc}	16.20 ± 0.25^{a}	0.04
1224	09.17 ± 0.07^{cc}	-7.51 ± 0.07^{a}	14.16 ± 0.11^{cc}	2.48
1836	09.50 ± 0.23^{b}	-7.64 ± 0.09^{ab}	14.62 ± 0.34^{b}	1.91
2448	09.55 ± 0.12^{b}	-7.79 ± 0.07^{c}	14.66 ± 0.17^{bb}	1.85
3060	09.38 ± 0.07^{bc}	-7.60 ± 0.11^{ab}	14.46 ± 0.09^{bc}	2.11
3672	09.64 ± 0.09^{b}	-7.61 ± 0.08^{ab}	14.86 ± 0.16^{b}	1.63

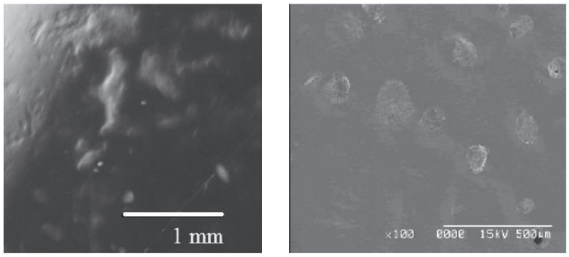
Values are givens as mean ± SD from triplicate determinations.
[a-c] Means in the same column with different superscripts are significantly ($p < 0.05$) different.



(a) (b)

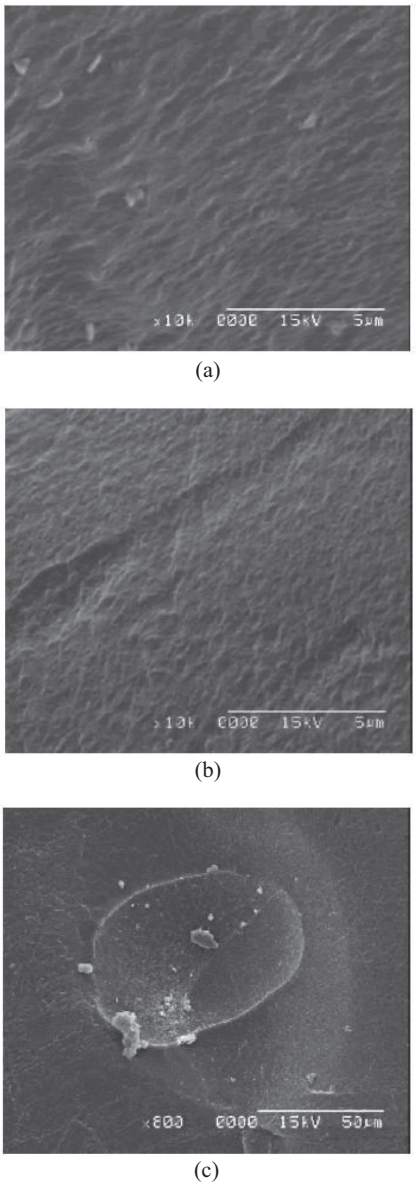
Scanning electronic micrographs of fish gelatin powder

Fig. 1. Appearance and scanning electronic micrographs of fish gelatin powder: (a) control; (b) ultraviolet irradiated at 3672 mJ/cm^2.



(a) (b)

Fig. 2. Appearance of fish gelatin solution: (a) Stereo and (b) Scanning electronic micrograph of insoluble gelatin granule at magnification 100×.



(a)

(b)

(c)

Fig. 3. Scanning electronic micrographs of fish gelatin gel: (a) control; (b) after ultraviolet irradiation at 3672 mJ/cm^2 at 10× magnification; (c) at 800× magnification.

evaporation of the moisture in gelatin powder and the shrinkage of the particle sizes, promoting more crosslinking sites in gelatin powder. Overcrosslinking or hydrogen bonding of gelatin caused gelatin powder to become insoluble, as shown in Fig. 2.

The most crucial physical property of gelatin is the gel strength. The gel strength determines the quality of processed products (Cho et al., 2005), and it depends on the hydrogen bonding between the free hydroxyl groups of amino acids and water molecules, the molecular weight distribution of gelatin, and the concentration and size of protein chains (Muyonga et al., 2004a). The increase in the gel strength of UV-treated fish gelatin is attributed to enhanced crosslinking, as explained by Bhat and Karim (2009). Bessho et al. (2007) described that the crosslinking sites of gelatin hydrogels were alkyl or phenyl groups of the side chains of protein structures. In contrast to the results of Bhat and Karim (2009), our results showed that fish gelatin samples exposed to UV irradiation ranging from 612 to 3060 mJ/cm^2 exhibited a significant reduction in gel strength. In this study, gelatin irradiated with UV at >1836 mJ/cm^2 (Fig. 2) was found to be insoluble. The insolubility of gelatin irradiated with UV can be attributed to overcrosslinking, covalent bonding, hydrophobic interaction, and hydrogen bonding. In general, 8 M urea can disrupt hydrogen bonds. In the present study, partially insoluble fish gelatin powder could not be dissolved in 8 M urea, or 5% sodium dodecyl sulfate (SDS) solution in a water bath at 60°C for 1 h. However, insoluble fish gelatin (6.67%) could be dissolved in acetic acid. The formation of gels with 6.67% gelatin solution in 8 M urea and acetic acid was evaluated. The gelatin solution did not form gels compared with the fish gelatin solution stored in a refrigerator at 7°C for 17 h (data not shown). This observation is probably because urea and acetic acid hindered the formation of covalent bonds between gelatin chains. Nevertheless, 6.67% fish gelatin (partial insoluble) formed gels in 5% SDS solution. Although SDS can disrupt noncovalent and hydrophobic interactions and add negative charges to the gelatin chain, preventing the refolding effect, the gel was still formed in 5% SDS in this study. This evidence suggests that gelatin is not stabilized by hydrogen bonds or hydrophobic interactions but by covalent bonds. The gel strength was enhanced by the reinforced polypeptide network (Fig. 3).

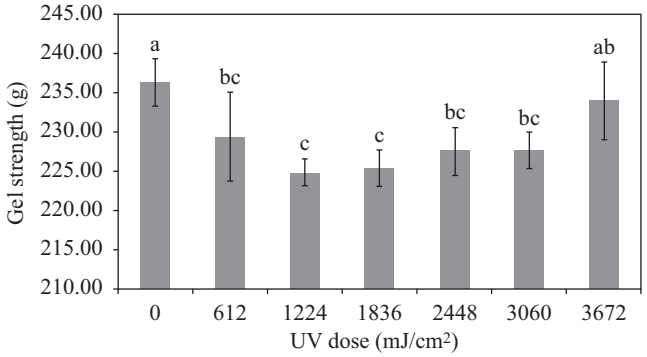


Fig. 4. Changes in gel strength of fish gelatin irradiated at different at dose ranged 612-3672 mJ/cm^2.

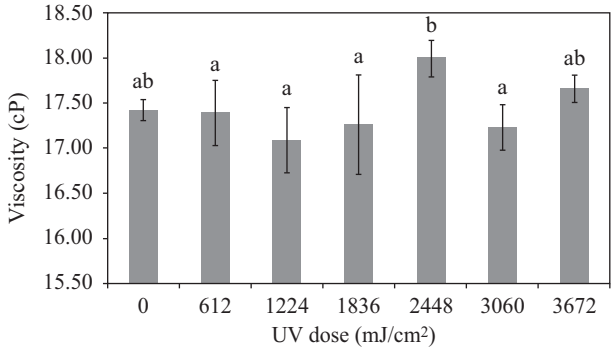


Fig. 5. Changes in viscosity of fish gelatin irradiated at different at dose ranged 612-3672 mJ/cm^2.

2. Effect of UV Irradiation on Gel Strength and Viscosity of Gelatin Solution

Irradiation at > 612 mJ/cm^2 significantly reduced ($p < 0.05$) the gel strength of fish gelatin (Fig. 4). Fish gelatin irradiated at 1224-1836 mJ/cm^2 exhibited minimal gel strength. These results indicate that the degradation of crosslinks increased with the irradiation dose, and that the higher dose enhanced the formation of crosslinks. Bessho et al. (2007) reported an insolubility phenomenon, in which γ irradiation at a dose above 8 kGy induced crosslinking of the gelatin hydrogels. UV and γ irradiation-induced substantial degradation seemed to occur simultaneously with the formation of new crosslinks. Gelatin samples exposed to γ irradiation exhibited a marked reduction in gel strength, but no insolubility phenomenon of gelatin was observed at 10 kGy in our previous study (Sung and Chen, 2014). The fish gelatin gels of 6.67% (w/v) exposed to UV irradiation between 612 and 3060 mJ/cm^2 exhibited reduced gel strength. This finding implies that UV irradiation induced overcrosslinking or covalent bonding, resulting in the insolubility of gelatin powder. UV and γ irradiation have been applied to pharmaceutical and medical uses (Bessho et al., 2007) but have not been reported to lead to the formation of crosslinks in gelatin used for producing shark fin analogs.

Fish gelatin irradiated with UV at 3672 mJ/cm^2 exhibited significantly increased ($p < 0.05$) gel strength (Fig. 4) compared with that of gelatin irradiated with UV at 1224 mJ/cm^2. Although UV irradiation at 1836-3672 mJ/cm^2 increased the gel strength, the gel strength of UV-treated fish gelatin was lower than that of the nonirradiated sample in this study (Fig. 4). The increase in gel strength observed after UV irradiation at 1836-3672 mJ/cm^2 might be due to the partially insoluble gelatin particles distributed in the gel, which slightly enhance the gel strength.

The fish gelatin solution showed an insignificant ($p > 0.05$) increase viscosity after UV irradiation at 2448 mJ/cm^2, compared with nonirradiated fish gelatin (Fig. 5). Notably, this result contrasts with that of Bhat and Karim (2009). They reported a marked reduction in viscosity at 25°C during rheological measurements with a rheometer (Bhat and Karim, 2009) and suggested that the viscosity decreased because of chain fragmentation. Fu et al. (2000) reported that the viscosity of the gelatin solution decreased with increasing γ irradiation dose. They demonstrated that protein microelements and amino acids in the gelatin solution remained unchanged after irradiation at 4 and 8 kGy. The viscosity of gelatin at 25°C could not be measured with a Brookfield viscometer with a No. 1 spindle, because the gelatin was too thick. Therefore, the viscosity of the gelatin solution [6.67% (w/v)] was measured at 40°C in this study. The viscosity values of gelatin solutions [10.00% (w/v)] from farmed giant catfish and calf skin were 112.5 cP and 31.3 cP, respectively (Jongjareonrak et al., 2010), which are higher than our data on the viscosity of farmed fish gelatin. This result is mainly attributed to the difference in the gelatin concentration of the tested solutions and the partial insolubility of fish gelatin. The viscosity of fish gelatin did not change significantly ($p > 0.05$) with increasing UV irradiation dose (Fig. 5), indicating that the hydration property of fish gelatin was not affected by the degradation or formation of crosslinks in fish gelatin, unlike the gel strength (Fig. 4).

3. Effect of UV Irradiation on Chemical Bonding of Fish Gelatin

The FTIR spectra of all UV-irradiated fish gelatin samples differed from those of nonirradiated samples (Fig. 6), indicating that changes in chemical bonding of gelatin powder occurred during UV treatment. The transmittance of the amide I peak at 1629-1630 cm^{-1} and the amide II peak at 1532-1535 cm^{-1} decreased. Although Bhat and Karim (2009) reported that the transmittance peak at 2324 cm^{-1} (amide I, CO, and CN-stretching) did not change, the transmittance band at 1700-1600 cm^{-1} decreased in this study primarily because of C=O and the CN-stretching vibration mode. Muyonga et al. (2004b), Sung and Chen (2014), and Yakimets et al. (2005) have reported a similar observation. The amide II peak is related to protein hydration (Wellner et al., 1996). The amide I peak at 1660-1650 cm^{-1} is contributed to by α-helix, and that at 1640-1620 cm^{-1} is contributed to by the β-sheet structure (Hashim et al., 2010). Fish gelatin samples exhibiting the absorption peaks at amide I and amide II are highly similar to the β-sheet structure described by Hashim et al. (2010). This finding indicates that the

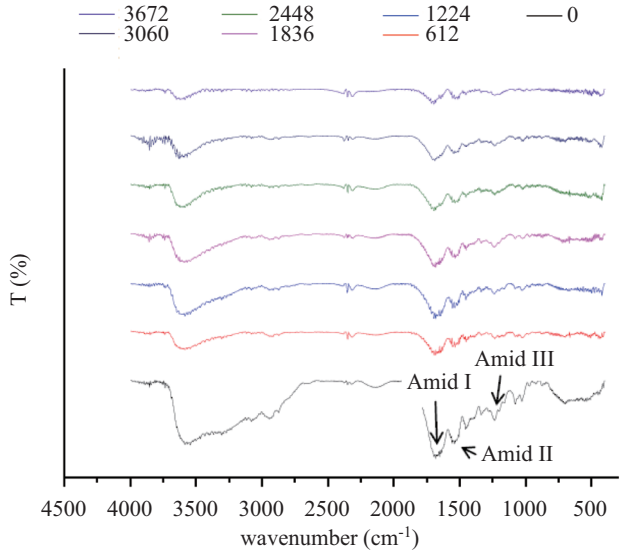


Fig. 6. Fourier transform infrated (FTIR) spectra of fish gelatin powder irradiated at different ultraviolet irradiation dose.

β-sheet structure was changed with reducing gelatin hydration. The FTIR spectra showed reductions in amide bonds indicative of bonding of amide groups.

UV irradiation of the fish gelatin samples reduced the transmittance of the amide I, II, and III peaks. The transmittance of amide I and II was reduced when the hydrogen bonds of the secondary protein structure were reduced by UV irradiation. Some hydrogen bonds at the surface enable interactions with other molecules, particularly during hydration. This might lead to a drop in gelatin strength after UV irradiation. Some other covalent bonds are intramolecular and help stabilize the β-sheet structure of gelatin, causing a reduction in gelatin solubility after UV irradiation.

4. Effect of UV Irradiation on Emulsifying Properties of Fish Gelatin Samples

The fish gelatin samples exhibited lower EAI and ESI after UV irradiation than those of the nonirradiated gelatin samples (Table 3). The EAI of the fish gelatin samples irradiated at 612-3060 mJ/cm^2 was lower than that of the control fish gelatin samples. The low solubility of the UV-irradiated fish gelatin samples prevents the dispersion of them to the surface of the oil droplets, indicating that UV-treated fish gelatin is not suitable for uses as an emulsifying agent in food products because of its low EAI and ESI. Nevertheless, the FE of gelatin made from tilapia skin remained unchanged after UV treatment (Table 3). Similarly, the viscosity of fish gelatin remained unchanged after UV irradiation (Fig. 5). A previous study reported that the foaming characteristic is positively correlated to the hydrophobicity of unfolded proteins (Townsend and Nakai, 1983). Molecules containing large hydrophobic regions can be improved by additional hydrophobic residues to form a larger hydrophobic sphere on the surface of gelatin (Jongjareonrak et al., 2010).

Table 3. Emulsifying properties and foam expansion of fish gelatin solution affected by UV irradiation dosage.

Dosage (mJ/cm^2)	EAI* (m^2/g)	ESI** (min)	Foam expansion (%)
0	10.33 ± 0.39^{a}	40.21 ± 3.11^{a}	318.3 ± 20.2^{ab}
612	07.61 ± 1.09^{b}	33.26 ± 4.20^{abc}	296.7 ± 15.3^{a}
1224	08.06 ± 0.46^{b}	30.65 ± 2.21^{bc}	333.3 ± 25.7^{ab}
1836	07.76 ± 1.78^{b}	29.26 ± 7.53^{bc}	336.7 ± 11.5^{b}
2448	07.22 ± 0.96^{b}	36.38 ± 2.08^{ab}	338.3 ± 10.4^{b}
3060	07.09 ± 0.68^{b}	26.24 ± 3.71^{cd}	311.7 ± 18.9^{ab}
3672	08.80 ± 0.58^{ab}	19.92 ± 2.38^{d}	323.3 ± 27.5^{ab}

* EAI: emulsion activity index.

** ESI: emulsion stability index.

Values are givens as mean ± SD from triplicate determinations.

$^{a-b}$ Means in the same column with different superscripts are significantly ($p < 0.05$) different.

Table 4. Water content, rehydration ratio and cooking loss of shark fin analogs affected by concentration of gelatin.

Gelatin (%)	Water content (%)	Rehydration ratio	Cooking loss (%)
0	93.68 ± 0.33^{a}	1.82 ± 0.06^{a}	32.17 ± 1.13^{a}
2.5	93.01 ± 0.09^{b}	2.20 ± 0.03^{b}	54.65 ± 0.89^{d}
5.0	91.93 ± 0.08^{c}	2.33 ± 0.08^{b}	55.78 ± 0.77^{d}
7.5	90.65 ± 0.07^{d}	3.70 ± 0.18^{d}	42.20 ± 0.86^{b}
10	90.43 ± 0.13^{d}	3.50 ± 0.03^{c}	46.96 ± 0.52^{c}

Values are given as mean ± SD from triplicate determinations.

$^{a-d}$ Means in the same column with different superscripts are significantly ($p < 0.05$) different.

Rehydration ratio: the weight of rehydrated imitation shark fin divided by the weight of dried imitation shark fin.

5. Effect of UV Irradiation on Cooking Loss and Diameter of Shark Fin Analogs

The cooking loss of shark fin analogs made from 2.5%-5.0% gelatin exhibited the highest cooking loss among analogs made from different concentrations of gelatin (Table 4). Shark fin analogs made from UV-irradiated fish gelatin exhibited a significantly diminished cooking loss (Table 5). Shark fin analogs made from 612 mJ/cm^2 UV-irradiated gelatin exhibited the lowest cooking loss among analogs made from gelatin irradiated with different UV doses. Panelists conducted sensory evaluations of cooked commercial shark fin analog products, shark fin analogs and shark fin analogs made from 612 mJ/cm^2 UV-irradiated gelatin. Cooking loss is one of the most critical physical properties of shark fin analogs and determines the quality of cooked products.

The diameters of the wet, dried, rehydrated, and cooked

Table 5. Water content, rehydration ratio and cooking loss of shark fin analogs affected by UV irradiation dosage.

Dosage (mJ/cm^2)	Water content (%)	Rehydration ratio	Cooking loss (%)
0	91.93 ± 0.08^{a}	2.33 ± 0.08^{a}	55.78 ± 0.77^{a}
612	91.50 ± 0.42^{a}	2.96 ± 0.14^{abcd}	37.58 ± 2.00^{b}
1224	91.94 ± 0.22^{a}	3.54 ± 0.65^{d}	39.91 ± 1.83^{b}
1836	92.29 ± 1.28^{a}	3.47 ± 0.58^{cd}	40.83 ± 0.49^{b}
2448	91.70 ± 0.89^{a}	2.72 ± 0.20^{ab}	39.68 ± 3.25^{b}
3060	92.37 ± 0.30^{a}	2.84 ± 0.21^{abc}	38.99 ± 2.21^{b}
3672	92.50 ± 0.31^{a}	3.23 ± 0.26^{bcd}	39.83 ± 1.40^{b}

Values are given as mean ± SD from triplicate determinations.

$^{a-d}$ Means in the same column with different superscripts are significantly ($p < 0.05$) different.

Rehydration ratio: the weight of rehydrated imitation shark fin divided by the weight of dried imitation shark fin.

Table 6. Relationship between diameter of shark fin analogs and UV dosage on gelatin.

Dosage (mJ/cm^2)	Diameter (mm)			
	IWP	ID	AR	AC
0	1.18 ± 0.03^{a}	0.52 ± 0.03^{a}	0.50 ± 0.05^{a}	0.43 ± 0.03^{a}
612	1.00 ± 0.05^{e}	0.55 ± 0.05^{a}	0.55 ± 0.05^{a}	0.50 ± 0.05^{ab}
1224	1.02 ± 0.03^{bc}	0.55 ± 0.05^{a}	0.55 ± 0.05^{a}	0.50 ± 0.05^{ab}
1836	1.03 ± 0.03^{bc}	0.55 ± 0.05^{a}	0.55 ± 0.05^{a}	0.50 ± 0.05^{ab}
2448	1.07 ± 0.03^{b}	0.55 ± 0.05^{a}	0.55 ± 0.05^{a}	0.50 ± 0.05^{ab}
3060	1.07 ± 0.03^{b}	0.55 ± 0.05^{a}	0.55 ± 0.05^{a}	0.55 ± 0.05^{b}
3672	1.07 ± 0.03^{b}	0.55 ± 0.05^{a}	0.55 ± 0.05^{a}	0.55 ± 0.05^{b}

Values are given as mean ± SD from triplicate determinations.

$^{a-b}$ Means in the same column with different superscripts are significantly ($p < 0.05$) different.

IWP: initial wet product.

ID: initial drying.

AR: after rehydration.

AC: after cooking.

shark fin analogs increased with the gelatin concentration (Fig. 7). The results demonstrated that initial diameters of the wet shark fin analogs made from UV- treated gelatins were smaller than those of the analogs made from non-irradiated gelatin (Table 6). However, no difference was observed in the diameters of the dried and rehydrated shark fin analogs made from UV-irradiated gelatin and nonirradiated gelatin (Table 6). The diameters of shark fin analogs made fish gelatin irradiated at > 3060 mJ/cm^2 remained unchanged after 1 h of cooking, and this is due to the partial insolubility of gelatin. Therefore, the partial insolubility of gelatin caused the shark fin analogs made from irradiated fish gelatin to retain their orignial size more favorably the did those made from nonirradiated gelatin (Table 6).

Table 7. Sensory evaluation scores of shark fin analogs unirradiated and UV irradiated with 612 mJ/cm2 compared to commercial shark fin analogs.

	Color	Aroma	Texture	Overall
Unirradiated	4.58 ± 1.13^{a}	4.10 ± 1.28^{a}	3.83 ± 0.96^{a}	4.04 ± 1.06^{a}
UV irradiated with 612 mJ/cm^2	4.75 ± 1.13^{ab}	3.25 ± 1.41^{b}	4.38 ± 0.93^{b}	3.73 ± 1.40^{a}
Commercial artificial shark fins	5.15 ± 1.33^{b}	4.23 ± 1.35^{a}	4.63 ± 1.43^{b}	4.85 ± 1.25^{b}

The hedonic scale: 1 = dislike extremely; 2 = dislike very much; 3 = dislike slightly; 4 = neither like nor dislike; 5 = like slightly; 6 = like very much; 7 = like extremely.

Values are givens as mean ± SD. (n = 40).

$^{a-b}$ Means in the same column with different superscripts are significantly ($p < 0.05$) different.

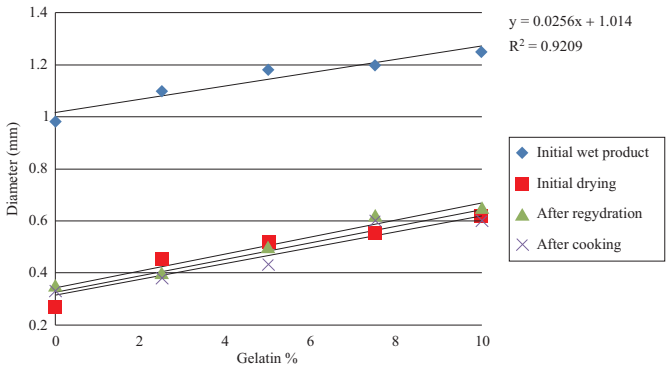


Fig. 7. Relationship between diameter of shark fin analogs and concentration of gelatin.

6. Sensory Evaluation of Shark Fin Analogs

The commercial shark fin analogs had the highest sensory scores for all attributes, whereas the shark fin analogs made from irradiated fish gelatin had the lowest sensory scores, except for the texture attribute (Table 7). The shark fin analogs made from nonirradiated gelatin had a more desirable aroma than did those made from irradiated gelatin. The texture of the shark fin analogs determined according to the sensory evaluations was not in favorable agreement with the gel strength measured using a texture analyzer. The shark fin analogs made from 612 mJ/cm^2 UV-irradiated fish gelatin had higher color and texture scores, although the first sensation of aroma was fishy, which downgraded all other sensory scores and overall acceptability (Table 7). The shark fin analogs made from UV-irradiated fish gelatin exhibited a lower cooking loss than did analogs made from nonirradiated fish gelatin (Table 5). Therefore, the cooked shark fin analogs made from UV-irradiated fish gelatin had a firmer texture when consumed. The panelists described that these analogs had an unpleasant fishy smell. UV irradiation improved the cooking loss of gelatin products, and the texture score of the shark fin analogs made from irra-

diated gelatin was higher than that of those made from nonirradiated gelatin. For future food application, UV-irradiated fish gelatin may be used as a food ingredient. Preparing suitable shark fin analogs by using fish gelatins as a substitute for porcine gelatin is also feasible.

IV. CONCLUSION

UV irradiation induced changes in the functional properties of fish gelatin. The gel strength of fish gelatin decreased after UV irradiation at 612 and 1224 mJ/cm^2. FTIR spectra showed that UV irradiation of fish gelatin caused changes in the amide bonds, covalent bonding sites, and crosslinking of dry gelatin powder, leading to reduced gel strength. UV exposure caused the discoloration of gelatin powder to pinkish yellow and reduced the particle size. It also caused fish gelatin to become partially insoluble and reduced the cooking loss of all shark fin analogs made from UV-irradiated fish gelatin. However, shark fin analogs made from UV-irradiated fish gelatin had a fishy smell. These analogs were slightly disliked by panelists in comparison with the control sample. Additional investigations are ongoing to identify factors contributing to the fishy smell of fish gelatin exposed to UV irradiation; these investigations are aimed at establishing an optimal method to avoid the fishy smell.

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