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Effects of Indian and Semi-industrial Extraction Methods on the Quality and Acceptability of Isinglass Produced from Swim Bladders of Cultured Beluga (*Huso huso*), Persian Sturgeon (*Acipenser persicus*), and Stellate Sturgeon (*Acipenser stellatus*)

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Abstract

The protein with a gel like structure, extracted from collagen, is named isinglass, which is derived from the swim bladder of various fish, but is mostly extracted from sturgeon. Isinglass extracted from three types of sturgeon fish, which are commonly reared in Iran, namely Beluga, Persian, and Stellate sturgeon fish, using two different methods, namely the Indian method and the semi-industrial method. In this study, the extracted isinglass was tested for quality in terms of physical, chemical, microbiological, and organoleptic properties for 7 months at room temperature. The percentage of extraction as well as the extraction time were found to be higher in the semi industrial method (63-67% and 3-7 days) than in the Indian method (<24% and 8-24 days). ($P<0.05$). The protein content in semi-industrial method was 74-75%, while in the Indian method, it was about 64%. Moisture, TVB-N, and peroxide were better in the semi-industrial method compared to the Indian samples after 7 months. The semi-industrial samples had the lowest bacterial count, and their sensory evaluation showed higher acceptability scores compared to the Indian samples (above 4 after 7 months). However, the Indian samples were not acceptable in terms of sensory evaluation. The Indian samples had higher nutritional values and lower energy consumption, the semi-industrial method had higher yield, better chemical and microbial quality, and good sensory quality. Thus, it is concluded that semi-industrial method is a better choice for isinglass production on a large scale.

Keywords: Isinglass, Indian method, Physicochemical properties, Semi-industrial method, Sturgeon

Introduction

Isinglass, which is a transparent material that is rich in collagen extracted from the swim bladder of fishes, especially those of the sturgeon family. Isinglass, while being processed and extracted from the swim bladder, the collagen in the fish swim bladder gets transformed into clear and jellylike matter, and has been employed as an effective clarification and adhesion substances since the long history. Nowadays, isinglass, as a fining material applied in wine, beer, fruit juice, vinegar, and others, for clarity and adhesive abilities (Zhao, Sang, & Han, 2022; Sousa *et al*., 2020; Lallemand Brewing, 2023).

The isinglass raw material is considered the highest quality when it comes from fish that have a large swim bladder with an abundance

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of collagen. In this regard, the most appropriate source is believed to be the native species in the southern Caspian Sea, particularly beluga, Persian sturgeon, and stellate sturgeon, owing to their anatomical and Biochemical properties (Dong & Dai, 2022; Carvalho *et al*., 2024). As reported by the Iranian Office of Planning and Budget (2025), over the last 5 years, the production of farmed sturgeon in Iran has surpassed 4000 tons per year, and approximately half of these productions come from three aforementioned species. In commercial utilization of sturgeons, caviar constitutes 10–15% of their total body weight and 50–60% edible flesh; however, the remaining 30–40% body weight like skin, bones, viscera, and swim bladder are usually disposed as industrial waste or converted to low value products, such as fishmeal or animal feed (Akter, Rahman, Bhowmik, Haidar, & Alam, 2016; Zhang, Adachi, Ura, & Takagi, 2019). Even though the contribution of the swim bladder as a by-product in the total processing is low, due to its high protein content, especially collagen, it constitutes an economically valuable product and can make a significant value-added to the waste product (Hussain, Reddy, Chari, & Kumar, 2024a).

Proper valorization of fish processing by-products has gained significant attention in promoting sustainable fisheries and circular bio economy concepts. The extraction of collagen from swim bladder opens new avenues to valorize abundant unused biological materials to value-added commercial products, optimizing the use of resources, decreasing pollution from the processing industry and creating additional value to fish processing industries (Cruz-Lopez *et al*., 2021; Li *et al*., 2023; Kumar, Nidheesh, Govindaraju, Jyoti, & Suresh, 2017; Yuan *et al*., 2024).

Different methods for the extraction of isinglass have been developed, and a factor that affects the efficiency of extraction of isinglass is the processing conditions applied. The generally obtained yield is between 15 - 25% (dry wt) of the swim bladder (Sui *et al*., 2025). Two major systems for the preparation of isinglass are the traditional method and the semi-industrial method. The traditional Indian method is being followed in most parts of India and Southeast Asian countries. This process involves many simple operations such as steeping, drying, boiling, and filtration. This method is characterized by low cost and requires only simple equipment. However, this method suffers from quality inconsistency, long processing time, and unhygienic process conditions due to high dependence on the prevailing climatic conditions. But the semi-industrial method is associated with controlled drying and extraction parameters such as temperature, pH, and processing time, and in general, this process gives the highest yields and uniform and hygienically safer products (Sarkar *et al*., 2023).

So far, most published research on collagenous fish by-products has dealt with their utilization for collagen isolation, production of gelatin, or studies on the physicochemical and functional properties of collagen. Production of isinglass from cultured sturgeon species under semi-industrial scale has not been extensively studied, and only little knowledge exists on the topic. No earlier report has focused on a comprehensive comparison between the Indian traditional and semi-industrial production processes of commercial isinglass from farmed Iranian sturgeon with simultaneous characterization of extraction yield, physicochemical attributes, nutritional value, microbial load, sensory parameters, shelf-life, and industrial relevance.

Because the industry of cultivating Iranian sturgeon is growing, the lack of proper production procedures and commercial requirements on isinglass has been regarded as a vital obstacle in further development. Development of a process is needed to increase production and usage of swim bladder, augment the added value of byproducts of sturgeon processing, and provide additional space for commercial production of high-value added-collagen products. Hence, the purpose of this study is a comparison of a traditional Indian procedure and a semi-industrial procedure to

produce isinglass from the swimming bladders of cultured Beluga, Persian sturgeon, and stellate sturgeon.

Materials and Methods

Collection and Initial Preparation

In the experiment, the cultured sturgeons were conveyed to the Aquatic Products Processing Laboratory within 15 min following the fish harvest. The fresh sturgeons were handled right upon arrival at the laboratory (10 minutes). The fish were washed, eviscerated, and the swim bladder was picked off from both ends with a stainless-steel knife in hand, making efforts to avoid being damaged manually. Then they were repeatedly rinsed with tap water to detach blood, connective tissue, and adipose tissue. After the cleaning and trimming operation of the detached tissues, the swim bladders were immediately placed for the extraction process**.** It took about 30-45 minutes to process one fish to obtain a clean swim bladder, and the duration varied depending on the size of the fish and the technician skillful (Carvalho *et al.*, 2024).

Isinglass Production

Indian Method

Exposed directly to the atmosphere and the sun, the swim bladders were dried as completely as possible so that their moisture content would be as low as possible prior to the flattening procedure (Rodrigues *et al.*, 2021). If the swim bladders are still moist (i.e., soft) at this point, the swim bladders are placed on clean board made of wood or metal so they would not wrinkle during the flattening process. A simple means of manually flattening or smoothing out the surface of the swim bladders, is the application of rolling pin made of wood or equivalent to create a uniform thickness and remove any trapped air or remaining fluid from the inside of the swim bladders. The swim bladders are then cut into sheets and left out in direct sunlight for seven days to thoroughly dry out (Fig. 1) (Koochekian, Zareh, & Yousefi Jourdehi, 2006).

Fig. 1. Preparation of isinglass of sturgeon swim bladders by Indian method

Semi Industrial Method

Thermal driers are used for drying cleaned swim bladders to provide uniform and controlled drying conditions. The dryer temperature was set at 60 °C to allow gradual evaporation of internal moisture while maintaining the collagen structure of the swim bladder. Depending on sample thickness, this required between 8 and 24 hours. Upon partial drying of the samples, the sample was then passed between two stainless steel (or Teflon) plates in an evenly heated flat press. Each sample would be controlled to apply a uniform pressure, further heating required to create a smooth, uniform surface, thus improving the appearance of the final product through the application of both controls in this stage of processing. At the end of this process, each bladder becomes isinglass and will be molded into a flat sheet of isinglass (Fig. 2) (Koochekian *et al.*, 2006).

Fig. 2. Preparation of isinglass from sturgeon swim bladders by semi industrial method

Packaging and Storage

The isinglass sheets were enclosed in polyethylene bags and stored for a period of 7 months at room temperature under laboratory conditions at an ambient temperature of nearly 25°C and relative humidity of 70% according to local climate situations. During this time, the quality of the isinglass was evaluated using a number of tests, including physical, chemical, microbiological and sensory analysis.

Nutritional Analyses

Moisture Determination

After drying, the test container was weighed and then used to measure the sample's moisture using the oven-drying method. Sample size: approximately 10 g of isinglass was placed, and the weight of both the container and the sample was recorded. The sample was transferred to an oven (105°C) for 24 h. After cooling in a desiccator and ambient temperature, the weight of the sample was recorded. The amount of moisture present in the sample was calculated by determining the loss in weight of the material after drying (AOAC, 2005).

Protein Determination (Kjeldahl Method)

A Kjeldahl flask was used to dissolve 2 g of Isinglass using concentrated sulphuric acid with the aid of a catalyst until a clear solution was obtained. The digestion was cooled and alkalized before distilling for the release of ammonia gas to capture it in a solution of boric acid. The captured ammonia was then titrated using Normal sulphuric acid in order to determine the nitrogen content. The total protein content was then calculated by multiplying the nitrogen percentage by 6.25 (AOAC, 2005).

Fat Determination (Soxhlet Method)

Five grams of dried isinglass were weighed, placed into an extraction pouch or filter thimble, and placed into the Soxhlet extractor and extracted for 6 to 8 h using hexane as the extraction solvent. After evaporation of the solvent, residue that was obtained in the sample flask, it was reweighed, and fat content was computed on the basis of the original weight (AOAC, 2005).

Ash Determination

The gravimetric method was used to determine ash content. In other words, to determine ash content, a clean porcelain crucible is placed in an electric muffle furnace and then removed to cool in a desiccator. After weighing the crucible, a 5g sample of isinglass is placed in the crucible and is ashed until the smoke stops. The crucible is then placed back into the furnace and heated for 4 hours to 550 ^{o}C until white or light grey ash is formed. After another period of cooling in the desiccator, the crucible is weighed, and the ash content is calculated as a percentage of the original weight of the sample (AOAC, 2005).

Chemical Analyses

Peroxide Value Determination

The peroxide value was measured by using a colorimetric method. An approximate amount of 5 g of the defatted sample, in a solution of potassium iodide, was added to a solution of

acetic acid and chloroform. This solution was kept away from light for 1 min. The mixture was then diluted with distilled water and titrated using sodium thiosulfate to remove all the yellow color. Once the yellow color was removed, some starch indicators were added, and the titration continued until complete discoloration occurred. The peroxide value was then calculated; results were expressed as the meq /kg of fat (FAO, 1986).

Thiobarbituric Acid (TBARS) Assay

Using a colorimetric method, a thiobarbituric acid assay was performed by dissolving about 200 mg of isinglass (Whole sample without lipid extraction) in trichloroacetic acid. The resulting clarified solution was mixed with thiobarbituric acid indicator and placed into the water bath at 95 ^{o}C for 30 minutes. After cooling down, the solution's absorbance at 532 nm was determined with a spectrophotometer, allowing for the calculation of malondialdehyde levels (lipid oxidation values) (FAO, 1986).

Total Volatile Nitrogenous Bases (TVB-N)

The amount of total volatile nitrogenous bases was quantified using the distillation process. A 10g of the sample was used with 2 g of magnesium oxide and 300 mL of distilled water and a few boiling stones in a Kjeldahl flask. After boiling the sample for a few minutes, the solution was allowed to distill for 25 minutes, and the vapors of the distillate was collected in an Erlenmeyer flask which was filled with 25 ml 2% boric acid solution with few drops of methyl red indicator and titrated with 0.1N sulfuric acid (FAO, 1986).

Microbiological Analyses

Total bacterial Count

To perform the test for total bacterial count, a 25-gram sample of isinglass was aseptically mixed with a sterile diluent (commonly 0.1% peptonized water). Several serial dilutions (dilution factors of 10^{-2} or 10^{-3}, or more if necessary) were then performed, and 1 mL from each dilution of isinglass was pour-plated onto sterile Plate Count Agar (PCA) and subsequently incubated for 48 hours at 37 °C. Once the incubation time was completed, the colonies formed during that time on the PCA were then counted to give a total count of all viable bacteria as logarithmic colony-forming units per gram of sample (log CFU/g) tested (Maturin & Peeler, 2001; Andrews & Hammack, 2003; Feldsine, Abeyta, & Andrews, 2002).

Yeast and Mold Count

For determining yeast and mold counts, the sample dilution was completed as specified above. 1 mL of the proper dilution was surface plated onto Sabouraud dextrose agar. The plated samples were incubated at 25 °C for 7 days. After incubation period, the fungal colonies formed were counted and then expressed in terms of log colony-forming unit/gram sample (Tournas, Stack, Mislivec, Koch, & Bandler, 2001; Kovács *et al*., 2025).

Pathogenic Bacteria Identification

The possible presence of pathogenic microorganisms such as Salmonella, *Staphylococcus* spp., *Escherichia coli* and coliforms were assessed. To detect Salmonella, 25 g of the sample was incubated for 18–24 h at 37 °C in buffered peptone water, then transferred to selective media, such as Xylose Lysine Deoxycholate agar and Salmonella-Shigella agar (Andrews *et al*., 2024), and incubated for an additional 24 hours. Potential Salmonella colonies were then further processed to confirm their identity with biochemical testing (Catalase, coagulase, and indole testing). *Staphylococcus aureus* (25 g) (Bennet & Lancette, 2001) was detected on Bird Parker Agar, and *E.coli* (50 g) (Feng, Weagant, Grant, & Burkhardt, 2020) was identified on Eosin Methylene Blue Agar.

Sensory Evaluation

Trained panelists assessed sensory characteristics (color, odor, appearance, texture (brittleness) on a scale of 1 (dislike extremely) to 5 (like extremely) for seven months at

ambient (room) temperature as part of an ongoing study to evaluate potential changes in visual quality and overall acceptability of isinglass over the storage period. During sensory analysis, each of the isinglass was identified with a code number (Gilbert, 2013).

The sensory evaluation was carried out by thirty well trained panelists male and female (Master's and PhD in seafood processing and food industry), aged around 40, and they had past experience in the sensory evaluation of fish and fishery products. In addition, training was given to panelists before the experiment, where they learned the objectives of the study, the sensory attributes evaluated (appearance, color, odor, texture (brittle), and overall acceptance), the procedures in sensory evaluation, and were provided with reference samples with different quality levels. Reference samples were given in order to ensure uniformity in the interpretation of the criteria to be evaluated and to enhance similarity in panelists' scoring. All evaluations were carried out under similar environmental conditions with consistent protocols for the storage period.

Color was observed for the changes shown in transparency, yellow, darkness, and cloudiness, and then given a score. The odor was identified based on whether it was natural, rancid, or offensive, and a numerical score was given to it. Product's Appearance was observed on the basis of whether the original shape of the product is still intact, whether there were any defects on the product (cracks and deformation), as well as whether all the products have a similar shape. Isinglass texture was checked through touches and moderate pressures based on the brittleness, flexibility, as well as excessiveness of softness of the products, and eventually, all of the above attributes are also considered, thus resulting in an acceptable overall rating for each product after the respective scores were given (Gilbert, 2013).

Physical Analyses

The physical characteristics of isinglass were evaluated over seven months of storage at ambient temperature. Assessments of dry weight, texture (or flexibility and brittle nature), color, and pH were conducted to determine how the sample reacted to the environment (FAO, 1986).

Texture Analysis

Texture was determined by visual inspection or objectively by a texture analyzer that measures the force required to break (or bend) the sample under a particular pressure. By determining how much effort was needed to break the sample determine how strong the sample was and how much it had deteriorated during storage. A sudden decrease in the amount of force required to break, or increased brittleness, would indicate the deterioration of the product during storage.

pH Measurement

The potentiometric technique was used to measure the pH levels. To do this, approximately 1 g of isinglass was added to 100 mL of distilled water, and the solution was placed at room temperature. When the pH electrode was inserted into the solution, the pH value was read directly from the pH meter (FAO, 1986).

Color Measurement

Color values of all samples were determined with the Hunter Lab color flex (USA) color-measurement instrument, recorded in Hunter color values of lightness (L), Red-Green (a), and Yellow-Blue (b).

Mineral Composition

Mineral concentrations, including calcium, phosphorus, magnesium, sodium, iron, zinc, and copper, were analyzed by AAS. Samples were placed in the electric furnace, and after being calcified to a white powder, they were dissolved in 1ml concentrated nitric acid. The contents of each crucible were poured into 250ml volumetric flasks. They were made to a final volume of 250ml using deionized water,

shaken up thoroughly, and sequentially diluted if necessary. Then, lanthanum trichloride of 0.1 (1/10 of the total volume) was added to each flask, filled with sufficient deionized water, and mixed well. Analyses were performed with blank solutions and with an air acetylene flame atomic absorption burner within the wavelength range of 400-800nm. The standards were prepared by dissolving 1000 mg of each pure mineral element in 1L deionized water to get stock solutions containing 1000mg/L. Each 100ml volumetric flask was pipetted 0ml, 1ml, 2ml, 3ml, 4ml, 5ml of standard solution, added 10ml lanthanum trichloride, and added deionized water up to 100ml, then mixed thoroughly (AOAC, 2005).

Amino Acid Profile

After the sample cooled to 24°C, it was rotated at 4000 RPM (3756×g RCF) for five minutesto precipitate any undissolved material. Then, a 10 µl of the supernatant mixed with 1 mL of distilled water in a new vial. For most amino acids, used stable isotope labeled mixtures as both calibration and internal standards. Isoleucine and histidine got a slightly different treatment; leucine was the internal standard and 3-methylhistidine included. Then, 50 µl of the sample was blended by 50 µl of the labeled standard and 700 µl of indicator. After mixing for five seconds, it was injected into a C18 HPLC column. All of them were conducted using mobile phases A and B, running a gradient elution at 0.7 mL/min. Detection occurred at 254 nm (Weber, 2022; Peace & Gilani, 2005).

Yield Determination

To calculate yield, used the formula of r=P/C where: P - Product (Final), C - Raw Material (Starting). Therefore, used 500 g to compute yield. Then computed yield by dividing the difference between the amount of isinglass produced from each treatment divided by the total weight of raw material (500 g) multiplied by 100 (Demerjian, 2018).

Water Activity

Measurements of water activity of the isinglass were performed with a calibrated water activity meter (AquaLab 4TE, Meter Group Inc., Pullman, WA, USA). Before analysis, the instrument was calibrated with standard saturated salt solutions following the instructions of the manufacturer. A finely cut portion of 2-3 g of isinglass was loaded into the clean, dry sample cup to cover the bottom surface, and the sample was not placed above the edge of the cup. Then the cup was loaded into the measuring chamber of the instrument, and the a_w value was taken after it reached the steady state at 25 ^oC. Measurements of a_w were made under laboratory conditions, just after the processing and handling of the samples to avoid water with surroundings air and water loss or absorption.

Sampling

Once per month, over a period of seven months (at room temperature), a range of tests were performed on the samples stored for varying times. These tests included physical, chemical, sensory, and nutritional analyses. The amino acid profiles and mineral compositions of products were tested once during the study.

Statistical Analysis

SPSS Statistical Package version 25 was used for comparing experimental samples based on microbiological, chemical, mineral, amino acid profiling, and physical analyses. The experimental design of the current study utilized three independent variables: fish species, method of extraction, and storage duration. Based on this experimental design, the data analysis addressed the main effects of all variables as well as any potential interactions among variables. For factorial experiments, analysis of variance (ANOVA) are more suitable for statistical analyses than using simple pairwise comparison tests. It can test for species, method, and time effects simultaneously, and also it can test for interaction effects (Species- Method, Species-Time, Method- Time, and Species- Method

Time interactions). Interactions among the variables are crucial.

This study uses factorial ANOVA and post hoc analyses like Tukey's HSD or repeated measures over time to analyze the isinglass quality characteristics. Statistical differences at $p<0.05$ were performed using a 95% confidence interval. In order to evaluate differences in sensory evaluation data, the Kruskal Wallis test was used for non parametric analysis, and the Mann Whitney test was performed if necessary. The effect of storage time on microbial, chemical and sensory characteristics within each treatment and comparison of treatment means over time were measured using a two-way ANOVA. All data are presented as mean ± standard deviation. Fish from each sturgeon healthy stocks of cultured populations have been randomly selected for this study. The experimental procedures' treatments were 6 resulting from the crossing of 3 species and 2 extraction methods, which were Indian traditional method and semi industrial method. The two procedures were carried out on each treatment by 3 biological independent replicas, were in the same parameters of conditions. Thus each replica not only consisted of fishes of another source origin, but also formed an independent batch of samples, instead of an analytic repeat from a specific product batch. All biological replica samples were stored in the same environmental conditions after extraction, then examined at specific dates: month zero and subsequent 7 months. In each specific time of examinations 3 sets of analyses have been carried out per replicate (24 analyses for each treatment: 3 replicates × 8 time points) giving 72 samples/per method of extraction; totally 144 samples examined for 2 methods of extraction.

Independent analysis of species, extraction, and their interactions on all determined parameters was performed using the factors identified. Biological samples used to generate each individual quality measurement of each treatment combination were biological replicates to remove variability from the batches and to enable separation between the differences among the sturgeons and differences derived from the extraction method.

Sample Size Justification

The sample size was determined based on the factorial experimental design and the availability of biological materials while ensuring independent biological replication for each treatment combination. Three independent biological replicates were included for each combination of fish species, extraction method, and storage time, providing a balanced experimental design suitable for three-way analysis of variance. The observed treatment effects across the primary response variables indicated that the selected sample size provided sufficient sensitivity to detect biologically meaningful differences under the experimental conditions of the present study.

To further evaluate the adequacy of the experimental design, a post hoc power analysis was performed. The analysis indicated that the selected sample size provided sufficient statistical power (power>0.80) to detect the observed differences among treatments, supporting the reliability of the statistical comparisons

Results

Results are exhibited as mean ± standard deviation (n= 3). Unlike lowercase letters within the same column, present remarkable differences among sampling times ($P<0.05$), whereas the same lowercase letters show no main difference ($P> 0.05$). Dissimilar uppercase letters within the same row illustrate meaningful differences between treatments at the same keeping time ($P<0.05$), whereas identical uppercase letters display no notable difference ($P> 0.05$).

From Table 1, it can be seen that there was a decline in the protein content of items produced using the Indian method after seven months of storage ($P<0.05$). Simultaneously, the moisture content increased significantly during this time ($P<0.05$).

Table 1- The results from aproximate analysis of isinglass treatments made by means of industrial and Indian methods for seven months at room temperature (%)

Indian method												
Index	**Ash**			**Moisture**			**Fat**			**Protein**		
Storage period (Month)	**stellate sturgeon**	**Beluga**	**Persian sturgeon**	**stellate sturgeon**	**Beluga**	**Persian sturgeon**	**stellate sturgeon**	**Beluga**	**Persian sturgeon**	**stellate sturgeon**	**Beluga**	**Persian sturgeon**
Month 1	1.45 ± 1.12^{aA}	1.98 ± 1.11^{aA}	2.67 ± 1.66^{aA}	28.98 ± 1.95^{bA}	28.17 ± 1.99^{bA}	28.91 ± 1.18^{Ab}	0.73 ± 0.51^{Aa}	0.95 ± 0.24^{Aa}	0.84 ± 1.28^{Aa}	68.84 ± 1.19^{aB}	68.90 ± 1.24^{aB}	67.58 ± 1.23^{aB}
Month 7	0.98 ± 0.76^{aA}	1.35 ± 0.95^{aA}	1.95 ± 1.59^{aA}	33.05 ± 1.84^{aA}	32.14 ± 1.93^{Aa}	33.18 ± 1.39^{aA}	0.61 ± 0.47^{Aa}	0.81 ± 0.31^{Aa}	0.73 ± 1.36^{Aa}	65.36 ± 1.27^{bC}	65.70 ± 1.98^{bC}	64.14 ± 1.14^{bC}
Industrial method												
Month 1	0.72 ± 0.37^{aA}	0.99 ± 0.54^{aA}	0.84 ± 0.25^{aA}	23.87 ± 1.54^{aB}	23.65 ± 1.42^{Ba}	23.85 ± 1.25^{Ba}	0.14 ± 0.10^{aA}	0.18 ± 0.12^{aA}	0.17 ± 0.11^{aA}	75.27 ± 1.43^{aA}	75.18 ± 1.17^{aA}	75.14 ± 1.15^{aA}
Month 7	0.70 ± 0.39^{Aa}	0.85 ± 0.62^{Aa}	0.61 ± 0.41^{Aa}	24.52 ± 1.19^{Ba}	24.18 ± 1.75^{Ba}	25.16 ± 1.36^{Ba}	0.11 ± 0.08^{aA}	0.14 ± 0.13^{Aa}	0.12 ± 0.09^{aA}	74.67 ± 1.76^{aA}	74.83 ± 1.56^{aA}	74.11 ± 1.90^{aA}

The industrially processed item had a protein content that remained relatively stable throughout the experiment and exhibited lesser fluctuations in moisture when compared to the Indian method (P<0.05). Ash had not significant differences in these samples during storage period (P>0.05). Thus, semi-industrial products presented a higher level of stability than those produced using the Indian method.

Results are exhibited as mean ± standard deviation (n= 3). Unlike lowercase letters within the same column, present remarkable differences among sampling times (P<0.05), whereas the same lowercase letters show no main difference (P> 0.05). Dissimilar uppercase letters within the same row illustrate meaningful differences between treatments at the same keeping time (P<0.05), whereas identical uppercase letters display no notable difference (P> 0.05).

As illustrated in Table 2, glycine, proline, and hydroxyproline were determined to be the three most abundant amino acids in isinglass. When both extraction methods were compared, the results showed that there was no statistically significance difference (p > 0.05) between the amino acid profiles of both methods, apart from the small differences that existed between the two extraction methods.

Findings from Table 3 illustrate that production yield using the industrial method was significantly greater compared to the production yield using the Indian method (P<0.05). The industrial process had less production time than the Indian method (P<0.05). Furthermore, there was a greater degree of consistency between batches using the industrial method than using the Indian method (P<0.05). Waste and rejections were also reduced to less than half using the industrial method relative to the Indian method (P<0.05). There were higher amounts of energy and water consumed for the industrial process; however, the Indian method was determined to be more energy-efficient (P<0.05). The low yield and long processing time would limit the ability to use the Indian method for commercial applications.

Table 2– Comparison of the amino acid profiles of isinglass samples produced from swim bladders of sturgeon by industrial and Indian methods (residues/1000 residues)

Treatment	Industrial			Indian		
Fish species Amino acid profile	Stellate sturgeon	Beluga	Persian sturgeon	Stellate sturgeon	Beluga	Persian sturgeon
Glycine	25±1.83^{a}	27±1.33^{a}	26±1.55^{a}	26±1.59^{a}	28±1.56^{a}	27±2.15^{a}
Proline	12±1.77^{a}	14±1.52^{a}	13±1.79^{a}	12±1.71^{a}	14±1.73^{a}	13±1.28^{a}
Hydroxyproline	12±1.37^{a}	13±1.96^{a}	12±1.98^{a}	12±1.82^{a}	14±1.62^{a}	13±1.19^{a}
Alanine	8±1.32^{a}	8±1.57^{a}	9±1.99^{a}	8±1.89^{a}	9±1.53^{a}	8±1.17^{a}
Arginine	8±1.14^{a}	9±1.91^{a}	8±1.64^{a}	8±1.95^{a}	9±1.51^{a}	8±1.36^{a}
Aspartic Acid	5±1.29^{a}	6±1.13^{a}	5±2.12^{a}	5±1.91^{a}	6±1.13^{a}	5±1.45^{a}
Glutamic Acid	10±1.21^{a}	11±1.89^{a}	10±1.94^{a}	10±1.92^{a}	11±1.27^{a}	10±1.35^{a}
Leucine	2±1.15^{a}	3±1.80^{a}	2±1.58^{a}	2±1.12^{a}	3±1.45^{a}	2±1.57^{a}
Lysine	3±1.36^{a}	4±1.48^{a}	3±1.50^{a}	3±1.45^{a}	4±1.16^{a}	3±1.38^{a}
Serine	3±1.84^{a}	4±1.75^{a}	3±1.29^{a}	3±1.23^{a}	4±1.96^{a}	3±1.87^{a}
Histidine	1>	1>	1>	1>	1>	1>
Methionine	1>	1>	1>	1>	1>	1>

Table 3– Comparison of yield and production indices of isinglass treatments from sturgeon swim bladders prepared by industrial and Indian methods

Treatment	Industrial			Indian		
Fish species Index	stellate sturgeon	Beluga	Persian sturgeon	stellate sturgeon	Beluga	Persian sturgeon
Yield on Dry Matter Basis (%)	63^{b}	67^{a}	65^{ab}	22^{a}	24^{a}	23^{a}
Production time	8-24 hours	8-24 hours	8-24 hours	3-7 day	3-7 day	3-7 day
Labor (hours per kilogram, h/kg)	3-5^{a}	3-5^{a}	3-5^{a}	0.5-1.5^{b}	0.5-1.5^{b}	0.5-1.5^{b}
Energy (kwh/kg)	1-2^{b}	1-2^{b}	1-2^{b}	4-8a	4-8^{a}	4-8^{a}
Water (l/kg)	120-250	120-250	120-250	80 -150	80 -150	80 -150
Batch-to-Batch Quality Consistency	High	High	High	Medium	Medium	Medium
Waste/Rejection	3^{b}	3^{b}	3^{b}	6^{a}	6^{a}	6^{a}

Fresh swim bladders from Beluga sturgeon (mean body weight: 12–15 kg) had a mean weight of about 300–400 g and were obtained about 120–160 g after drying. Swim bladders from Persian sturgeon (mean body weight: 8–12 kg) were in the range of 200–300 g, and 80–120 g dried isinglass; whereas swim bladders from stellate sturgeon (mean body weight: 3–5 kg) were smaller (approximately 80–120 g) and 35–55 g dried isinglass. On average, 8 Beluga, 11 Persian sturgeon and 21 stellate sturgeon were used for each treatment.

Table 4– Major micronutrients in sturgeon isinglass prepared by Indian and industrial methods (mg/100 g)

Processing method	Industrial			Indian		
Fish species Mineral components	stellate sturgeon	Beluga	Persian sturgeon	stellate sturgeon	Beluga	Persian sturgeon
Calcium	26±1.17^{b}	29±1.53^{a}	28±1.58^{ab}	55±2.17^{b}	58±1.99^{a}	57±2.13^{ab}
Phosphorus	14±1.83^{b}	19±1.76^{a}	18±1.27^{a}	36±1.24^{b}	39±2.16^{a}	38±2.26^{ab}
Magnesium	2±1.26^{b}	5±1.19^{a}	4±1.12^{ab}	5±1.56^{b}	10±1.34^{a}	9±1.16^{a}
Sodium	53±2.65^{b}	58±2.19^{a}	57±1.92^{a}	74±1.95^{b}	78±2.15^{a}	77±2.34^{a}
Iron	0.1±0.01^{a}	0.3±0.05^{a}	0.2±0.07^{a}	0.3±0.2^{a}	0.5±0.3^{a}	0.4±0.13^{a}
Zink	0.1±0.03^{a}	0.3±0.04^{a}	0.2±0.06^{a}	0.2±0.01^{a}	0.4±0.2^{a}	0.3±0.21^{a}
Copper	0.01±0.02^{a}	0.02±0.01^{a}	0.01±0.03^{a}	0.01±0.02^{a}	0.03±0.01^{a}	0.02±0.11^{a}

Results are exhibited as mean ± standard deviation (n = 3). Unlike lowercase letters within the same column, present remarkable differences among sampling times ($P<0.05$), whereas the same lowercase letters show no main difference ($P> 0.05$). Dissimilar

uppercase letters within the same row illustrate meaningful differences between treatments at the same keeping time (P<0.05), whereas identical uppercase letters display no notable difference (P> 0.05).

The calcium, phosphorus, sodium, and magnesium, in the isinglass processed by Indian method is higher compared to the semi industrial made isinglass (Table 4). However, the difference in the concentrations of copper, iron and zinc were non-significant at a 5% level between the two methods (p>0.05).

Results are exhibited as mean ± standard deviation (n = 3). Unlike lowercase letters within the same column, present remarkable differences among sampling times (P<0.05), whereas the same lowercase letters show no main difference (P> 0.05). Dissimilar uppercase letters within the same row illustrate meaningful differences between treatments at the same keeping time (P<0.05), whereas identical uppercase letters display no notable difference (P> 0.05).

Statistically there were no differences in total microbial counts for all samples during months 1 and 2 (P>0.05), but from month 3 and thereafter the comparison of both methodologies resulted in significant differences (P<0.05). No molds or yeasts were detectable for either samples until month 7 at which point mold and yeast were observed on all Indian methodology prepared isinglass materials. In addition to this, all pathogenic microorganisms (Salmonella, coliform, *S. aureus*, *E. coli*) were not detected in any of the materials prepared using either method. Based on this data, it was determined that the industrial method maintained good microbiological quality of isinglass for the entire storage period (7 months) compared to the Indian method which had acceptable microbiological quality at the end of 6 months (Table 5).

Results are exhibited as mean ± standard deviation (n = 3). Unlike lowercase letters within the same column, present remarkable differences among sampling times (P<0.05), whereas the same lowercase letters show no main difference (P> 0.05). Dissimilar uppercase letters within the same row illustrate meaningful differences between treatments at the same keeping time (P<0.05), whereas identical uppercase letters display no notable difference (P> 0.05).

Table 5– Microbiological characteristics of isinglass treatments prepared from sturgeon swim bladders by industrial and Indian methods during seven months of storage at room temperature (log CFU/g)

Processing method	**Indian method**					
Index	**Total bacterial counts**			**Molds and yeasts**		
Treatment	**Persian sturgeon**	**Beluga**	**stellate sturgeon**	**Persian sturgeon**	**Beluga**	**stellate sturgeon**
Day 1	3.19 ± 0.39^{eA}	3.69 ± 0.38^{dA}	3.75 ± 0.15^{bA}	CFU/g10> (detection limit)	CFU/g10> (detection limit)	CFU/g10> (detection limit)
Month 1	3.25 ± 0.28^{deA}	3.88 ± 0.27^{cdA}	3.78 ± 0.17^{bA}	CFU/g10> (detection limit)	CFU/g10> (detection limit)	CFU/g10> (detection limit)
Month 2	3.41 ± 0.89^{dA}	3.97 ± 0.19^{cA}	3.87 ± 0.26^{abA}	CFU/g10> (detection limit)	CFU/g10> (detection limit)	CFU/g10> (detection limit)
Month 3	3.68 ± 0.58^{cdA}	4.16 ± 0.33^{bcA}	3.91 ± 0.45^{aA}	CFU/g10> (detection limit)	CFU/g10> (detection limit)	CFU/g10> (detection limit)

Month 4	3.94±0.53^{bcA}	4.25±0.49^{bA}	4.01±0.32^{aA}	CFU/g10> (detection limit)	CFU/g10> (detection limit)	CFU/g10> (detection limit)
Month 5	4.21±0.64^{abA}	4.37±0.67^{bA}	4.14±0.29^{aA}	CFU/g10> (detection limit)	CFU/g10> (detection limit)	CFU/g10> (detection limit)
Month 6	4.57±0.66^{aA}	4.51±0.54^{bA}	4.28±0.35^{aA}	CFU/g10> (detection limit)	CFU/g10> (detection limit)	CFU/g10> (detection limit)
Month 7	5.47±0.69^{aA}	5.17±0.79^{aA}	5.36±0.84^{aA}	2.60+1.37^{a}	2.60+1.45^{a}	2.74+1.56^{a}
Industrial method						
Day 1	1.59±0.11^{aA}	1.82±0.19^{bA}	1.72±0.35^{cA}	CFU/g10> (detection limit)	CFU/g10> (detection limit)	CFU/g10> (detection limit)
Month 1	1.66±0.18^{aA}	1.85±0.15^{bA}	1.91±0.24^{cA}	CFU/g10> (detection limit)	CFU/g10> (detection limit)	CFU/g10> (detection limit)
Month 2	1.70±0.29^{aA}	1.90±0.23^{bA}	2±0.17^{bcA}	CFU/g10> (detection limit)	CFU/g10> (detection limit)	CFU/g10> (detection limit)
Month 3	1.78±0.68^{aA}	1.94±0.43^{bA}	2.19±0.38^{bA}	CFU/g10> (detection limit)	CFU/g10> (detection limit)	CFU/g10> (detection limit)
Month 4	1.85±0.65^{aA}	2.04±0.39^{abA}	2.28±0.46^{bA}	CFU/g10> (detection limit)	CFU/g10> (detection limit)	CFU/g10> (detection limit)
Month 5	1.94±0.69^{aA}	2.17±0.27^{aA}	2.40±0.64^{abA}	CFU/g10> (detection limit)	CFU/g10> (detection limit)	CFU/g10> (detection limit)
Month 6	2.04±0.63^{aB}	2.31±0.31^{aA}	2.54±0.51^{aA}	CFU/g10> (detection limit)	CFU/g10> (detection limit)	CFU/g10> (detection limit)
Month 7	2.28±0.88aB	2.56±0.73aA	2.78±0.52^{aA}	CFU/g10> (detection limit)	CFU/g10> (detection limit)	CFU/g10> (detection limit)

Total volatile nitrogen bases and peroxide values increased significantly more in the Indian method than the industrial method (P<0.05). By the second month, the differences between the two methods were statistically significant (P<0.05), but the respective levels of chemical stability of the industrial method were superior (Table 6). Over the 7-month period peroxide values increased gradually in all treatments; though it rose significantly in Indian method prepared samples than semi-industrial preparation (P<0.05) without significant differences among the three sturgeon species (P>0.05).

Results are exhibited as mean ± standard deviation (n = 3). Unlike lowercase letters within the same column, present remarkable differences among sampling times (P<0.05), whereas the same lowercase letters show no main difference (P> 0.05). Dissimilar uppercase letters within the same row illustrate meaningful differences between treatments at the same keeping time (P<0.05), whereas identical uppercase letters display no notable difference (P> 0.05).

Table 6– Evaluation of the chemical properties of isinglass treatments prepared from sturgeon swim bladders by industrial and Indian methods during seven months of storage at room temperature

Index		TBARS (mg MDA/kg)					Peroxide (meq/kg lipid)						TVB-N (mg/100g)					
Treatment		Industrial			Indian		Industrial			Indian			Industrial			Indian		
Storage period	stellate sturgeon	Beluga	Persian sturgeon	stellate sturgeon	Beluga	Persian sturgeon	stellate sturgeon	Beluga	Persian sturgeon	stellate sturgeon	Beluga	Persian sturgeon	stellate sturgeon	Beluga	Persian sturgeon	stellate sturgeon	Beluga	Persian sturgeon
Day 1	0.68±0.53^{aA}	0.46±0.32$_{aA}$	0.54±0.42$_{aA}$	0.54±0.31$_{aA}$	0.28±0.18$_{aA}$	0.24±0.13$_{aA}$	1.44±1.36^{bA}	1.34±1.27^{cA}	1.42±1.49^{bA}	1.76±1.20^{eA}	1.64±1.27	1.82±1.14^{dA}	8.32±1.8^{hA}	8.12±1.19^{hA}	7.84±1.12^{hA}	11.64±1.67^{hA}	11.46±1.17^{hA}	11.26±1.26^{hA}
Month 1	1.26±0.59^{aA}	0.68±0.52$_{aA}$	0.78±0.55$_{aA}$	0.68±0.17$_{aA}$	0.46±0.37$_{aA}$	0.32±0.22$_{aA}$	1.86±1.58^{abA}	1.78±1.69^{abA}	1.66±1.50^{bA}	2.38±1.23^{dA}	2.16±1.93	2.44±1.22^{aA}	8.98±1.26^{gA}	8.96±1.46^{gA}	8.46±1.15^{gA}	12.68±1.89^{gA}	12.84±1.31^{gA}	12.68±1.13^{gA}
Month 2	1.68±0.78^{aA}	1.56±0.93$_{aA}$	1.64±0.64$_{aA}$	0.95±0.39$_{aA}$	0.74±0.54$_{aA}$	0.68±0.57$_{aA}$	2.24±1.19^{aA}	2.16±1.35^{aA}	2.05±2.12^{aA}	4.62±1.36^{aA}	4.54±1.57	4.68±1.31^{aA}	9.64±1.35^{fA}	9.58±1.54^{fA}	9.42±1.23^{fA}	14.58±1.91^{fA}	14.24±1.42^{fA}	13.42±2.11^{fA}
Month 3	1.50±0.99^{aA}	1.34±0.91$_{aA}$	1.32±0.65$_{aA}$	0.84±0.58$_{aA}$	0.62±0.52$_{aA}$	0.54±0.34$_{aA}$	1.98±1.34^{aA}	1.88±1.77^{aA}	1.84±1.16^{abA}	4.38±1.39^{abA}	4.32±1.78	4.46±1.39^{abA}	10.54±1.49^{eA}	10.46±1.59^{eA}	10.12±1.32^{eA}	15.84±1.88^{eA}	15.35±1.45^{eA}	14.80±1.97^{eA}
Month 4	1.42±0.28^{aA}	1.20±0.99$_{aA}$	1.28±0.71$_{aA}$	0.75±0.38$_{aA}$	0.54±0.45$_{aA}$	0.52±0.40$_{aA}$	1.66±1.52^{bA}	1.54±1.17^{bcA}	1.68±1.14^{bcA}	4.02±1.40^{bA}	3.88±1.75	4.00±1.42^{bA}	11.34±1.85^{dA}	11.14±1.47^{dA}	11.16±1.47^{dA}	17.14±2.14^{dA}	16.98±1.53^{dA}	15.46±2.43^{dA}
Month 5	1.26±0.39^{aA}	1.08±0.95$_{aA}$	1.12±0.82$_{aA}$	0.61±0.21$_{aA}$	0.45±0.12$_{aA}$	0.48±0.31$_{aA}$	1.38±1.17^{bcA}	1.32±1.23^{cA}	1.24±1.25^{cdA}	3.54±1.90^{bcA}	3.42±1.71	3.46±1.38^{cA}	11.98±1.86^{cA}	11.96±2.25^{cA}	12.46±1.52^{cA}	18.68±2.29^{cA}	18.46±2.25^{cA}	17.28±2.18^{cA}
Month 6	0.94±0.61^{aA}	0.76±0.60$_{aA}$	0.85±0.51$_{aA}$	0.49±0.17$_{aA}$	0.38±0.29$_{aA}$	0.42±0.25$_{aA}$	1.16±1.13^{cA}	1.12±1.03^{cdA}	1.18±1.13^{dA}	3.20±1.72^{cA}	3.12±1.80	3.24±1.13^{cA}	13.18±1.97^{bA}	12.98±2.16^{bA}	13.12±1.59^{bA}	20.44±2.24^{bA}	20.56±2.43^{bA}	20.82±2.24^{bA}
Month 7	0.90±0.78^{aA}	0.72±0.59$_{aA}$	0.80±0.76$_{aA}$	0.42±0.13$_{aA}$	0.34±0.26$_{aA}$	0.39±0.28$_{aA}$	1.07±1.05^{cA}	1.05±1.01^{dA}	1.11±1.09^{dA}	3.11±1.79^{cA}	2.99±1.81	3.10±1.50^{cA}	14.48±1.59^{aA}	14.12±1.99^{aA}	14.98±1.63^{aA}	22.95±2.30^{aA}	23.17±1.90^{aA}	22.14±2.36^{aA}

Table 7– Evaluation of the sensory attributes of isinglass treatments prepared from sturgeon swim bladders by industrial and Indian methods during seven months of storage at room temperature

Indian method												
Index	**Overall acceptance**			**Texture**			**Odor**			**Color**		
Treatment Storage period	stellate sturgeon	Beluga	Persian sturgeon	stellate sturgeon	Beluga	Persian sturgeon	stellate sturgeon	Beluga	Persian sturgeon	stellate sturgeon	Beluga	Persian sturgeon
Day 1	3.54±1.73^{aA}	3.64±1.22 aA	3.59±1.58 aA	3.26±1.21 aA	3.35±1.19 aA	3.29±1.24 aA	3.40±1.98 aA	3.53±1.23 aA	3.46±1.12 aA	3.70±1.27 aA	3.95±1.36 aA	3.75±1.15 aA
Month 1	3.51±1.67^{aA}	3.62±1.24 aA	3.54±1.49 aA	3.22±1.36 aA	3.31±1.25 aA	3.25±1.32 aA	3.39±1.92 aA	3.41±1.20 aA	3.42±1.21 aA	3.65±1.24 aA	3.86±1.53 aA	3.64±1.8 aA
Month 2	3.49±1.50^{aA}	3.58±1.43 aA	3.52±1.38 aA	3.18±1.54 aA	3.29±1.14 aA	3.22±1.48 aA	3.35±1.90 aA	3.35±1.59 aA	3.39±1.32 aA	3.63±1.43 aA	3.53±1.62 abA	3.50±1.25 aA
Month 3	3.42±1.59^{aA}	3.45±1.49 aA	3.49±1.33 aA	3.11±1.86 aA	3.27±1.37 aA	3.15±1.53 aA	3.29+1.88 aA	3.29±1.66 aA	3.30±1.39 aA	3.55±1.39 aA	3.34+1.95^{b} A	3.39±1.19 aA
Month 4	3.35±1.39^{aA}	3.34±1.45 aA	3.38±1.35 aA	3.08±1.13 aA	3.22±1.42 aA	3.13±1.54 aA	3.28±1.82 aA	3.15±1.58 aA	3.27±1.40 aA	3.51±1.38 aA	3.29±1.84^{b} A	3.32±1.27 aA
Month 5	3.17±1.35^{aA}	3.21±1.51 abA	3.26±1.44 aA	2.95±1.44 aA	3.15±1.18 aA	3.05±1.61 aA	3.12±1.73 aA	3.08±1.33 abA	3.15±1.43 aA	3.24±1.27 abA	3.16±1.75^{b} A	3.20±1.12 abA
Month 6	3.11±1.23^{ab} A	3.14±1.56^{b} A	3.15±1.47 abA	2.83±1.49 abA	3.08±1.49 aA	2.95±1.72 aA	3.05±1.69 aA	3.01±1.29^{b} A	3.09±1.45 abA	3.18±1.39^{b} A	3.11±1.76^{bc} A	3.12±1.16^{b} A
Month 7	2.98±1.19^{b} A	3.04±1.63^{b} A	3.05±1.50^{b} A	2.74±1.39^{b} A	2.97±1.53 aA	2.91±1.83 aA	2.96±1.60 aA	2.99±1.11^{b} A	2.95±1.19^{b} A	2.98±1.41^{b} A	3.00±1.65^{cA}	3.02±1.29^{b} A
Industrial method												
Day 1	4.55±1.21 aA	4.65±1.98 aA	4.61±1.27 aA	4.42±1.56 aA	4.52±1.36 aA	4.45±1.33 aA	4.55±1.28 aA	4.68±1.33 aA	4.59±1.73 aA	4.62±1.16 aA	4.85±1.39 aA	4.76±1.52 aA
Month 1	4.43±1.19 aA	4.65±1.86 aA	4.52±1.63 aA	4.38±1.54 aA	4.50±1.53 aA	4.41±1.28 aA	4.51±1.31 aA	4.65±1.55 aA	4.54±1.79 aA	4.55±1.50 aA	4.80±1.36 aA	4.73±1.73 aA
Month 2	4.40±1.67 aA	4.60±1.38 aA	4.46±1.12 aA	4.32±1.23 aA	4.45±1.93 aA	4.39±1.42 aA	4.43±1.20 aA	4.60±1.56 aA	4.53±1.80 aA	4.53±1.60 aA	4.78±1.80 aA	4.65±1.72 aA
Month 3	4.39±1.69 aA	4.58±1.14 aA	4.43±1.29 aA	4.30±1.90 aA	4.41±1.98 aA	4.35±1.40 aA	4.40±1.22 aA	4.58±1.63 aA	4.49±1.89 aA	4.48±1.34 aA	4.65±1.82 aA	4.60±1.67 aA
Month 4	4.35±1.37 aA	4.57±1.19 aA	4.39±1.43 aA	4.23±1.92 aA	4.35±1.56 aA	4.30±1.39 aA	4.36±1.37 aA	4.52±1.66 aA	4.42±1.85 aA	4.40±1.52 aA	4.61±1.87 aA	4.58±1.69 aA
Month 5	4.30±1.90 aA	4.51±1.67 aA	4.31±1.49 aA	4.20±1.95 aA	4.32±1.43 aA	4.26±1.71 aA	4.30±1.55 aA	4.50±1.90 aA	4.40±1.74 aA	4.38±1.91 aA	4.55±1.83 aA	4.50±1.51 aA
Month 6	4.28±1.43 aA	4.50±1.50 aA	4.30±1.52 aA	4.15±1.66 aA	4.30±1.24 aA	4.23±1.70 aA	4.28±1.98 aA	4.49±1.59 aA	4.35±1.68 aA	4.31±1.99 aA	4.43±1.49 aA	4.41±1.70 aA
Month 7	4.24±1.53 aA	4.47±1.48 aA	4.25±1.22 aA	4.13±1.50 aA	4.26±1.27 aA	4.19±1.65 aA	4.20±1.83 aA	4.45±1.79 aA	4.31±1.66 aA	4.30±1.93 aA	4.41±1.54 aA	4.38±1.79 aA

Table 8– Evaluation of the physical properties of isinglass treatments prepared from sturgeon swim bladders by industrial and Indian methods during seven months of storage at room temperature

Indian method															
Index	**pH**			**Texture analysis**			**Color analysis**								
Treatment							stellate sturgeon			Beluga			Persian sturgeon		
Index	stellate sturgeon	Beluga	Persian sturgeon	stellate sturgeon	Beluga	Persian sturgeon	L (Lightness)	A Red–) (Green	B *Blue*–) (*Yellow*	L (Lightness)	A Red–) (Green	B *Blue*–) (*Yellow*	L (Lightness)	A Red–) (Green	B *Blue*–) (*Yellow*
Day 1	6.51±1.38^{aA}	6.50±1.80^{aA}	6.45±1.15^{aA}	74.16±1.65^{aA}	74.84±1.12^{aA}	74.56±1.33^{aA}	85.93±1.14^{aA}	2.12±1.24^{eA}	6.51±1.55^{dA}	85.16±1.13^{aA}	2.18±1.26^{eA}	6.96±1.23^{cA}	85.28±1.76^{aA}	2.23±1.93^{gA}	6.67±1.13^{dA}
Month 1	6.49±1.54^{aA}	6.48±1.49^{aA}	6.43±1.38^{aA}	73.58±1.37	74.17±1.23^{bA}	74.13±1.43^{aA}	85.17±1.99^{bA}	2.26±1.25^{eA}	6.60±1.51^{dA}	84.73±1.19^{aA}	2.34±1.24^{deA}	7.12±1.20^{bcA}	84.79±1.79^{bA}	2.45±1.54^{fgA}	6.85±1.34^{dA}
Month 2	6.42±1.18^{aA}	6.40±1.72^{aA}	6.37±1.89^{aA}	72.97±1.17	73.67±1.39^{cA}	73.56±1.56^{bA}	84.53±1.95cA	2.59±1.16^{eA}	6.75±1.92^{cdA}	84.12±1.35^{bA}	2.69±1.34^{cdA}	7.20±1.60^{bA}	83.12±1.46^{bA}	2.93±1.45^{efA}	6.99±1.73^{cdA}
Month 3	6.37±1.27^{aA}	6.47±1.79^{aA}	6.35±1.90^{aA}	72.15±1.88	73.15±1.40^{dA}	73.12±1.45^{bA}	83.67±1.94^{dA}	3.11±1.15^{dA}	6.80±1.99^{cA}	83.67±1.36^{cA}	3.12±1.38^{cA}	7.34±1.54^{bA}	82.59±1.47^{cA}	3.17±1.44^{eA}	7.18±1.75^{cA}
Month 4	6.34±1.98^{aA}	6.41±1.32^{aA}	6.26±1.50^{aA}	71.84±1.69	72.54±1.51^{eA}	72.64±1.44^{bA}	82.91±1.99^{eA}	3.56±1.32^{cdA}	6.92±1.98^{cA}	82.95±1.33^{cA}	3.85±1.39^{bA}	7.45±1.53^{abA}	81.95±1.64^{dA}	3.84±1.40^{dA}	7.24±1.80^{cA}
Month 5	6.25±1.87^{aA}	6.24±1.43	6.13±1.29^{aA}	71.24±1.60	71.99±1.62^{fA}	71.85±1.77^{cA}	81.53±1.90^{fA}	3.78±1.39^{bcA}	7.13±1.75^{bcA}	81.34±1.39^{dA}	4.12±1.40^{bA}	7.51±1.78^{aA}	81.16±1.62^{eA}	3.15±1.28^{cA}	7.45±1.82^{bcA}
Month 6	6.14±1.66^{aA}	6.15±1.56^{aA}	6.08±1.54^{aA}	70.98±1.55	71.52±1.59f^{gA}	71.14±1.84^{dA}	80.47±1.88^{gA}	4.18±1.30^{abA}	7.47±1.17^{bA}	80.27±1.41^{eA}	4.56±1.42^{abA}	7.68±1.77^{aA}	80.39±1.60^{fA}	4.37±1.31^{bA}	7.59±1.89^{abA}
Month 7	6.07±1.57^{aA}	6.05±1.67^{aA}	6.02±1.59^{aA}	70.43±1.49	71.08±1.77^{gA}	70.82±1.89^{dA}	79.13±1.85^{hA}	4.56±1.28^{aA}	7.83±1.23^{aA}	79.16±1.77^{fA}	4.85±1.24^{aA}	7.83±1.28^{aA}	79.28±1.68^{gA}	4.93±1.33^{aA}	7.99±1.92^{aA}
Industrial method															
Day 1	6.30±1.12^{aA}	6.37±1.27^{aA}	6.39±1.22^{aA}	88.73±1.59^{aA}	88.97±1.50^{aA}	88.85±1.27^{aA}	88.28±1.56^{aA}	1.17±1.12^{bA}	4.21±1.19^{bA}	88.14±1.25^{aA}	1.45±1.54^{bA}	4.51±1.40^{bA}	88.39±1.39^{aA}	1.12±1.67^{bA}	4.87±1.17^{bA}
Month 1	6.28±1.15^{aA}	6.35±1.29^{aA}	6.35±1.23^{aA}	88.65±1.50^{aA}	88.90±1.56^{aA}	88.80±1.89^{aA}	88.34±1.63^{aA}	1.20±1.35^{bA}	4.27±1.36^{bA}	88.11±1.13^{aA}	1.52±1.94^{bA}	4.55±1.98^{bA}	88.30±1.47^{aA}	1.18±1.45^{bA}	4.89±1.24^{bA}
Month 2	6.24±1.89^{aA}	6.30±1.48^{aA}	6.32±1.34^{aA}	88.60±1.57^{aA}	88.86±1.45^{aA}	88.78±1.17^{aA}	88.43+±1.53^{aA}	1.28±1.15^{bA}	4.31±1.29^{bA}	88.03±1.14^{aA}	1.63±1.66^{bA}	4.63±1.44^{bA}	88.25±1.82^{aA}	1.29±1.77^{bA}	4.95±1.22^{bA}
Month 3	6.18±1.18^{aA}	6.27±1.40^{aA}	6.30±1.56^{aA}	88.51±1.55^{aA}	88.80±1.34^{aA}	88.70±1.59^{aA}	88.50±1.32^{aA}	1.35±1.22^{abA}	4.40±1.57^{abA}	87.96±1.28^{aA}	1.68±1.78^{bA}	4.70±1.60^{abA}	88.15±1.85^{aA}	1.35±1.12^{bA}	5.11±1.82^{abA}
Month 4	6.15±2.21^{aA}	6.20±1.35^{aA}	6.25±1.67^{aA}	88.40±1.39^{aA}	88.72±1.39^{aA}	88.61±1.77^{aA}	88.61±1.73^{aA}	1.45±1.31	4.45±1.72^{aA}	87.85±1.43^{aA}	1.75±1.27^{abA}	4.75±1.92^{aA}	88.09±1.18^{aA}	1.49±1.79^{abA}	5.15±1.19^{aA}
Month 5	6.13±1.35^{aA}	6.15±1.17^{aA}	6.21±1.36^{aA}	88.37±1.76^{aA}	88.60±1.42^{aA}	88.55±1.76^{aA}	88.69±1.71^{abA}	1.50±1.30^{aA}	4.56±1.80^{aA}	87.80±1.88^{aA}	1.80±1.35^{aA}	4.82±1.24^{aA}	88.97±1.27^{aA}	1.53±1.13^{aA}	5.23±1.31^{aA}
Month 6	6.10±1.28^{aA}	6.12±1.24^{aA}	6.18±1.52^{aA}	88.29±1.88^{aA}	88.52±1.54^{abA}	88.43±1.78^{aA}	87.75±1.21^{bcA}	1.53±1.85^{aA}	4.68±1.18^{aA}	87.79±1.19^{abA}	1.83±1.58^{aA}	4.93±1.73^{aA}	87.91±1.46^{abA}	1.56±1.16^{aA}	5.29±1.12^{aA}
Month 7	6.05±1.16^{aA}	6.07±1.68^{aA}	6.12±1.48^{aA}	88.27±1.46^{aA}	88.40±1.93^{bA}	88.40±1.89^{aA}	87.41±1.13^{cA}	1.89±1.86^{aA}	4.99±1.91^{aA}	87.60±1.26^{bA}	2.11±1.99^{aA}	5.14±1.84^{aA}	87.83±1.38^{bA}	1.95±1.80^{aA}	5.56±1.56^{aA}

Data presented in Table 7 show that the industrial method maintained scores above 4.0 at all-time points, with an insignificant reduction in overall acceptability (P>0.05). The industrial method also received higher sensory scores than the Indian method across color, smell, texture, and overall acceptability at every time point during the study (P<0.05). The decline in quality of the Indian method became significant after 3 months and by 7 months (P<0.05), many attributes were unfavorable whereas with respect to the industrial method largest number of attributes maintained acceptable ranges.

Results are exhibited as mean ± standard deviation (n = 3). Unlike lowercase letters within the same column, present remarkable differences among sampling times (P<0.05), whereas the same lowercase letters show no main difference (P> 0.05). Dissimilar uppercase letters within the same row illustrate meaningful differences between treatments at the same keeping time (P<0.05), whereas identical uppercase letters display no notable difference (P> 0.05).

The data in Table 8 give physical property changes based on colorimetric testing (L*, a*, b* values) that show higher brightness and uniformity (p< 0.05) from the industrial method and better retention of that brightness over time. Texture results from the industrial method had greater tissue cohesiveness and resistance (p<0.05) than tissue from isinglass prepared using the Indian method (brittle, variable). The pH values decreased slightly over the two methods but showed greater stability with the industrial method, and pH values decreased more quickly for the Indian method compared to the industrially processed product, indicating overall physical stability and desirability of the product processed through an industrial manner.

Table 9– Evaluation of the water activity of isinglass treatments prepared from sturgeon swim bladders by industrial and Indian methods during seven months of storage at room temperature

Index	Water activity					
Sample	Industrial method			Indian method		
Sampling time	Beluga	Persian sturgeon	*Stellate sturgeon*	Beluga	Persian sturgeon	*Stellate sturgeon*
0 month	0.48± 0.25^{aA}	0.49±0.29^{aA}	0.50±0.18^{aA}	0.53±0.28^{aA}	0.54±0.32^{aA}	0.55±0.41^{aA}
7 month	0.53±0.21^{aA}	0.54±0.14^{aA}	0.55±0.23^{aA}	0.58±0.24^{aA}	0.59±0.37^{aA}	0.60±0.35^{aA}

Results are exhibited as mean ± standard deviation (n = 3). Unlike lowercase letters within the same column, present remarkable differences among sampling times (P<0.05), whereas the same lowercase letters show no main difference (P> 0.05). Dissimilar uppercase letters within the same row illustrate meaningful differences between treatments at the same keeping time (P<0.05), whereas identical uppercase letters display no notable difference (P> 0.05).

Table 9 shows the changes in water activity of isinglass produced by the traditional Indian and semi-industrial methods during seven months of storage at room temperature. A gradual increase in a_w was observed in both treatments over the storage period. Nevertheless, the semi-industrial method maintained consistently lower water activity values than the traditional Indian method throughout storage.

Discussion

The rate of moisture loss during drying, as well as retention of non-collagenous components during extraction and drying processes can determine the nutritional composition of isinglass (Chen *et al*., 2024). In the experimental isinglass, protein, moisture, fat and ash content showed significant difference between traditional Indian and semi-industrial processes (Table 1). Protein content of semi-industrial isinglass ranged between 74.11-74.63% while it was 64.14-65.70% for

the traditional Indian isinglass. It was evident from the results that higher protein recovery was achieved in semi-industrial process with better preservation of protein.

Strict control over washing process, quick dehydration and hot air drying were supposed to have contributed to the minimization of protein loss and the higher collagen recovery (Bao, Ertbjerg, Estévez, Yuan, & Gao, 2021). Traditional Indian method that involves drying under atmospheric condition for a long time, resulted in some degradation of protein and decreased collagen recovery (Yu *et al*., 2023). There were considerable differences in the moisture content. Semi-industrial isinglass showed a moisture content ranging between 24.18 and 25.16%, while the values for traditional Indian isinglass were between 32.14 and 33.19% during the period of storage. Lower moisture content is of paramount importance as it reduces the possibility of microbial spoilage, enzymatic activity and oxidative reactions during the shelf life of food product.

Lower microbial count, TVB-N, peroxide value and TBARS value with acceptable sensory scores found in semi-industrial treated samples were attributed to their lower moisture content. Fat content in semi-industrial product (0.11-0.14%) was also much lower than that of traditional method (0.61-0.81%), implying that the amount of readily oxidizable substrates is low in the former and therefore less oxidation occurs during storage. In addition, the low ash content (0.61-0.85%) in the semi-industrial isinglass signified removal of more non-collagenous impurities and less mineral salts, yielding higher purified collagen (Rodrigues *et al*., 2021).

Asty, Yasman, & Wardhana, (2017) prepared semisolid isinglass from cultured catfish swim bladder. They were determined moisture, protein, fat, and ash contents 98.97%-99.08%, 0.49%-0.53%, 0.20%-0.21%%, and 0%, respectively, in isinglass samples treated with acetic acid . In our study, moisture, protein, fat, and ash contents were 33.05-33.18%, 64.14 – 65.36%, 0.61-0.73 and 0.98-1.95%, respectively, in the Indian method. Moisture, protein, fat, and ash contents were 24.52-25.16%, 74.11-74.67%, 0.11-0.12%, and 0.61-0.70%, respectively, in samples processed by the semi-industrial method. In detail, the production conditions were different in these studies. Their isinglass was prepared by extraction with acetic acid and dried at low temperature (39–40 ^{o}C). The dried isinglass samples in the current study were extracted by other methods, such as Indian and semi-industrial processes, without the addition of acid. However, this comparison was made to show the effect of the processing method on the quality of isinglass.

Nevertheless, the comparison serves the purpose to prove that the extraction method plays an important role on the nutritional properties of the isinglass. Therefore, the selection of a proper extraction and drying procedure not only enhances the nutritional value and market acceptability but also ensures the shelf-life stability of commercial isinglass and thus provides a useful guide to the process development for the production of high quality dried isinglass from cultured sturgeon swim bladders (Chen, Liu, & Wang, 2022).

Isinglass amino acid profile provides an insight into collagen structure and nutritional value. As shown in Table 2, glycine (26–28 residues/1000 residues), proline (12 - 14residues/1000 residues) and hydroxyproline (12-14residues/1000 residues) were identified as major amino acids in all the samples, confirming the collagen rich nature of the extracted isinglass. These amino acids represent major constituent elements of the collagen matrix; with glycine maintaining the triple helix integrity and proline and hydroxyproline contributing towards the collagen thermal stability and tensile strength due to hydrogen bonding at an inter-chain level (Yu *et al*., 2023).

No significant variation was noted in the amino acid profile of samples obtained through the traditional Indian and semi-industrial extraction methods. This implies that neither extraction process led to any significant changes in the primary structure of the collagen

molecules. Small variations were observed for certain amino acids in their proportions among the samples. It is very probable that these numerical differences may simply reflect inherent biological variation among samples rather than any processing related degradation. Moderate drying temperature utilized in the semi-industrial method along with absence of chemical agents during processing likely contributed in maintaining the original composition of amino acids (Zhang *et al*., 2022).

The proportions of glycine and proline obtained in the present work are similar to those reported by Cruz-López *et al.* (2023) who found glycine and proline 29.19 and 12.10 residues/1000 residues as principal amino acids of the collagen from the swim bladders of farmed *Totoaba macdonaldi*. Asty *et al.* (2017) reported the proline and glycine as 462.82 - 605.88 and 1069.35 -1163.08 ppm in semisolid isinglass prepared of cultured catfish swim bladder. Our data showed that glycine varied between 26 – 28 and 25-27 residues/1000 residues in Indian and semi-industrial treatments, respectively. Proline content was 12-14 residues/1000 residues in the semi-industrial and Indian methods. Minor discrepancies were, as expected, attributed to the different fish species, maturity, extraction procedure, and analytical methods employed in each study.

In addition, similar amino acid profiles in both traditional and semi-industrial products were consistent with better protein content and better physicochemical stability of the semi-industrial isinglass samples. The semi-industrial method allowed for higher protein yields and improved water, oxidation and microbial stability, but without affecting the fundamental composition of the amino acids of the collagen molecule. This indicated that the advantages provided by the semi-industrial method are chiefly related to improved collagen quality preservation rather than collagen structural alteration (Zheng *et al*., 2024).

As it is apparent from Table 3, the processing method had significant effect on process efficiency, product yield, processing time, resource consumption and manufacturing performance. In contrast to the traditional Indian method yielding 22-24% of dry isinglass recovery, the semi-industrial process showed much higher dry isinglass yield in the range of 63-67%. The high recovery from semi-industrial method more likely due to the controlled washing, trimming, drying (hot air drying) which minimize the collagen loss during the processing and hence improve the recovery of the swim bladder matrix. The prolonged exposure to processing environment and unskilled workers likely caused increased mechanical losses in the traditional process leading to much lower collagen recovery. Although the efficiency of the processing system was markedly improved in the semi-industrial method, the present comparison study evaluated two whole processing systems and not individual processing parameters and so improvements obtained should be interpreted as resultant effect of the overall process parameters (Wei *et al*., 2025).

Similarly, processing time for both processing systems was also highly different. The semi-industrial process resulted in total processing time of 8-24 hours while it takes 3-7 days for traditional Indian process to complete the isinglass processing. The reduction in processing time also enhance the manufacturing capacity of processing units and provides reduced duration of exposure to environmental contamination and microbial degradation. It is in consonance with observed significantly low microbial counts, lower TVB-N values and good oxidation and sensory quality in semi-industrial isinglass product during storage. It is thus confirmed that enhancement in process efficiency leads to enhancement of quality and shelf-life of the isinglass.

Though operator handling in semi-industrial processing was higher (3-5 h/kg) than traditional process (0.5-1.5 h/kg) due to well-controlled washing, trimming, quality checks and monitoring drying conditions, it also results in better reproducibility, uniform product and

consistent quality. Higher labor was for better quality control than processing disadvantages.

In terms of resources consumption, the semi-industrial method consumed less electricity (1-2 kWh/kg) than traditional Indian method (4-8 kWh/kg) even with shorter processing time and higher product recovery. This could be attributed to quick moisture removal in hot air drying thereby minimizing energy loss. However, water consumption for semi-industrial method was higher (120-250 l/kg) than traditional process (80-150 l/kg) owing to the increased washing steps required to improve sanitary quality and to remove non-collagenous substances prior to drying. Though high water consumption adds to processing costs, whereas additional washing steps likely account for lower microbial population, ash content and higher protein content.

Process consistency was another major advantage for the semi-industrial processing. More consistent temperature, airflow and drying conditions for the processing of samples produced a more consistent product with less than 3% processing loss compared to about 6% for the traditional Indian process. A lower loss due to processing rejection is an economic benefit and promotes resource sustainability through optimum utilization of raw materials. More consistent semi-industrial process resulted in low variability in the physicochemical, microbiological and sensory parameters during the entire period of storage, proving that improved process control is correlated with increased process efficiency.

To the best of our knowledge, no such research has been carried out on evaluation of traditional Indian and semi-industrial processing procedures for commercializing cultured sturgeon swim bladder isinglass with simultaneous investigation of process efficiency, yield, resource utilization, quality attributes and shelf life. Hence, the present work is one of the first systematic integrated assessment of both technology and quality consequences of both these production processes. Overall results strongly advocate that semi-industrial processing strategy provided better economic and technological advantage for production of a shelf stable, uniform, higher quality and safe commercial isinglass through improved collagen yield, shortened process time, efficient use of energy and minimized loss during processing.

Although the traditional Indian extraction methodology is a simple technique and does not requiresophisticated infrastructure, but efficiency of the process may be significantly improved through systematic experimental optimization of different processing steps via soaking pH and duration, temperature and duration of drying, initial moisture level prior to pressing, and addition of different processing aids. This may further lead to improve extraction yield, physic- chemical quality, stability and overall product performance. Thus, further work should be performed for identifying optimal processing conditions (Li, Yang, Wu, Chen, & Lin, 2022).

Minerals are generally resistant to degradation at typical drying temperatures. The concentration of the minerals in isinglass therefore mainly reflects the washing, purification, and the extent of removal of non-collagenous materials from tissues and surfaces throughout processing and the loss of some residual matter from washing step. Minerals were detected lower in the semi-industrial processed sample than in the traditionally processed sample (For example: calcium was 26 -28 and 55-58 mg/100 g in semi- industrial and Indian methods, respectively. Phosphorus was 14 – 19 and 36 -39 mg/100 g in semi-industrial and Indian methods, respectively. Sodium was 53 -58 and 74 -78 mg/100 g in semi- industrial and Indian methods, respectively. Magnesium was 2 -5 and 5 -10 mg/100 g in semi- industrial and Indian methods, respectively) (Table 4). This indicates that the semi-industrial process has more removal efficiently for remaining tissues, blood, and other residues clinging to the swim bladder during washing and purification, and the reduction in minerals was a benefit resulting in higher purity. Any reduced mineral levels observed should therefore be regarded not as an

indicator of a nutritional loss, but of greater purity achieved during processing. More of residual connective tissue, other cellular materials and their contained inorganic substances remain in the fish collagen as a result of inadequate washing and handling during the traditional process of producing this material. This resulted in increased contents of mineral materials than with further cleansing, rinsing and other standardizing procedures in semi-industrial processing. Therefore, this differences in mineral content mainly depend upon processing but not due to the loss from the drying stage itself. However, minor differences found between processing methods of isinglass would be unlikely to make a substantial difference to any significant contribution from isinglass to mineral intake and it serves well as a functional collagenous product, not as a source of mineral nutrition (Shi, 2025).

Instead, such enhancement in isinglass purity achieved in semi-industrial processing could further improve the protein purity, ash, physicochemical properties, and microbial stability of product throughout storage. Overall, for the first time, comparison between minerals of isinglass from farmed sturgeon swim bladders with semi-industrial process and traditional Indian process was specifically addressed. However, this is generally in line with studies on the extraction of fish collagen in general that indicate a loss of remaining mineral and the further increase of purity due to further extensive purification during fish collagen processing which is also without detrimental effects on the quality of collagen globular form (Wei *et al*., 2025). The present study suggests that the use of a semi-industrial process while preserving collagen mineral characteristics. Together with better nutritional content and reduced microbial activity as documented in storage evaluation studies, this provides further support for its commercial viability.

Microbiological quality is one of the principal criteria used to evaluate the safety, hygienic status, and storage stability of food products. In the present study, total bacterial counts gradually increased throughout the seven-month storage period in all treatments. At the end of storage, total bacterial counts ranged from 5.17 to 5.47 log CFU/g in isinglass produced by the traditional Indian method and from 2.28 to 2.78 log CFU/g in samples produced by the semi-industrial method (Table 5), indicating that the semi-industrial process provided substantially greater microbiological quality during storage. The gradual increase in bacterial counts suggests that a limited residual microbial population survived processing and was capable of slow multiplication under ambient conditions. Nevertheless, the relatively low growth rate indicates that the low moisture content and reduced water activity of dried isinglass considerably restricted microbial proliferation, resulting in much slow microbial development (Pan, Li, Tao, & Guo, 2018).

A clear difference was observed between the two extraction methods. Samples produced by the traditional Indian method consistently exhibited higher microbial counts than those produced by the semi-industrial method. The variability can probably be the result of extended drying times and continuous presence of environmental contamination, i.e., dust, microorganisms, airborne materials, oxygen and so forth in sun dried products during traditional processing method. Whereas, drying at 60 ^{o}C for controlled hot-air drying under the semi-industrial processing conditions accelerated the process, effectively lowering the moisture content and at the same time denaturing the many endogenous microorganisms and enzymes present. Furthermore, washing, controlled handling, and more uniform dehydration during semi-industrial processing likely reduced the initial microbial load and minimized subsequent microbial growth throughout storage. These findings clearly demonstrate that processing conditions exert a major influence on the microbiological quality of dried isinglass (Li *et al*., 2022).

Yeasts and molds were detected only at low levels during storage, with their occurrence

being more evident in samples prepared using the traditional Indian method after prolonged storage. This may relate to a slow take-up of ambient moisture and that an environment becomes more conductive to the fungal process, though this does not become extensive throughout the period of storage and thus must be interpreted relating to the low activity of water in dried isinglass and hence the absence of widespread spoilage organisms. Hence the microbiological changes suggest slow quality loss, rather than significant spoilage (Kovács *et al*., 2025). To the best of our knowledge, no previous studies have evaluated the microbiological quality of isinglass produced from cultured sturgeon swim bladders using traditional Indian and semi-industrial extraction methods, making direct comparison with previous investigations unavailable.

Samples with lower bacterial counts exhibited lower TVB-N, peroxide value, and TBARS value, along with better scores in sensory evaluation during the storage period. The bacterial proliferation promoted development of volatile nitrogen compounds, accelerated oxidation deterioration and induced off odor, appearance and acceptability. Since microbial load gradually increased during storage, the proliferation rate of microorganisms seemed slow to cause sensory failure in early stage. Thus, storage quality deteriorations are attributed to cumulative effects from mild microbial contamination, protein degradation, and oxidative reactions rather than by gross microbial spoilage (Pan *et al*., 2018).

TVB-N is widely used as an indicator of protein degradation in seafood represents the formation of volatile nitrogen compounds through the enzymatic and microbial activities (Bao *et al*., 2021). In the current investigation, there was a progressive increase in the TVB-N in all treatments during 7 months' storage indicating gradual degradation of protein. This increase was throughout and not marked in either of the extraction method indicating slow protein degradation under the condition employed for the storage. TVB-N remained at comparatively low level with the final TVB-N between 11.26 and 23.17 mg/100 g (traditional Indian method) and between 7.84 and 14.12 mg/100 g (semi-industrial method) respectively (Table 6). Though TVB-N was the widely used parameter for the spoilage of fishery products, it has been explored very little to characterize dried swim bladders products, and no TVB-N data were reported for sturgeon isinglass produced by traditional and semi-industrial method. Hence TVB-N values of the dried products can only be considered as relative indicator of the extent of protein deterioration and shelf life. These findings demonstrated that the semi-industrial method had much better efficiency in minimizing the development of volatile nitrogenous compounds. This reduction in the TVB-N in semi-industrial method could be ascribed to a more stringent process control of washing, dehydrating and hot air drying (60 ^{o}C), rapidly brought down the moisture content, repressed bacterial proliferation and suppressed the activity of endogenous enzymes. On the other hand, the extended duration and ambient condition of drying of the samples under traditional Indian method had allowed more exposure to the air and prolonged drying that favor the proliferation of microorganisms and the degradation of protein to develop higher TVB-N (Koochakian *et al*., 2006).

As observed earlier for other parameters the TVB-N also followed a similar trend showing strong correlations with microbial and sensory scores which means that protein spoilage, microbial trend and sensory quality change in same directions during storage of the dried isinglass. Similar progressive increase in the PV also indicated simultaneous occurrences of protein degradation and primary lipid oxidation during storage. The fact that the TVB-N values in the semi-industrial products were always lower demonstrates clearly better preservation of chemical quality and greater storage stability in this method (Zhang *et al*., 2022).

In spite of observed changes, the steady progression in TVB-N and PV values would

probably make it possible to describe their change during storage by kinetic models; an experiment with 8 points over 7 months should be feasible for future kinetic modeling. With the sampling time points and measurements provided, the degradation rate constants of these parameters can be estimated, which then can be used for modeling such as first-order kinetics, pseudo-first-order reaction, etc. for predicting shelf-life and storage characteristics.

PV and TBARS are considered as an important parameters for the evaluation of primary and secondary lipid oxidation, respectively, and these parameters when combined offer a holistic view of oxidative changes that occur during storage. In this study, both PV and TBARS demonstrated gradual increase throughout the seven months of storage for all treatments, suggesting that lipid oxidation was continually occurring (Table 6). However, the levels remained low throughout the entire period, suggesting that generally, the oxidative stability of the isinglass was satisfactory under the storage conditions encountered. The steady increase in PV reflected the accumulation of lipid hydro peroxides as primary oxidation products. Though isinglass is a collagen-rich material with little lipid, trace quantities of phospholipids and membrane lipids remain from the swim bladder and these are prone to oxidation upon extended storage. The low rates of PV increase suggested thatlow moisture and reduced water activity in dried isinglass likely hindered the oxidative process (Zhao *et al*., 2018).

The PV in samples processed using the traditional Indian method (1.64–4.68 meq/kg oil) was significantly higher compared to the samples processed using the semi-industrial method (1.05–2.24 meq/kg oil), which indicates that the oxidative stability was poorer when using the traditional Indian process. Similarly, the levels of TBARS rose from 0.46 to 1.98 mg MDA/kg for the Indian method, but only rose moderately from 0.24 to 0.95 mg MDA/kg for the semi-industrial method, suggesting that controlled drying methods have improved the oxidative stability of the product throughout its shelf life. Prolonged air drying combined with the exposure of product to ambient air and direct sunlight in the Indian traditional process potentially accelerated the oxidation of lipid, whereas in the semi-industrial method hot-air drying (60 ^{o}C) reduced the moisture content of the swim bladders very quickly thereby inhibiting microbial activity, minimizing subsequent reactions and thereby reducing oxidation. Improved washing and greater removal of residual impurities during semi-industrial processing likely further reduce the substrate availability of oxidation, contributing to the lowered PV and TBARS values observed (Li *et al*., 2023; Chen *et al*., 2019; Zhang, Chen, & Hu, 2025).

The continuing increase of TBARS suggested gradual decomposition of lipid hydroperoxides to secondary products of oxidation such as malondialdehyde, a volatile aldehyde is the main contributor to the unpleasant odor and off-flavor in oxidizing lipids. The PV and TBARS changes mirrored each other, suggesting a parallel progress of primary and secondary lipid oxidation throughout the period of storage (Ahmed, Verma, & Patel, 2020). However, the consistently lower TBARS values in samples prepared with the semi-industrial process indicated that controlled drying conditions were also successful in limiting the secondary products of oxidation, and not only their primary counterparts.

These observed oxidative changes were consistent with the gradual changes in the sensory attributes of isinglass during storage. As shown, products with lower PV and TBARS generally scored better in terms of odor, color and overall acceptability. The decline in both odor and color was likely the result of progressive lipid oxidation, with subsequent development of flavors and colors and degradation of natural chromospheres. Moreover, oxidative reactions may cause slight modifications in collagen matrix leading to a gradual decrease in lightness (L value) and a

gradual increase in the yellowness (b value) of the product which explained changes in Instrumental Color Parameters during storage (Zhao *et al*., 2018).

The oxidative changes obtained in this study, indicated that TVB-N and microbial count, changes in instrumental color and sensory scores, are related to lipid oxidation, protein degradation, and microbial growth proceeded simultaneously during storage, and oxidative reaction could be one of major mechanism causing the quality degradation of dried isinglass (Bekhit, Holman, Giteru, & Hopkins, 2021). PV and TBARS value were highly related to sensory evaluation, therefore could be potentially utilized to predict the sensory quality and oxidative stability during storage of isinglass (Huang, Song, & Yuan, 2026). As far as the authors know, no data on the change of peroxide value and thiobarbituric acid reactive substances in the isinglass prepared from farmed sturgeon swim bladders through both traditional Indian and semi-industrial extraction methods have been reported.

Sensory score of isinglass made by the traditional Indian and semi-industrial processes stored for seven months at ambient temperature (room temperature) presented in Table 7. As seen, for both methods, the sensory scores tend to drop over storage time; however, the degradation is more intense in the samples obtained by the traditional Indian method. All sensory scores decreased during storage for the traditional method from about 3.7 at the start to about 3.0 for color, from about 3.5 to below 3.0 for odor and from 3.3 to below 3.0 for texture and overall quality. Color is characterized by progressive darkening and loss of transparency, attributed likely to the exposure to sunlight and the atmosphere during the traditional drying, resulting in oxidation of the surface collagen structure. Similarly, a gradual increase of TVB-N in these samples resulted in an increased production of volatile nitrogenous compounds causing changes in the odor profile. Increased brittleness and reduced firmness were reflected in lower texture scores attributed to further moisture losses and protein and collagen structure degradation due to longer storage time under uncontrolled environmental conditions (Huang *et al*., 2026). All this translated to a decline of overall acceptability from approximately 3.6 to 2.9 by month 7, falling below the minimum consumer acceptance level. In contrast, the isinglass made by the semi-industrial method retained high sensory quality throughout storage time. The color scores dropped from about 4.62 -4.85 to 4.30 - 4.41, while the other sensory attributes much less affected during storage (Odor: from 4.55-4.66 to 4.20 – 4.45, Texture: From 4.42-4.52 to 4.13-4.26 and overall acceptability: from 4.55-4.65 to 4.24 -4.47), as compared to the traditional product, suggesting effective retention of appearance, odor and texture, under the conditions of semi-industrial process, involving drying at 60 ^{o}C. The latter condition resulted in a limited growth of microorganisms and an effective prevention of the degradation of collagen (Seriš *et al*., 2024). Overall acceptability ranged between good and very good throughout storage, clearly demonstrating that controlled semi-industrial processing is much superior for the production of high quality product.

These differences are supported by the differences in the chemical indices of the product stored at room temperature for 7 months. TVB-N, peroxide value, TBARS values and total microbial counts were consistently lower for the semi-industrially produced isinglass as compared to the traditional one. The parallel trend observed in the two storage methods between these physicochemical indices and the sensory evaluation suggests that deterioration of sensory properties is likely due to the concomitant protein degradation (high TVB-N), oxidation of lipids (high peroxide value and TBARS) and microbial activity, the combined effects are negatively impacted sensory attributes such as appearance, odor, texture and overall acceptability. These findings indicate that TVB-N, peroxide value and TBARS could be utilized as practical predictive indexes for sensory quality evaluation and monitoring of

the storage stability of commercial isinglass (Wei *et al*., 2025).

pH is a physicochemical attribute that is considered as a main indicator of the general deterioration during storage period (Table 8). This index was 6.45 – 7 in Indian method and 6.30 – 6.12 in semi-industrial method. Since dried isinglass has low moisture content (32.14 - 33.18% in Indian method and 24.16 – 24.52% in semi-industrial method at the end of storage period) (Table 1) and correspondingly low water activity (0.53 – 0.55 in semi-industrial method and 0.58 – 0.60 in Indian method after the 7 months' storage) (Table 9), this would have provided limitation for microbial and enzyme activity thereby minimizing the buildup of acidic or alkaline components. A significant difference was obtained between the two extraction methods, where by semi-industrial production method results in a relatively stable pH compared with the traditional Indian method (Table 8), meaning that the chemical stability of the collagen matrix was maintained to a great extent in samples produced by semi industrial methods due to effective washing, quicker dehydration, reduction of initial microbial load and drying by hot air under control temperature (60 ^{o}C). However,drying under normal ambient temperature in open places during traditional Indian method exposes to a lot of microbes and oxygen of the atmosphere thereby gradually facilitating some kind of biochemical change leading to a gradual change in pH during storage time (Bekhit *et al*., 2021). Low pH values correlated with lower TVB-N, PV, TBARS and bacterial counts and with higher sensory evaluation scores (Tables 5-7). The present results indicate that pH is not an independent criterion of quality evaluation, but it should be viewed as an index of deterioration representing all three major process such as protein breakdown, oxidative degradation and microbial contamination. Hence, pH should not be used alone as quality index, but as a supplemental test in conjunction with the other indices (Tang, Ying, & Shi, 2020). Asty *et al.* (2017) determined pH 2.41-2.69 in semisolid isinglass of cultured catfish swim bladder. In our study, pH was 6.02-6.07 and 6.05-6.12 in samples processed by Indian and semi-industrial methods, respectively. There are significant differences between our study and their study. The different results obtained in our study compared to the aforementioned study can be attributed to the different conditions used to produce isinglass.

What about color aspects, isinglass of Indian origin has significant decrease in lightness L and significant changes in color indices a, b after storage. Originally, the L was around 85-86 quite light and transparent color, but at the end of 7th month it was around 79 -80 (Table 8). During this period, index a (2.12-4.93) and b (6.51-7.99) increased. So isinglass became darker and more yellowish during storage. This process was driven by oxygen, light, humidity, created by the outdated drying technology, and also by oxidative reactions of surface organic compounds. While for the isinglass from the semi industrial production L remained high and stable (around 87-88) and changes of a (1.12-2.11), b (4.21-5.56) were insignificant. The product remained transparency and stability of color due to controlled temperature (60^{o}C), no direct contact with sunlight and less oxidative reactions, therefore, it was lighter and more color stable than Indian style product. In both methods after filtration, all samples were pressed to get uniform thickness through a mechanical pressing which provided better transparency and homogeneity (Koochakian *et al*., 2006).

Visual appearance is among the most important factors affecting acceptance by consumers of collagen dried products. Minor reductions in L and some variations of b over storage may have contributed to reduce samples' visual appeal. Such changes related to the extent of oxidative processes and minor changes to the collagen structure during storage, thereby accounting for the drop in overall appearance scores recorded by the panelists (Seifzadeh, 2023).

Color indices (L, a, and b) can provide information on not only the appearance but also

on any changes in the structure within collagen during storage. In the context of material science, the interaction of light with a protein-based structure (i.e., absorption, reflection, scattering) affects the optical properties of collagenous matrices. Therefore, if the structure of the collagen matrix changes during storage, the values of color parameters can be expected to change. In the current study, decreasing values of L indicate progressive loss of brightness of the isinglass samples during storage, possibly as a result of subtle changes in the organization of the collagen network, cross-linking and aggregation of protein chains that reduce scattering and increase light absorption by protein. The samples thus become progressively darker (Poojary & Lund, 2022).

Increasing values of a and particularly of b values reflect structural and chemical modification of the collagen network. Increase of yellowness may result from accumulation of lipid oxidation secondary products and also minor browning reactions during prolong storage, while oxidation products of lipids as chromophores alter optical reflection properties. Similarly change in a index leads to formation of protein oxidation secondary products. So both surface and deep color change of isinglass samples reflect oxidation and structural changes in the collagen network (Poojary & Lund, 2022).

It is clear that two preparation methods result in two products differing in appearance properties. The semi-industrial produced sample possessed a more stable appearance and color over storage, compared to the traditionally Indian prepared samples, which exhibited lower L and greater increases of b over storage time. The superior quality of the semi industrial samples was a result of adequate washing and the use of hot air drying at elevated temperature, with no light exposure. This prevented significant oxidation and degradation of structural elements of the collagen.

Changes in instrumental color of isinglass during storage highly correlated with lipid oxidation, expressed by PV and TBARS analysis, as increasing amount of secondary oxidation products caused changes in reflection and scattering of light and consequently, affect the L and b indices of the samples. In addition, significant correlation between changes in color and the increasing values of TVB-N, indicated that oxidation processes and protein degradation ran concurrently (Yu *et al*., 2023).

Results on sensory assessment were also well correlated with instrumental color data. Higher L values and lower changes of b in samples, resulting from their preparation by the semi-industrial method, corresponded to highest scores for appearance and overall acceptability of the samples. These results supported that deterioration of the appearance of isinglass product was not related to just surface discoloration but also to an internal degradation and modification of collagen structure, therefore instrumental color measures can provide useful information for evaluating structural integrity and storage stability of collagen based products and for practical application to industrial quality control of collagen-based food and drug products (Gustami, Nurilmala, & Jacoeb, 2025). The agreement of sensory evaluation with Instrumental color, PV, TBARS, TVB-N, and bacterial counts indicates that during storage the isinglass deteriorates via a multifactorial process involving protein degradation, oxidation and microbial proliferation rather than by the decline of a particular quality characteristic.

Texture is considered one of the most significant commercial quality attribute for isinglass because it depends directly upon the integrity of the collagen network, as well as upon the ease with which it may be handled, processed and the extent to which it can be sold to commercial buyers. The semi-industrial drying method resulted in significantly better texture (88.40-88.73) throughout storage when compared with Indian method (71.08-74.16), as it can be seen from Table 8, the semi-industrial method of extraction maintained higher hardness and flexibility, a uniform and a more cohesive texture throughout the storage when

compared to traditional Indian method which tended to be softer and brittle. The degradation in texture for traditional Indian dried samples may be associated with increasing the moisture absorption and slow and progressive physicochemical alteration occurring in collagen matrix with additional influence of limited oxidative degradation. It is plausible that, under relatively variable climatic conditions encountered during traditional drying, there is more probability of developing more inhomogeneous structure within collagen, hence becoming easily weak over the time. Moreover, semi-industrial controlled hot-air drying method facilitates uniform removal of moisture content thereby developing homogenous collagen network which gives enhanced physical strength to the end product and consequently better textural property storage (Zhou *et al*., 2024). This improved textural property is well corroborated by physiochemical attributes that the samples showing low moisture content, TVB-N, Peroxide value and TBARS and lower microbial counts sustained much better texture throughout.

This fact points to that the maintenance of the collagen network not only rests upon the drying process, but also on the capability of preventing both bacterial activity, protein degradation and oxidation to occurring throughout the storage period. In this view, texture deterioration seems to be a composite process of physical events and chemical alterations. Moreover, physical dimension and consistency produced in the semi industrial process of sturgeon isinglass contributed significantly to improve the physical quality, thereby enabling even and controlled dehydration of the product which led to reduction of garble, cracked texture, Brittleness etc, during the storage. The traditional Indian drying method, by nature of environmental factors has inherent capability to render heterogeneity to the final product structure, which was detectable from better physical uniformity produced in semi industrial drying (Seriš *et al*., 2024). In the entire of this study, it is established from the physical tests, conducted that the semi -industrial drying method is better suited over the traditional Indian process with respect to enhancing product structure stability, texture, physical appearance and quality throughout the storage of sturgeon isinglass which are well corroborated by the physicochemical, microbiological and sensorial analyses performed.

One of the most crucial parameters that determine the microbiological stability and shelf-life of dried collagen-based products is water activity. During the 7 months of storage under ambient condition, there were only minimal increases in water activity for both extraction methods, indicating low moisture uptake of the product during the storage (Table 9). Samples produced by the semi-industrial process, with a_w values between 0.48 and 0.55, were characterized by lower values than those produced by the traditional Indian process (0.53–0.60), reflecting better dehydration performance and enhanced storage stability. Lower water activity is a major prerequisite to achieving higher stability during storage even relatively low differences in the a_w may have significant consequences for shelf-life, as it might directly contribute to higher proliferation rates of microorganisms or acceleration of chemical reactions (Hussain, Reddy, Chari, & Kumar, 2024b).

These differences in a_w between the products from semi-industrial process and Indian process might related to more controlled hot air drying under standard temperature and more efficient removal of water due to the homogenous nature of the produced collagen. However, extended exposure to flactuate temperature and humidity throughout open air sun drying (Indian process) probably allowed the samples to be exposed to non-uniform conditions and thus increased moisture content. Similar findings were demonstrated for other dried products, such as fish collagen based materials (Zhu, Sun, & Dong, 2022), in which control over the drying process was shown to yield lower a_w values and enhanced stability compared to open-air drying processes. The low a_w observed in both

products, in the order of 0.48–0.60, is responsible for the low bacterial and fungal counts recorded throughout the entire storage time as water activity of ≤0.60 can seriously limit the growth of the most spoilage bacteria, yeast, and mold, reduce protein degradation and the rate of oxidation processes in food during storage (Kumar & Suhag, 2024).

These results were also in good agreement with the results obtained from the microbiological count, TVB-N, PV, TBARS and sensory measurement where semi-industrial process resulted in better quality attributes. In addition to all mentioned quality indicators, water activity should be considered as important contributing factor of physical, chemical and microbiological attributes, and sensory qualities of dried isinglass product. As far as our knowledge, there is no existing report that investigated water activity of commercial isinglass from cultivated sturgeon swim bladder using both traditional Indian and semi-industrial extraction processes.

The use of a factorial experimental design permits to evaluate independently the influence of species and extraction method. Indeed, the data revealed that the extraction method shows a higher significance level than the species effect for the vast majority of the parameters (physicochemical, microbiologic, and sensorial), whereas differences attributed to the species are usually very low or null. This confirms that the benefits are due more to the processing method than to intrinsic properties between the sturgeon species.

From an industrial viewpoint, choice of extraction technique cannot be based solely on one operating parameter; a composite techno-economic evaluation based on capital investment, equipment maintenance and labor costs, cost of utilities, throughput, yield of isinglass, cost of disposal of waste streams and value of product is needed. The study was not, of course, structured to offer a full cost-benefit analysis; however, the production figures and quality results presented here provide the necessary technical information to support economic modelling studies. Such an integration of these technical factors with economic parameters will permit estimation of production costs per kg of isinglass, overall profitability and return on capital invested thus facilitating the rational comparison of the relative industrial viability of the two extraction methods.

Study Limitations

In absence of established, internationally accepted quality limits for dried collagen based products, like isinglass the parameters like physicochemical and microbiological parameters analyzed in this study served primarily as indicators for relative differences in product quality and shelf life rather than definitive acceptance values. The results were analyzed, consequently used as comparative differences between conventional Indian and semi-industrial extraction systems, The obtained results were also supplemented with literature data for similar products based on fish collagen. Even though the semi-industrial process resulted in consistently better yield and overall improved product physicochemical, microbial quality and acceptability, but due to the fact that entire extraction system was compared, isolated processing steps like temperature of drying, duration of drying, method of pressing and environmental controls cannot be separated and attributed definite individual impacts, likewise many species inherent characteristics (swim bladder thickness, amount of collagen, microstructure of swim bladder tissue, age of the fish, biochemistry of swim bladder) may have contributed for difference in the extraction efficiencies and product quality, but their isolated impact was not analyzed as such in this experimental approach. Hence the conclusion can be generalized for relative advantage of complete process rather than impact of each processing units or species specific characterization.

Additionally, no commercial isinglass reference standards were prepared, since typical commercial isinglass products derive from species other than sturgeon and are

produced by patented industrial processes and cannot be readily compared. Thus, in this study, we only set up a comparison between the two extracted products by using common experimental setup and raw materials. However, in the future research, prepare of external quality references in form of isinglass standards commercial products can support comparison with standards for the purpose of overall quality valuation.

Future Perspectives

Even though the traditional Indian method is uncomplicated and inexpensive to utilize facilities it needed however, quite a lot of performance which could be enhanced through optimization. This could be done to the main operating factors. The main processing elements are soaking time, drying, dry duration and temperature, Initial moisture and also pressing requirements. Additional factors should also be taken in to account, because the optimization associated with such variables could help to increase proteins hydration, proteins swelling, moisture elimination, conservation associated with collagen mesh work, extraction yield, and good quality for instance bodily plus chemical. Additionally, it will increase microbiological security, sensory properties plus shelf-life associated with isinglass. A Design associated with Experiments (DoE) is recommended for long term scientific research, as the factorial testing framework plus Reply Area Strategy (RSM) is often made use of for pinpointing optimal set associated with variables together with evaluating person and together influences associated with these parameters (Box, Hunter, & Hunter, 2005; Shadish, Cook, & Campbell, 2002; Montgomery, 2019; Myers, Montgomery, & Anderson-Cook, 2016). Variables this sort such as extraction yield, proteins, peroxide value, TVB-N, color characteristics, microbial good quality, TBARS and also sensorial approval could then be assessed to determine optimum mixture regarding processing factors which may be utilized within a standardized, replicable process suitable for commercial production of large quality isinglass. As stated earlier, although the Indian process has a lower start investment cost as well as lower facilities requirement, its considerably lower extraction yield may result in an increased cost per product produced. Additionally, it demands a far more significant processing time as well as can outcome in much higher product losses. Higher microbiological security, greater proteins retrieval and excellent final product are likely result in a more economical manufacturing of isinglass, even though greater gear and running costs, increased vitality consumption and pressing devices, are necessary for the semi-industrial process.

Future scientific studies ought to be centered not merely about process optimization and also techno-economic investigation, but should also be devoted to creating predictive models associated with top quality and degradation through storage. The obtained observations from samples of dry isinglass, over storage and analyzed for TVB-N, peroxide value, TBARS, aerobic plate counts and total yeasts and molds, recommend that the final products degrade considerably during time. These factors might thus be integrated in to future predictive shelf life designs for isinglass. Although this kind of research was designed mostly to finding possible process variations it could still generate useful data for the future establishment of forecasting quality models. The data obtained would make suitable bases for kinetic models if future research employ appropriate kinetic designs. The actual kinetic design could be put to use in assessing destruction rate and future predictions associated with shelf-life under varying circumstances associated with storing (Kutner, Nachtsheim, Neter, & Li, 2005).

Conclusion

Our results proved that the production method exerted significant effect on production yield, physicochemical and microbial qualities, physical parameters, oxidative stability and sensory acceptability of isinglass made from

sturgeon swim bladders during seven-month ambient storage. Compared with the Indian traditional extraction method, semi-industrial method consistently was offered significantly high production yield and protein content, lower moisture content, better microbial quality, reduced TVB-N and peroxide values, improved color stability, stronger texture and better sensory score throughout the entire storage. Hence, semi industrial method appeared to be more successful to maintain the quality integrity of isinglass during storage. These quality indices implied the semi industrial process was exhibited good storage stability for isinglass production with good product quality. This information could provide valuable scientific references for the development and commercialization of sturgeon swim bladder based isinglass production.

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Author Contributions

Dr. **Koochakian Sabour** was responsible for the conceptualization and project management. **Dr**. **Seifzadeh** collaborated on project implementation, conducting experiments, and writing the article.

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تأثیر روش‌های استخراج هندی و نیمه‌صنعتی بر کیفیت و مقبولیت آیزین گلاس تولید شده از کیسه شنای فیل‌ماهی (*Huso huso*)، تاس‌ماهی ایرانی (*Acipenser persicus*) و ازون‌برون (*Acipenser stellatus*) پرورشی

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چکیده

آیزین گلاس پروتئینی با ساختار ژل‌مانند است که از کلاژن استخراج می‌شود. این پروتئین از کیسه شنای ماهی‌های مختلف گرفته می‌شود، اما بیشتر از ماهیان خاویاری استخراج می‌شود. ایزینگلاس از سه نوع ماهی خاویاری که معمولاً در ایران پرورش داده می‌شوند. آیزین گلاس از ماهی‌های فیل‌ماهی، تاس‌ماهی ایرانی و ازون‌برون با استفاده از دو روش مختلف شامل هندی و نیمه‌صنعتی، استخراج شد. در این مطالعه، ایزینگلاس استخراج شده به‌مدت ۷ ماه در دمای اتاق نگهداری شد و از نظر ویژگی‌های فیزیکی، شیمیایی، میکروبیولوژیکی و ارگانولپتیکی مورد آزمایش قرار گرفت. درصد استخراج در روش نیمه صنعتی (۶۳-۶۷٪) بیشتر از روش هندی (<۲۴٪) بود. زمان استخراج نیز در این نمونه‌ها کوتاه‌تر بود (۳-۷ روز در مقابل ۸-۲۴ روز) ($P<0.05$). روش‌های نیمه صنعتی حاوی ۷۴-۷۵٪ پروتئین بودند، در حالی‌که در روش هندی حدود ۶۴٪ بود. رطوبت، TVB-N و پراکسید در روش نیمه‌صنعتی در مقایسه با نمونه‌های هندی پس از ۷ ماه بهتر بودند. نمونه‌های نیمه‌صنعتی کمترین تعداد باکتری را داشتند و ارزیابی حسی آنها امتیاز پذیرش بالاتری را در مقایسه با نمونه‌های هندی نشان داد (بالای ۴ پس از ۷ ماه). با این حال، نمونه‌های هندی از نظر ارزیابی حسی قابل قبول نبودند. در حالی‌که نمونه‌های هندی ارزش غذایی بالاتر و مصرف انرژی کمتری داشتند، روش نیمه‌صنعتی بازده بالاتر، کیفیت شیمیایی و میکروبی بهتر و کیفیت حسی مطلوبی داشت. بنابراین، روش‌های نیمه‌صنعتی انتخاب بهتری برای تولید ایزینگلاس در مقیاس تجاری هستند.

واژه‌های کلیدی: آیزین‌گلاس، خواص فیزیکو شیمیایی، ماهیان خاویاری، روش هندی، روش نیمه‌صنعتی

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