Indonesian Journal of Halal Research
E-ISSN: 2657-0165
P-ISSN: 2656-3754

ARTICLE

Indonesian Journal of HALAL RESEARCH

Physicochemical Properties of Halal Alternative Gelatin from Parrotfish *(Scarus quoyi)* Scales Optimized by Response Surface Methodology

Muammar Yulian[1], Muhammad Reza[2], Nofa Ramadani[3], Rosi Hamama[4], Raudhatul Fadhilah[5], Yusrizal Akmal[6], Kasim Sakran Abass[7], Epa Paujiah[8], Sukree Hajisamae[9], Ilham Zulfahmi[10]*

Abstract: *The increasing demand for halal-friendly gelatin, combined with concerns over health risks associated with mammalian sources, has created a need for alternative raw materials. Fish scales from local species, such as parrotfish, offer a sustainable and promising option that has yet to be extensively explored. The study aims to investigate the physicochemical properties of gelatin extracted from the scales of the parrotfish (Scarus quoyi) scales. Response Surface Methodology (RSM) was employed to determine the optimal concentration of hydrochloric acid (HCl) and immersion time to maximize yield and quality. Physicochemical properties, including yield, moisture content, ash content, pH, and viscosity, were evaluated, and the structural characteristics of the gelatin were analyzed using Fourier-Transform Infrared Spectroscopy (FTIR). All processing steps were conducted in compliance with Halal Critical Control Points (HCCPs) to ensure the final product remained free from cross-contamination with non-halal substances. Response surface methodology optimization identified 4% HCl concentration and 29.4 hours of immersion as optimal conditions. These conditions produce gelatin with a yield, moisture, ash, pH, and viscosity are 14.5%, 4%, 0.48%, 4.15, and 1.78 cP, respectively. FTIR analysis confirmed that the extracted gelatin exhibited absorption peaks consistent with those of commercial gelatin, indicating a functional group similarity. Compared to gelatin from other fish species, parrotfish gelatin demonstrated a competitive yield and notably low moisture content, thereby enhancing its stability and storage potential. These findings highlight the potential of parrotfish scales as a sustainable source of halal gelatin, contributing to waste reduction and offering a viable alternative to mammalian gelatin.*
Keywords: *extraction, fish scale waste, gelatin, halal assurance, response surface methodology*

e-mail: muammar.yb@ar-raniry.ac.id[1], muhammad.reza@ar-raniry.ac.id[2], noffaramadhani@gmail.com[3], rosihamama@gmail.com[4], raudhatul.fadhilah@unmuhpnk.ac.id[5], yusrizalakmal@umuslim.ac.id[6], kasim.s.abass@uoalkitab.edu.iq[7], epapaujiah@uinsgd.ac.id[8], sukree.h@psu.ac.th[9], ilham.zulfahmi@usk.ac.id*[10]
*Corresponding Author

Received: August 30, 2024	Accepted: August 31, 2025	Published: August 31, 2025

How to cite this article (APA 7th Edition Reference Style): Yulian, M., Reza, M., Ramadani, N., Hamama, R., Fadhilah, R., Akmal, Y., Abass, K. S., Paujiah, E., Hajisamae, S., & Zullfahmi, I. (2025). Physicochemical Properties of Halal Alternative Gelatin from Parrotfish *(Scarus quoyi)* Scales Optimized by Response Surface Methodology. *Indonesian Journal of Halal Research*, *7*(2), 78–91. https://doi.org/10.15575/ijhar.v7i2.38678

[1,2,3,4]Departement of Chemistry Education, Faculty of Education and Teacher Training, Universitas Islam Negeri Ar-Raniry, Jl. Syech Abdurrauf, KOPELMA Darussalam, Banda Aceh, Aceh, 23111, Indonesia. [1,2]Center for Halal Studies and Integrated Science, Universitas Islam Negeri Ar-Raniry, Jl. Syech Abdurrauf, KOPELMA Darussalam, Banda Aceh, Aceh, 23111, Indonesia. [1]Department of Chemistry, Faculty of Science and Technology, Universitas Islam Negeri Ar-Raniry, Jl. Syech Abdurrauf, KOPELMA Darussalam, Banda Aceh, Aceh, 23111, Indonesia. [5]Department of Chemical Education, Faculty of Education and Teacher Training, Universitas Muhammadiyah Pontianak, Jl. Jenderal Ahmad Yani No. 111, Pontianak, West Kalimantan, Indonesia. [6]Department of Aquaculture, Faculty of Agriculture, Universitas Almuslim, Jl. Almuslim, Matang Glumpang Dua, Peusangan, Bireuen, 24261, Aceh, Indonesia. [7]College of Veterinary Medicine, Department of Physiology, Biochemistry, and Pharmacology, University of Kirkuk, Kirkuk, Iraq. [8]Department of Biology Education, Faculty of Tarbiyah and Teacher Training, Universitas Islam Negeri Sunan Gunung Djati, Jl. Cimincrang, Gede Bage, Bandung, West Java, 40294, Indonesia. [9]Department of Agricultural and Fishery Science, Faculty of Science and Technology, Prince of Songkla University Pattani Campus, 181 Charoenpradit Rd, Rusamilae, Muang, Pattani, 94000, Thailand. [10]Department of Fisheries Resources Utilization, Faculty of Marine and Fisheries, Universitas Syiah Kuala, Jl. Teuku Nyak Arief Darussalam, Banda Aceh, Aceh, 23111, Indonesia. [10]Department Marine and Coastal Resources Management, Faculty of Environmental Management, Prince of Songkla University, 15 Karnchanavanich Road, Hat Yai, Songkhla, Thailand.

1. Introduction

Gelatin, a natural polymer derived from the hydrolytic degradation of collagen protein, is characterized by its distinctive amino acid profile and is widely recognized for its high protein content, making it a viable alternative to lipids and carbohydrates in various applications (Kumosa et al., 2018; Lv et al., 2019). The production of gelatin involves the hydrolysis of collagen obtained from animal sources, such as pigs, cattle, and fish (Alipal et al., 2021). In 2020, global demand for gelatin reached approximately USD 3.2 billion, with an annual production volume of about 620 kilotons (Karim & Bhat, 2009). Gelatin exhibits a range of functional properties, including water-binding capacity, film-forming ability, foaming capacity, and emulsifying properties. These characteristics make gelatin a versatile material with broad applications in the food, pharmaceutical, cosmetic, and biomedical industries (Ahmad et al., 2017).

The demand for gelatin has been steadily increasing in parallel with the growth of human needs (Said, 2020). Gelatin is utilized in diverse sectors, including food (Tümerkan, 2021; Usman et al., 2022), pharmaceuticals (Tümerkan, 2021), photography (Calixto et al., 2018; Hodgson, 2024), cosmetics (Abdullah et al., 2018; Al-Nimry et al., 2021), and healthcare (Herrera-Ruiz et al., 2022; Mushtaq et al., 2022). To date, the primary sources of gelatin are pork skin (49.6%), cattle hide (29.4%), and bovine bones (23.1%) (Sultana et al., 2018). However, the use of mammalian-derived gelatin has been controversial due to its potential association with transmissible diseases such as Bovine Spongiform Encephalopathy (BSE) and foot-and-mouth disease (FMD) (Rawdkuen et al., 2013). In addition, non-halal gelatin is prohibited for consumption by Muslims and certain other religious groups because it does not meet their dietary and ethical requirements. For Muslim consumers, halal compliance necessitates that all production stages adhere to Halal Critical Control Points (HCCPs), ensuring that raw materials, processing aids, and facilities are free from contamination with non-halal substances (Nurilmala et al., 2022). Consequently, there is growing interest in gelatin alternatives from permissible sources, including fish, plants, and other halal-certified materials.

Fish-derived gelatin, including that from fish scales, offers a viable halal alternative because fish are considered permissible (halal) regardless of slaughter method, and the risk of contamination can be minimized through proper handling and processing (Atma, 2022; Machado et al., 2023). In addition, fish scale gelatin contributes to sustainability by valorizing fishery by-products. Proteins are present not only in fish flesh and bones but also in fish scales, which comprise approximately 70% water, 27% protein, 1% lipid, and 2% ash; of the organic fraction, which ranges from 40% to 90%, collagen is the predominant component (Nagai et al., 2004). Currently, the utilization of fish scales as an alternative source of gelatin has been explored in several species, including bighead carp (*Hypophthalmichthys nobilis*) (Huang et al., 2017; Tu et al., 2015), skipjack tuna (*Katsuwonus pelamis*) (Qiu et al., 2019), *Oreochromis* spp. (Shiao et al., 2021), and lizardfish (*Saurida* spp.) (Wangtueai et al., 2016). Qiu et al. (2019) reported that gelatin extracted from skipjack tuna scales exhibited the following characteristics: moisture content of 3.78%, lipid content of 0.53%, ash content of 1.05%, protein content of 94.8%, and an extraction yield of 3.46%.

The parrotfish (*Scarus quoyi*) is a commercially important species widely consumed by local communities (Prihanto et al., 2022). Its abundance has been reported in various regions of Indonesia, including Sabang, Aceh Province (Zulfahmi et al., 2022), Riau Islands (Putra et al., 2020), North Maluku (Rahaningmas & Mansyur, 2018), and North Sulawesi (Rachmad et al., 2018). The high consumption of parrotfish generates a significant amount of fish scales as waste (Andakke et al., 2020). To the best of our knowledge, no prior research has investigated the characteristics and physicochemical properties of gelatin extracted from parrotfish scales. The previous study by Andakke et al. (2020) focused solely on the molecular characterization of gelatin in *Scarus* spp. scales and did not involve gelatin extraction or optimization. Hence, this research aimed to describe the characteristics and physicochemical properties of gelatin derived from parrotfish scales and its potential as an alternative raw material for Halal products.

2. Materials and Methods

A total of 50 g of parrotfish (*Scarus quoyi*) scales were collected from the Al-Mahirah Market, Banda Aceh, Aceh Province, Indonesia (5°34’57.6” N, 95°19’42.9” E). The collected scales had diameters ranging from 1.5 to 2.0 cm. Gelatin preparation was conducted in four stages: degreasing, demineralization, extraction, and drying (Winarti et al., 2021). Degreasing was performed by washing the scales to remove dirt, residual flesh, and skin, followed by heating at 40°C for 30 min. The scales were then rinsed with distilled water and air-dried at room temperature for 24 h. Demineralization was

carried out by soaking the scales in 200 mL of hydrochloric acid (HCl) at concentrations of 3%, 6%, and 9% for 12, 30, or 42 h. The samples were rinsed with distilled water until a neutral pH (≈7) was achieved (Zhang et al., 2011). For extraction, the demineralized samples were mixed with distilled water at a 1:4 (w/v) ratio and heated on a hot plate (C-MAG HS7, Germany) at 70°C for four h, followed by filtration. The filtrate was oven-dried (Memmert UN30, Germany) at 70°C for 24 h, producing gelatin in the form of glass-like flakes, which indicated that it was completely dried.

2.1. Treatment

The gelatin extraction procedure was adapted from Mardiyah et al. (2019), with a focus on optimizing hydrochloric acid (HCl) concentration and immersion duration to maximize yield and quality. Optimization was carried out using Response Surface Methodology (RSM) with a three-level Box–Behnken Design (BBD). Two independent variables were selected: HCl concentration (3%, 6%, and 9% w/v) and immersion time (12, 27, and 42 h). The design generated 13 experimental runs consisting of factorial, axial, and central points to evaluate the interaction between factors. The response variable was gelatin yield (%), while additional physicochemical properties (moisture content, ash, and pH) were measured as supporting parameters. Three-dimensional response surface plots were constructed to visualize the combined effects of factors. The optimized conditions predicted by the model were validated experimentally in triplicate, and the relative error (%) between predicted and observed yields was calculated to confirm model accuracy and process reproducibility. This design allowed comprehensive evaluation of the main and interactive effects of acid concentration and immersion time on hydrolysis efficiency, thereby identifying optimal conditions for producing gelatin with desirable physicochemical characteristics.

2.2. Gelatin Functional Groups

The functional groups present in the produced gelatin were analyzed by Fourier-transform infrared (FTIR) spectroscopy following the method of Muyonga et al. (2004) with modifications. FTIR spectra were obtained using a PerkinElmer FTIR spectrometer (USA) equipped with an attenuated total reflectance (ATR) accessory. Gelatin samples were finely ground into powder prior to analysis to ensure uniformity. Each spectrum was recorded in the range of 4000–400 cm^{-1}.

2.3. Yield

The yield test was used to determine the amount of gelatin extracted from parrotfish scales according to the Association of Official Analytical Chemists (AOAC) standard. Yield was calculated by comparing the mass of the initial fish scale sample to the mass of the dried gelatin obtained after extraction. The percentage yield was determined using the following equation developedd by Duan et al. (2011).

2.4. Ash Content

The ash content was determined following the protocol of Almeida and Lannes (2013). Briefly, approximately 1 g of gelatin was placed in a pre-weighed porcelain dish and heated in a furnace at 600°C until completely ashed. This process removes all organic material, leaving only inorganic mineral residue. The mass of the remaining ash was then measured, and the ash content was calculated as the percentage of the initial sample weight.

2.5. Moisture

The moisture content was determined according to the National Standardization Agency (2018) using the oven-drying method. Briefly, approximately 0.50 g of gelatin was placed in a pre-weighed vessel, and the initial weight was recorded. The vessel was then placed in an oven at 105°C for two hours, or until a constant weight was achieved, before being cooled in a desiccator. The final weight was recorded, and the moisture content was calculated as the percentage weight loss relative to the initial sample weight, following the equation described by Tkaczewska et al. (2018).

2.6. pH

The pH measurement was conducted following the method of Nasution et al. (2018) with slight modifications. Briefly, 0.50 g of gelatin was dissolved in 30 mL of distilled water at 45°C. The solution was then allowed to cool to room temperature, after which the pH was measured using a calibrated pH meter.

2.7. Viscosity

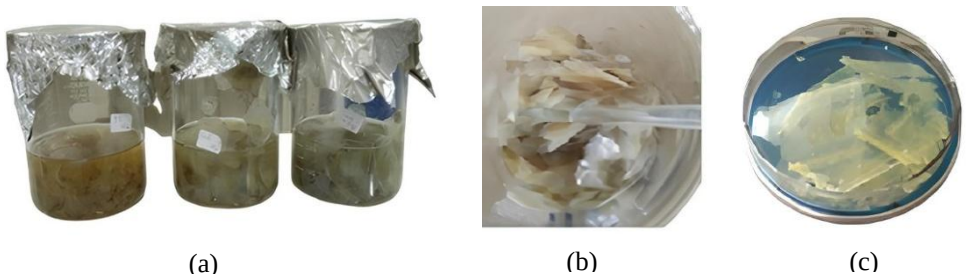
The viscosity of gelatin was measured according to the method of Nasution et al. (2018) with modifications to match the Gelatin Manufacturers Institute of America (GMIA) standard conditions

(Gelatin Manufacturers Institute of America, 2019). Briefly, a 1.5% (w/v) gelatin solution was prepared by dissolving 0.45 g of gelatin in 30 mL of distilled water at 60°C with gentle stirring until fully dissolved. The solution was then cooled to 30 ± 0.5°C before measurement. Viscosity was determined using an Ostwald capillary viscometer (Germany), which was calibrated with distilled water at the same temperature prior to measurements.

3. Results and Discussion

3.1. Optimal HCl Concentration and Immersion Time

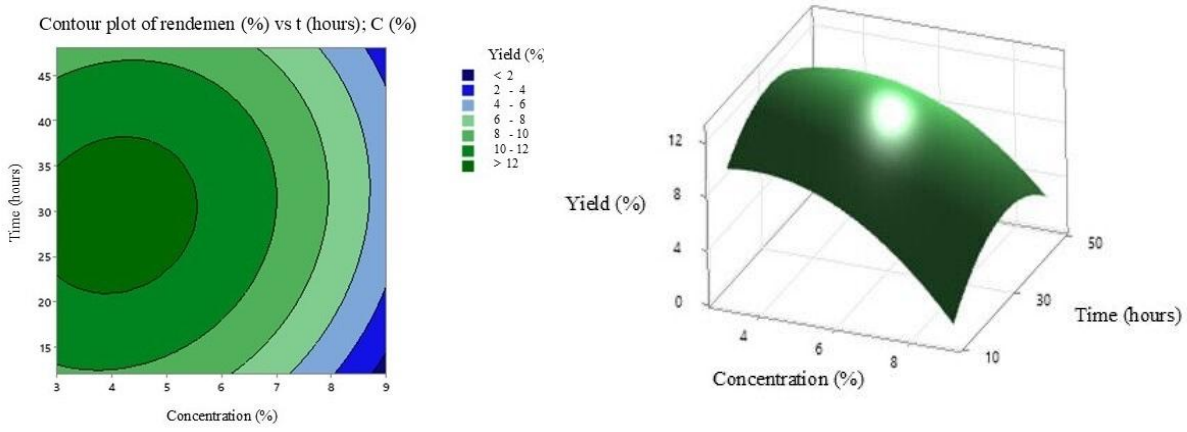
Figure 1(a) illustrates the immersion process, during which water molecules bind to the polar chains of collagen in the fish scales, forming hydrogen bonds that help prevent protein aggregation in the solution. The process was further supported by heating at 40°C, which enhanced the water solubility of the protein's polar chains (Wang et al., 2018). As a result, non-collagen proteins were effectively removed during this phase. Protein solubility was closely related to molecular weight (Alrosan et al., 2024). Proteins with higher molecular weight tended to promote gel formation, while those with lower molecular weight had the opposite effect (Scott & Awika, 2023). Due to the low water solubility of some proteins, the number of water–protein linkages was fewer than protein–protein linkages (Kramer et al., 2012). Consequently, this step not only reduced impurities but also decreased the content of water-soluble components. The remaining water-insoluble protein–protein linkages were subsequently targeted for hydrolysis in the next phase, which involved the combined action of hydrochloric acid (HCl) and heat. In the extraction stage, distilled water was used to break collagen fibers into gelatin at 70°C. Figure 1(b) shows the demineralization step, where HCl dissolved mineral components such as calcium salts from the scales, improving collagen accessibility for extraction. Figure 1(c) presents the outcome of the 24-hour drying process, resulting in the formation of gelatin sheets.



(a) (b) (c)

Figure 1. (a) Immersion process of parrotfish scales, (b) demineralization process, and (c) gelatin obtained in sheet form.

Figure 2 presents the results in graphical form to facilitate visualization of the optimal conditions for gelatin extraction. The data revealed that gelatin yield was dependent on both immersion time and hydrochloric acid (HCl) concentration. The optimal concentration of hydrogen ions (H^+) interacted with negatively charged functional groups in gelatin, promoting the formation of a more gradual and ordered gelatin structure. This structure, in turn, enhanced gel strength due to the presence of higher molecular weight molecules (Sun et al., 2025).



(a) (b)

Figure 2. Response Surface Methodology Results. (a) Contour plot of yield (%) vs time (hours); (b) 3D surface plot of yield (%) vs time (hours) and concentration (%w/v).

In Figure 2(a), the black region indicates a yield of less than 4%, reflecting insufficient immersion time for effective gelatin chain entanglement. As polymer chain length increased, the hydrolysis process became more efficient (Qing & Wyman, 2011). The transition to dark green in the plot corresponded to yields above 12%, indicating improved extraction efficiency. Figure 2(b) shows the relationship between yield, HCl concentration, and immersion time, with optimal conditions achieved at 4% HCl and 29.4 hours of immersion. Under these parameters, collagen hydrolysis was maximized without causing excessive degradation. The surface response methodology (RSM) was employed to generate these data, testing HCl concentrations of 3%, 6%, and 9% (v/v) and immersion times of 12, 24, and 48 hours, allowing for precise optimization of extraction conditions.

3.2. FTIR Characterization

FTIR analysis was conducted to identify the characteristic absorption peaks of functional groups in gelatin extracted from parrotfish scales. The FTIR spectrum of the selected gelatin was presented in Figure 3, and it confirmed that its spectral profile closely resembled that of commercial gelatin. The N–H stretching vibration, known as amide A, was observed at 3280 cm^{-1}, matching the absorption peak of commercial gelatin (Wang et al., 2008). This band was associated with hydrogen bonding in the peptide structure. Free N–H stretching vibrations typically appeared within the range of 3600–3000 cm^{-1}, but when hydrogen bonds formed, the peak shifted to a lower wavenumber, around 3300 cm^{-1}. The C=O stretching vibration of the polypeptide chain, corresponding to amide I, was detected at 1629 cm^{-1}. This peak reflected the confirmation of peptide bonds and variations in protein secondary structure, and it was consistent with the amide I peak in commercial gelatin (Gómez-Guillén et al., 2011).

Amide II was observed at 1523 cm^{-1}, slightly lower than the typical range of 1550–1600 cm^{-1} reported for this band (Wang et al., 2008). This vibration arose from N–H bending coupled with C–N stretching (Phillips & Williams, 2011). A shift in amide II to 1449 cm^{-1} was also noted, indicating the preservation of the triple-helix structure (Heng et al., 2022). Amide III, which represented C–N stretching and N–H bending vibrations and was also influenced by the $–CH_2$ groups of amino acids such as glycine and proline, was recorded at 1235 cm^{-1}. This position closely matched both the theoretical range (1240–750 cm^{-1}) and the commercial gelatin peak at 1293 cm^{-1} (Zhang et al., 2016).

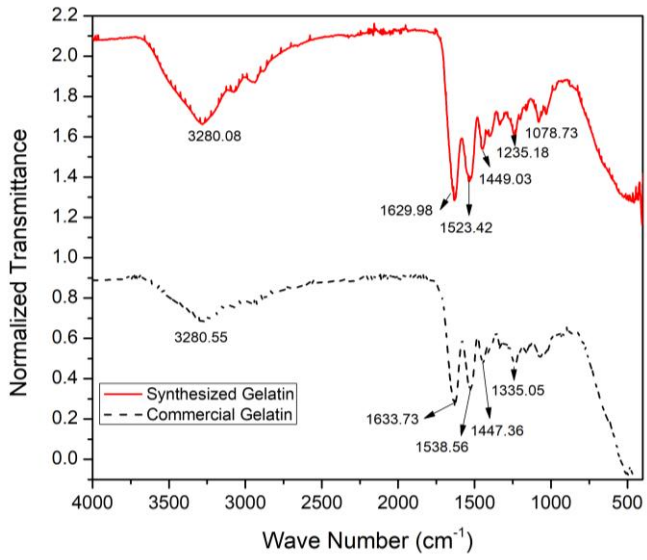


Figure 3. FTIR spectra of gelatin extracted from parrotfish scales and commercial gelatin.

3.3. Yield

Figure 4 showed that the extraction achieved the highest yield at 4% HCl and 29.4 hours of immersion time. Figure 4(a) indicates that the yield was higher at lower HCl concentrations and decreased at higher concentrations. Similarly, Figure 4(b) demonstrated that yield decreased with both higher concentrations and longer immersion times. Yield represented the amount of gelatin produced relative to the initial sample weight and served as an indicator of extraction efficiency. It was also a key parameter for assessing the quality of gelatin extracted from parrotfish scales. A reduced yield could have resulted from incomplete collagen hydrolysis or the leaching of extracted collagen during the washing steps in pretreatment (Mhd Sarbon et al., 2013). The yield of gelatin extraction was influenced by multiple stages in the process, including degreasing, demineralization, and extraction (Asih et al., 2019).

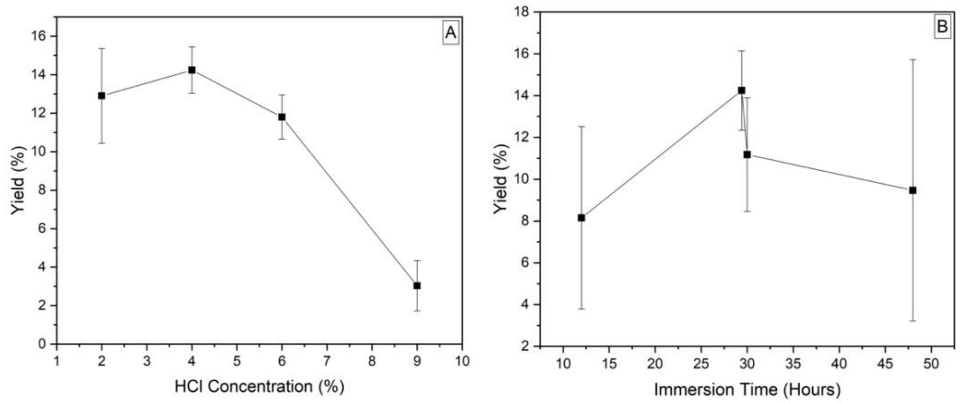


Figure 4. Effect of HCl concentration (a) and immersion time on the yield of gelatin extraction (b).

In general, as HCl concentration increased to an optimal level, gelatin yield tended to improve. Previous studies reported that using HCl in the range of 0.06–0.4 M enhanced yield (Wang & Regenstein, 2009), and other research using 0.05–1 M HCl produced yields between 10.45% and 22.25% (Ismail & Abdullah, 2016). However, in the present study, yields at concentrations of 6% and 9% were lower, likely because gelatin was more readily degraded, leading to losses during washing to neutralize pH. Excessively high HCl concentrations appeared to reduce yield by accelerating gelatin hydrolysis and dissolution during immersion, which increased the rate of degradation (Mahmoodani et al., 2014). Both Figure 4(a) and Figure 4(b) showed that the maximum yield was obtained when a 4% HCl concentration was combined with an immersion time of 29.4 hours. Under these conditions, collagen hydrolysis was optimized without causing excessive damage to the gelatin structure. Therefore, gelatin yield was significantly affected by both HCl concentration and immersion time, and the results at 4% concentration were considered favorable compared with previously reported yields.

3.4. Moisture

Figure 5 presents the moisture content of gelatin derived from parrotfish scales. The moisture content of gelatin varied depending on the dehydration process, typically ranging from 10% to 13%. In this study, the calculated moisture content ranged from 4% to 10% for HCl concentrations between 3% and 9%, with the lowest value of 4% obtained under optimal extraction conditions (4% HCl and 29.4 hours of immersion). Moisture content was determined using thermogravimetric analysis, which involved heating the sample to a constant weight to evaporate water (Duthen et al., 2021). Controlling the moisture content of gelatin was considered essential because it influenced product quality, stability, price, and potential applications in the food, pharmaceutical, and cosmetic industries. In general, a lower moisture content indicated better quality, as it reduced hygroscopicity and improved storage stability.

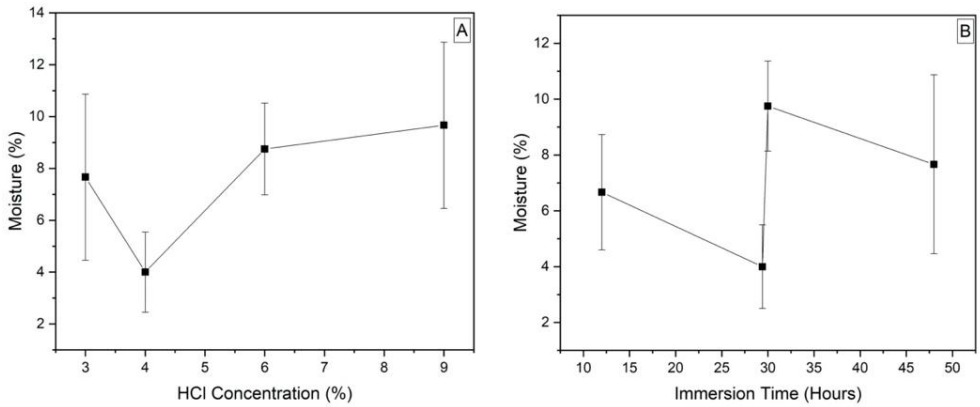


Figure 5. Effect of HCl concentration (a) and immersion time on the moisture of gelatin (b).

The moisture values obtained in this study were comparable to those reported by Esfahani et al. (2019), who produced gelatin with a moisture content of 4–7%. Both products were of similar grade, although the method in the present study, extraction and demineralization with HCl, differed from the complexation approach used in Esfahani et al.'s work. In contrast, Fonseca et al. (2020) reported higher moisture values of 14–16%, suggesting that the parrotfish gelatin produced here had lower water content and potentially better quality for manufacturing applications. The optimal extraction conditions not only

maximized yield but also minimized moisture content. Previous studies suggested that increasing acid concentration generally reduced gelatin moisture content due to more effective collagen hydrolysis, which produced smaller, more hydrophobic molecules with lower water-binding capacity (Gumilar et al., 2024). The combination of optimal HCl concentration (4%) and appropriate immersion time (29.4 h) in this study resulted in gelatin with both high yield and controlled moisture content, meeting the commercial standard for gelatin, which specifies a maximum moisture content of 16% (National Standardization Agency, 1995).

The findings from a comparative analysis of the yield and moisture properties of gelatin from parrotfish scales with those of other gelatins produced using HCl or other acids as demineralization agents are presented in Table 1. In this study, gelatin yield reached 14.20% under optimal conditions (4% HCl), which was higher than that obtained from black tilapia scales (11.88%) and tilapia scales (12.10%), but slightly lower than the yield from spotted golden goatfish scales (15.73%) and bighead carp scales (19.15%). The higher yields reported in these studies could be attributed to differences in species-specific collagen structure, acid concentration, extraction temperature, or pretreatment methods.

Table 1. Comparison of gelatin yield and moisture content between this study and previous studies

Source of gelatin	Solvent for demineralization	Yield (%)	Moisture (%)	References
Parrot fish scale	HCl 4%	14.20	4.00	
Spotted golden fish scale	HCl 0.75 M	15.73	-	(Chuaychan et al., 2017)
Bighead carp scale	HCl 0.5 M	19.15	13.65	(Tu et al., 2015)
Black talipia scale	HCl 3%	11.88	8.20	(Sockalingam & Abdullah, 2015)
Tilapia scale	HCl 0.4 M	12.10	-	(Martins et al., 2018)
Seabass scale	HCl 6.0 M	14.10	-	(Cao et al., 2017)

Regarding moisture content, the gelatin from parrotfish scales in this study had a moisture level of 4.00%, which was lower than the values reported for bighead carp scales (13.65%) and black tilapia scales (8.20%) (Table 1). Lower moisture content is advantageous as it improves gelatin stability, reduces hygroscopicity, and extends shelf life. This suggests that the drying step in the present study was more efficient and contributed to producing a product closer to the moisture specifications recommended by GMIA and SNI standards (maximum 16%) (Gelatin Manufacturers Institute of America, 2019; National Standardization Agency, 1995).

3.5. Ash Content

In this study, the optimal gelatin extraction conditions produced an ash content of 0.48%. Ash content was used as an indicator of product quality and purity, representing the inorganic mineral residue remaining after combustion of the sample. In gelatin, higher ash content typically indicates a greater presence of residual organic and mineral components, which can reduce product quality, while lower ash content suggests higher purity (Nurilmala et al., 2022). The acid soaking process influences ash content, or demineralization, which is intended to remove mineral components such as calcium, as well as certain organic matter from parrotfish scales (Al-Kahtani et al., 2017). The ash content obtained in this study was lower than values reported in several earlier works: 1.06% for gelatin from ganglomo fish skin (Alemán et al., 2011), 4.02% for gelatin from red snapper skin (Ahmed et al., 2020), and 2.13% for gelatin from red snapper bones (Bahar et al., 2018). Previous research has shown that the concentration of HCl significantly affects the efficiency of calcium and mineral removal during demineralization (El-Bassyouni et al., 2013). This finding aligns with studies reporting that both HCl concentration and immersion time influence calcium elimination (Figueiredo et al., 2011). The conditions applied in the present study, 4% HCl concentration and 29.4 hours of immersion, were determined to be optimal for demineralizing *Scarus quoyi* scales and met the quality standards established by SNI and GMIA (Gelatin Manufacturers Institute of America, 2019; National Standardization Agency, 1995).

3.6. pH

The pH of gelatin was evaluated to determine its acidity level and compliance with standards for human consumption. In gelatin, pH is closely associated with the type and intensity of acid treatment applied during the immersion process. Commercial gelatin typically has a pH range of 3.80–5.00. In this study, pH values of gelatin extracted from parrotfish scales ranged from 3.50 to 4.20 across treatments using 3%–9% HCl and immersion times of 12–48 hours (Figure 6(a) and Figure 6(b)). The lowest pH value (3.50) was recorded at 9% HCl, while the highest pH value (4.15) was observed under optimal extraction conditions (4% HCl, 29.4 hours). At both 3% and 6% HCl concentrations, the gelatin pH remained

within the acceptable commercial range, whereas at 9% HCl, the pH dropped below 3.80, failing to meet the commercial standard.

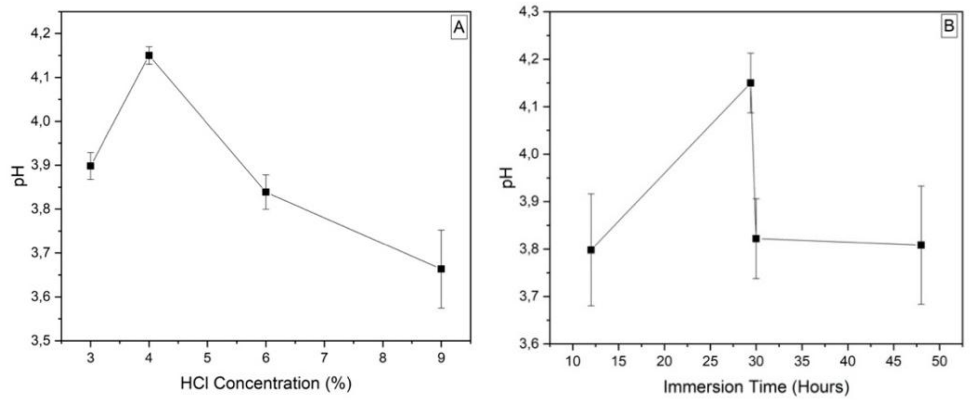


Figure 6. Effect of HCl concentration (a) and immersion time on the pH of gelatin (b).

For comparison, previous studies have reported higher pH values for gelatin from other sources, such as 6.87 for swim bladder gelatin from sturgeon (Wang et al., 2021) and 5.21 for pigskin gelatin (Sompie et al., 2015). Other research found pH values in the range of 3–5 for various fish gelatins (Chakka et al., 2017) and 4.38 for mammalian-derived gelatin (Rafieian et al., 2015). The relatively low pH observed in the present study may have been due to residual acid remaining in the fish scales despite repeated washing. Additionally, variations in pH can be influenced by differences in amino acid composition and extraction methods (Abedinia et al., 2017). The neutralization step during washing aimed to remove residual HCl. However, insufficient washing could leave traces of acid in the gelatin, especially within the collagen matrix of the scales. In this study, the higher pH observed at 4% HCl compared with 9% HCl was likely due to more effective neutralization during processing. Under optimal conditions, the pH value complied with the GMIA standard for commercial gelatin (Gelatin Manufacturers Institute of America, 2019).

3.7. Viscosity

The viscosity of gelatin extracted from parrotfish scales ranged from 1.5 to 2.1 cP (Figure 7). Viscosity reflects the resistance of a liquid to flow and is influenced by both the source of gelatin and the extraction method, for gelatin, factors such as solvent concentration, temperature, pH, and extraction time significantly affected viscosity (da Trindade Alfaro et al., 2014). Generally, higher solvent concentrations produced thicker mixtures, while higher pH values tended to reduce viscosity. This trend was consistent with the data in Figure 6(a), which showed higher pH values for gelatin extracted at 4% and 6% HCl concentrations. The presence of hydrogen ions (H^+) during demineralization also played a key role in determining viscosity (Zhou & Regenstein, 2004). Intermolecular hydrogen bonding between the hydroxyl groups of collagen and water molecules restricted water flow, thereby increasing viscosity. However, viscosity fluctuations were influenced by both extraction time and H^+ concentration. Increased values for these variables enhanced collagen hydrolysis and chain fragmentation, increasing the number of low–molecular–weight (Mw) peptides (da Trindade Alfaro et al., 2014).

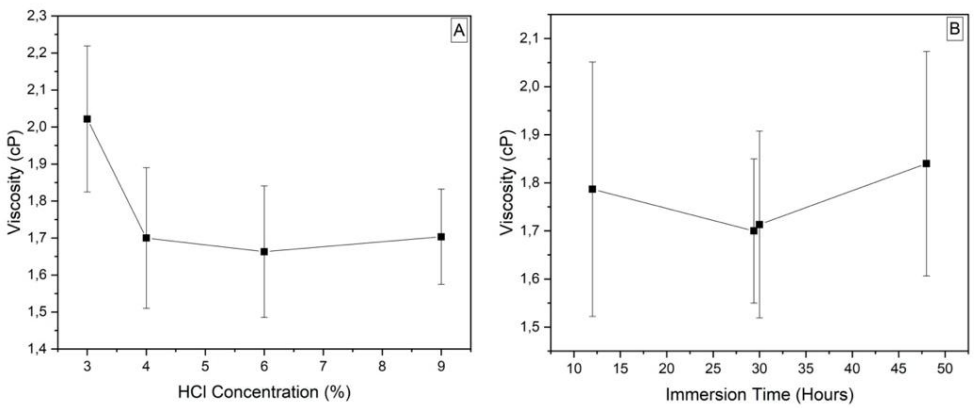


Figure 7. Effect of HCl concentration (A) and immersion time on the viscosity of gelatin (B).

At 9% HCl, viscosity decreased sharply, likely due to excessive hydrolysis, which produced low-Mw collagen fragments with reduced thickening capacity (Koli et al., 2012). High HCl concentrations may also have left excess H^+ in the gelatin, accelerating polymer breakdown. Under optimal extraction conditions (4% HCl, 29.4 hours), yield was maximized, but the gelatin exhibited a lower Mw, possibly due to the temperature applied during extraction (Arnesen & Gildberg, 2002). Previous studies have shown that higher extraction temperatures can reduce the Mw of gelatin (Muyonga et al., 2004). Despite these variations, the viscosity of gelatin under optimal conditions was 1.78 cP. Temperature control during extraction should be considered in future studies to maintain desirable viscosity while optimizing yield.

4. Conclusion

Response Surface Methodology (RSM) was successfully applied to optimize the extraction parameters for gelatin derived from parrotfish (*Scarus quoyi*) scales. The optimal conditions, 4% HCl concentration and 29.4 hours of immersion, produced gelatin with optimal physicochemical properties, including a yield of 14.5%, moisture content of 4%, ash content of 0.48%, pH of 4.15, and viscosity of 1.78 cP. FTIR analysis confirmed that the absorption peaks of parrotfish gelatin were comparable to those of commercial and theoretical gelatin, indicating structural similarity. These results suggest that gelatin from parrotfish scales is a viable alternative source of halal gelatin, meeting the quality requirements specified by the National Standardization Agency and Gelatin Manufacturers Institute of America. Future studies should focus on evaluating the gel strength, amino acid composition, and functional properties of parrotfish gelatin in various food, pharmaceutical, and industrial applications. Additionally, scaling up the extraction process and assessing its economic feasibility and environmental impact would provide valuable insights for potential commercial production.

CRediT Authorship Contribution Statement

Muammar Yulian: Writing – original draft, Formal analysis, review & editing. **Muhammad Reza:** Writing – original draft, Formal analysis, Methodology. **Nofa Ramadani:** Formal analysis, **Rosi Hamama:** Formal analysis, **Raudhatul Fadhilah:** Formal analysis, Methodology. **Yusrizal Akmal:** Writing – review & editing, **Kasim Sakran Abass:** Writing – review & editing. **Epa Paujiah:** Writing – review & editing. **Sukree Hajisamae:** Writing – review & editing, **Ilham Zulfahmi:** Writing – original draft, Writing – review & editing.

Acknowledgments

We sincerely express our gratitude to Universitas Islam Negeri Ar-Raniry and the Ministry of Religious Affairs of the Republic of Indonesia for providing financial support and access to laboratory facilities, which were essential to the successful completion of this research.

References

Abdullah, M. S. P., Noordin, M. I., Mohd Ismail, S. I., Mustapha, N. M., Jasamai, M., Danik, M. F., Wan Ismail, W. A., & Shamsuddin, A. F. (2018). Recent advances in the use of animal-sourced gelatine as a natural polymers for food, cosmetics and pharmaceutical applications. *Sains Malaysiana*, *47*(2), 323–336. https://doi.org/10.17576/jsm-2018-4702-15

Abedinia, A., Ariffin, F., Huda, N., & Nafchi, A. M. (2017). Extraction and characterization of gelatin from the feet of Pekin duck (Anas platyrhynchos domestica) as affected by acid, alkaline, and enzyme pretreatment. *International Journal of Biological Macromolecules*, *98*, 586–594. https://doi.org/10.1016/j.ijbiomac.2017.01.139

Ahmad, T., Ismail, A., Ahmad, S. A., Khalil, K. A., Kumar, Y., Adeyemi, K. D., & Sazili, A. Q. (2017). Recent advances on the role of process variables affecting gelatin yield and characteristics with special reference to enzymatic extraction: A review. *Food Hydrocolloids*, *63*, 85–96. https://doi.org/10.1016/j.foodhyd.2016.08.007

Ahmed, M. A., Al-Kahtani, H. A., Jaswir, I., AbuTarboush, H., & Ismail, E. A. (2020). Extraction and characterization of gelatin from camel skin (potential halal gelatin) and production of gelatin nanoparticles. *Saudi Journal of Biological Sciences*, *27*(6), 1596–1601. https://doi.org/10.1016/j.sjbs.2020.03.022

Al-Kahtani, H. A., Jaswir, I., Ismail, E. A., Ahmed, M. A., Monsur Hammed, A., Olorunnisola, S., & Octavianti, F. (2017). Structural characteristics of camel-bone gelatin by demineralization and extraction. *International Journal of Food Properties*, *20*(11), 2559–2568.

https://doi.org/10.1080/10942912.2016.1244543

Al-Nimry, S., Dayah, A. A., Hasan, I., & Daghmash, R. (2021). Cosmetic, biomedical and pharmaceutical applications of fish gelatin/hydrolysates. *Marine Drugs*, *19*(3), 145. https://doi.org/10.3390/md19030145

Alemán, A., Giménez, B., Montero, P., & Gómez-Guillén, M. C. (2011). Antioxidant activity of several marine skin gelatins. *LWT - Food Science and Technology*, *44*(2), 407–413. https://doi.org/10.1016/j.lwt.2010.09.003

Alipal, J., Mohd Pu'ad, N. A. S., Lee, T. C., Nayan, N. H. ., Sahari, N., Basri, H., Idris, M. I., & Abdullah, H. Z. (2021). A review of gelatin: Properties, sources, process, applications, and commercialisation. *Materials Today: Proceedings*, *42*, 240–250. https://doi.org/10.1016/j.matpr.2020.12.922

Almeida, P. F., & Lannes, S. C. da S. (2013). Extraction and physicochemical characterization of gelatin from chicken by-product. *Journal of Food Process Engineering*, *36*(6), 824–833. https://doi.org/10.1111/jfpe.12051

Alrosan, M., Almajwal, A. M., Al-Qaisi, A., Gammoh, S., Alu'datt, M. H., Al Qudsi, F. R., Tan, T.-C., Mahmood, A. A. R., & Maghaydah, S. (2024). Molecular forces driving protein complexation of lentil and whey proteins: Structure-function relationships of trehalose-conjugated protein complexes on protein digestibility and solubility. *Current Research in Structural Biology*, *7*, 100135. https://doi.org/10.1016/j.crstbi.2024.100135

Andakke, J. N., Rumengan, I. F. M., Nainggolan, H. H. Y., Parapat, L. R. M. E., Pandey, E., Suptijah, P., & Luntungan, A. H. (2020). Molecular structure of gelatin extracted from parrot (Scarus sp) fish scales. *Jurnal Pesisir Dan Laut Tropis*, *8*(1), 15. https://doi.org/10.35800/jplt.8.1.2020.27286

Arnesen, J. A., & Gildberg, A. (2002). Preparation and characterisation of gelatine from the skin of harp seal (Phoca groendlandica). *Bioresource Technology*, *82*(2), 191–194. https://doi.org/10.1016/S0960-8524(01)00164-X

Asih, I. D., Kemala, T., & Nurilmala, M. (2019). Halal gelatin extraction from patin fish bone (Pangasius hypophthalmus) by-product with ultrasound-assisted extraction. *IOP Conference Series: Earth and Environmental Science*, *299*(1), 012061. https://doi.org/10.1088/1755-1315/299/1/012061

Atma, Y. (2022). Synthesis and application of fish gelatin for hydrogels/ composite hydrogels: A review. *Biointerface Research in Applied Chemistry*, *12*(3), 3966–3976. https://doi.org/10.33263/BRIAC123.39663976

Bahar, A., Rusijono, R., & Kusumawati, N. (2018). Extraction and characterization of the base halal gelatin based on bovine bone. *Proceedings of the Seminar Nasional Kimia - National Seminar on Chemistry (SNK 2018)*. https://doi.org/10.2991/snk-18.2018.10

Calixto, S., Ganzherli, N., Gulyaev, S., & Figueroa-Gerstenmaier, S. (2018). Gelatin as a photosensitive material. *Molecules*, *23*(8), 2064. https://doi.org/10.3390/molecules23082064

Cao, T. H., Nguyen, T. T. O., Nguyen, T. M. H., Le, N. T., & Razumovskaya, R. G. (2017). Characteristics and physicochemical properties of gelatin extracted from scales of seabass (Lates calcarifer) and grey mullet (Mugil cephalus) in Vietnam. *Journal of Aquatic Food Product Technology*, *26*(10), 1293–1302. https://doi.org/10.1080/10498850.2017.1390026

Chakka, A. K., Muhammed, A., Sakhare, P. Z., & Bhaskar, N. (2017). Poultry processing waste as an alternative source for mammalian gelatin: Extraction and characterization of gelatin from chicken feet using food grade acids. *Waste and Biomass Valorization*, *8*(8), 2583–2593. https://doi.org/10.1007/s12649-016-9756-1

Chuaychan, S., Benjakul, S., & Sae-Leaw, T. (2017). Gelatin hydrolysate powder from the scales of spotted golden goatfish: Effect of drying conditions and juice fortification. *Drying Technology*, *35*(10), 1195–1203. https://doi.org/10.1080/07373937.2016.1236129

da Trindade Alfaro, A., Fonseca, G. G., Balbinot, E., de Souza, N. E., & Prentice, C. (2014). Yield, viscosity, and gel strength of wami tilapia (Oreochromis urolepis hornorum) skin gelatin: Optimization of the extraction process. *Food Science and Biotechnology*, *23*(3), 765–773. https://doi.org/10.1007/s10068-014-0103-7

Duan, R., Zhang, J., Xing, F., Konno, K., & Xu, B. (2011). Study on the properties of gelatins from skin of carp (Cyprinus carpio) caught in winter and summer season. *Food Hydrocolloids*, *25*(3), 368–373. https://doi.org/10.1016/j.foodhyd.2010.07.002

Duthen, S., Levasseur-Garcia, C., Kleiber, D., Violleau, F., Vaca-Garcia, C., Tsuchikawa, S., Delgado Raynaud, C., & Daydé, J. (2021). Using near-infrared spectroscopy to determine moisture content, gel strength, and viscosity of gelatin. *Food Hydrocolloids*, *115*, 106627.

https://doi.org/10.1016/j.foodhyd.2021.106627

El-Bassyouni, G. T., Guirguis, O. W., & Abdel-Fattah, W. I. (2013). Morphological and macrostructural studies of dog cranial bone demineralized with different acids. *Current Applied Physics*, *13*(5), 864–874. https://doi.org/10.1016/j.cap.2012.12.026

Esfahani, R., Jafari, S. M., Jafarpour, A., & Dehnad, D. (2019). Loading of fish oil into nanocarriers prepared through gelatin-gum Arabic complexation. *Food Hydrocolloids*, *90*, 291–298. https://doi.org/10.1016/j.foodhyd.2018.12.044

Figueiredo, M., Cunha, S., Martins, G., Freitas, J., Judas, F., & Figueiredo, H. (2011). Influence of hydrochloric acid concentration on the demineralization of cortical bone. *Chemical Engineering Research and Design*, *89*(1), 116–124. https://doi.org/10.1016/j.cherd.2010.04.013

Fonseca, J. de M., Valencia, G. A., Soares, L. S., Dotto, M. E. R., Campos, C. E. M., Moreira, R. de F. P. M., & Fritz, A. R. M. (2020). Hydroxypropyl methylcellulose-TiO2 and gelatin-TiO2 nanocomposite films: Physicochemical and structural properties. *International Journal of Biological Macromolecules*, *151*, 944–956. https://doi.org/10.1016/j.ijbiomac.2019.11.082

Gelatin Manufacturers Institute of America. (2019). *Standard testing methods for edible gelatin*. Gelatin Manufacturers Institute of America. http://www.gelatin-gmia.com/uploads/1/1/8/4/118450438/gmia_official_methods_2019.pdf

Gómez-Guillén, M. C., Giménez, B., López-Caballero, M. E., & Montero, M. P. (2011). Functional and bioactive properties of collagen and gelatin from alternative sources: A review. *Food Hydrocolloids*, *25*(8), 1813–1827. https://doi.org/10.1016/j.foodhyd.2011.02.007

Gumilar, J., Mahardika, D., & Suryaningsih, L. (2024). The effect of chloride acid submersion with various concentrations on viscosity, pH, and gel strength of rabbit skins gelatine. *International Journal of Multidisciplinary Education and Research*, *9*(3), 16–19. https://www.multieducationjournal.com/assets/archives/2024/vol9issue3/9043.pdf

Heng, T. T., Tey, J. Y., Soon, K. S., & Woo, K. K. (2022). Utilizing fish skin of belida fish (Notopterus lopis) as a source of collagen: Production and rheology properties. *Marine Drugs*, *20*(8), 525. https://doi.org/10.3390/md20080525

Herrera-Ruiz, A., Tovar, B. B., García, R. G., Tamez, M. F. L., & Mamidi, N. (2022). Nanomaterials-incorporated chemically modified gelatin methacryloyl-based biomedical composites: A novel approach for bone tissue engineering. *Pharmaceutics*, *14*(12), 2645. https://doi.org/10.3390/pharmaceutics14122645

Hodgson, A. (2024). Dry gelatin 'Photo-mechanical' plates – their significance in the evolution of scientific & technical photography. *The Imaging Science Journal*, *72*(1), 140–152. https://doi.org/10.1080/13682199.2023.2195701

Huang, T., Tu, Z., Wang, H., Shangguan, X., Zhang, L., Zhang, N., & Bansal, N. (2017). Pectin and enzyme complex modified fish scales gelatin: Rheological behavior, gel properties and nanostructure. *Carbohydrate Polymers*, *156*, 294–302. https://doi.org/10.1016/j.carbpol.2016.09.040

Ismail, N., & Abdullah, H. Z. (2016). Effects of hydrochloric acid concentration on the properties of black tilapia fish skin gelatin. *Materials Science Forum*, *840*, 165–169. https://doi.org/10.4028/www.scientific.net/MSF.840.165

Karim, A. A., & Bhat, R. (2009). Fish gelatin: properties, challenges, and prospects as an alternative to mammalian gelatins. *Food Hydrocolloids*, *23*(3), 563–576. https://doi.org/10.1016/j.foodhyd.2008.07.002

Koli, J. M., Basu, S., Nayak, B. B., Patange, S. B., Pagarkar, A. U., & Gudipati, V. (2012). Functional characteristics of gelatin extracted from skin and bone of tiger-toothed croaker (Otolithes ruber) and Pink perch (Nemipterus japonicus). *Food and Bioproducts Processing*, *90*(3), 555–562. https://doi.org/10.1016/j.fbp.2011.08.001

Kramer, R. M., Shende, V. R., Motl, N., Pace, C. N., & Scholtz, J. M. (2012). Toward a molecular understanding of protein solubility: Increased negative surface charge correlates with increased solubility. *Biophysical Journal*, *102*(8), 1907–1915. https://doi.org/10.1016/j.bpj.2012.01.060

Kumosa, L. S., Zetterberg, V., & Schouenborg, J. (2018). Gelatin promotes rapid restoration of the blood brain barrier after acute brain injury. *Acta Biomaterialia*, *65*, 137–149. https://doi.org/10.1016/j.actbio.2017.10.020

Lv, L.-C., Huang, Q.-Y., Ding, W., Xiao, X.-H., Zhang, H.-Y., & Xiong, L.-X. (2019). Fish gelatin: The novel potential applications. *Journal of Functional Foods*, *63*, 103581. https://doi.org/10.1016/j.jff.2019.103581

Machado, I., Marques, C. F., Martins, E., Alves, A. L., Reis, R. L., & Silva, T. H. (2023). Marine gelatin-methacryloyl-based hydrogels as cell templates for cartilage tissue engineering. *Polymers*, *15*(7), 1674. https://doi.org/10.3390/polym15071674

Mahmoodani, F., Ardekani, V. S., See, S. F., Yusop, S. M., & Babji, A. S. (2014). Optimization and physical properties of gelatin extracted from pangasius catfish (Pangasius sutchi) bone. *Journal of Food Science and Technology*, *51*(11), 3104–3113. https://doi.org/10.1007/s13197-012-0816-7

Mardiyah, U., Widjanarko, S. B., & Fibrianto, K. (2019). Optimization of time and temperature gelatin extraction from pink perch (Nemipterus bathybius) head using response surface methodology (RSM). *The Journal of Experimental Life Sciences*, *9*(2), 97–104. https://doi.org/10.21776/ub.jels.2019.009.02.06

Martins, M. E. O., Sousa, J. R., Claudino, R. L., Lino, S. C. O., Vale, D. A. do, Silva, A. L. C., Morais, J. P. S., De Souza Filho, M. de S. M., & De Souza, B. W. S. (2018). Thermal and chemical properties of gelatin from tilapia (Oreochromis niloticus) scale. *Journal of Aquatic Food Product Technology*, *27*(10), 1120–1133. https://doi.org/10.1080/10498850.2018.1535530

Mhd Sarbon, N., Badii, F., & Howell, N. K. (2013). Preparation and characterisation of chicken skin gelatin as an alternative to mammalian gelatin. *Food Hydrocolloids*, *30*(1), 143–151. https://doi.org/10.1016/j.foodhyd.2012.05.009

Mushtaq, F., Raza, Z. A., Batool, S. R., Zahid, M., Onder, O. C., Rafique, A., & Nazeer, M. A. (2022). Preparation, properties, and applications of gelatin-based hydrogels (GHs) in the environmental, technological, and biomedical sectors. *International Journal of Biological Macromolecules*, *218*, 601–633. https://doi.org/10.1016/j.ijbiomac.2022.07.168

Muyonga, J. H., Cole, C. G. B., & Duodu, K. G. (2004). Extraction and physico-chemical characterisation of Nile perch (Lates niloticus) skin and bone gelatin. *Food Hydrocolloids*, *18*(4), 581–592. https://doi.org/10.1016/j.foodhyd.2003.08.009

Nagai, T., Izumi, M., & Ishii, M. (2004). Fish scale collagen. Preparation and partial characterization. *International Journal of Food Science and Technology*, *39*(3), 239–244. https://doi.org/10.1111/j.1365-2621.2004.00777.x

Nasution, A. Y., Harmita, & Harahap, Y. (2018). Karakterisasi gelatin hasil ekstraksi dari kulit ikan patin (Pangasius hypophthalmus) dengan proses asam dan basa. *Pharmaceutical Sciences and Research*, *5*(3), 142–151. https://doi.org/10.7454/psr.v5i3.4029

National Standardization Agency. (1995). *SNI 06-3735-1995: Mutu dan cara uji gelatin*. National Standardization Agency. https://www.bsn.go.id

National Standardization Agency. (2018). *SNI 01-2891-2018: Food quality testing methods*. National Standardization Agency. https://www.bsn.go.id

Nurilmala, M., Suryamarevita, H., Husein Hizbullah, H., Jacoeb, A. M., & Ochiai, Y. (2022). Fish skin as a biomaterial for halal collagen and gelatin. *Saudi Journal of Biological Sciences*, *29*(2), 1100–1110. https://doi.org/10.1016/j.sjbs.2021.09.056

Phillips, G. O., & Williams, P. A. (2011). *Handbook of food proteins*. Woodhead Publishing Limited. https://doi.org/10.1533/9780857093639

Prihanto, A. A., Jaziri, A. A., Pratomo, M. D., Putri, S. E., Fajriati, C., Nurdiani, R., & Firdaus, M. (2022). Characteristics of collagen from parrotfish (Chlorurus sordidus), tiger grouper (Epinephelus fuscoguttatus) and pink ear emperor (Lethrinus lentjan): Effect of acetic acid concentration and extraction time. *Online Journal of Biological Sciences*, *22*(1), 26–35. https://doi.org/10.3844/ojbsci.2022.26.35

Putra, R. D., Siringoringo, R. M., Abrar, M., Abrar, M., Purnamasari, N. W., Purnamasari, N. W., & Syakti, A. D. (2020). The Pattern of herbivorous fish assemblages in the in western and eastern outermost island Indonesia. *Omni-Akuatika*, *16*(2), 116. https://doi.org/10.20884/1.oa.2020.16.2.805

Qing, Q., & Wyman, C. E. (2011). Hydrolysis of different chain length xylooliogmers by cellulase and hemicellulase. *Bioresource Technology*, *102*(2), 1359–1366. https://doi.org/10.1016/j.biortech.2010.09.001

Qiu, Y.-T., Wang, Y.-M., Yang, X.-R., Zhao, Y.-Q., Chi, C.-F., & Wang, B. (2019). Gelatin and antioxidant peptides from gelatin hydrolysate of skipjack tuna (Katsuwonus pelamis) scales: Preparation, identification and activity evaluation. *Marine Drugs*, *17*(10), 565. https://doi.org/10.3390/md17100565

Rachmad, B., Suharti, R., Irayana, D. A., & Zulkifli, D. (2018). Distribusi spasial ikan famili Scaridae

di perairan Taman Nasional Bunaken, Sulawesi Utara. *Jurnal Kelautan Dan Perikanan Terapan (JKPT)*, *1*(2), 69–76. https://doi.org/10.15578/jkpt.v1i2.7260

Rafieian, F., Keramat, J., & Shahedi, M. (2015). Physicochemical properties of gelatin extracted from chicken deboner residue. *LWT - Food Science and Technology*, *64*(2), 1370–1375. https://doi.org/10.1016/j.lwt.2015.04.050

Rahaningmas, J. M., & Mansyur, A. (2018). Influence of differences bait types on the catching result of kakatua fish (family Scaridae) using handlines. *Jurnal Sumberdaya Akuatik Indopasifik*, *2*(1), 25–34. https://doi.org/10.30862/jsai-fpik-unipa.2018.Vol.2.No.1.45

Rawdkuen, S., Thitipramote, N., & Benjakul, S. (2013). Preparation and functional characterisation of fish skin gelatin and comparison with commercial gelatin. *International Journal of Food Science & Technology*, *48*(5), 1093–1102. https://doi.org/10.1111/ijfs.12067

Said, M. I. (2020). Role and function of gelatin in the development of the food and non-food industry: A review. *IOP Conference Series: Earth and Environmental Science*, *492*(1), 012086. https://doi.org/10.1088/1755-1315/492/1/012086

Scott, G., & Awika, J. M. (2023). Effect of protein–starch interactions on starch retrogradation and implications for food product quality. *Comprehensive Reviews in Food Science and Food Safety*, *22*(3), 2081–2111. https://doi.org/10.1111/1541-4337.13141

Shiao, W.-C., Wu, T.-C., Kuo, C.-H., Tsai, Y.-H., Tsai, M.-L., Hong, Y.-H., & Huang, C.-Y. (2021). Physicochemical and antioxidant properties of gelatin and gelatin hydrolysates obtained from extrusion-pretreated fish (Oreochromis sp.) scales. *Marine Drugs*, *19*(5), 275. https://doi.org/10.3390/md19050275

Sockalingam, K., & Abdullah, H. Z. (2015). Extraction and characterization of gelatin biopolymer from black tilapia (Oreochromis mossambicus) scales. *AIP Conference Proceedings*, 020053. https://doi.org/10.1063/1.4919191

Sompie, M., Surtijono, S. E., Pontoh, J. H. W., & Lontaan, N. N. (2015). The Effects of acetic acid concentration and extraction temperature on physical and chemical properties of pigskin gelatin. *Procedia Food Science*, *3*, 383–388. https://doi.org/10.1016/j.profoo.2015.01.042

Sultana, S., Ali, M. E., & Ahamad, M. N. U. (2018). Gelatine, collagen, and single cell proteins as a natural and newly emerging food ingredients. In *Preparation and Processing of Religious and Cultural Foods* (pp. 215–239). Elsevier. https://doi.org/10.1016/B978-0-08-101892-7.00011-0

Sun, W., Lu, Q., Chen, J., Fan, X., Zhan, S., Yang, W., Huang, T., & Li, F. (2025). Influences of pH on gelling and digestion–fermentation properties of fish gelatin–polysaccharide hydrogels. *Foods*, *14*(15), 2631. https://doi.org/10.3390/foods14152631

Tkaczewska, J., Morawska, M., Kulawik, P., & Zając, M. (2018). Characterization of carp (Cyprinus carpio) skin gelatin extracted using different pretreatments method. *Food Hydrocolloids*, *81*, 169–179. https://doi.org/10.1016/j.foodhyd.2018.02.048

Tu, Z., Huang, T., Wang, H., Sha, X., Shi, Y., Huang, X., Man, Z., & Li, D. (2015). Physico-chemical properties of gelatin from bighead carp (Hypophthalmichthys nobilis) scales by ultrasound-assisted extraction. *Journal of Food Science and Technology*, *52*(4), 2166–2174. https://doi.org/10.1007/s13197-013-1239-9

Tümerkan, E. T. A. (2021). Sustainable utilization of gelatin from animal-based agri–food waste for the food industry and pharmacology. In *Valorization of Agri-Food Wastes and By-Products* (pp. 425–442). Elsevier. https://doi.org/10.1016/B978-0-12-824044-1.00041-6

Usman, M., Sahar, A., Inam-Ur-Raheem, M., ur Rahman, U., Sameen, A., & Aadil, R. M. (2022). Gelatin extraction from fish waste and potential applications in food sector. *International Journal of Food Science & Technology*, *57*(1), 154–163. https://doi.org/10.1111/ijfs.15286

Wang, L., An, X., Yang, F., Xin, Z., Zhao, L., & Hu, Q. (2008). Isolation and characterisation of collagens from the skin, scale and bone of deep-sea redfish (Sebastes mentella). *Food Chemistry*, *108*(2), 616–623. https://doi.org/10.1016/j.foodchem.2007.11.017

Wang, L., Li, P., Ren, Y., Bai, F., Wang, J., Zhang, Y., Jin, W., El-Seedi, H., & Gao, R. (2021). A novel extraction approach and unique physicochemical properties of gelatin from the swim bladder of sturgeon. *Journal of the Science of Food and Agriculture*, *101*(7), 2912–2919. https://doi.org/10.1002/jsfa.10923

Wang, Q., Jin, Y., & Xiong, Y. L. (2018). Heating-Aided pH shifting modifies hemp seed protein structure, cross-linking, and emulsifying properties. *Journal of Agricultural and Food Chemistry*, *66*(41), 10827–10834. https://doi.org/10.1021/acs.jafc.8b03901

Wang, Y., & Regenstein, J. M. (2009). Effect of EDTA, HCl, and citric acid on Ca salt removal from

Asian (silver) carp scales prior to gelatin extraction. *Journal of Food Science*, *74*(6), 1–6. https://doi.org/10.1111/j.1750-3841.2009.01202.x

Wangtueai, S., Siebenhandl-Ehn, S., & Haltrich, D. (2016). Optimization of the preparation of gelatin hydrolysates with antioxidative activity from lizardfish (Saurida spp.) scales gelatin. *Chiang Mai Journal of Science*, *43*(1), 68–79. https://epg.science.cmu.ac.th/ejournal/journal-detail.php?id=6372

Winarti, S., Sarofa, U., & Prihardi, M. Y. R. (2021). The effect of type and concentration of acid on the characteristics of gelatine from bones of milkfish (Chanos chanos). *Food Research*, *5*(4), 404–409. https://doi.org/10.26656/fr.2017.5(4).690

Zhang, F., Xu, S., & Wang, Z. (2011). Pretreatment optimization and properties of gelatin from freshwater fish scales. *Food and Bioproducts Processing*, *89*(3), 185–193. https://doi.org/10.1016/j.fbp.2010.05.003

Zhang, Q., Wang, Q., Lv, S., Lu, J., Jiang, S., Regenstein, J. M., & Lin, L. (2016). Comparison of collagen and gelatin extracted from the skins of Nile tilapia (Oreochromis niloticus) and channel catfish (Ictalurus punctatus). *Food Bioscience*, *13*, 41–48. https://doi.org/10.1016/j.fbio.2015.12.005

Zhou, P., & Regenstein, J. M. (2004). Optimization of extraction conditions for pollock skin gelatin. *Journal of Food Science*, *69*(5), 1–6. https://doi.org/10.1111/j.1365-2621.2004.tb10704.x

Zulfahmi, I., Apriansyah, M., Batubara, A. S., Kautsari, N., Sumon, K. A., Rahman, M. M., & Nur, F. M. (2022). Commercial marine fish species from Weh Island, Indonesia: Checklist, distribution pattern and conservation status. *Biodiversitas Journal of Biological Diversity*, *23*(4), 1977–1989. https://doi.org/10.13057/biodiv/d230432

Declaration of Competing Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.