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Physicochemical and Functional Comparison of Gelatin Extracted from Rainbow Trout (*Oncorhynchus mykiss*) and Silver Carp (*Hypophthalmichthys molitrix*) Byproducts

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Abstract

In this research, gelatin was extracted from various by-products of silver carp (*Hypophthalmichthys molitrix*) (SC) and rainbow trout (*Oncorhynchus mykiss*) (RT), including skin, soft tissue, head, and vertebrae. The extracted gelatins were evaluated for proximate composition, molecular weight, functional properties, and structural characteristics. The findings revealed that the protein content of the gelatin samples ranged from 69.25% to 85.75%, with fat levels below 1.5%. The highest moisture content was observed in RT-skin gelatin (16.8%), while the lowest was found in RT-vertebral bone gelatin (2.97%). SDS-PAGE analysis showed clear 1α (~114–121 kDa) and 2α (~100–112 kDa) chains in skin and cranial soft tissue gelatins, whereas bone-derived samples lacked distinct bands, indicating extensive collagen degradation due to harsh acid treatment. In terms of viscosity, the highest value (11 cP) was recorded for SC-cranial soft tissue gelatin, and the lowest (2.6 cP) for RT-head gelatin. Gel strength ranged from 573.5 g (SC-skin) to 19.6 g (RT-head). The melting point of SC-gelatins was significantly higher than that of RT, with some samples approaching values similar to bovine skin gelatin. SC-vertebral bone gelatin exhibited the greatest foaming capacity (120 ± 2%), while SC-head gelatin demonstrated the highest foam stability (48.03 ± 2.12%). These results suggest that non-commercial by-products from these two fish species, especially SC-skin and cranial soft tissue, represent valuable potential sources for producing high-quality gelatin for food applications.

Keywords: Fish gelatin, Functional properties, *Hypophthalmichthys molitrix*, *Oncorhynchus mykiss*, SDS-PAGE analysis

Introduction

In the past decade, the aquaculture and fishing industries have experienced significant growth, with aquatic production increasing from 128 million tons in 2012 to 223 million tons in 2024 (FAO, 2024). This substantial increase in aquatic animal production aims to meet the growing demand for animal protein and serves various industries including food, healthcare, pharmaceuticals, and more (Naghdi *et al*., 2024). Additionally, rising awareness of the high nutritional value of aquatic products has shifted consumer preference toward seafood. Consequently, the fish processing industry has developed significantly to meet this demand, enabling the efficient processing of whole fish and separation of their various parts.

During fish processing, approximately 20 to 60 percent of the initial weight is considered

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non-edible waste, resulting in the generation of large volumes of fish byproducts (Guan *et al*., 2022; Naghdi *et al*., 2024). This not only raises environmental concerns but also reduces the economic profitability of the aquaculture sector. However, these byproducts are rich in fats, proteins, and other valuable compounds (Yuan, Ye, Hou, & Chen, 2024). The protein-rich waste includes meat scraps, spinal bones, heads, skin, ovaries, viscera, and blood. These protein fractions are easily digestible and can be utilized to produce hydrolyzed products, surimi, heat-resistant protein dispersions, various peptides and amino acids, gelatin, collagen, and protamine (Olaniran *et al*., 2024). Among these, gelatin has attracted considerable attention from both industry and researchers due to its diverse applications in food, pharmaceuticals, healthcare, and more (Ruan *et al*., 2023; Wang *et al*., 2024).

Gelatin is a fibrous protein obtained through the partial thermal hydrolysis of collagen. It is a biopolymer with important functional properties and has wide-ranging applications in the food, pharmaceutical, photographic, and other industries (Ruan *et al*., 2023; Wang *et al*., 2024). Currently, most commercial gelatin is derived from mammalian sources, particularly pig and bovine skins (Nurilmala, Suryamarevita, Hizbullah, Jacoeb, & Ochiai, 2022; Usman *et al*., 2022). However, for cultural reasons, such as its non-halal status in Islamic countries, and concerns over zoonotic disease transmission, alternative sources are increasingly in demand (Nurilmala *et al.,* 2022; Usman *et al.*, 2022). As a result, researchers are continuously exploring alternative gelatin sources. Over the past two decades, interest in gelatin derived from fish and poultry has grown (Duasa, Husin, Asmy Mohd Thas Thaker, & Rahman, 2022). Nonetheless, commercial gelatin production from poultry skin and bones has been limited due to low yields. Fish gelatin, in particular, is considered a superior alternative to mammalian gelatin from ethical and religious perspectives (Duasa *et al.*, 2022; Nurilmala *et al*., 2022).

Rainbow trout (*Oncorhynchus mykiss*) and silver carp (*Hypophthalmichthys molitrix*), a phytophagous species, are two of the most widely farmed species globally and in Iran (Iranian Fisheries Organization Statistical Yearbook, 2024). According to the Food and Agriculture Organization (FAO), global production of rainbow trout and silver carp in 2022 was approximately 848,000 tons and 5.1 million tons, respectively (FAO, 2024). Rainbow trout is among the most important farmed migratory species, while silver carp holds the highest production volume among farmed freshwater species worldwide (FAO, 2024).

In Iran, rainbow trout production exceeded 200,000 tons in 2022, while warm-water fish production reached approximately 240,000 tons, the majority of which was silver carp (FAO, 2024). The production of various products, including gutted fish, headed and gutted fish, fillets of these two species, and value-added products based on fish paste, is continuously expanding (Iranian Fisheries Organization Statistical Yearbook, 2024). These diverse processing methods generate a significant volume of waste from both species. For rainbow trout, the head, spinal column, and skin account for approximately 15.52%, 10.78%, and 8.10% of the body weight, respectively, highlighting the substantial amount of waste produced (Abdollahi, Rezaei, & Jafari, 2014). Therefore, the large volume of waste generated from these species, combined with the growing global demand for halal gelatin, underscores the importance of research into gelatin extraction from fish byproducts (Naghdi, Rezaei, Tabarsa, & Abdollahi, 2025). Moreover, differences exist in the quantity and type of collagen cross-links between various byproducts (soft tissues versus bones), which affect collagen solubility and its conversion to gelatin (Silviwanda & Najib Tuisina Naenum, 2024). These differences may lead to variations in the properties of gelatin extracted from different tissues (Silviwanda & Najib Tuisina Naenum, 2024; Yu *et al*., 2023).

Accordingly, the present study aims to investigate and compare the yield and functional properties, and molecular weight analysis of gelatin extracted from various byproducts (skin, spinal column, and head) of rainbow trout and silver carp.

Materials and Methods

Preparation of Fish and Waste Separation

A total of 10 silver carp weighing between 1.5 to 2 kilograms and 20 rainbow trout weighing between 250 to 350 grams were procured from local fish vendors in Noor County. The fish were frozen and transported in polystyrene containers to the central laboratory of the Faculty of Natural Resources and Marine Sciences at Tarbiat Modares University. The skin, bones, and heads of the fish were manually removed gradually until sufficient amounts of skin and other waste were collected. The flesh and additional waste from the skins and bones were separated using a sharp knife before being placed in polyethylene bags, which were then sealed tightly. The bags were stored in a freezer at -20 °C for further experiments (for a maximum of 2 months) (Göçer, 2022).

Proximate Analysis

The proximate analysis of fish byproducts regarding fat, moisture, ash, and protein content was conducted using standard methods numbered 46/950, 08/928, 39/960, and 153/920 (AOAC, 2000). For the proximate analysis of the extracted gelatin samples, the same standards were applied for measuring fat, moisture, and ash content; however, protein content was determined using the Biuret method (Zhou & Regenstein, 2006). In this procedure, 0.1 gram of each gelatin sample extracted from various tissues was dissolved in 10 milliliters of 0.9% NaCl solution at 50 °C. One milliliter of this solution was mixed with 4 milliliters of Biuret reagent and allowed to react for 30 minutes at room temperature. The absorbance of the samples was then measured using a spectrophotometer at 540 nm, and the protein concentration was calculated from a standard curve ($y = 0.0419 x + 0.0008$, $R^2 = 0.9999$). The standard curve was created by diluting a stock solution of bovine serum albumin (BSA) with a concentration of 10 mg/ml.

Extraction of Gelatin

This section presents the methods used for gelatin extraction from various fish processing wastes, categorized by the type of raw material from each fish species.

Gelatin Extraction from Silver Carp (*H. molitrix*) Byproducts

From Silver Carp (SC) Skin

The optimized method of Boran & Regenstein (2009) was applied. Frozen skins were thawed overnight at 4 °C, cut into 0.5 × 0.5 cm pieces, and washed with cold distilled water. The skins were treated sequentially at room temperature with 0.55 N NaOH for 67.5 minutes and 0.1 N HCl for 45 minutes (1:5 v/w). After each treatment, the skins were rinsed with cold water, and excess water was removed by pressing them with cheesecloth. Final extraction was performed at 50 ± 2 °C in a water bath with a 4:1 (w/v) water-to-skin ratio for 3 hours. The gelatin solution was then filtered through cheesecloth, freeze-dried, and stored for analysis.

From SC-Vertebral Bones

Frozen bones were thawed for 30 minutes, cut into 0.5–1 cm piece, and defatted by immersion in warm water (35–40 °C) for 20–30 minutes. Non-collagenous proteins were removed by treatment with 0.1 N NaOH (1:4 w/v) for 24 hours at 4 °C, with solution replacement after 12 hours. The bones were washed until a neutral pH was reached, then demineralized with 3% HCl (3:1 w/v) at room temperature. The acid was replaced every 3 days over approximately 9 days until no hard nuclei remained. The resulting ossein was washed, and gelatin was extracted at 50 ± 2 °C for 16 hours (3:1 w/v). Filtration utilized a Buchner funnel and filter paper due to higher impurities. The gelatin was freeze-dried and

stored (Koli, Basu, Venkteshwarlu, Choukasy, & Nayak, 2013).

From SC-Head

Heads were separated into soft tissue and bones after treatment with 0.1 N NaOH (3:1 w/v) for 3 hours, with hourly solution changes to remove non-collagenous proteins. Soft tissues were acid-treated with 0.15 N HCl (4:1 w/v) for 3 hours, washed, and then extracted at 50 ± 2 °C for 16 hours (3:1 w/v). The bones were dried, crushed, defatted in warm water, demineralized with 3% HCl (3:1 w/v) over approximately 9 days, washed, and extracted similarly. Filtration and freeze-drying followed as described (Elavarasan *et al*., 2017).

Gelatin Extraction from Rainbow Trout (*O. mykiss*) Byproducts

From Rainbow Trout (RT) Skin

Frozen skins were thawed overnight at 4 °C, cut into small pieces, and washed. The skins were treated with 0.19 N NaOH (3:1 w/v) for 3 hours at 7 °C, washed until a neutral/slightly alkaline pH was achieved, and excess water was removed. They were then treated with 0.121 N acetic acid (3:1 w/v) for 3 hours at 7 °C, washed again, and finally extracted at 50 ± 2 °C for 16 hours (3:1 w/v). Subsequent steps matched those for SC-skin (Tabarestani, Maghsoudlou, Motamedzadegan, Sadeghi Mahoonak, & Mahoonak, 2010).

From RT-Vertebral Bones

The extraction procedure was the same as for SC-bones, except the acid treatment lasted about 6 days instead of 9.

From RT-Head

Due to incomplete ossification of the heads (250–350 g), the collected head were ground (3 mm mesh) without separating soft and hard tissues. The ground heads were treated with 0.1 N NaOH (5:1 w/v) for 1.5 hours, washed to a neutral/slightly alkaline pH, pressed to remove excess water, and then treated with 0.018 N HCl (2:1 w/v) for 30 minutes. After washing, final extraction was performed at 55 ± 2 °C for 16 hours (2:1 w/v). The gelatin solution was filtered and freeze-dried as previously described (Tabarestani *et al*., 2010).

Extraction Yield Determination

The extraction yield was calculated based on the dry weight and wet weight of the raw material using the following formulas:

Equation 1: Yield Based on Dry Weight = Weight of dry gelatin / Weight of dry raw material ×100

Equation 2: Yield Based on Wet Weight = Weight of dry gelatin / Weight of wet raw material ×100

Equation 3: Yield Based on Protein Content = Weight of dry gelatin / Protein content of raw material ×100

Measurement of Gel Strength

The gel was prepared according to the method of Kittiphattanabawon, Benjakul, Visessanguan, & Shahidi, (2010). For this purpose, gelatin was dissolved in distilled water at 60 °C to achieve a concentration of 6.67% (w/v). The solution was stirred until the gelatin was completely dissolved and then transferred to a plastic container with a height of 3 cm and a diameter of 2.5 cm. The gelatin solution was allowed to set for 18 hours at 4 ± 2°C to undergo gel maturation before testing its gel strength. After the specified time, the gel strength was measured immediately upon removal from the refrigerator (within 30 seconds), while still in the plastic container. This measurement was conducted using a texture analyzer under the following conditions: a cylindrical piston made of cast iron with a diameter of 12.7 mm, a penetration speed of 1 mm/s, and a penetration depth of 4 mm. The maximum force (in grams) required for the piston to penetrate 4 mm into the gel was recorded and reported as the gel strength.

Measurement of Viscosity

The viscosity of gelatin samples was measured according to the method of Yazid *et al*. (2024). For this purpose, 20 mL of gelatin solutions at a concentration of 6.67% (w/v)

were prepared and maintained at 60 °C for 30 minutes to ensure complete dissolution of gelatin before measurement. Viscosity measurements were conducted at 60 °C using a Brookfield viscometer equipped with spindle S31, operating at a rotational speed of 100 rpm. The viscosity values obtained under these conditions were recorded for analysis.

Determination of Foaming Properties

The foaming ability (FA) and foaming stability (FS) of gelatin were determined according to the method described by Du, Khiari, Pietrasik, & Betti, (2013). A 1% (w/v) gelatin solution was prepared and held at 60 °C for 30 minutes. The solution was then transferred to a beaker. To generate foam, the gelatin solution was homogenized at 10,000 rpm for 5 minutes using a homogenizer. Immediately after homogenization, the solution was quickly transferred to a 250 mL graduated cylinder.

Foaming Ability (FA) was calculated as the ratio of the foam volume to the initial volume of the liquid:

FA=Foam volume / Initial liquid volume ×100

Foaming Stability (FS) was determined by measuring the volume of foam remaining after 30 minutes relative to the initial foam volume:

FS=Foam volume after 30 min / Initial foam volume ×100

Determination of Molecular Weight Distribution

The protein profiles of various gelatin samples were analyzed using the method of Laemmli (1970) with minor modifications. In this procedure, samples were dissolved at a concentration of 2 mg/mL in 5% SDS solution. The resulting mixtures were heated at 85 °C for 1 hour to denature the proteins, followed by centrifugation at 8500 × g for 5 minutes at room temperature to ensure complete dissolution. The dissolved samples were then mixed with sample buffer in a 1:1 (v/v) ratio. After mixing, the samples were heated again at 100 °C for 5 minutes. Finally, 15 µL of the prepared samples and 5 µL of molecular weight marker (standard) were loaded onto a polyacrylamide gel consisting of a 7.5% separating gel and a 4.5% stacking gel. After loading, the gel apparatus cables were connected to the electrodes and electrophoresis was initiated. The initial voltage was set at 50 mV, and once the samples entered the resolving gel, the voltage was increased to 120 mV and maintained at this level until the dye front reached the bottom of the gel. Upon completion of electrophoresis, the gel was carefully removed from the glass plates and stained for 30 minutes in a staining solution. Destaining was performed by immersing the gel in a destaining solution for 15 minutes to remove excess dye and enhance band visibility.

Measurement of Melting Point

The melting point of gelatin was determined according to the BS755 method (BSI, 1975). Gelatin solutions at a concentration of 6.67% (w/v) were prepared using distilled water and poured into test tubes. To remove oxygen bubbles trapped in the samples, the test tubes were placed in a vacuum desiccator for 5 minutes. Subsequently, the test tubes were sealed and heated in a water bath at 60 °C for 15 minutes. Next, the samples were refrigerated at 4 ± 1 °C for 18 hours to allow gel maturation. After the maturation period, 2 to 3 drops of 0.5% (w/v) methyl red-chloroform solution were added to each sample, which were then placed back into the water bath. Starting at an initial water temperature of approximately 4 °C, the temperature was gradually increased. The temperature at which the chloroform droplet began to fall through the gelatin gel was recorded as the melting point of the gelatin.

Statistical Analysis

Data analysis was conducted using SPSS software version 22.0. To assess significant differences among the variables, one-way analysis of variance (ANOVA) was applied, followed by Duncan's multiple range test for pairwise comparisons. Statistical significance was defined at a threshold of $p < 0.05$. All results are presented as the mean ± standard

deviation (SD) based on three independent replicates (n = 3).

Results and Discussion

Extraction Yield of Gelatin

To provide a comprehensive evaluation of extraction efficiency, gelatin yield was calculated based on wet weight, dry weight, and protein recovery percentage, with results presented in Table 1. The extraction yield varied considerably depending on fish species and by-product type (Table 1). In SC, the highest wet weight yield was obtained from skin (15.78%), followed by head bone (11.24%), head soft tissue (3.08%), and vertebral bones (2.85%). Notably, the wet-weight extraction yield of gelatin from SC-skin in the present study (15.78%) was higher than values reported for some other tropical fish species. For example, Barman *et al*. (2021) reported a yield of 10.85% for gelatin extracted from pangas catfish (*Pangasius pangasius*) skin, approximately 5 percentage points lower than the value obtained here. This higher yield may be attributed to the optimized acid–alkali pretreatment, which, compared to conventional extraction methods applied to catfish by-products, more effectively enhances collagen accessibility and consequently improves gelatin recovery. On a dry weight basis, skin again showed the highest yield (43.38%), followed by head bone (18.13%), head soft tissue (13.18%), and vertebral bones (6.34%). Protein recovery was highest in head bone-derived gelatin (38.25%), followed by head soft tissue (13.26%), skin (10.58%), and vertebral bones (6.57%). In RT, skin exhibited the highest wet weight yield (9.58%), followed by head (6.37%) and vertebral bones (1.52%). However, on a dry weight basis, head showed the highest value (31.99%), followed by skin (26.94%) and vertebral bones (3.36%). Protein recovery ranged from 2.15% in vertebral bones to 18.7% in head-derived gelatin, with skin at 3.38%. Overall, skin and head tissues generally produced higher wet weight yields than bony tissues, attributable to greater collagen accessibility and lower mineral content. Bone-derived samples showed lower efficiency, particularly SC vertebral bones, likely due to extended demineralization. The elevated dry weight and protein recovery in SC head bone and RT head may reflect species-specific collagen distribution and extraction optimization. These findings underscore the influence of species and tissue type on gelatin yield, guiding sustainable by-product utilization. The yields obtained in this study align well with literature values reported for fish gelatin extraction. Notably, the silver carp skin yield (15.78% wet weight) substantially exceeds values from the same species reported by Tavakolipour (2011) [7.5% wet weight], likely attributable to optimized alkaline pretreatment conditions. Similarly, the results for rainbow trout in the present study closely match those reported by Duman (2025), with observed differences in reported values probably stemming from variations in initial tissue protein content, extraction solvent composition, or analytical quantification methods (total protein versus gelatin-specific recovery) (Anandito, Purwanto, Praseptiangga, & Zaman, 2024). In a comprehensive study investigating gelatin and oil extraction from mixed by-products of striped catfish (*Pangasius hypophthalmus*), catfish (*Clarias gariepinus*), and tilapia (*Oreochromis mossambicus*) using a hydrothermal process, gelatin yields of 6.4–11.8% were reported. In comparison, our results for SC-skin (15.78%) and SC-head bone (11.24%) demonstrate considerably higher recovery efficiency. This difference suggests that targeting gelatin extraction from specific fish by-product fractions can play a key role in both yield and the quality of the extracted collagen (Adnan, Kresnowati, Marlina, & Bindar, 2024). The significant variations in yield across different tissues and species provide a strategic roadmap for industrial application. The superior yield of SC-skin positions it as the primary raw material for large-scale production, ensuring higher process efficiency and economic viability. Conversely, the lower yields from bone tissues, while less productive, are essential for a

comprehensive biorefinery approach, where every by-product is valorized to minimize environmental impact and maximize total biomass utilization.

Table 1- Extraction yield of gelatin from silver carp (SC) and rainbow trout (RT) by-products

Species	By-product	Yield (Wet weight, %)	Yield (Dry weight, %)	Protein recovery (%)
SC	Skin	15.78	43.38	10.58
SC	Vertebral bones	2.85	6.34	6.57
SC	Head bone	11.24	18.13	38.25
SC	Head soft tissue	3.08	13.18	13.26
RT	Skin	9.58	26.94	3.38
RT	Vertebral bones	1.52	3.36	2.15
RT	Head	6.37	31.99	18.7

Values are expressed as percentages. Wet weight yield was calculated based on the initial fresh weight of raw material. Dry weight yield was calculated based on the dry matter of raw material. Protein recovery (%) represents the ratio of extracted gelatin protein to the initial protein content of the raw material.

Proximate Analysis of Extracted Gelatins from SC-and RT-Byproducts

The proximate analysis of raw materials and extracted gelatins in this study revealed significant insights into the biochemical composition of gelatin derived from SC-and RT-byproducts (Table 2 and Table 3). All extracted gelatins exhibited high protein content. In SC, no significant difference was observed in protein content between gelatin extracted from skin and soft head tissue ($P > 0.05$). Similarly, gelatins obtained from vertebral bones and head bones showed comparable protein levels ($P > 0.05$). However, in rainbow trout, significant difference ($P < 0.05$) was found in protein content among gelatins extracted from different byproducts. Overall, in both species, soft tissue-derived gelatins contained significantly higher protein content than those from bony tissues ($P < 0.05$). These findings align with previous reports by Koli *et al.* (2012), who documented protein contents of 72.63% and 69.49% for skin and bone gelatins of Nile perch, respectively. These results are consistent with the general range of 70-90% protein content in fish gelatins, as reviewed by Karim & Bhat (2009), confirming the suitability of these fish byproducts as valuable gelatin sources. The moisture content analysis revealed significant variation among the extracted gelatins. RT-skin gelatin showed the highest moisture level (16.8%), while the lowest was recorded in bone-derived gelatin (2.97%) from the same species. Similarly, SC-head soft tissue gelatin exhibited elevated moisture content. Notably, all samples except RT-skin gelatin and SC-head soft tissue gelatin complied with the established moisture standard (<15%) for edible gelatin (GME, 2011). The slightly higher moisture content in RT-skin gelatin (exceeding the 15% threshold) may be attributed to variations in drying efficiency or extraction parameters. These findings are consistent with previous studies: Gomez-Guillen, Gimenez, Lopez-Caballero, & Montero, (2011) reported moisture levels of 5-12% in gelatins from various fish species, while He, Zhang, Xu, Ma, & Guo, (2022) documented a moisture content of 8.82% for food-grade pigskin gelatin compared to a range of 4–5% for collagens derived from fish scales. Although all gelatin samples were subjected to identical freeze-drying conditions, noticeable differences in residual moisture content were observed among treatments. These variations are likely attributable to intrinsic differences in tissue origin, molecular weight distribution, and structural characteristics of the extracted gelatins. SDS-PAGE results indicated varying degrees of collagen degradation, particularly in bone-derived samples, which may influence network density, porosity, and water-binding capacity during freeze drying. Additionally, residual mineral components in bone-derived gelatins and differences in initial solid content could affect sublimation efficiency and moisture retention. Therefore, the observed moisture variability is more plausibly related to

structural and compositional differences among tissue-derived gelatins rather than incomplete drying under standardized processing conditions. All gelatin samples demonstrated low lipid content, consistently measuring below 2%, which is characteristic of the predominantly proteinaceous nature of gelatin. These results are in agreement with prior research findings reporting typical fat contents below 1.5% in fish-derived gelatins (He *et al*., 2022; Siburian, Rochima, Andriani, & Praseptiangga, 2020). The extracted gelatins exhibited ash contents ranging from 0.51% to 3.32%, with the highest value observed in SC-head bone gelatin and the lowest in RT-skin gelatin. The elevated ash content in bone-derived samples reflects the inherent mineral richness of the source tissues, particularly the calcium phosphate composition of skeletal structures. It should be noted that the demineralization process for silver carp and rainbow trout bones differed in duration (approximately 9 and 6 days, respectively). This variation was not arbitrarily imposed but was determined by the completion of full demineralization, continuing until no hard bone cores remained, confirming complete mineral removal. Nevertheless, this difference in acid exposure duration may have influenced collagen degradation extent, potentially affecting certain physicochemical and functional properties of the extracted gelatins.

Table 2- Proximate analysis of raw materials used for gelatin extraction

Source	Material	Moisture (%)	Protein (%)	Fat (%)	Ash (%)
SC	Skin	66.63 ± 0.76^{c}	29.8 ± 0.69^{a}	1.73 ± 0.15^{e}	2.42 ± 0.79^{e}
	Bone	54.98 ± 0.04^{d}	19.93 ± 0.34^{e}	5.3 ± 0.28^{b}	21.77 ± 0.16^{b}
	Head Bone	40.42 ± 1.26^{e}	22.3 ± 0.58^{c}	2.8 ± 0.12^{d}	39.24 ± 0.56^{a}
	Soft Tissue (Head)	76.61 ± 0.94^{a}	18.67 ± 0.43^{h}	5.9 ± 0.45^{a}	1.7 ± 0.08^{f}
RT	Skin	71.43 ± 1.2^{b}	24.53 ± 0.96^{g}	1.3 ± 0.11^{f}	1.69 ± 0.06^{f}
	Bone	65.58 ± 1.56^{c}	20.83 ± 0.92^{f}	1.85 ± 0.35^{e}	14.42 ± 0.68^{c}
	Head	69.65 ± 1.33^{b}	23.96 ± 0.16^{b}	3.36 ± 0.09^{c}	3.65 ± 0.37^{d}

Mean ± SD of three replicates. Different letters within each column indicate statistically significant differences ($P < 0.05$). Identical letters indicate no significant difference.

Table 3- Proximate analysis of extracted gelatins from SC-and RT-byproducts

Source	Byproduct	Moisture (%)	Protein (%)	Fat (%)	Ash (%)
SC	Skin	6.04 ± 0.03^{f}	84.64 ± 0.59^{b}	0.63 ± 0.02^{b}	1.11 ± 0.08^{f}
	Bone	9.6 ± 0.08^{e}	68.68 ± 0.46^{d}	0.46 ± 0.12^{c}	3.02 ± 0.14^{c}
	Head Bone	13.54 ± 0.15^{c}	69.25 ± 0.21^{d}	0.27 ± 0.04^{e}	3.20 ± 0.09^{b}
	Soft tissue (head)	15.92 ± 0.12^{b}	84.81 ± 0.35^{b}	1.20 ± 0.28^{a}	2.15 ± 0.31^{d}
RT	Skin	16.8 ± 0.23^{a}	83.66 ± 0.08^{c}	0.15 ± 0.05^{e}	0.51 ± 0.11^{g}
	Bone	2.97 ± 0.05^{g}	79.23 ± 0.18^{e}	0.31 ± 0.34^{d}	1.89 ± 0.14^{a}
	Head	10.56 ± 0.09^{d}	85.75 ± 0.43^{a}	0.36 ± 0.06^{e}	1.32 ± 0.21^{e}

Mean ± SD of three replicates. Different letters within each column indicate statistically significant differences ($P < 0.05$). Identical letters indicate no significant difference.

Molecular Weight Distribution and Electrophoretic Patterns of the Gelatin Samples

Fig. 1 illustrates the molecular weight distribution of proteins in various gelatin samples. As shown, no bands appeared in the electrophoretic patterns of gelatin extracted from the bones of SC-heads and vertebrae. According to Feng *et al*. (2024), acid pretreatment parameters, particularly acid concentration and exposure time, are critical factors influencing the extent of collagen degradation. This effect is evident in SDS-PAGE profiles through reduced intensity or complete absence of high-molecular-weight bands, as observed in gelatin extracted from SC bone samples. This is likely attributable to extensive collagen hydrolysis into low-molecular-weight peptides (<5 kDa) during prolonged acid exposure, though method sensitivity limitations or poor Coomassie staining of small fragments cannot be ruled out.

In contrast, since the acid treatment of RT-vertebral bones was shorter, less hydrolysis occurred, resulting in a faint 2α band at approximately 104 kDa in its pattern. The molecular weights of the 1α (114 kDa) and 2α (105 kDa) components in SC-skin gelatin were slightly higher than those of the corresponding 1α (107 kDa) and 2α (100 kDa) components in RT-skin gelatin. The β components, observed only in the skin gelatin samples of SC-and RT-(approximately 200 kDa and 204 kDa, respectively), indicate less collagen hydrolysis during the pretreatment steps in these samples. In the electrophoretic profiles of gelatin derived from the soft tissues of SC-and RT-heads, two bands corresponding to 1α and 2α chains with nearly similar molecular weights (1α at ~121 kDa and 2α at ~112 kDa) were detected. However, the bands in the SC-soft head tissue gelatin appeared with greater clarity. Valcarcel, Hermida-Merino, Piñeiro, Hermida-Merino, & Vázquez, (2021) reported that gelatin derived from fish skin typically retains higher molecular weight α and β chains, indicating less collagen degradation. This observation aligns with the present findings, where clearer α and β bands were detected in the skin gelatin samples of SC and RT. The presence of β chains, representing collagen dimers, further supports the notion of milder hydrolysis and better preservation of collagen structure in skin-derived gelatin. Furthermore, Alves *et al.* (2022) noted that interspecies and inter-tissue variations in molecular weight profiles can be attributed to differences in collagen cross-linking and extraction conditions. This explains the slight molecular weight differences observed in the α chains between the two species, as well as the greater band clarity in gelatin extracted from the soft head tissue of SC compared to that of RT. Overall, the electrophoretic patterns provide valuable insights into the structural integrity and functional quality of gelatin extracted from different fish byproducts. These results underscore the importance of optimizing pretreatment conditions to achieve a balance between maximizing extraction yield and preserving molecular structure, which directly influences functional properties such as gel strength and viscosity.

Gel Strength

In terms of gel strength (Fig. 2), all extracted gelatins showed significant differences from each other ($P < 0.05$), except for the gelatins derived from RT-skin and the soft tissue of SC-head, which did not differ significantly. In this study, the highest gel strength was recorded for SC-skin gelatin (573.5 g), while the lowest was observed for RT-head gelatin (19.6 g). The gel strength of SC- skin extracted gelatin (573.5 g) was markedly higher than the value reported by Adnan, Kresnowati, Marlina, & Bindar, (2025) for gelatin obtained from striped catfish (*Pangasianodon hypophthalmus*) skin.

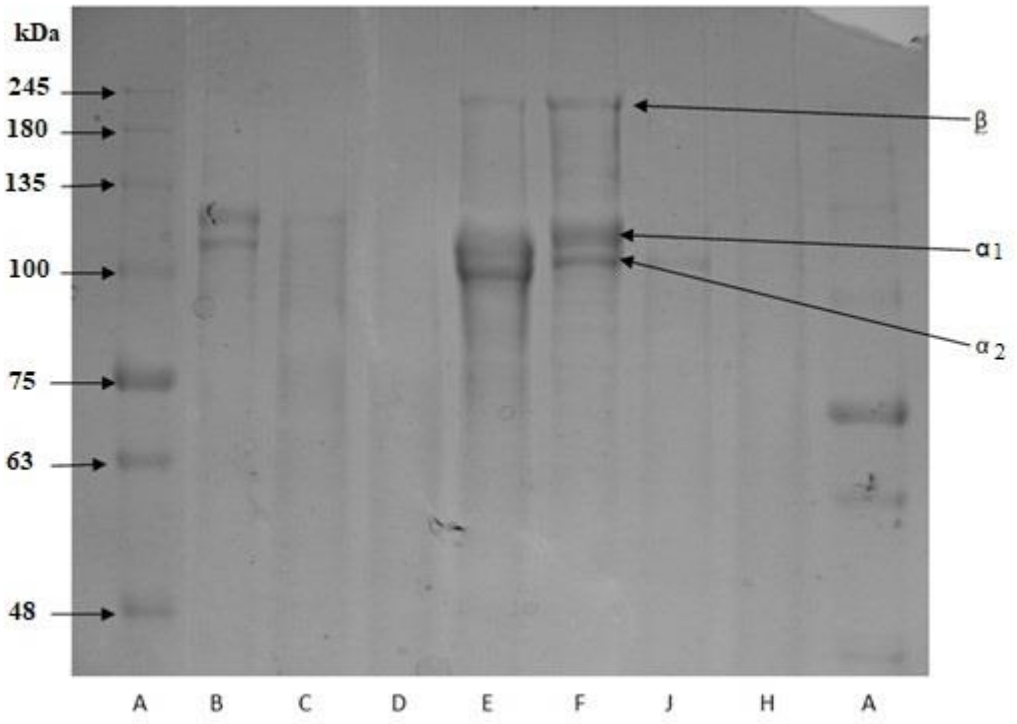

Fig. 1. SDS-PAGE electrophoretic profiles of gelatin extracted from by-products of silver carp (SC) and rainbow trout (RT). Lane A: molecular weight marker (protein ladder); Lane B: SC head soft tissue gelatin; Lane C: RT head gelatin; Lane D: SC head bone gelatin; Lane E: RT skin gelatin; Lane F: SC skin gelatin; Lane G: RT vertebral bone gelatin; Lane H: SC vertebral bone gelatin. Major α- and β-chain bands are indicated where visible

This substantial difference may indicate that SC skin is a superior raw material for producing high-strength gelatin, potentially due to a more stable collagen cross-linking architecture and a higher density of intermolecular hydrogen bonding within the resulting gelatin network. Moreover, the gel strength of gelatin extracted from the soft tissue of SC-head (453 g) was substantially higher than that reported for gelatin from cod fish head soft tissue (123.2 g) (Arnesen & Gildberg, 2006) and even exceeded the gel strength of three types of tilapia scale gelatins (hot water-pretreated gelatin, acetic acid-pretreated gelatin, and pepsin enzyme-pretreated gelatin) reported by Peng *et al.* (2022). Another notable finding was that the gel strength of gelatin extracted from the bones of both species was significantly lower than that of gelatin from their skin and the soft tissue of SC-head ($P < 0.05$). This difference can be attributed to the more intensive hydrolysis of bone collagen due to the use of a stronger acid treatment compared to skin and soft tissue, aimed at further reducing mineral content and extracting more collagen from the mineralized bone matrix to improve extraction yield (Koli *et al.*, 2013). As shown in the protein electrophoretic patterns (Fig. 1), except for the RT-bone gelatin, which exhibited a very faint 2α band, none of the bone samples showed distinct protein bands. This likely results from severe collagen hydrolysis during pretreatment, explaining the lower gel strength of bone gelatin compared to skin gelatin of both species and gelatin from SC-head soft tissue. The lack of distinct protein bands in SC-bone gelatins (Fig. 1) confirms that the harsh demineralization process led to significant cleavage of peptide bonds. This structural disintegration is the primary reason for the

lower gel strength in these samples compared to skin and soft tissue gelatins, where α and β chains were well-preserved. Despite this relatively severe hydrolysis, the gel strength of SC-head bone gelatin (329.3 g) was higher than values reported for channel catfish head bone gelatin (209 g) by Liu, Han, & Guo, (2009), and even exceeded gel strength values reported for skin gelatin of some species such as skipjack tuna (206 g) (Shyni *et al*., 2014), Amur sturgeon (141 g) (Nikoo *et al*., 2014). As mentioned, the lowest gel strength was observed in gelatin extracted from RT-head. Sinthusamran, Benjakul, & Kishimura, (2015) compared the properties of gelatin extracted from sea bass skin of different sizes, reporting that fish size affects gelatin yield and gel characteristics. Larger fish produced gelatin with higher yield and better gel properties. They also noted that gelatin cross-linking plays a fundamental role in gel formation and gel strength. Also, in a study published by Adnan *et al.* (2024), gelatin extracted from the skin of striped catfish exhibited a gel strength of 66.01 ± 0.83 g, which is significantly lower than the values obtained for gelatin in the present study. Furthermore, the study by Wang *et al.* (2024) reported that gelatin extracted from cold-water fish skin had a gel strength of 340 g, which was lower than some samples in the current study, such as gelatin derived from the skin of RT-and SC, as well as the soft tissue of SC-head, but higher than other extracted gelatins. Based on previous studies, it has been established that the gel properties of fish gelatin are influenced by various factors. For instance, processing methods, fish species, and additives affect the protein structure and chemical interactions, thereby impacting gelation (Xie, Tang, & Dong, 2024). Additionally, preparation conditions such as solid-to-liquid ratio, pH, temperature, and time significantly affect gelatin yield and gel strength (Sha *et al*., 2013). Moreover, the unique amino acid composition of fish gelatin results in a lower melting point compared to mammalian gelatin, while its higher molecular weight fractions contribute to increased dynamic viscosity (Bekesheva & Yakubova, 2018). Although gel strength was measured following the general principles of the Bloom test (6.67% gelatin, 18 h maturation at 4 °C, 12.7 mm probe, 4 mm penetration depth), the gel was prepared in a smaller cylindrical container (3 cm height × 2.5 cm diameter) rather than a standard Bloom jar (>100 mL). Therefore, the absolute gel strength values obtained in this study may not be directly comparable to standardized Bloom values reported in the literature. However, since all samples were prepared and analyzed under identical experimental conditions, the results remain valid for relative comparison among treatments within this study. Future studies should consider using standard Bloom jars or appropriately scaled probe–sample dimensions to ensure full methodological standardization. To fully understanding the functional variations between gelatin types, characterizing their total amino acid composition and rheological gelling points is crucial. While not addressed in this paper, evaluating these factors in subsequent studies will provide deeper insights into how the tissue source influences the structure–performance dynamics of the resulting gelatin. If we consider the use of extracted gelatins for applications in the food industry, it can be noted that the high gel strength of SC-skin gelatin (573.5 g) demonstrates its potential for use in the confectionery and pharmaceutical industries. This is because high gel strength is particularly important in products such as pastille candies, where structural integrity and chewability are of great importance (Yin *et al.,* 2025).

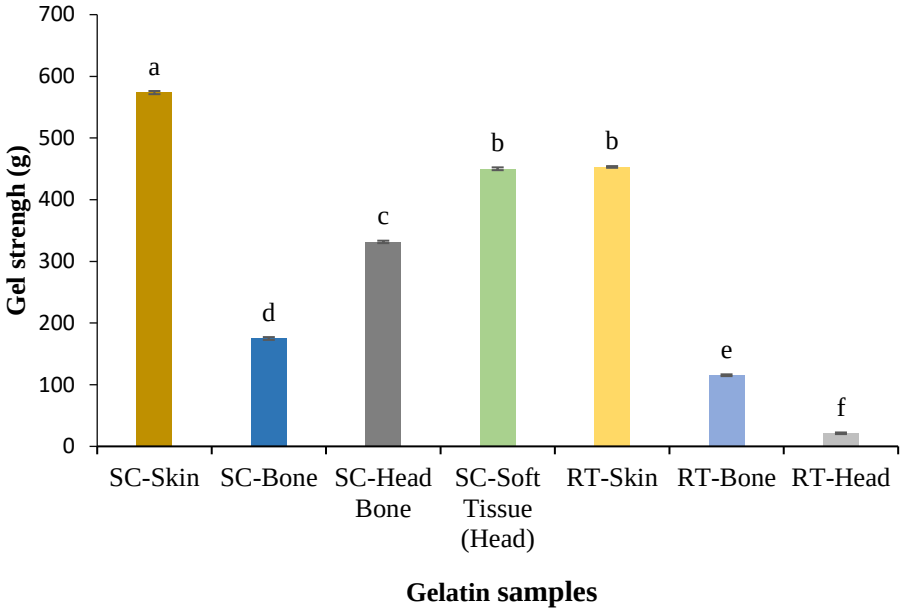

Fig. 2. Gel strength (g) of gelatins extracted from different by-products of silver carp (SC) and rainbow trout (RT). Values are expressed as mean ± SD (n = 3)
Different letters above bars indicate statistically significant differences (P < 0.05).

Viscosity of Gelatin Samples

Viscosity is considered the second most important commercial property of gelatin (Bekesheva & Yakubova, 2018). Fig. 3 illustrates the viscosity values of the extracted gelatins. The viscosity of the samples ranged from 2.6 to 11 cP. The highest viscosity was observed in gelatin extracted from the soft tissue of the SC-head (11 cP), whereas the lowest was recorded for head-derived gelatin from RT (2.6 cP). There was no statistically significant difference (P > 0.05) among the gelatins extracted from the head bone of SC, vertebral bone, and head bone of RT. However, these samples showed significantly lower viscosities compared to gelatin extracted from the skin and bone of SC, the skin of RT, and the soft tissue and head bone of SC (P < 0.05). Interestingly, the relatively high viscosity of SC-head bone gelatin, despite its degraded protein profile, suggests that residual mineral-protein complexes or non-collagenous impurities might contribute to flow resistance, a phenomenon that warrants further purification studies. Also, the viscosity of SC-skin gelatin (over 5 cP) was higher than the 4.62 cP reported for pangas catfish skin gelatin by Barman *et al.* (2021). This difference is notable, as skin-derived gelatins generally retain higher viscosity due to their broader molecular weight distribution. The elevated viscosity observed in SC-skin indicates better preservation of the triple-helix structure and greater retention of β and γ chains during our extraction process compared to the catfish skin gelatin studied by Barman *et al.* (2021). The primary factor influencing gelatin viscosity is the molecular weight distribution and size of its components (Bekesheva & Yakubova, 2018; Kwak *et al.*, 2017). According to Karim & Bhat (2009), the β and γ chains of gelatin play a critical role in enhancing viscosity. As shown in the electrophoretic protein patterns (Fig. 1), gelatins extracted from the skin of both species contained a greater proportion of high-molecular-weight compounds than other samples. The higher viscosity of SC-skin gelatin compared to that of RT may be attributed to its higher content of high-

molecular-weight components (He *et al.*, 2022). However, despite this, the gelatin extracted from the soft tissue of the SC-head exhibited even higher viscosity than skin-derived gelatins, possibly due to the inefficiency of the alkaline treatment in removing non-collagenous proteins, which could have remained in the gelatin solution during thermal extraction. Interestingly, the gelatin obtained from the head bones of SC, despite showing no visible protein bands in its electrophoretic pattern, exhibited higher viscosity than gelatins derived from the vertebral bones of both fish species, and even higher than that of RT-skin. This could be due to the presence of impurities in the gelatin solution, which might be reduced through successive filtration (He *et al.*, 2022; Yu *et al.*, 2023). In addition to the aforementioned points, it has been established that pH is a key parameter influencing gelatin viscosity and its functional properties, typically ranging from 4.5–6.5 for commercial type A/B gelatins (Goudie, McCreath, Parkinson, Davidson, & Liggat, 2023). Furthermore, at the isoelectric point, the net electrical charge of proteins is minimized, leading to chain entanglement (coil entanglement) along with hydrophobic interactions, which in turn increases solution viscosity (Hu *et al.*, 2024). It is worth noting that the high viscosity of the gelatin samples from SC-soft tissue (11 cP) and SC-skin makes them a good candidate for use as a thickening and stabilizing agent in products such as sauces, gravies, and low-fat spreads (Karim & Bhat, 2009).

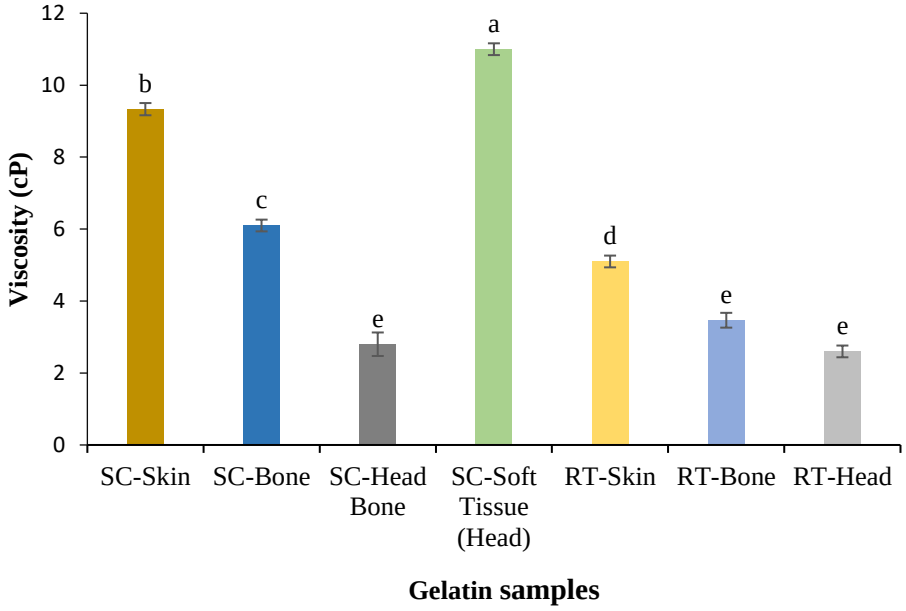

Fig. 3. Viscosity (cP) of gelatins extracted from various by-products of silver carp (SC) and rainbow trout (RT). Values are expressed as mean ± SD (n = 3)
Different letters above bars indicate statistically significant differences (P < 0.05).

Melting Temperature of Gelatin Samples

Melting points of gelatins extracted from various by-products of SC and RT are presented in Fig. 4. Gelatins derived from the skin and bones of RT did not exhibit a statistically significant difference in melting temperature (P > 0.05). However, the melting point of gelatin extracted from the RT-head was significantly different from that of the skin- and bone-derived gelatins (P < 0.05). A slight, statistically insignificant difference (P > 0.05) was observed between the melting points of

gelatin from the skin and soft head tissue of SC. Overall, however, the gelatins extracted from SC by-products exhibited significantly higher melting points compared to those extracted from RT by-products ($P < 0.05$). Among the samples in this study, the melting points of gelatins extracted from SC-skin and soft head tissue were found to be closer to that of bovine skin gelatin. In contrast, the melting points of gelatin extracted from SC-vertebral bones and head bones were lower than the values reported for red snapper (26 °C) and grouper (25 °C), but higher than that reported for mammalian bone gelatin (21 °C) (Shakila, Jeevithan, Varatharajakumar, Jeyasekaran, & Sukumar, 2012). Although fish gelatin has gained attention as a potential substitute for mammalian gelatin, its practical applications remain limited due to its lower melting point and low gel strength. Commercial fish gelatin typically melts at around 7 °C, whereas mammalian gelatin melts at significantly higher temperatures, ranging from 22 °C to 34 °C (Bekesheva & Yakubova, 2018; Derkach, Voron'ko, Kuchina, & Kolotova, 2020; Silviwanda & Naenum, 2024). The relatively lower melting point of fish gelatin compared to mammalian gelatin facilitates better flavor and aroma release during oral processing, making it highly advantageous for applications in texture and aroma-controlled food products (Choi & Regenstein, 2000; Koli *et al.*, 2012; Uddin, Hossain, Sagadevan, Al Amin, & Johan, 2021). According to Karim & Bhat (2009), the melting point of gelatin is closely related to gel maturation time and the concentration of specific amino acids such as proline and hydroxyproline. Also, they reported that the α/β chain ratio also plays a role in determining the melting behavior of gelatin (Huang *et al.*, 2019).

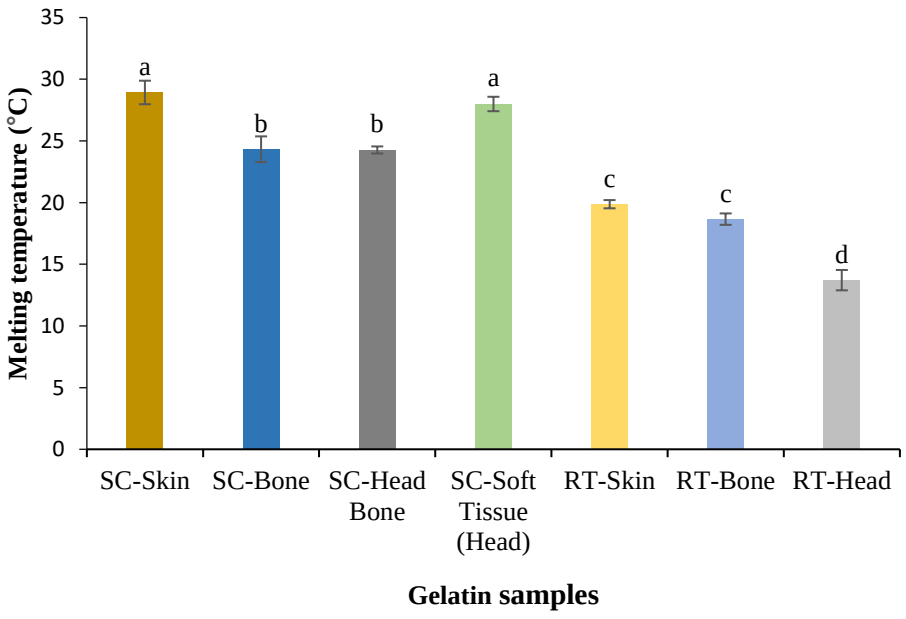

Fig. 4. Melting temperature (°C) of gelatins extracted from different by-products of silver carp (SC) and rainbow trout (RT). Values are expressed as mean ± SD (n = 3)
Different letters above bars indicate statistically significant differences ($P < 0.05$).

Foaming Capacity and Stability

Foaming capacity and foam stability are considered as critical functional properties of gelatin in food applications, particularly in products like marshmallows (Uddin *et al.*, 2021). The foaming capacity and stability of the

extracted gelatins are presented in Table 4. Among all samples, the highest foaming capacity was observed in gelatin extracted from SC-vertebral bones (120 ± 2%), while the greatest foam stability was recorded for gelatin derived from the fish's head bones (48.03 ± 2.12%). The inverse relationship between molecular weight and foaming capacity was evident; SC-vertebral bone gelatin, which underwent the most extensive hydrolysis, exhibited the highest foaming capacity (120%). This confirms that smaller peptide fragments, resulting from prolonged acid treatment, possess higher interfacial mobility than intact collagen chains. Gelatin obtained from the soft tissue of the SC-head also showed relatively good foaming properties (foaming capacity: 99.66 ± 2.08%, foam stability: 44.98 ± 0.10%). In RT samples, the gelatin extracted from the skin and vertebral bones showed no significant difference in foaming capacity ($P > 0.05$); however, both differed significantly from the head-derived gelatin in this regard ($P < 0.05$). Furthermore, foam stability of the gelatin from RT-vertebral bones was significantly higher than that of the skin-derived gelatin ($P < 0.05$). Interestingly, RT-skin gelatin demonstrated significantly higher foaming capacity and stability than that from SC-skin ($P < 0.05$), whereas in the case of other tissues (head, bones), SC gelatins outperformed those from RT. The lowest foam stability was observed in gelatin extracted from the head of RT. According to Nagarajan, Benjakul, Prodpran, Songtipya, & Kishimura, (2012), proteins with shorter chains can migrate more quickly to the interface, resulting in superior foaming behavior. In the present study, gelatin samples derived from the head and vertebral bones of SC, which showed no visible protein bands on SDS-PAGE (Fig. 1), indicating the presence of very low molecular weight compounds, exhibited the best foaming capacity and stability. Conversely, gelatin from RT-vertebral bones, which contained larger protein fragments including a prominent 2α-chain band, demonstrated weaker foaming performance than those from SC. Foam stability depends on multiple factors, including the rate at which surface tension equilibrates, overall solution viscosity, surface viscosity, structural stability of the foam layer, and electrostatic repulsion across the foam interface (Barman *et al*., 2020; He *et al*., 2022). It has been reported that the foaming properties of gelatin are significantly influenced by the pH of the environment, primarily through its effect on the net electrostatic charge of the protein molecules. Near the isoelectric point (pI), where the net charge approaches zero, gelatin molecules exhibit a higher propensity to migrate toward the air-water interface (Goudie *et al*., 2023; Nurul & Sarbon, 2015). This migration reduces surface tension and potentially enhances initial foam formation. Conversely, at pH values distant from the pI, the increased electrostatic repulsion between protein chains prevents molecular aggregation, which can lead to enhanced foam stability (Nurul & Sarbon, 2015).

Table 4- Foam properties of extracted fish gelatins

Source	Byproduct	Foam capacity (%)	Foam stability (%)
SC	Skin	48.33 ± 0.57 ^{e}	20.68 ± 0.24 ^{e}
	Bone	120.00 ± 2.00 ^{a}	44.57 ± 0.32 ^{b}
	Head Bone	68.00 ± 1.00 ^{c}	48.03 ± 2.12 ^{a}
	Soft tissue (head)	99.66 ± 2.08 ^{b}	44.98 ± 0.10 ^{b}
RT	Skin	59.00 ± 2.00 ^{d}	23.52 ± 0.18 ^{d}
	Bone	57.33 ± 1.15 ^{d}	37.68 ± 0.22 ^{c}
	Head	94.33 ± 1.52 ^{f}	non

Mean ± SD of three replicates. Different letters within each column indicate statistically significant differences ($P < 0.05$). Identical letters indicate no significant difference.

Bone-derived gelatins exhibited remarkable performance despite their lower molecular weight distribution. Their high foaming capacity (up to 120%) makes them particularly suitable for aerated food systems. In products such as marshmallows, mousses, and whipped toppings, rapid migration of peptides to the air–water interface is more critical than the development of a strong gel network. Therefore, these bone-derived by-products may have strong potential for targeted application in the confectionery industry as efficient foaming agents.

Conclusion

In conclusion, this study demonstrates that the functional properties of fish gelatin are highly tissue-specific, determining their eventual industrial suitability. Specifically, the gelatin derived from silver carp (SC) head soft tissue, characterized by its remarkably high viscosity, is ideally suited for use as a thickening and stabilizing agent in liquid or semi-solid food systems like sauces and gravies. In contrast, bone-derived gelatins, despite their lower gel strength, exhibit superior foaming properties, making them excellent candidates for aerated confectionery products such as marshmallows and mousses. Furthermore, it should be noted that the moisture content of RT-skin gelatin (16.8%) exceeded the standard limit (15%), which represents a limitation of the current laboratory-scale drying process. Future industrial applications would require optimized dehydration techniques to ensure long-term microbial stability and compliance with commercial quality standards.

Author Contribution

A. Amirafzali: Data curation, Formal analysis, Investigation, Methodology, Writing–original draft. **M. Rezaei:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Resources, Software, Validation, Visualization, Writing – review and editing. **Sh. Naghdi:** Data curation, Formal analysis, Validation, Visualization, Writing– original draft, Writing – review and editing.

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Conflict of Interest

The authors certify that they have no conflict of interest.

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مقایسه فیزیکوشیمیایی و عملکردی ژلاتین استخراج شده از ضایعات ماهی قزل‌آلای رنگین‌کمان (*Oncorhynchus mykiss*) و کپور نقره‌ای (*Hypophthalmichthys molitrix*)

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چکیده

در این پژوهش، ژلاتین از ضایعات مختلف ماهی‌های کپور نقره‌ای (*Hypophthalmichthys molitrix*) و قزل‌آلای رنگین‌کمان (*Oncorhynchus mykiss*) شامل پوست، بافت نرم جمجمه و ستون فقرات استخراج شد. نمونه‌های ژلاتین استخراج‌شده از نظر ترکیب تقریبی، وزن مولکولی، ویژگی‌های عملکردی و ساختاری مورد ارزیابی قرار گرفتند. نتایج نشان داد که تمامی نمونه‌ها دارای محتوای پروتئینی بالا (بین ۶۹/۲۵ ٪ تا بیش از ۸۵/۷۸ ٪) و چربی بسیار پایین (کمتر از ۱/۵ ٪) بودند. بیشترین میزان رطوبت در ژلاتین پوست قزل‌آلا (۱۶/۸ ٪) و کمترین میزان در ژلاتین استخوان مهره‌ای همان گونه (۲/۹۷ ٪) مشاهده شد. تحلیل SDS-PAGE حضور واضح زنجیره‌های ۱α (۱۱۴~۱۲۱-۱۱۴~ کیلو دالتون) و α۲ (۱۰۰~-۱۱۲ کیلو دالتون) را در ژلاتین‌های پوست و بافت نرم جمجمه نشان داد، در حالی‌که نمونه‌های استخوانی فاقد نوارهای مشخص بودند که نشان‌دهنده تخریب شدید کلاژن در اثر تیمار اسیدی شدید است. از نظر ویسکوزیته، بیشترین مقدار (۱۱ cP) مربوط به ژلاتین بافت نرم جمجمه کپور و کمترین مقدار (۲/۶ cP) مربوط به ژلاتین سر قزل‌آلا بود. قدرت ژل بین ۵۳۷/۵ گرم (پوست کپور) تا ۱۹/۶ گرم (سر قزل‌آلا) متغیر بود. نقطه ذوب ژلاتین‌های کپور به‌طور قابل‌توجهی بالاتر از ژلاتین‌های قزل‌آلا بود و برخی نمونه‌ها به مقادیر مشابه ژلاتین پوست گاوی نزدیک شدند. ژلاتین استخوان مهره‌ای کپور بیشترین ظرفیت کف‌زایی (۱۲۰±۲ ٪) و ژلاتین جمجمه‌ای کپور بیشترین پایداری کف (۲/۱۲ ± ۰۳/ ۴۸ ٪) را نشان دادند. این نتایج بیانگر آن است که ضایعات غیرتجاری این دو گونه ماهی، به‌ویژه پوست و بافت نرم جمجمه کپور نقره‌ای، منابع بالقوه ارزشمندی برای تولید ژلاتین با کیفیت بالا جهت کاربردهای غذایی محسوب می‌شوند.

واژه‌های کلیدی: تحلیل SDS-PAGE، ژلاتین ماهی، ضایعات ماهی، ویژگی‌های عملکردی، *Hypophthalmichthys molitrix*، *Oncorhynchus mykiss*

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