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By-Products from the Processing of Canned African Catfish (*Clarias gariepinus*): Potential for the Production of Fishmeal, Collagen, and Gelatin

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ABSTRACT

By-products generated during the canning process of African catfish (*Clarias gariepinus*), particularly heads and skins, represent a promising source of biologically and industrially valuable compounds. This study investigated the valorization of these by-products for the production of fishmeal, collagen, and gelatin. Biochemical analysis of fishmeal derived from the heads revealed high protein (48.42%) and ash (32.88%) contents. Collagen and gelatin extracted from the skins exhibited protein concentrations of 89.09% and 77.40%, respectively. Fourier Transform Infrared (FTIR) spectroscopy confirmed the characteristic structural features of these biomolecules, consistent with reference samples and previously reported data. Sodium dodecyl sulfate–polyacrylamide gel electrophoresis (SDS-PAGE) of the gelatin extract showed protein bands with molecular weights ranging from 20 to 150 kDa, with α-type polypeptide chains identified between 100 and 150 kDa. These findings highlight the significant valorization potential of African catfish processing by-products and suggest promising applications in the pharmaceutical, food, and biomedical industries.

INTRODUCTION

The African catfish (*Clarias gariepinus*) (Burchell, 1822) is a commercially significant aquaculture species worldwide, valued for its rapid growth, resilience to fluctuating water quality, and ability to thrive under high stocking densities with efficient feed conversion **(Akinwole & Faturoti, 2007; Behmene *et al.*, 2022)**. In recent years, the global production of Siluridae has grown substantially. In Africa, farmed *Clarias* production is estimated at approximately 220,000 tons, with Nigeria leading as the top producer **(Diveco2, 2022)**. In Algeria, this species is mainly found in the Tassili n'Ajjer region, particularly in Iherir and Oued Takhamalte–Illizi in the southeast, where local Tuareg communities have maintained an ancestral relationship with these fish for

centuries **(Behmene *et al.*, 2021)**. Globally, the most commonly traded products from catfish are skinless fresh or frozen fillets. However, the by-products generated during filleting represent a valuable raw material for the production of processed products **(Diveco2, 2022)**, thus offering opportunities for the development and diversification of derived products.

On average, by-products account for approximately 50% of the total catch weight. Their valorization provides opportunities for additional income streams, alternative sources of animal protein, and bioactive molecules with high added value for the food, pharmaceutical, and cosmetic industries. A significant portion of fish production not destined for direct human consumption is processed into fishmeal and fish oil. Fishmeal is particularly rich in protein, and according to the Food and Agriculture Organization **(FAO, 2022)**, around 86% of fishmeal produced in 2020 was used in aquaculture. In addition, bioactive compounds such as collagen and gelatin, extracted from fish by-products, are gaining increasing interest in biotechnological and pharmaceutical applications. These biomolecules offer an attractive alternative to terrestrial animal sources, such as pork-derived products, thereby aligning with dietary restrictions observed by Muslim populations **(Usman *et al.*, 2022; Farooq *et al.*, 2024)**.

Collagen, a major structural protein of the extracellular matrix, has wide potential applications in cosmetic sectors **(Avila Rodriguez *et al.*, 2018; Martins *et al.*, 2023)**, pharmaceutical and biomedical **(Kulkarni & Maniyar, 2020; Gaikwad & Kim, 2024)**, and the food **(Farooq *et al.*, 2024)** due to its bioavailability, biocompatibility, biodegradability, and diverse biological functions **(Shi *et al.*, 2025)**. Gelatin, a fibrous protein obtained by partial hydrolysis of collagen, is widely used in the food industry **(Usman *et al.*, 2022)**. It is utilized as an emulsifying, thickening, and stabilizing agent **(Kaiser *et al.*, 2016; Henriet *et al.*, 2020; He *et al.*, 2022)**. In the pharmaceutical sector, gelatin is employed in tablet coatings and in the manufacture of soft and hard capsules **(Al-Nimry *et al.*, 2021; Fazial *et al.*, 2024)**.

This study aimed to explore the potential of the African catfish (*Clarias gariepinus*) processing by-products, specifically heads and skins, as a source for the production of fishmeal, collagen, and gelatin. These materials represent an underexploited resource in Algeria. To our knowledge, this is the first study in the country to investigate the valorization of *Clarias gariepinus* by-products, providing new perspectives for the sustainable development and utilization of these biomaterials.

MATERIALS AND METHODS

1. By-products from canned catfish processing

The processing of catfish into canned products generated a significant quantity of by-products, estimated at 55% of the total weight. These consisted of 29.10% heads, 4.70% skins, 6.89% viscera, and 14.33% bones. Each by-product was washed with tap

water and was then stored at -20°C. In this study, three derived products were targeted: fishmeal from the heads, and gelatin and collagen from the skins.

2. Preparation of fishmeal

An amount of 1.70kg of catfish heads was used for fishmeal production through heating, pressing, and drying **(De Koning, 2002)**. The heads were cut into small pieces and steamed for 30min in a steam cooker, then pressed to separate solid and liquid fractions. The solid fraction was dried in a ventilated dryer at 45°C and ground into a fine, homogeneous, light beige powder of catfish fishmeal.

3. Yield and biochemical composition of the fishmeal

The yield was estimated as the weight of the fishmeal powder per 100g of fresh catfish heads, according to Equation (1).

$$Yield\ (\%) = [weight\ of\ fish\ meal\ (g)/weight\ of\ fresh\ heads] \times 100 \quad (1)$$

The biochemical composition of the fishmeal was determined by analyzing the following parameters:

- **Moisture content**: weight loss after oven drying **(AOAC, 1990)**.
- **Ash content**: weight loss after incineration **(AOAC, 1990)**.
- **Lipid content**: fat extraction using a biphasic chloroform–methanol system (2:1, v/v) **(Folch *et al.*, 1957)**.
- **Free fatty acids**: titration with sodium hydroxide solution **(De Koning, 2002)**.
- **Protein content**: Kjeldahl method **(ISO 1871, 2009)**.

4. Gelatin extraction

Extraction conditions strongly influence gelatin quality, particularly during pretreatment **(Boran & Regenstein, 2010)**. In this study, skin samples underwent saline pretreatment **(Giménez *et al.*, 2005)** followed by acid treatment **(Winarti, 2021; Lestari *et al.*, 2024)**. Gelatin extraction was then performed with water at 65°C for 1h **(Boran & Regenstein, 2010)**.

The procedure was as follows: skins, weighed, washed, and cut into small pieces, they were treated with 0.75 M NaCl solution at a ratio of 1:5 (w/v), stirred for 20min, and rinsed with distilled water until NaCl was removed (confirmed using $AgNO_3$ solution). The samples were then immersed in 0.1% citric acid solution (1:5, w/v) for 30min, followed by rinsing with distilled water until attaining neutral pH. Gelatin extraction was performed in distilled water at 65°C for 1h. The mixture was filtered through Whatman filter paper, and the filtrate was freeze-dried and ground into a whitish powder.

5. Collagen extraction

Collagen was extracted according to **Nagai and Suzuki (2000)**, with slight modifications. Skin fragments were stirred in distilled water for 5min, then immersed in 0.2 M NaOH solution (1:10, w/v) for 24h at 4°C for deproteinization. The sample was

filtered and rinsed until neutral pH. Demineralization was performed by immersing the sample in 0.2 M EDTA (1:10, w/v) for 48h at 4°C, followed by washing to neutral pH. Pre-extraction was carried out in 0.5M acetic acid for 4 days at 4°C. The viscous solution was centrifuged at 14,000 × g for 30min at 4°C, and the supernatant was collected. Collagen precipitation was achieved with 2.4 M NaCl in 0.5 M acetic acid, followed by dialysis against distilled water for 48h at 4°C. The final product was freeze-dried and ground into collagen powder.

6. Physicochemical analysis of gelatin and collagen

6.1. Yield and protein content

The yield was calculated as the weight of the dry extract of gelatin and collagen per 100g of fresh catfish skin, according to equations (2) and (3).

$$Yield\ (\%) = [weight\ of\ \text{lyophilized gelatin}\ (g)/weight\ of\ fresh\ skin] \times 100 \quad (2)$$

$$Yield\ (\%) = [weight\ of\ \text{lyophilized collagen}\ (g)/weight\ of\ fresh\ skin] \times 100 \quad (3)$$

Protein content was determined using the Kjeldahl method **(ISO 1871:2009 (F))**, based on nitrogen determination after mineralization and distillation.

6.2. Viscosity measurement

The viscosity of gelatin and collagen samples extracted from catfish skin was measured following the method described by **GMIA (2012)**.

Extract solutions were prepared at a mass concentration of 6.67%, stirred for 30 minutes at 60°C. The viscosity of the samples was then measured using a Brookfield DV-I+ viscometer.

6.3. Fourier Transform Infrared (FTIR) spectroscopy analysis

Two pellets were prepared by separately mixing potassium bromide (KBr) with collagen and gelatin extracts, respectively, at a mass ratio of 1:100. Each pellet was then analyzed using Fourier Transform Infrared (FTIR) spectroscopy with a Shimadzu IRAffinity-1S spectrometer. Spectra were recorded over the wavenumber range of 400 to 4000 cm^{-1}. Spectral analysis was carried out using the OriginPro software.

6.4. SDS-PAGE analysis

The molecular weight of the extracted collagen and gelatin was determined using sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE, Cleaver Scientific Ltd), according to the method described by **Laemmli (1970)** with slight modifications. A 10% resolving gel and a 5% stacking gel were used. A molecular weight marker (Invitrogen™ Novex™ BenchMark™ Protein Ladder Unstained, Thermo Fisher Scientific), covering a range from 15 to 220 kDa, was used to estimate the molecular weight of the proteins present in the collagen and gelatin extracts.

RESULTS

1. Yield of derived products

The yields obtained for fishmeal, gelatin, and collagen extracted from the catfish by-products are presented in Table (1). In the present study, the use of catfish heads from the canning process yielded approximately 23% of fishmeal, while catfish skin produced around 10% gelatin and 6.5% collagen.

2. Biochemical quality of fishmeal

The chemical composition of fishmeal derived from African catfish (*Clarias gariepinus*) heads is presented in Table (2). The fishmeal showed a high protein content, indicating its potential as a rich source of protein. The lipid content was moderate, while free fatty acids reflected the degree of lipid breakdown. The moisture content was relatively low which is favorable for the product's stability. Finally, the ash content, representing the mineral fraction, was notably high.

Table 1. Yield of fishmeal, gelatin, and collagen from *Clarias gariepinus* by-products

Derived Product	Fishmeal	Gelatin	Collagen
Yield (%)	22.94 ± 1.02	10.36 ± 0.76	6.57 ± 0.40

Table 2. Proximate composition of fishmeal from *Clarias gariepinus* heads

Parameter	Result
Protein (%)	48.42 ± 0.37
Lipids (%)	11.48 ± 0.39
Free fatty acids (%)	11.75 ± 3.70
Moisture (%)	6.65 ± 0.13
Ash (%)	32.88 ± 0.01

3. Properties of gelatin and collagen

3.1. Determination of protein content and viscosity

The protein content and viscosity values recorded for gelatin and collagen extracted from African catfish (*Clarias gariepinus*) skin are presented in Table (3). Collagen exhibited a higher protein content compared to gelatin. In terms of viscosity, collagen also showed a significantly greater value.

Table 3. Protein content and viscosity of gelatin and collagen extracted from catfish skin

Product	Gelatin	Collagen
Protein (%)	77.4 ± 0.93	89.09 ± 1.59
Viscosity (cP)	24 ± 0.56	80 ± 2.03

3.2. FTIR characterization

The infrared spectra of the extracted gelatin and collagen are presented in Fig. (1). There is a notable similarity between the extracted gelatin and commercial gelatin, and a partial similarity with collagen beyond 1200 cm^{-1}. This similarity between collagen and gelatin is explained by the fact that gelatin is a protein derived from the partial hydrolysis of collagen.

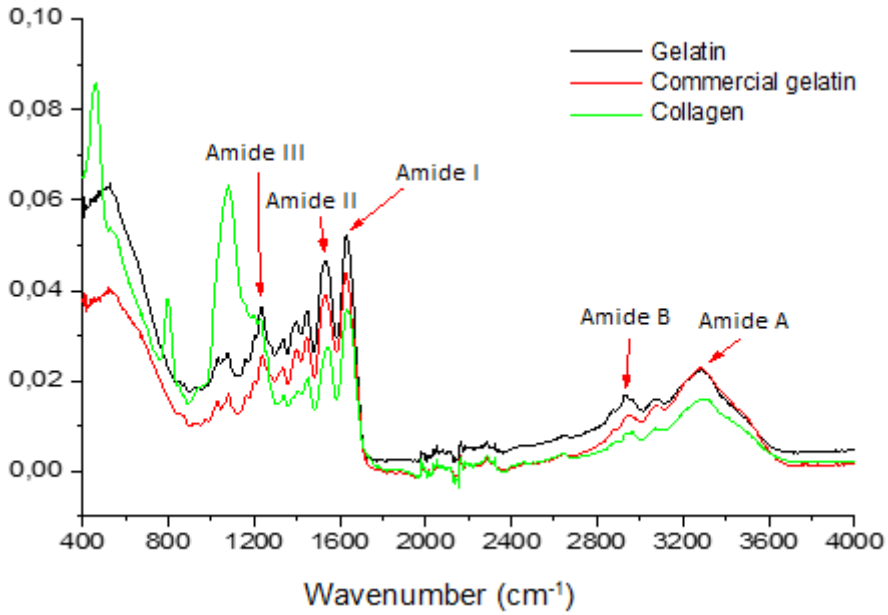

Fig. 1. FTIR spectra of extracted gelatin, commercial gelatin, and extracted collagen

3.3. Molecular weight distribution

The characterization of gelatin and collagen by SDS-PAGE electrophoresis allowed the separation of polypeptides according to their molecular weight. The protein bands are presented in Fig. (2). Sample molecules with the same molecular weight as the marker appear as characteristic bands aligned on the same level. Both the commercial gelatin and the gelatin extracted from catfish skin exhibited proteins with molecular weights ranging from 20 to 150 kDa. The analysis of collagen revealed poorly resolved protein bands.

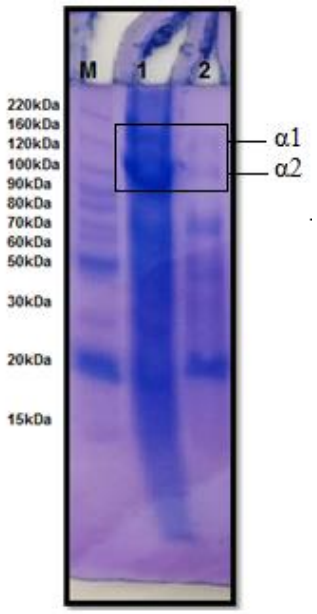

Fig. 2. SDS-PAGE profile of gelatin (2) extracted from catfish skin.
(M) : molecular weight and (1): commercial gelatin.

DISCUSSION

Fishmeal production largely depends on the type and quantity of processing by-products, which vary with fish species and processing methods. The fishmeal yield obtained from African catfish (*Clarias gariepinus*) heads in this study is consistent with the findings of **Jensen *et al.* (1990)**. Similarly, Bratt, in his technical guide on fish canning, noted that canneries generate significant amounts of organic by-products **(Bratt, 2013)**. Comparatively, tuna and salmon canneries typically produce between 30–35% fishmeal, while sardine canneries yield 20–30%.

The gelatin yield obtained from catfish skin is lower than that from tilapia, which reached 13% **(Nurilmala *et al.*, 2024)**, a species regarded as a promising gelatin source. Gelatin yield is strongly influenced by pretreatment conditions (e.g., acid or base type and concentration) **(Kasankala *et al.*, 2007; Niu *et al.*, 2013; Arpi *et al.*, 2018; Lestari *et al.*, 2024)** and extraction parameters such as temperature, duration, and skin-to-water ratio **(Kasankala *et al.*, 2007; Koli *et al.*, 2013; Arpi *et al.*, 2018)**. For example, acid pretreatment of catfish skin yields between 14.97% and 24.1%, with the highest values achieved using higher concentrations of acetic acid **(Lestari *et al.*, 2024)**. Optimization of extraction conditions with response surface methodology (RSM) further increased gelatin yields, reaching 19.83% in grass carp skin **(Kasankala *et al.*, 2007)** and 9.5% in tilapia **(Arpi *et al.*, 2018)**.

The collagen yield from catfish skin is similar to that reported for the shabout (*Arabibarbus grypus*) **(Göçer, 2022)** but lower than that of the grass carp (*Ctenopharyngodon idella*), which reached 10.41% **(Shen *et al.*, 2022)**. Studies on acetic acid concentration have shown significant effects on collagen yield: **Kiew and Don**

(2013) reported the highest yield (26.69%) at 0.7 M acetic acid, with a sharp decline at 0.9 M. Similarly, **Xu *et al.* (2017)** developed a hydrogen peroxide–based pretreatment for *Silurus meridionalis* skin, enabling extraction of collagen with high yield and purity (23.14%).

According to **De Koning (2002)**, standard fishmeal typically contains 8–10% moisture and 10–12% lipids. Elevated moisture encourages microbial growth, while excessive fat accelerates rancidity through peroxide formation, reducing storage stability **(Bayraklı & Duyar, 2021a)**. The fishmeal in this study had low moisture and lipid contents, suggesting good storage potential. Fish lipids are highly digestible and rich in essential polyunsaturated fatty acids (PUFAs) **(Cho & Kim, 2011)**. Free fatty acid content, or acid value, was low compared to the aquaculture standard, which should not exceed 21% **(Jensen *et al.*, 1990)**.

The ash content of catfish head fishmeal was higher than the typical 11–18% range reported in standard fishmeal **(Jensen *et al.*, 1990)**, likely due to the predominance of cranial bones, which are mineral-rich. Fishmeal is a valuable source of minerals such as sodium, calcium, phosphorus, magnesium, and potassium, along with trace elements including zinc, iron, copper, and manganese **(Bayraklı & Duyar, 2021b)**. Although protein levels in catfish head fishmeal were significant, they were lower than the 71.4% protein content of standard aquaculture fishmeal **(Jensen *et al.*, 1990)**. Fishmeal is nevertheless considered highly nutritious due to its easily digestible proteins and balanced amino acid profile (lysine, methionine, cysteine) **(Cho & Kim, 2011; FAO, 2022)**. Its composition, however, is influenced by raw material type, production process, and drying conditions. Fresh raw materials and controlled evaporation during processing yield fishmeal of superior nutritional quality **(Bayraklı & Duyar, 2021b)**.

Variability in fishmeal composition is evident across regions. Fishmeal from the northwest coast of Mexico showed ash contents of 13–25% and protein contents of 53–62% **(Lizárraga-Hernández *et al.*, 2024)**. Samples from Pakistan ranged from 9.9–29.5% fat, 12.7–28.2% ash, and 37.49–66.47% protein **(Khan *et al.*, 2012)**, while Bangladeshi samples showed 31.3–61.2% protein and 13.3–36.7% ash **(Hossain *et al.*, 2016)**.

The gelatin extracted from catfish skin was recorded with a lower protein content than that reported in other studies (≈88%) **(Nurilmala *et al.*, 2022; Rather *et al.*, 2022)** and lower than that of carp and the bighead carp gelatin (≈92.5%) **(He *et al.*, 2022)**. In contrast, collagen protein content coincides with that reported for *Silurus meridionalis* skin (≈89%) **(Xu *et al.*, 2017)**. Protein content in collagen and gelatin is affected by extraction variables, including acid type/concentration and temperature **(Maia *et al.*, 2023; Prasetyo *et al.*, 2023; Gong *et al.*, 2024)**.

The viscosity of gelatin was 24 cP, within the 15–75 mPs range specified for edible gelatin **(GMIA, 2012)**. This is higher than values for *Pangasianodon* sp. (10–12.8 mPa·s) **(Yang *et al.*, 2007; Lestari *et al.*, 2024)** and the channel catfish (*Ictalurus punctatus*,

3.23 cP), but lower than tilapia scale gelatin (56.30 mPs) **(Nurilmala *et al.*, 2024)**. Gelatin viscosity varies with fish species **(Koli *et al.*, 2013)**, fish age, by-product source, and extraction method. For instance, gelatin from the adult Nile perch skins had higher viscosity than that from juveniles **(Muyonga *et al.*, 2004)**. Extraction conditions also influence viscosity, with acidic/alkaline pretreatments in tilapia skins producing viscosities of 9.28–20.16 mPs **(Maia *et al.*, 2023)**. Variation is also linked to hydroxyproline content and non-collagenous protein impurities **(Nurilmala *et al.*, 2024)**. In this study, collagen extracts showed high viscosity, consistent with the view that rod-like collagen molecules form networks around water molecules, enhancing system cohesion **(Kawamata *et al.*, 2017)**.

FTIR analysis revealed characteristic absorption bands of collagen and gelatin, consistent with previous studies **(Kiew & Don, 2013; Jaswir *et al.*, 2017; Xu *et al.*, 2017; Nuryanto *et al.*, 2018; He *et al.*, 2022)**. Five polypeptide bands were identified: amides A and B, and amides I, II, and III. Amide A was observed at 3303 cm^{-1} (collagen) and 3268 cm^{-1} (gelatin), corresponding to N–H stretching vibrations, with shifts due to hydrogen bonding **(He *et al.*, 2022)**. Amide B appeared at 2930–2936 cm^{-1}, linked to CH_2 stretching. Amide I, detected at 1633 cm^{-1}, reflected C=O stretching. Amide II (1549 cm^{-1}) corresponded to N–H bending with C–N stretching. Amide III was observed at 1231–1236 cm^{-1}.

SDS-PAGE revealed α-type collagen polypeptides (100–150 kDa), consistent with reports for the pangasius catfish and freshwater fish such as *Coregonus peled*, carp, and bighead carp **(He *et al.*, 2022; Nurilmala *et al.*, 2022)**. Tilapia gelatin also showed α1 (111 kDa), α2 (97 kDa), and β (212 kDa) chains **(Nurilmala *et al.*, 2024)**. Variations in molecular weight depend on raw material, pretreatment, and extraction **(He *et al.*, 2022; Yu *et al.*, 2024)**. Molecular weight distribution is a critical determinant of gelatin functionality, especially gel strength **(Nurilmala *et al.*, 2022; Wu *et al.*, 2023; Yu *et al.*, 2024)**. Inadequate protein separation during SDS-PAGE may arise from improper sample preparation, unsuitable conditions, or overloading of wells **(Kurien & Scofield, 2012)**.

CONCLUSION

In Algeria, freshwater fish are gaining increasing importance due to the abundance of natural and artificial water bodies across the country. The present study focused on the valorization of African catfish (*Clarias gariepinus*) processing by-products for the production of value-added products, namely fishmeal, collagen, and gelatin. The fishmeal obtained from catfish heads demonstrated promising biochemical quality, while the collagen and gelatin extracted from the skins were confirmed to be proteinaceous in nature through the characterization of key polypeptide chains.

Overall, catfish by-products represent a valuable resource with strong potential for application in the food, pharmaceutical, and related industries.

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