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# Effect of Gamma Irradiation (Cesium-137) on the Properties of Chemical Functional Groups from Collagen Extraction of Snakehead Fish Scales (*Channa striata*)

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**ABSTRACT**–This study aims to determine the absorption spectrum of the functional groups of snakehead fish scale collagen before irradiation and the effect of the dose of Cesium-137 irradiation on the functional groups in snakehead fish scale collagen. The extraction method used is acid extraction. Measurement of the absorption spectrum of collagen samples from snakehead fish scales using an FTIR spectrophotometer. Samples were irradiated using doses of 10 mGy, 30 mGy and 50 mGy. The results of the functional group values before irradiation produce amide A, amide I, amide II and amide III which fill the absorption area of the functional group. The results of the functional group values produced after irradiation for a dose of 10 mGy produced amide I, amide II and amide III which filled the absorption area. Amide A and amide B do not fill the absorption region at a dose of 10 mGy. Doses of 30 mGy and 50 mGy produced amide A, amide I, amide II and amide III which filled the absorption area. Amide B did not fill the absorption area at doses of 30 mGy and 50 mGy. Amide groups that are not detected or do not meet standard collagen functional group standards can be caused by the chemical composition of the fish scale extraction process.

*KEYWORDS: collagen; cesium-137; functional groups; irradiation; snakehead fish*

## INTRODUCTION

Snakehead fish is a fish that has the highest albumin among freshwater fish and other marine fish. Egg albumin, which is often used in healing post-operative patients, is of much lower quality than the albumin found in snakehead fish. Snakehead fish cooked for 60 minutes and then consumed for eight days by post-operative patients is used as a therapeutic method. Therefore, the patient's wounds will heal faster and without negative consequences. This is caused by the high protein content of snakehead fish, which helps the patient's body regenerate new cells after surgery. Snakehead fish contain approximately 16.75% collagen, which is a byproduct of albumin supplement production (Rahayu et al., 2021).

The collagen in fish can replace collagen from beef and pork. Due to the risk of transmitting diseases to humans, some people avoid using bovine collagen, including Bovine Spongiform Encephalopathy (BSE) and foot and mouth disease. Fish collagen has a high biological value due to its concentration of essential amino acids and low hydroxyproline levels (Komala, 2015).

Collagen from fish has a smaller atomic structure than beef or pork collagen. Fish skin makes up 6-10% of a fish's weight, while fish scales make up only 3-4%. Fish skin is more processed to produce collagen than fish scales. Fish scales have a fat content of around 0.06%,

while fish skin only contains about 3-6% fat (Ramdhani et al., 2016).

Collagen has a weakness in its use due to its atomic structure being quite swollen, making it difficult to melt in the skin and decompose in water. Additionally, the collagen layer on fish scales has a hard structure due to mineralization, which reduces its flexibility. The most common method for sterilization in the medical field and food preservation is to break down collagen using protein through gamma irradiation. The limitation of this research is the use of radiation doses that do not use the kilo Gray scale (kGy) and use milli Gray (mGy) scale doses on the Cessium-137 device. This research explains the effect of the milli Gray scale on the functional groups produced after irradiation.

Irradiation technology is a non-thermal process that offers several advantages. It does not leave any residue, does not cause materials to become radioactive, and does not alter the structure, color, or taste of the materials. Additionally, it does not significantly reduce the nutritional content of the materials. Gamma radiation can impact the physical, chemical and biological makeup of animals. Research indicates that fish scale waste can be a viable alternative to mammalian collagen. The benefits of fish scale collagen can also be utilized in cosmetics and other beauty products (Rosidah, 2009).

Gamma radiation can impact animals physical, chemical, and biological makeup. Fish scale waste can replace mammal collagen. The benefits of collagen in fish scales can also be used in the manufacture of cosmetics and other beauty products. The novelty of this research is using snakehead fish scales as a sample and using gamma irradiation (Cesium-137) as the radiation source. The objective of the study was to identify the absorption spectrum of the functional groups present in collagen extracted from the scales of snakehead fish, and to investigate the impact of gamma irradiation (Cesium-137) on these functional groups. The specific focus was on the collagen extracted from Channa striata species of snakehead fish.

In 2022, Mehran and his colleagues conducted research on the effect of gamma rays on the microbial quality of salmon fish during storage in a refrigerator at 4°C using radiation doses of 0 kGy, 1 kGy, 2 kGy, 3 kGy and 4 kGy (Moslemi & Naderi, 2022). The effect of Gamma Irradiation on fish was also studied to determine the levels of proximate content, pH and ALT of Jenaha Fish Fillets (Widya Pangestika et al., 2022). In 2023, research will be conducted on Irradiation as a promising technology for improving the bacteriological and physicochemical quality of fish. The application of gamma irradiation is a highly effective method for the inactivation, reduction and eradication of pathogenic and spoilage microorganisms in a dose-dependent manner. Therefore, it can be used as a control measure to reduce health risks from fish-borne pathogens without changing the organoleptic, proximate composition and physical-chemical properties of fish (Mohamed et al., 2023).

## METHOD

### Materials

The equipment utilized in this research includes a gamma radiation source (Cesium-137), an irradiator, a Fourier Transform Infra Red (FTIR) spectrophotometer, a centrifuge, a laser, a steel ruler, a CCTV as monitor, a water phantom, a measuring pipette, a bald, a measuring flask, analytical scales, a beaker, a dropper pipette, plaster, polypropylene plastic, and Whatman paper. The materials used are acetic acid solution ($CH_3COOH$), snakehead fish scales, NaOH solution, NaCl solution, and distilled water.

### Extraction of Collagen from Snakehead Fish Scales

The process involves washing the fish scales obtained from snakehead fish with water until they are thoroughly cleaned. To proceed, immerse the fish scales in a 0.2 M

NaOH solution and let them soak for 12 hours. The soaking solution should be changed every 6 hours to remove fat and dirt. Fish scales soaked in NaOH solution are rinsed with distilled water until neutral pH is reached. After adjusting the pH to neutral, soak the fish scales in a 0.5 M acetic acid solution for 48 hours. To prepare the fish scales, immerse them in a 0.9 M NaCl solution and let them soak for 24 hours.

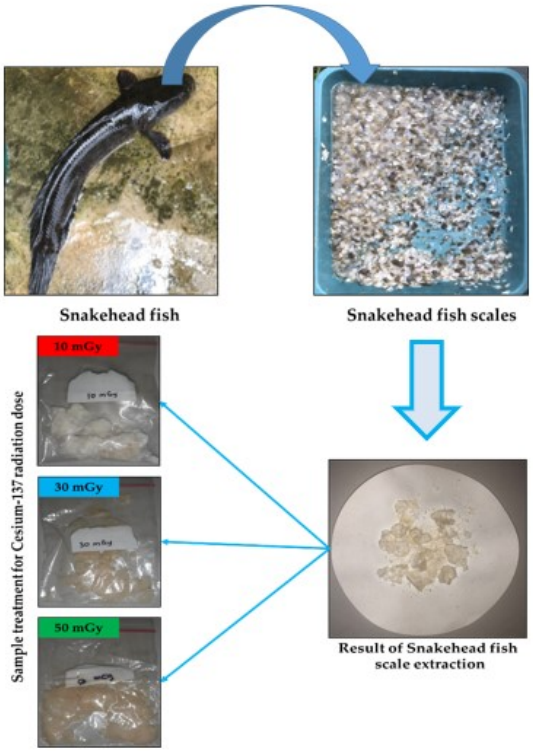


**Figure 1 Preparation of Snakehead Fish Scale Samples to Become Collagen.**

Figure 1 shows the process of preparing and extracting collagen. The scales of snakehead fish were extracted, separated, and labeled with dose markers of 10, 30, and 50 mGy. Next, perform a 30-minute centrifuge at 4℃ and 3500 rpm to separate collagen particles from the solution. To proceed, you need to filter the sediment that has been extracted using the Whatman paper. After filtering, let it dry at room temperature.

**Collagen Irradiation is a Process that Involves the Use of Gamma Irradiation (Cesium-137).**

Set up an irradiator that has a Cesium-137 source which is calibrated. Put the extracted collagen dissolved in 0.5 M acetic acid solution into a 15gram polypropylene plastic bag. Irradiate with 10 mGy for 1691 sec, 30 mGy for 5063 sec, and 50 mGy for 8435 sec. Figure 2 is a tool used as a source of irradiator and Cesium-137 radiation. The Cesium-137 irradiator used is a facility located at the Makassar City Health Facilities Security Center.

**Figure 2 Gamma irradiator (Cesium-137).**

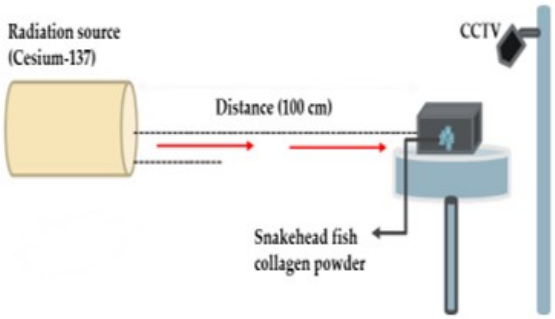


**Figure 3 Method of irradiating Cesium-137 on samples.**

The distance between the sample and the Gamma radiation source (Cesium-137) is fixed at 100 cm. Monitor the sample irradiation process via CCTV until it is completeThe collagen solution that has been irradiated undergoes Fourier Transform Infra Red (FTIR) testing to determine the functional groups present. Figure 3 illustrates the irradiation process using Cesium-137. The collagen sample is positioned at the focus of the laser and Cesium-137 beams to ensure accurate targeting.

**Testing of Collagen Functional Group Properties Using FTIR.**

Collagen samples were characterized using an FTIR spectrophotometer after being irradiated with Cesium-137 in 0.5 M acetic acid

(5 mg). The wave number range was 400 $cm^{-1}$ to 4000 $cm^{-1}$. The process involves placing the sample on the surface of the ATR crystal. The sample is then moved at a rate of 20 scans per second with a resolution of 0.2 cm. After this, the FTIR spectrum measures the transmittance spectrum of the wave numbers absorbed by the collagen.

## RESULTS AND DISCUSSION

### Collagen from Snakehead Fish Scale Extract

**Figure 4 Collagen Extraction of Snakehead Fish Scales.**

The use of 0.2 M NaOH in the base pretreatment of snakehead fish scales can remove non-collagen proteins, fat, minerals, and dyes (Hashim et al., 2014). Tropocollagen can be transformed into procollagen by using a solution of NaOH. Soaking fish scales in NaOH can speed up the penetration of water into the scales. This helps to retain proteins and non-collagen impurities in the matrix and makes it easier to excrete them. (Safithri et al., 2019).

After being exposed to an acid or base, a precipitate forms, allowing the pigment to be washed away (Safithri et al., 2019). When collagen is treated with acetic acid, and the concentration of acetic acid is high, the yield value of collagen also increases. For instance, when collagen with a yield of 0.5 M is treated with acetic acid, the yield value obtained is 11.03%. Therefore, it can be concluded that the concentration of acetic acid plays a crucial role in determining the yield value of collagen. It is possible that the low yield results are due to the substandard solubility of collagen in snakehead fish scales. However, this can also be influenced by the small amount of acetic acid treatment applied (Figure 4).

### Functional Groups of Collagen Before Irradiation

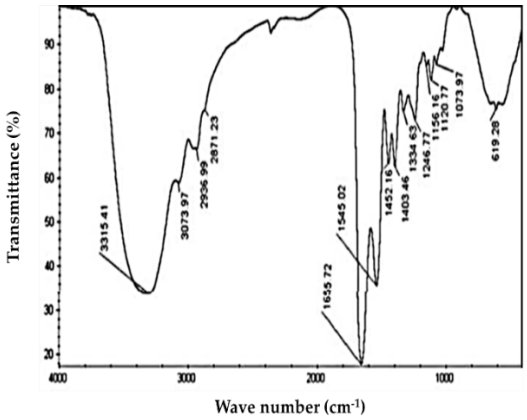


**Figure 5 FTIR spectrum of standard collagen (Riaz et al., 2018).**

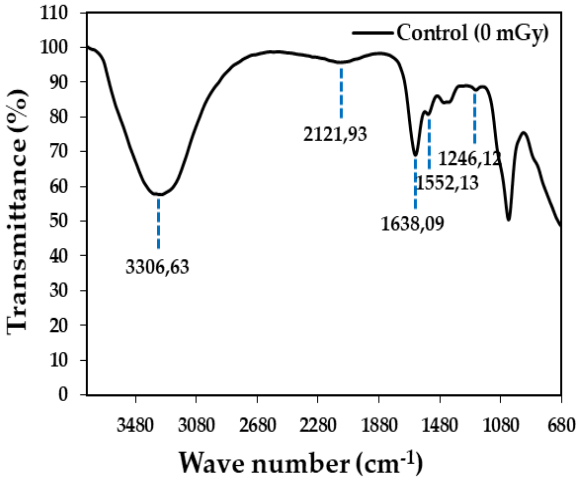


**Figure 6 FTIR spectrum of snakehead fish scales collagen before irradiation.**

Graphic image 5 shows the absorption data of a standard collagen analyzed using FTIR spectrophotometry. The image displays the functional groups amide A, amide B, amide I, amide II, and amide III, which all fill the absorption area. The FTIR spectrum results of the standard collagen in Figure 5 display absorption peaks for amide A, amide B, amide I, amide II, and amide III. These peaks are typical and meet the standard absorption area for the amide region. Amide A produces an

absorption peak at 3315.41 $cm^{-1}$ within the range of 3300-3500 $cm^{-1}$. The FTIR spectrum and Table 1 display the results of snakehead fish collagen before irradiation, as shown in Figure 6.

**Table 1 shows the results of the characterization of collagen chemical function groups before irradiation.**

| Functional groups | Wave numbers ($cm^{-1}$) | Abs. area ($cm^{-1}$) | Description |
|---|---|---|---|
| Amide A | 3306,63 | 3300-3500 | Vibration stretching NH |
| Amide B | - | 2915-2935 | Vibration stretching $CH_2$ Asimetrikal |
| Amide I | 1638,09 | 1600-1690 | Vibration stretching C=O |
| Amide II | 1552,13 | 1480-1575 | CH stretching, NH bending |
| Amide III | 1246,12 | 1229-1301 | CH stretching, NH bending |

The presence of the OH group component affects the position of amide A, indicating the involvement of water molecules in collagen. Amide B exhibits a wave number of 2936.99 $cm^{-1}$, which falls within the standard absorption range of 2915-2935 $cm^{-1}$. Amide I, II, and III also produce wave numbers within the absorption region (Riaz et al., 2018). Amide B does not produce absorption wave numbers that meet the standard absorption region for amide B (Li et al., 2013a). This can be caused by the influence of radiation which can trigger chemical reactions in functional groups and cause changes in the structure and properties of collagen molecules. Amide groups that are not detected or do not meet standard collagen functional group standards can be caused by the chemical composition of the fish scale extraction process, such as the concentration of acetic acid used during extraction and the dose used when irradiating collagen.

Table 1 data displays typical absorption peaks for the amide region, including amide A, amide B, amide I, amide II, and amide III. The NH strain was detected by extracting collagen from snakehead fish scales using the acid-soluble collagen method containing amide A with a wave number of 3306.63 $cm^{-1}$ and an absorption area of (3300-3500 $cm^{-1}$). The position of amide A is influenced by the presence of the OH group component, indicating the active involvement of water molecules in collagen (Erizal et al., 2014). In the amide, the functional group A shifts to lower frequency or to the right. This may be due to the NH group of the peptide forming hydrogen bonds with water and hydroxyproline during the extraction process. (Li et al., 2013b).

The analysis results of the amide B functional group are presented in Table 1. The absorption wave number of amide B is 2121.93 $cm^{-1}$, and the peak wave number corresponding to the absorption of amide B appears between 2915 and 2935 $cm^{-1}$. Due to the asymmetric stretching of the $CH_2$ groups, the absorption wavenumber produced by amide B does not approach the typical absorption range for amide B (Kolanus et al., 2019).

Upon analyzing the amide I functional group, the wave number was found to be 1638.09 $cm^{-1}$. The amide I absorption peak wave number was observed in the range of 1600 to 1690 $cm^{-1}$ (Li et al., 2013b). The peptide's C=O portion indicates binding. The number of amide I and secondary structure are closely related. The collagen triple helix is made up of the amino acids glycine and proline. This is evidence of the stretching vibration of the C=O amide I group. The amide I group is formed by the four overlapping components of alpha-helix, beta-sheet, beta-turn, and random-coil. (Erizal et al., 2014).

The absorption zone for amide II is found at wave numbers 1480–1575 $cm^{-1}$ with bending CH and NH stretching vibrations at the peptide bond. The functional group analysis for amide II resulted in a wave number of 1552.13 $cm^{-1}$. Although amide II exhibits the same vibrations as amide I, it does not undergo side chain vibrations. However, the relationship between its frequency and protein secondary structure is less clear than that of amide I (Barth, 2007).

The functional group analysis for amide III indicates a wave number of 1246.13 cm-1. The amide III absorption area ranges from 1229-1301 $cm^{-1}$ and shows characteristics of intermolecular interactions in collagen related to CH and NH stretching (buckling). A ratio value close to 1.0 in the intensity ratio between the absorption peak at wave number 1450 cm-1 and the amide III absorption peak indicates that collagen has a triple helix structure which is a typical collagen group (Safithri et al., 2018). This indicates that the collagen from the scales of snakehead fish has not degraded into gelatin.

According to the research, a material can be considered to contain collagen if it has at least three out of the five required functional groups. The study has shown that snakehead fish scales do contain collagen as the functional groups produced from these scales meet the standard collagen functional group requirements. The presence of amide groups in collagen extracted from fish scales may not be detected or may not meet the standard functional group criteria. This can be attributed to the chemical composition of the extraction process, including the concentration of acetic acid used and the temperature at which collagen is extracted (Pasaribu, 2021).

**FTIR Spectrum of Collagen After Gamma Irradiation (Cesium-137)**

For doses of 10 mGy, 30 mGy, and 50 mGy, amide B does not exhibit any functional groups that produce absorption wave numbers meeting the standard absorption area (Li et al., 2013). This can be caused by radiation, which triggers chemical reactions in functional groups, altering the structure and properties of collagen molecules.

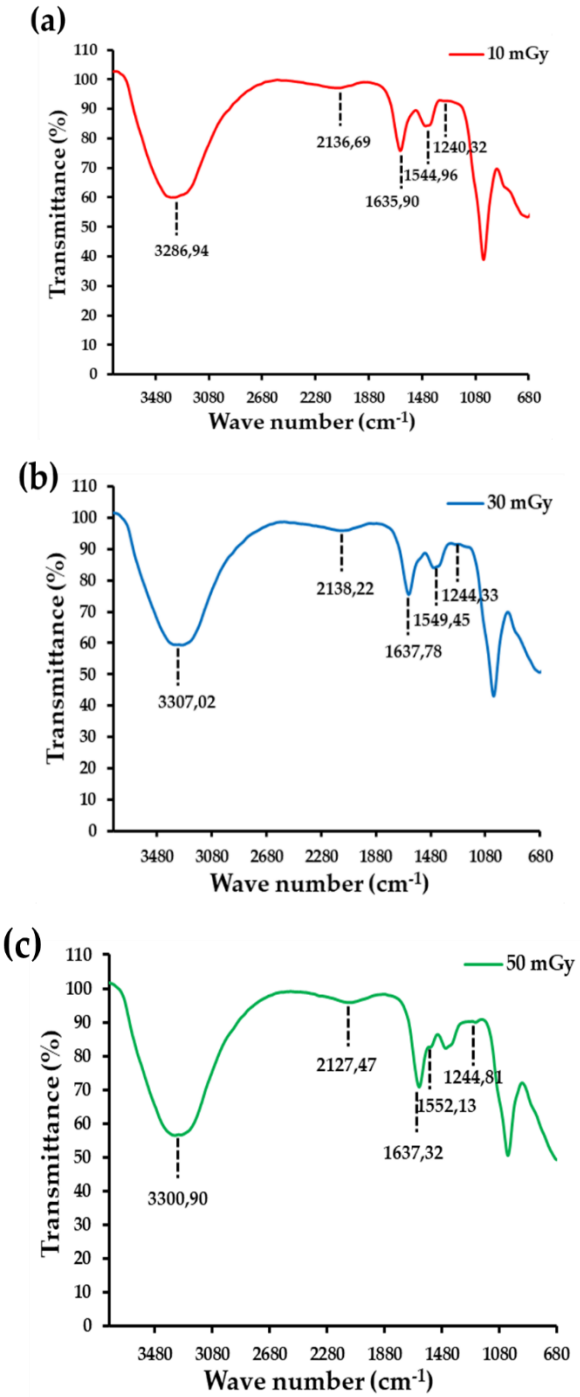


**Figure 7 (a, b, c) FTIR Spectrum of Snakehead Fish Scale Collagen After Irradiation.**

The spectrum and FTIR data of snakehead fish scale collagen after being exposed to radiation can be found in Figure 7 (a, b, c) and Table 2. The spectrum of the amide A, amide B, amide I, amide II, and amide III groups of the resulting snakehead fish scale collagen after

being exposed to 10 mGy, 30 mGy, and 50 mGy of radiation is presented in Figure 7 (a, b, c), and the wave number spectrum data is presented in Table 2. The amide A functional group does not show a significant difference. It can be observed that the resulting absorption dose of 10 mGy does not meet the standard absorption area of amide A.

**Table 2 Results of Characterization of Collagen Chemical Function Groups After Irradiation**

| Functional groups | Wave numbers ($cm^{-1}$) | | | Abs. area ($cm^{-1}$) | Description |
|---|---|---|---|---|---|
| | 10 mGy | 30 mGy | 50 mGy | | |
| Amide A | - | 3307,02 | 3333,90 | 3300-3500 | Vibration stretching NH |
| Amide B | - | - | - | 2915-2935 | Vibration stretching $CH_2$ Asimetrical |
| Amide I | 1635,90 | 1637,78 | 1637,32 | 1600-1690 | Vibration stretching C=O |
| Amide II | 1544,96 | 1549,45 | 1552,13 | 1480-1575 | CH stretching, NH bending |
| Amide III | 1240,32 | 1244,33 | 1244,81 | 1229-1301 | CH stretching, NH bending |

According to Erizal and his colleagues, this occurrence was caused by the collagen amide A band experiencing a shift to a lower frequency. This shift indicates that the thermally induced hydrogen bonds were disrupted, leading to changes in the collagen structure (Erizal et al., 2014). Meanwhile, doses of 30 and 50 mGy produced absorption numbers that met the standard absorption area for amide A.

The radiation dose has been increased from 10 mGy to 50 mGy. The amide I band is a peak that can be found in the range of wave numbers between 1600 $cm^{-1}$ and 1690 $cm^{-1}$. The peak has maximum absorption at around 1650 $cm^{-1}$. This peak is a result of the vibration of the peptide bond of the C=O group (bend). This group can be used to analyze secondary changes that occur in polypeptide compounds. Meanwhile, the amide II band with maximum absorption at wave number 1544 cm-1 is closely related to the CNH group. As the irradiation dose increases, the position of this band moves towards a higher wave number. There was no significant difference in the amide III group. However, all the absorption numbers produced at each dose filled the absorption region for amide I, amide II, and amide III (Erizal et al., 2014).

Radiation can cause chemical degradation and modification of functional groups. When exposed to higher doses of radiation (more than 10 kGy), functional groups can be impacted. For instance, collagen in acetic acid solution experiences denaturation as the radiation dose increases up to 50 kGy. The denaturation process leads to the formation of cross-links, which can cause a shift in the location of the amide group. This shift can be triggered by an increase in exposure to radiation (Erizal et al., 2014). Collagen protein of high quality contains the amino acids glycine, alanine, proline, hydroxyproline, and glutamic acid. Quality collagen protein should have an amino acid composition that includes at least three of the five types of protein (Tamilmozhi et al., 2013).

## CONCLUSION

The use of FTIR in analyzing the functional groups present in the collagen of snakehead fish scales can reveal a triple helix structure. This is indicated by the absorption ratio value between amide III and the absorption peak, where amide III signifies the presence of a triple helix structure, which is a characteristic of collagen. Radiation has the ability to initiate chemical reactions in functional groups, which can lead to changes in the structure and properties of collagen molecules. When a low radiation dose (less than 10 mGy) is given, it usually does not have a significant impact on the functional groups in the collagen solution. However, higher doses (more than 10 mGy)

can affect the functional groups due to the fact that high radiation doses can cause degradation and chemical modification of functional groups. The research results obtained from the functional group values before irradiation produced amide A, amide I, amide II and amide III which filled the absorption area of the functional group. Meanwhile, amide B does not fill the absorption area of the functional group. Meanwhile, the functional group values produced after irradiation at a dose of 10 mGy produced amide I, amide II and amide III which filled the absorption area, while amide A and amide B did not fill the absorption area. And for doses of 30 mGy and 50 mGy it produces amide A, amide I, amide II and amide III which fill the absorption area, for amide B none of them fill the absorption area.

**REFERENCES**


Barth, A. (2007). Infrared spectroscopy of proteins. *Biochimica et Biophysica Acta (BBA) - Bioenergetics*, *1767*(9), 1073–1101 https://doi.org/10.1016/j.bbabio.2007.06.004

Erizal. E., Abbas. B., Setyo. R.A.K., Sulistioso G.S., & Sudirman. S. (2014). Pengaruh Iradiasi Gamma Pada Sifat Fisiko-Kimia Kolagen Dalam Larutan. *Jurnal Sains Materi Indonesia*. 15 (4).

Hashim, P., Mohd Ridzwan, M. S., Bakar, J. & Mat Hashim, D. (2014). Mini Review: Collagen in Food and Beverage Industries. *International Food Research Journal 22* (1): 1 - 8.

Kolanus, J. P. M., Hadinoto, S., & Idrus, S. (2019). The Characterization of Collagen Acid Soluble From Yellow. *Jurnal Riset Teknologi Industri. Vol.13 No.1*.

Komala, A. H. (2015). Ekstraksi Dan Karakterisasi Kolagen Dari Kulit Ikan Tongkol (Euthynnus Affinis). *Skripsi. Institut Pertanian Bogor*

Li, Z.-R., Wang, B., Chi, C., Zhang, Q.-H., Gong, Y., Tang, J.-J., Luo, H., & Ding, G. (2013a). Isolation and characterization of acid soluble collagens and pepsin soluble collagens from the skin and bone of Spanish mackerel (Scomberomorous niphonius). Food Hydrocolloids, 31(1), 103–113. https://doi.org/10.1016/j.foodhyd.2012.10.001

Li, Z.-R., Wang, B., Chi, C., Zhang, Q.-H., Gong, Y., Tang, J.-J., Luo, H., & Ding, G. (2013b). Isolation and characterization of acid soluble collagens and pepsin soluble collagens from the skin and bone of Spanish mackerel (Scomberomorous niphonius). Food Hydrocolloids, 31(1), 103–113. https://doi.org/10.1016/j.foodhyd.2012.10.001

Mohamed, E. F. E., Hafez, A. E.-S. E., Seadawy, H. G., Elrefai, M. F. M., Abdallah, K., Bayomi, R. M., Mansour, A. T., Bendary, M. M., Izmirly, A. M., Baothman, B. K., Alwutayd, K. M., & Mahmoud, A. F. A. (2023). Irradiation as a Promising Technology to Improve Bacteriological and Physicochemical Quality of Fish. Microorganisms, 11(5), 1105. https://doi.org/10.3390/microorganisms11051105

Moslemi, M., & Naderi, T. (2022). Effect of gamma rays on microbial quality of salmon fish during storage in refrigerator at 4 C. Central Asian Journal of Environmental Science and Technology Innovation, 3(3).
https://doi.org/10.22034/CAJESTI.2022.03.02

Pasaribu, P., Sari. N. I., & Iriani. D. (2021). Rendemen Kolagen Yang Diekstrak Dari Cangkang Kijing (*pilsbryoconcha sp*.) dari Perairan Sungai dan Kolam. *Jurnal On Line Mahasiswa*.

Rahayu, G. K., Solihin, D. D., & Butet, N. A. (2021). Population diversity of striped snakehead, Channa striata (Bloch, 1793) from Bekasi, West Java and Barito Kuala, South Kalimantan using Cytochrome B gene. Jurnal Iktiologi Indonesia, 21(1), 61–73.
https://doi.org/10.32491/jii.v21i1.552

Riaz, T., Zeeshan, R., Zarif, F., Ilyas, K.,

Muhammad, N., Safi, S. Z., Rahim, A., Rizvi, S. A. A., & Rehman, I. U. (2018). FTIR analysis of natural and synthetic collagen. *Applied Spectroscopy Reviews, 53(9)*, 703–746. https://doi.org/10.1080/05704928.2018.1426595

Rosidah, F. (2009). Efektivitas Dekontaminan Ammonium Iron (III) Hexacyanoferrate ($NH_4Fe[Fe(Cn)_6$) Terhadap Cesium-137 Pada Monyet. *Skripsi*. Universitas Islam Negeri Syarif Hidayatullah Jakarta.

Safithri, M., Setyaningsih, I., Tarman, K., Yuhendri, V. M., & Meydia, M. (2018). Potensi Kolagen Teripang Emas Sebagai Inhibitor Tirosinase. *Jurnal Pengolahan Hasil Perikanan Indonesia, 21(2)*, 296. https://doi.org/10.17844/jphpi.v21i2.23085

Safithri, M., Tarman, K., Suptijah, P., & Widowati, N. (2019). Physicochemical characteristics of acid soluble collagen from the skin of Parang parang fish (*Chirocentrus dorab*). *Jurnal Pengolahan Hasil Perikanan Indonesia, 22(3)*, 441–452. https://doi.org/10.17844/jphpi.v22i3.28924

Tamilmozhi, S., Veeruraj, A., & Arumugam, M. (2013). Isolation and characterization of acid and pepsin-solubilized collagen from the skin of sailfish (Istiophorus platypterus). *Food Research International, 54*(2), 1499–1505. https://doi.org/10.1016/j.foodres.2013.10.002

Widya Pangestika, Abrian, S., Maulid, D. Y., Arumsari, K., Putra, S., Windiarti, F. F., & Herawati, V. (2022). Pengaruh Iradiasi Gamma dan Penyimpanan Dingin terhadap Kandungan Proksimat, pH, dan ALT Filet Ikan Jenaha. *Jurnal Pengolahan Hasil Perikanan Indonesia, 25(1)*, 80–87. https://doi.org/10.17844/jphpi.v25i1.38521