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# Exploring Marine Fish Skin, Bones, and Scales as Sources of Halal Gelatin

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***Abstract***

*Gelatin is widely utilized in food, pharmaceutical, cosmetic, and other industries because of its distinctive gelling and functional properties. However, conventional gelatin is predominantly derived from mammalian sources, raising halal, safety, and traceability concerns. This review evaluates marine fish skin, bones, and scales as alternative sources of halal gelatin and compares their extraction yield, gel strength, and viscosity. A qualitative descriptive literature review was conducted using studies retrieved from major academic databases and relevant scientific publications. The findings demonstrate that marine fish by-products contain substantial collagen resources, although their extraction performance varies according to species, anatomical source, pretreatment, and processing conditions. Fish skin generally provides higher gelatin yields because its collagen matrix is less mineralized and more accessible to hydrolysis. Fish bones and scales require additional demineralization because collagen is strongly associated with inorganic minerals. Nevertheless, gelatin derived from all three sources can exhibit satisfactory gel strength and viscosity compatible with relevant SNI and GMIA requirements. Overall, marine fish by-products represent promising halal, sustainable, and value-added raw materials for gelatin production and fishery-waste valorization across diverse future industrial applications worldwide.*

***Keywords:*** *fish bones, fish scales, fish skin, halal gelatin, fishery waste.*



## INTRODUCTION

Gelatin is a multifunctional protein-based biopolymer produced through the partial hydrolysis and thermal denaturation of collagen derived from animal tissues, particularly skin, bones, and connective tissues. Its physicochemical properties are strongly influenced by the biological origin of the collagen, chemical composition of the raw material, and extraction conditions used during processing (Siburian et al., 2020). Owing to its reversible sol–gel transition, water-binding capacity, film-forming ability, and viscosity-modifying properties, gelatin has become an important functional ingredient in numerous industrial applications (Mukhaimin et al., 2022). It is extensively utilized as a gelling agent, stabilizer, emulsifier, thickener, water-binding agent, and encapsulating material in the food, pharmaceutical, cosmetic, and photographic industries (Rakhmanova et al., 2018; Febriana et al., 2021).

The expanding applications of gelatin have been accompanied by increasing global concern regarding the origin, safety, and religious acceptability of conventional gelatin sources. Commercial gelatin production has historically relied predominantly on mammalian tissues, particularly porcine skin and bovine bones and hides, which can create substantial challenges for Muslim consumers and halal-oriented industries (Nurilmala et al., 2022). Porcine-derived gelatin is prohibited under Islamic dietary principles, whereas bovine-derived gelatin is considered permissible only when the animal and slaughtering process comply with Islamic requirements (Ahmad Anuar et al., 2023). Concerns regarding bovine-derived materials have also been reinforced by animal-health issues, including the potential risks historically associated with bovine spongiform encephalopathy, thereby encouraging the identification of safer and religiously acceptable alternative gelatin sources (Elyasi et al., 2020; Zin et al., 2021).

Marine resources provide a promising alternative because fish and their derivatives are generally acceptable for halal applications while also offering abundant collagen-containing materials.

Fish-processing activities generate substantial quantities of by-products, including skin, bones, scales, heads, and other tissues that are frequently discarded or used only for low-value purposes (Nurilmala et al., 2022). Inadequate utilization of these materials may contribute to environmental pollution, unpleasant odors, and increased organic waste originating from fish-processing industries. Converting collagen-rich fishery residues into gelatin therefore represents an integrated strategy for improving resource efficiency, increasing the economic value of processing by-products, and reducing the environmental burden associated with fish waste (Junianto & Maulina, 2024; Reza & Annissa, 2023).

Among fish-processing by-products, skin has attracted considerable attention because of its relatively high collagen content and comparatively simple structural characteristics. Fish skin contains a collagen-rich dermal connective-tissue matrix that can be converted into gelatin through acid- or alkali-assisted pretreatment followed by thermal extraction (Ranasinghe et al., 2022). Previous studies have demonstrated that gelatin can be successfully extracted from the skins of tuna, Spanish mackerel, starry triggerfish, red snapper, shark, parrotfish, and several other marine species, although the resulting yield and functional characteristics vary substantially among species and processing conditions (Nugraheni et al., 2021; Marhayuni & Syakina, 2023). The relatively accessible collagen structure of fish skin facilitates chemical penetration during pretreatment and can promote efficient conversion of triple-helical collagen into soluble gelatin (Kusumaningrum et al., 2018; Nurilmala et al., 2022).

Fish bones constitute another important collagen-containing by-product with considerable potential for halal gelatin production, although their structural complexity differs markedly from that of fish skin. Bone collagen is closely associated with inorganic minerals such as calcium phosphate and calcium carbonate, necessitating a demineralization step before effective gelatin extraction can be achieved (Rachmania et al., 2013; Al-Faroji et al., 2023). Acid pretreatment using hydrochloric acid, acetic acid, citric acid, or other organic acids can facilitate mineral removal, promote ossein formation, and weaken intermolecular bonds within the collagen structure (Rodiah et al., 2018; Kholis et al., 2023). Studies involving tuna, Spanish mackerel, gulamah fish, barramundi, and little tuna bones indicate that appropriate pretreatment and extraction conditions can produce gelatin with potentially acceptable yields and physicochemical properties (Fernianti et al., 2020; Sindi et al., 2025).

Fish scales are also increasingly recognized as a viable collagen source despite their dense mineralized structure and generally lower extraction yield compared with fish skin. Their matrix contains collagen together with calcium-rich compounds and hydroxyapatite, making controlled demineralization, swelling, washing, and neutralization critical stages in gelatin production (Rohani et al., 2026). Previous investigations on parrotfish, red snapper, tuna, and yellowstripe goatfish scales have demonstrated that acid- or alkali-assisted extraction can generate gelatin with measurable gel strength and viscosity characteristics (Fadilla et al., 2019; Safi'i et al., 2021). These findings suggest that fish scales should not merely be considered processing residues but may constitute an underutilized raw material for the development of value-added halal biomaterials.

The industrial applicability of fish-derived gelatin is primarily determined by its extraction yield and functional properties, particularly gel strength and viscosity. Variations in these characteristics are influenced by fish species, anatomical source, collagen composition, pretreatment conditions, acid or alkali concentration, extraction temperature, and extraction duration (Sinthusamran et al., 2014; Sousa et al., 2017). Several marine fish gelatins have demonstrated gel strength and viscosity values within or approaching the ranges specified by the Indonesian National Standard and the Gelatin Manufacturers Institute of America, indicating their potential suitability for food and pharmaceutical applications (Badan Standardisasi Nasional, 1995; Balqis et al., 2025). Nevertheless, excessive hydrolysis, inappropriate chemical concentration, or overly severe thermal conditions may shorten gelatin polypeptide chains and consequently reduce extraction efficiency or alter the desired physicochemical performance (Bhernama, 2020; Sindi et al., 2025).

Despite the growing number of studies on fish gelatin, existing investigations frequently focus on a single species, anatomical part, or extraction treatment, making broader comparisons among marine fish skin, bones, and scales difficult. A comprehensive evaluation of these three major fish-processing by-products is therefore necessary to determine their relative potential in terms of extraction yield, gel strength, viscosity, processing requirements, and compliance with relevant quality standards. Such comparative evidence is particularly important for identifying raw materials that can simultaneously support halal assurance, industrial functionality, and sustainable utilization of marine-processing waste (Ahmed et al., 2020; Reza & Annissa, 2023). Accordingly, this review aims to explore and compare marine fish skin, bones, and scales as alternative sources of halal gelatin by examining their extraction performance and major physicochemical characteristics while highlighting their potential contribution to sustainable fishery-waste valorization.

The rapid growth of Islamic finance over the last two decades has transformed the global financial landscape, positioning Sharia-compliant banking as an increasingly significant alternative to conventional financial systems, particularly in Muslim-majority countries where ethical finance, risk-sharing principles, and compliance with Islamic jurisprudence have become central considerations in financial decision-making. Among the various financing instruments developed by Islamic banks, the murabahah contract remains the most widely utilized mechanism due to its operational simplicity, legal certainty, and compatibility with consumer financing needs, especially in home purchase financing schemes. The increasing demand for housing ownership, coupled with the expansion of Islamic banking services, has strengthened the strategic role of murabahah based Home Purchase Financing Pembiayaan Pemilikan Rumah (PPR) as a major financing product within the Islamic banking industry. This phenomenon reflects not only market preferences but also the institutional development of Islamic banking regulations and contract designs that seek to harmonize commercial objectives with Sharia principles (Akhmad, 2016; Anggraini, 2022).

Previous studies have consistently demonstrated that murabahah financing occupies a dominant position in Islamic banking portfolios because it provides predictable returns while maintaining compliance with Islamic legal requirements. Research conducted by Andriani (2019) found that murabahah remains the preferred financing structure in Islamic home ownership programs due to its clear contractual framework and ease of implementation compared with more complex partnership-based contracts. Similar findings have been reported in studies examining housing financing products in Islamic banks, which indicate that customers generally perceive murabahah as more transparent and understandable than alternative financing mechanisms (Ismail, n.d.). At the same time, legal analyses have emphasized that the legitimacy of murabahah financing depends heavily on the proper implementation of ownership transfer, disclosure of profit margins, and compliance with Sharia contractual requirements (Basri, Dewi, & Iswahyudi, 2022). A critical synthesis of these studies suggests that the success of murabahah financing cannot be explained solely by its contractual structure, but must also be understood through the interaction between regulatory compliance, institutional practices, and customer perceptions of Sharia legitimacy.

Despite the substantial body of literature concerning murabahah financing, significant conceptual and empirical limitations remain evident. A considerable proportion of existing studies focus primarily on legal compliance, profitability, or operational procedures, while comparatively limited attention has been devoted to examining how murabahah contracts are implemented in contemporary Islamic banking institutions following major structural transformations within the Indonesian Islamic banking sector. Furthermore, previous research frequently treats contract implementation as a formal administrative process, often overlooking the practical dynamics through which contractual provisions are translated into financing practices at the institutional level. Studies investigating housing financing products have also produced varying conclusions regarding the consistency between theoretical murabahah principles and actual banking practices, particularly when hybrid arrangements such as murabahah bil wakalah are employed (Hubbi & Hrp, 2023). These inconsistencies indicate the existence of an unresolved gap between normative contractual doctrines and their practical application in Islamic financial institutions.

The persistence of this gap carries important implications for both Islamic banking development and public trust in Sharia-compliant financial services. Housing financing represents one of the largest and most socially significant financing sectors because access to adequate housing remains a fundamental economic need. Questions concerning the authenticity of Sharia implementation become increasingly relevant when customers rely on Islamic banks not merely for financial transactions but also for compliance with religious principles. Existing studies have demonstrated that contract design, margin determination, and financing structures significantly influence customer perceptions and institutional performance (Dewi & Setyowati, 2017; Iriani, 2018). Concerns regarding the practical implementation of murabahah contracts therefore extend beyond technical banking procedures and directly affect the credibility, competitiveness, and sustainability of Islamic banking institutions within an increasingly sophisticated financial environment.

Within this context, Bank Syariah Indonesia (BSI) presents a particularly important case for investigation because it represents the largest Islamic banking institution in Indonesia and serves as a key actor in advancing Sharia financial inclusion following the consolidation of major state-owned Islamic banks. The implementation of murabahah contracts in BSI's Home Purchase Financing program provides a valuable empirical setting for examining how classical Sharia contract principles are operationalized within a modern banking institution facing both commercial demands and regulatory obligations. While previous studies have explored Islamic home financing in institutions such as Bank Muamalat Indonesia and Bank BTN Syariah (Andriani, 2019; Khamzah & Rachmat, 2023), relatively limited research has specifically examined the implementation dynamics of murabahah contracts within BSI as an institution that plays a dominant role in Indonesia's contemporary Islamic banking sector. This position creates an opportunity to generate a more nuanced understanding of the relationship between contractual doctrine, institutional practice, and Sharia compliance in Islamic housing finance.

This study aims to analyze the implementation of the murabahah contract in Sharia Home Purchase Financing (PPR) at Bank Syariah Indonesia. The research seeks to examine the extent to which contractual principles are translated into financing practices and to identify factors influencing the implementation process within a contemporary Islamic banking context. Theoretically, the study contributes to the development of Islamic banking literature by bridging the gap between normative contract theory and institutional implementation practices. Methodologically, it contributes by employing a case-study perspective that enables a deeper examination of contractual application within a leading Islamic banking institution, thereby providing a more comprehensive understanding of Sharia-compliant housing finance in Indonesia.

## RESEARCH METHODS

This study employed a qualitative descriptive approach using a literature review design to systematically examine the potential utilization of marine fish skin, bones, and scales as alternative sources of halal gelatin. Secondary data were collected from scientific publications retrieved through major academic databases, including Google Scholar, ScienceDirect, ResearchGate, and PubMed, in accordance with the literature-based research framework adopted in the original manuscript. The literature selection focused on studies reporting the extraction and characterization of gelatin derived from marine fish-processing by-products, particularly skin, bones, and scales. Eligible publications were assessed based on their relevance to gelatin yield, extraction procedures, physicochemical characteristics, and the potential application of fish-derived gelatin as a halal alternative to mammalian gelatin.

The analytical process was conducted by extracting and comparatively evaluating quantitative and qualitative information reported in the selected studies. Particular attention was given to three major indicators, namely gelatin yield, gel strength expressed in Bloom values, and viscosity, because these parameters represent important determinants of gelatin quality and functional performance. Data obtained from different marine fish species, anatomical sources, and hydrolysis or extraction treatments were organized and synthesized descriptively to identify variations, similarities, and potential advantages among fish skin-, bone-, and scale-derived gelatin. The reported physicochemical characteristics were subsequently interpreted in relation to relevant gelatin quality requirements, including the Indonesian National Standard (SNI) and the specifications commonly referenced from the Gelatin Manufacturers Institute of America (GMIA), in order to evaluate the feasibility of marine fish by-products as sustainable and halal gelatin sources.

## RESULTS AND DISCUSSION

### Marine Fish Skin as a Source of Halal Gelatin

Marine fish skin represents one of the most promising raw materials for the production of fish-derived gelatin because it contains a substantial collagen-rich connective tissue matrix. In fish-processing industries, skin is generated in considerable quantities during filleting and surimi production and is frequently treated as a low-value by-product despite its potential for higher-value applications (Junianto & Saputra, 2024). Anatomically, the dermal layer of fish skin is dominated by collagen fibers that can undergo thermal denaturation and hydrolysis to form gelatin with functional characteristics suitable for industrial applications (Nurilmala et al., 2022). Consequently, the valorization of marine fish skin provides an opportunity to simultaneously develop halal gelatin and reduce the environmental burden associated with fishery-processing waste (Ahmed et al., 2020; Reza & Annissa, 2023).

The suitability of fish skin for gelatin extraction is closely associated with the structural organization and chemical composition of its collagen. Collagen in fish skin is predominantly organized in a triple-helical configuration stabilized by hydrogen bonds and other intermolecular interactions, which can be disrupted through controlled chemical pretreatment and thermal extraction (Siburian et al., 2020). Compared with highly mineralized tissues such as bones and scales, skin generally requires less intensive demineralization because its collagen is embedded in a softer connective-tissue matrix (Ranasinghe et al., 2022). This structural advantage facilitates the penetration of acids or alkalis into the tissue and improves the conversion of native collagen into soluble gelatin during extraction (Sousa et al., 2017).

Pretreatment conditions represent a critical determinant of gelatin recovery and functional quality because they influence collagen swelling, intermolecular bond disruption, and subsequent solubilization. Acid pretreatment is particularly common for fish skin because the relatively less cross-linked collagen matrix can be efficiently hydrolyzed within shorter processing periods than those generally required for strongly cross-linked mammalian tissues (Kusumaningrum et al., 2018). Nugraheni et al. (2021) demonstrated that phosphoric, acetic, and citric acids produced different yields, gel strengths, and viscosities from starry triggerfish skin, indicating that the chemical characteristics of the hydrolyzing agent significantly influence gelatin properties. Extraction conditions must therefore be carefully optimized because excessively severe chemical treatment may promote excessive degradation of collagen chains and adversely affect the molecular characteristics of the resulting gelatin (Balqis et al., 2025).

Species-related variation is another major factor explaining the differences observed in gelatin obtained from marine fish skin. Differences in habitat, fish size, age, amino-acid composition, collagen cross-linking, and tissue thickness can produce substantial variation in extraction yield and physicochemical performance (Sinthusamran et al., 2014). Studies involving tuna, Spanish mackerel, starry triggerfish, red snapper, sharks, parrotfish, and croaker have reported a broad range of gelatin yields, demonstrating that no single extraction condition is universally optimal for all marine species (Marhayuni & Syakina, 2023). This variability emphasizes the need to assess the interaction between biological source and processing conditions rather than considering fish skin as a chemically uniform raw material.

The quantitative evidence compiled from previous studies further demonstrates the heterogeneous but generally favorable performance of marine fish skin as a gelatin source. Reported yields extend from approximately 5.51% in red snapper skin to more than 24% in parrotfish skin, while several species exhibit gel strengths exceeding 200 g Bloom. Considerable variation is also observed in viscosity, suggesting that molecular-weight distribution and collagen degradation differ substantially among species and hydrolysis treatments (Nugraheni et al., 2021; Kusumaningrum et al., 2018). A comparative summary of representative marine fish skin gelatin studies is presented in Table 1.

**Table 1. Comparative Yield and Physicochemical Characteristics of Gelatin Derived from Marine Fish Skin**

| Marine fish species | Hydrolysis/extraction treatment | Yield (%) | Gel strength (g Bloom) | Viscosity (cP) | Reference |
|---|---|---|---|---|---|
| Starry triggerfish (*Abalistes stellaris*) | Phosphoric acid | 11.10 | 219.02 | 2.20 | Nugraheni et al. (2021) |
| Starry triggerfish (*Abalistes stellaris*) | Acetic acid | 7.93 | 294.47 | 3.61 | Nugraheni et al. (2021) |
| Starry triggerfish | Citric acid | 8.69 | 281.40 | 3.21 | Nugraheni et al. |

| | | | | | |
|---|---|---|---|---|---|
| (*Abalistes stellaris*) | | | | | (2021) |
| Tuna (*Thunnus* sp.) | Controlled acid treatment | 11.81–16.95 | 59.43–219.51 | 4.30–7.10 | Marhayuni & Syakina (2023) |
| Spanish mackerel (*Scomberomorus commerson*) | HCl hydrolysis | 13.03 | 292.00 | 8.07 | Kusumaningrum et al. (2018) |
| Spanish mackerel (*Scomberomorus commerson*) | Acetic acid | 6.61 | – | 5.51 | Junianto & Saputra (2024) |
| Brownbanded bamboo shark (*Chiloscyllium punctatum*) | Acetic acid | 20.38 | – | 4.35 | Suptijah et al. (2013) |
| Parrotfish (*Scarus ghobban*) | Acid–alkali hydrolysis | 20.00–24.65 | 118.40 | 16.00–22.00 | Nurilmala et al. (2022) |
| Croaker | Acid hydrolysis | 6.00–19.00 | 193.40 | 5.56 | Sousa et al. (2017) |

The yield data presented in Table 1 indicate that marine fish skin can provide economically meaningful gelatin recovery, although the magnitude varies considerably according to species and extraction procedure. Parrotfish and shark skin show relatively high reported yields, whereas some other species produce more moderate recovery rates, confirming the importance of raw-material structure and pretreatment efficiency. Higher gelatin yield generally reflects greater conversion of collagen into soluble protein; however, yield alone cannot be regarded as an indicator of superior gelatin quality because excessive hydrolysis may increase protein solubilization while simultaneously reducing molecular-chain integrity (Siburian et al., 2020; Balqis et al., 2025). Evaluation of industrial feasibility should therefore integrate yield with gel strength, viscosity, purity, and other physicochemical characteristics rather than relying on extraction recovery as an isolated parameter.

Gel strength is particularly important because it reflects the capacity of gelatin molecules to reorganize into a three-dimensional network during cooling. The compiled studies show that starry triggerfish gelatin obtained through acetic-acid pretreatment reached 294.47 g Bloom, while Spanish mackerel gelatin was reported at approximately 292 g Bloom, demonstrating the ability of certain marine fish skins to form strong gels (Nugraheni et al., 2021; Kusumaningrum et al., 2018). Tuna skin gelatin also exhibited substantial variation in gel strength, from approximately 59.43 to 219.51 g Bloom, reinforcing the influence of processing conditions and molecular-weight distribution on gel formation (Marhayuni & Syakina, 2023). These values demonstrate that selected fish-skin gelatins can achieve characteristics compatible with applications requiring relatively strong and elastic gel networks, including confectionery and selected pharmaceutical formulations (Badan Standardisasi Nasional, 1995; Rakhmanova et al., 2018).

Viscosity provides additional information concerning the hydrodynamic behavior and molecular integrity of gelatin in solution. Most of the marine fish skin samples summarized in Table 1 exhibit moderate viscosity values, although relatively high values have been reported for parrotfish and certain Spanish mackerel preparations. Variations in viscosity may arise from differences in molecular-chain length, protein concentration, extraction temperature, acid concentration, and the extent of collagen degradation during processing (Sinthusamran et al., 2014; Ranasinghe et al., 2022). Appropriate control of these processing variables is therefore required to obtain fish gelatin with consistent rheological properties suitable for specific food, pharmaceutical, or biomaterial applications.

The functionality of marine fish skin gelatin also has direct implications for the development of halal-oriented products. Fish-derived gelatin offers an important alternative to porcine gelatin and reduces several religious concerns associated with the traceability and slaughtering requirements of bovine raw materials (Rakhmanova et al., 2018; Zin et al., 2021). Its potential application is especially relevant to food formulations, capsule production, coatings, edible films, and other products in which gelatin performs critical structural or stabilizing functions (Nurilmala et al., 2022). Nevertheless, halal suitability at the raw-material level should be complemented by appropriate control of processing aids, handling systems, storage, and possible cross-contamination throughout the production chain.

Overall, the available evidence indicates that marine fish skin represents a technically promising and strategically important source of halal gelatin. Its relatively collagen-rich and less mineralized structure contributes to easier hydrolysis and, in many cases, higher gelatin recovery than that typically obtained from harder fish tissues such as bones and scales (Marhayuni & Syakina, 2023; Junianto & Saputra, 2024). The substantial differences in yield, gel strength, and viscosity among species nevertheless demonstrate that optimization must be conducted individually according to raw-material characteristics and intended application. These findings establish marine fish skin as a strong candidate for sustainable gelatin production while simultaneously highlighting the necessity of standardized extraction protocols and comprehensive physicochemical characterization before large-scale industrial utilization.

**Marine Fish Bones as a Source of Halal Gelatin**

Marine fish bones constitute an important collagen-containing by-product that can be utilized as an alternative raw material for halal gelatin production. Fish-processing industries generate substantial quantities of skeletal residues during filleting, deboning, and other processing activities, and these materials are frequently underutilized or discarded despite their protein value (Febriana et al., 2021). Structurally, fish bones contain both organic and inorganic fractions, with collagen serving as the principal structural protein embedded within a mineralized matrix. Previous studies have therefore identified fish bones as promising sources of gelatin for food and pharmaceutical applications, particularly when appropriate pretreatment and extraction procedures are applied (Kholis et al., 2023; Sindi et al., 2025).

The collagen content of fish bones varies considerably according to skeletal type and species. Hard-boned teleost fish generally contain approximately 15–17% collagen by weight, whereas cartilaginous fish may contain higher collagen proportions of approximately 22–24% (Rachmania et al., 2013; Sindi et al., 2025). This difference is important because the proportion of collagen available in the raw material directly influences the potential quantity of gelatin recovered during extraction. Nevertheless, collagen abundance alone does not determine extraction efficiency because the structural association between collagen fibers and inorganic minerals strongly affects the accessibility of the protein matrix.

A major technological challenge in fish-bone gelatin production is the presence of mineral components, particularly calcium phosphate and calcium carbonate. These inorganic compounds form a rigid structural framework surrounding collagen fibers, making direct thermal extraction less effective than extraction from softer tissues such as fish skin. A demineralization step is therefore required to remove mineral constituents and convert the rigid bone matrix into a softer collagen-rich material commonly referred to as ossein (Rodiah et al., 2018; Al-Faroji et al., 2023). Effective demineralization increases collagen accessibility and facilitates the subsequent disruption of intermolecular bonds during gelatin extraction.

Various acidic and alkaline agents have been investigated for fish-bone pretreatment, including hydrochloric acid, acetic acid, citric acid, sodium hydroxide, and naturally derived acidic solutions. Hydrochloric acid is particularly effective in dissolving mineral salts, whereas organic acids such as acetic and citric acids can provide milder hydrolysis conditions that may better preserve collagen chains under appropriate concentrations (Fernianti et al., 2020; Bhernama, 2020). Rachmania et al. (2013) also demonstrated that alkaline hydrolysis can be used for gelatin extraction from Spanish mackerel bones, indicating that both acid- and base-assisted treatments may be technically applicable. The selection of pretreatment chemicals should therefore consider demineralization efficiency, gelatin yield, molecular integrity, environmental impact, and intended product characteristics.

Extraction performance reported for marine fish bones varies substantially across species and processing conditions. Tuna bones, for example, have shown yields ranging from relatively low values under controlled acid extraction to considerably higher yields when stronger hydrochloric-acid pretreatment is employed (Kholis et al., 2023; Marhayuni & Syakina, 2023). Similar variations have been reported for Spanish mackerel, gulamah fish, barramundi, and little tuna bones, illustrating the combined influence of raw-material composition and processing intensity. Table 2 summarizes representative data concerning extraction treatments, yield, gel strength, and viscosity of gelatin produced from selected marine fish bones.

**Table 2. Comparative Yield and Physicochemical Characteristics of Gelatin Derived from Marine Fish Bones**

| Marine fish species | Hydrolysis/extraction treatment | Yield (%) | Gel strength (g Bloom) | Viscosity (cP) | Reference |
|---|---|---|---|---|---|
| Tuna (*Thunnus* sp.) | HCl 4% | 22.00–24.13 | – | – | Kholis et al. (2023) |
| Tuna (*Thunnus* sp.) | Controlled acid treatment | 2.61–8.05 | 151.80–167.85 | 5.57 | Marhayuni & Syakina (2023) |
| Spanish mackerel (*Scomberomorus commerson*) | Citric acid 20% | 3.79–6.00 | 61.05 | 29.83 | Fernianti et al. (2020) |
| Spanish mackerel (*Scomberomorus commerson*) | Lime juice | 2.46 | – | – | Rodiah et al. (2018) |
| Spanish mackerel (*Scomberomorus commerson*) | NaOH 5% | 7.93 | – | – | Rachmania et al. (2013) |
| Gulamah fish (*Johnius trachycephalus*) | Acetic acid 5% | 7.32 | – | – | Sindi et al. (2025) |
| Barramundi (*Lates calcarifer*) | HCl 7% | 1.90 | – | 2.36 | Bhernama (2020) |
| Little tuna (*Euthynnus affinis*) | Acetic acid | 67.54* | 67.54* | 3.44 | Al-Faroji et al. (2023) |

The data presented in Table 2 demonstrate that extraction yield is highly sensitive to both species and hydrolysis conditions. Tuna bones pretreated with 4% hydrochloric acid yielded approximately 22.00–24.13%, whereas controlled acid treatments produced substantially lower values of approximately 2.61–8.05% (Kholis et al., 2023; Marhayuni & Syakina, 2023). This contrast indicates that more intensive demineralization can substantially increase collagen solubilization when it effectively disrupts the mineral matrix without excessively degrading the protein. However, higher yield should still be interpreted cautiously because severe hydrolysis may increase soluble protein recovery while reducing the molecular length necessary for desirable gel-forming characteristics.

Gel strength provides a more functional assessment of whether bone-derived gelatin can form stable three-dimensional networks after cooling. Tuna bone gelatin has been reported to exhibit gel strengths of approximately 151.80–167.85 g Bloom, while Spanish mackerel bone gelatin extracted using citric acid produced a lower value of approximately 61.05 g Bloom (Marhayuni & Syakina, 2023; Fernianti et al., 2020). These differences may reflect variations in collagen molecular weight, amino-acid composition, thermal history, and the extent of hydrolysis occurring during pretreatment and extraction. From an application perspective, bone-derived gelatin with moderate gel strength may remain suitable for confectionery, encapsulation, stabilizing, or textural functions depending on the specific product requirements (Febriana et al., 2021; Mukhaimin et al., 2022).

Viscosity is another important quality parameter because it is related to molecular size distribution and the interaction of gelatin chains in solution. Several bone-derived gelatins, including those from tuna, barramundi, and little tuna, exhibit viscosity values within or close to commonly referenced food-grade ranges, indicating potentially acceptable rheological performance (Bhernama, 2020; Al-Faroji et al., 2023). In contrast, Spanish mackerel bone gelatin extracted with citric acid has been reported to exhibit a much higher viscosity of approximately 29.83 cP, illustrating the wide variation that can result from species-specific collagen structures and extraction conditions (Fernianti et al., 2020). Such findings demonstrate that standardization of pretreatment concentration, extraction temperature, time, and solid-to-liquid ratio is necessary to achieve reproducible gelatin functionality.

The demineralization stage is especially critical because inappropriate acid concentration or prolonged exposure can cause excessive collagen hydrolysis. Although acid treatment is required to dissolve mineral salts and facilitate ossein formation, overly aggressive conditions may break peptide chains into shorter fragments that are lost during washing or produce gelatin with reduced network-forming capacity (Bhernama, 2020; Balqis et al., 2025). Conversely, insufficient acid concentration or inadequate soaking time may leave residual minerals within the bone matrix and restrict collagen extraction. Optimization must therefore balance mineral removal with preservation of collagen molecular integrity to maximize both gelatin recovery and physicochemical performance (Kholis et al., 2023; Sindi et al., 2025).

From a halal and sustainability perspective, marine fish bones provide considerable advantages because they can reduce dependence on mammalian gelatin while creating value from processing residues. Fish-bone gelatin may be particularly relevant for pharmaceutical capsules and food products where gelatin serves as a structural, encapsulating, or textural component (Febriana et al., 2021). The conversion of skeletal waste into functional gelatin also supports circular-resource utilization by transforming a mineral- and collagen-rich by-product into a higher-value biomaterial rather than disposing of it as waste (Ahmed et al., 2020). The development of such applications nevertheless requires control over raw-material traceability, processing chemicals, cross-contamination, and final physicochemical quality to ensure both halal integrity and industrial acceptability.

Marine fish bones represent a technically viable source of halal gelatin, although their extraction is more complex than that of fish skin because of the strongly mineralized collagen matrix. The available evidence demonstrates that appropriate acid or alkaline pretreatment can substantially improve collagen accessibility, gelatin yield, and functional characteristics, but the optimal conditions differ markedly among fish species (Rachmania et al., 2013; Kholis et al., 2023). Variability in yield, gel strength, and viscosity highlights the need for species-specific process optimization and standardized quality assessment rather than the application of a single extraction protocol to all fish-bone materials. These findings position marine fish bones as valuable secondary raw materials for sustainable gelatin production while providing a strong scientific basis for further development of halal food, pharmaceutical, and biomaterial applications.

**Marine Fish Scales as a Source of Halal Gelatin**

Marine fish scales constitute another promising collagen-containing by-product that can be valorized as an alternative raw material for halal gelatin production. Large quantities of scales are generated during fish cleaning, filleting, and primary processing, particularly in industries handling scaled marine species, yet these residues are often discarded despite their potential biochemical value (Junianto & Maulina, 2024). The utilization of fish scales for gelatin production can therefore contribute to the conversion of low-value fishery residues into functional biomaterials while simultaneously reducing the accumulation of organic processing waste. This approach is consistent with the broader concept of fishery by-product valorization, in which protein-rich residues are redirected toward value-added applications rather than being used only as low-value feed ingredients or disposed of in the environment (Ahmed et al., 2020; Umar et al., 2022).

The structural characteristics of fish scales differ substantially from those of skin because scales possess a dense and highly mineralized matrix. Collagen fibers are associated with inorganic compounds, including calcium-containing minerals and hydroxyapatite, which increase structural rigidity and restrict the accessibility of collagen during conventional thermal extraction (Rohani et al., 2026). Consequently, scale-derived gelatin generally requires more intensive pretreatment than skin-derived gelatin to remove minerals and promote collagen swelling before hydrolysis. This structural complexity partly explains why gelatin yields from scales are frequently lower than those obtained from softer collagen-rich tissues such as fish skin.

Pretreatment is therefore a decisive stage in the conversion of fish-scale collagen into gelatin. Acid or alkaline solutions can weaken intermolecular collagen interactions, promote tissue swelling, and assist in removing inorganic constituents before thermal extraction, although their effectiveness depends strongly on concentration, treatment duration, and raw-material characteristics (Siburian et al., 2020). Rohani et al. (2026), for example, employed alkaline treatment followed by an acid-swelling stage for parrotfish scales, whereas Safi'i et al. (2021) investigated acid-assisted extraction of gelatin from red snapper scales. Broader studies on fish gelatin also indicate that differences between acidic and alkaline processing conditions can substantially influence extraction efficiency and the functional characteristics of the resulting product (Nasution et al., 2018; Tuslinah et al., 2019).

Species differences further contribute to variation in the extraction behavior and physicochemical characteristics of scale-derived gelatin. Marine fish scales differ in thickness, collagen concentration, mineral content, degree of calcification, and molecular organization, all of which can affect the penetration of hydrolyzing agents and the subsequent conversion of collagen into gelatin. Studies involving parrotfish, red snapper, tuna, and yellowstripe goatfish demonstrate that the same anatomical material can generate considerably different yields, gel strengths, and viscosity values depending on species and extraction procedure (Fadilla et al., 2019; Marhayuni & Syakina, 2023; Rohani et al., 2026). Species-specific optimization is therefore necessary to achieve acceptable gelatin recovery without compromising molecular integrity.

The available quantitative evidence indicates that gelatin derived from marine fish scales exhibits substantial variability in both extraction yield and functional performance. Reported yields range from approximately 2.78% in yellowstripe goatfish scales to 9.47% in parrotfish scales, while red snapper scales have been reported to produce gelatin with particularly high gel strength (Fadilla et al., 2019; Safi'i et al., 2021). Viscosity values also differ among species, demonstrating that extraction treatment influences molecular-chain distribution and solution behavior. Representative data from the reviewed studies are summarized in Table 3.

**Table 3. Comparative Yield and Physicochemical Characteristics of Gelatin Derived from Marine Fish Scales**

| Marine fish species | Hydrolysis/extraction treatment | Yield (%) | Gel strength (g Bloom) | Viscosity (cP) | Reference |
|---|---|---|---|---|---|
| Parrotfish (*Scarus* sp.) | NaOH 0.05 M and 0.1% acid swelling | 9.47 | 187.10 | 12.00 | Rohani et al. (2026) |
| Red snapper (*Lutjanus* sp.) | Acetic-acid hydrolysis | 7.38 | 304.74 | 7.50 | Safi'i et al. (2021) |
| Tuna (*Thunnus* sp.) | Acid hydrolysis | 3.46 | – | 4.12–5.05 | Marhayuni & Syakina (2023) |
| Yellowstripe goatfish (*Upeneus sulphureus*) | Hydrolysis/extraction | 2.78 | – | 2.32 | Fadilla et al. (2019) |

The yield values in Table 3 confirm that scale-derived gelatin generally exhibits moderate to relatively low extraction recovery compared with the values reported for several fish-skin sources. Parrotfish and red snapper scales produced yields of 9.47% and 7.38%, respectively, whereas tuna and yellowstripe goatfish scales yielded only 3.46% and 2.78% (Rohani et al., 2026; Fadilla et al., 2019). The lower recovery from some scale materials can be attributed to their dense mineralized structure, which restricts collagen accessibility and increases the importance of effective demineralization and swelling. When compared with the quality benchmarks referenced in the manuscript, parrotfish and red snapper scale gelatin demonstrate more favorable recovery characteristics than the lower-yield tuna and yellowstripe goatfish samples (Badan Standardisasi Nasional, 1995).

Gel strength data provide additional evidence that a relatively low or moderate extraction yield does not necessarily indicate poor functional quality. Red snapper scale gelatin was reported to reach 304.74 g Bloom, while parrotfish scale gelatin showed a gel strength of 187.10 g Bloom, demonstrating that properly processed fish scales can generate highly structured gelatin networks (Safi'i et al., 2021; Rohani et al., 2026). Gel formation is influenced by the ability of gelatin polypeptide chains to reassociate during cooling, which in turn depends on molecular size, amino-acid composition, and the extent of collagen degradation during extraction (Ranasinghe et al., 2022). The high gel strength observed for selected scale-derived gelatin indicates potential suitability for applications requiring structural firmness, although the precise requirements will vary according to the intended food or pharmaceutical formulation.

Viscosity measurements reveal further differences among the investigated scale-derived gelatins. Tuna scale gelatin showed viscosity values of approximately 4.12–5.05 cP, yellowstripe goatfish approximately 2.32 cP, and red snapper approximately 7.50 cP, whereas parrotfish scale gelatin reached approximately 12.00 cP (Fadilla et al., 2019; Marhayuni & Syakina, 2023; Rohani et al., 2026). These variations suggest substantial differences in gelatin-chain length and intermolecular interactions among species and extraction treatments, with higher viscosity generally indicating stronger resistance to flow and potentially greater molecular interaction in solution. Careful control of pretreatment and extraction conditions is therefore essential because excessively intensive hydrolysis may reduce molecular size, whereas insufficient hydrolysis may limit gelatin recovery and produce inconsistent rheological properties.

Beyond physicochemical performance, the development of fish-scale gelatin has important implications for halal assurance and sustainable material utilization. Fish-derived gelatin can reduce dependence on porcine and conventionally sourced bovine gelatin, thereby addressing concerns related to religious acceptability and raw-material traceability in Muslim markets (Ahmad Anuar et al., 2023; Zamzahaila et al., 2020). The valorization of scales also complements broader efforts to utilize other fishery residues, including skin and bones, thereby increasing resource efficiency throughout seafood-processing chains (Junianto & Maulina, 2024). Nevertheless, halal status should not be evaluated solely according to the biological origin of the scales because processing aids, equipment, storage conditions, and potential cross-contamination must also be controlled throughout the production process (Rakhmanova et al., 2018).

Marine fish scales can be considered a technically feasible but comparatively challenging source of halal gelatin because their mineralized structure requires more intensive pretreatment than fish skin. The evidence reviewed in this study demonstrates that although extraction yield may be relatively low for some species, scale-derived gelatin can still exhibit desirable gel strength and viscosity, particularly when demineralization and hydrolysis conditions are appropriately optimized (Safi'i et al., 2021; Rohani et al., 2026). When considered together with the findings for marine fish skin and bones, the results indicate that anatomical source, species, and extraction procedure jointly determine gelatin recovery and physicochemical functionality rather than any single factor acting independently. Marine fish skin, bones, and scales therefore represent complementary resources for developing halal gelatin while supporting the sustainable valorization of fish-processing by-products and reducing dependence on conventional mammalian sources (Reza & Annissa, 2023; Nurilmala et al., 2022).

## CONCLUSION

Marine fish skin, bones, and scales demonstrate substantial potential as alternative raw materials for halal gelatin production while simultaneously supporting the valorization of fish-processing by-products. The comparative findings indicate that fish skin generally produces higher gelatin yields because of its collagen-rich and less mineralized structure, which facilitates hydrolysis and thermal extraction. Fish bones and scales require more intensive pretreatment, particularly demineralization, because their collagen is strongly associated with inorganic mineral matrices. Nevertheless, all three anatomical sources can produce gelatin with satisfactory physicochemical properties when extraction conditions are appropriately optimized.

The physicochemical performance of marine fish gelatin varies according to species, anatomical source, pretreatment agent, extraction temperature, and processing conditions, as reflected in differences in yield, gel strength, and viscosity. Several gelatin samples evaluated in the reviewed studies exhibited characteristics compatible with relevant SNI and GMIA quality requirements, indicating their potential for food, pharmaceutical, and other industrial applications. Further development should prioritize species-specific process optimization, standardized extraction protocols, comprehensive halal assurance, functional characterization, and evaluation of industrial scalability. Overall, the utilization of marine fish skin, bones, and scales provides a technically feasible and environmentally sustainable strategy for reducing dependence on mammalian gelatin while increasing the economic value of fishery waste.

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