**Promoting Sustainability and Profitability: Innovations in Freshwater Fish Value Addition**

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**Abstract**

This article explores the critical role of value addition in the fisheries sector, emphasizing its potential to enhance profitability, ensure food security, and improve nutrition globally. Recognized for its rich nutritional profile, fish is an essential source of proteins and omega fatty acids. However, its high perishability presents challenges that can be mitigated through innovative processing techniques that extend product shelf life and increase market value. The article highlights the underutilized potential of freshwater fish species and the strategic importance of using fish by-products to develop both food and non-food products, thereby optimizing resource utilization and reducing environmental impact. It discusses the challenges faced by the sector, such as high tariffs on processed products in developing countries and the need for advanced technology for processing high-value products from bioactive compounds. The article also outlines strategies for overcoming these challenges, including leveraging simpler technologies, improving quality assurance, conducting comprehensive market studies, and fostering supportive policies for local processing. Through these approaches, the fisheries sector can significantly enhance its economic viability and contribute to sustainable food systems worldwide.

Keywords: value addition, food security, fish by products, fresh water fishes, sustainable practices

**Introduction**

Fish is widely recognized as an excellent source of food, not only for its appealing taste and high digestibility but also for its rich content of unsaturated fatty acids, essential amino acids, vitamins, and minerals (Jayasankar, 2018; Allam et al., 2020; Maulu, 2020; Tacon et al., 2020; Maulu et al., 2021). It serves as an ideal alternative to meat, because of its high protein and polyunsaturated fatty acids (PUFA), making it dietary staple across the world. The fisheries sector significantly contributes to global nutrition, accounting to 17% of population’s animal protein intake (FAO & WHO 2020), highlighting its essential role in human nutrition. The global fish production of 177.8 m metric tons in 2019 indicates that the sector plays a pivotal role as source of protein, foreign exchange, livelihood, and human well-being (Sea Fish Organization, 2019).

However, fish is a highly perishable commodity and spoils quick if not consumed or processed immediately (Tom and Chitra, 2020). Addressing this, innovative value addition not only extend the shelf life of fish products but also enhances their market value (Binsi et al., 2018; Ninan, 2018). Unlike marine fishes’ freshwater species have appealed to a more limited market due to their distinct flavour and characteristics. Nevertheless, with the decline in the marine fish stock, there is a growing imperative to add value to both farmed freshwater fishes to meet increasing demands for fishery products (Venugopal, 2005).

In India, where the potential for developing value-added freshwater fish products remains largely untapped, there exist a considerable opportunity to expand the market through innovative strategies (Kamble et al., 2023). Unfortunately, a significant portion of fishes consumed globally results in 50-70% waste from the original materials, which often contributes to environmental pollution (Nagai and Suzuki, 2000; Kittiphattanabawon et al., 2005; Penarubia et al., 2021)). Optimizing the use of fish by-products through creation of fishmeal, fish oil, collagen, and biodiesel can offer substantial environmental and economic benefits. Large-scale processing companies are pivotal in transforming these by-products into valuable goods, thus enhancing resource efficiency and reducing waste (Olsen et al., 2014; Islam et al., 2021).

The fish processing industry is leveraging value addition as a crucial strategy to augment profitability and minimize waste. This involves transforming low-value fish through techniques such as deboning, and creating high-value products through various preservation and processing methods, thereby extending shelf life and improving marketability (Prakasan, 2022). These techniques include refrigeration, freezing, drying, salting, smoking, and vacuum packaging (Datta 2015; Binsi et al., 2018; Coppola et al., 2021). Such approaches not only better utilize low-value fish but also cater to the growing consumer demand for convenient, ready-to-eat, and nutritionally enriched fish products (Datta, 2015; Fitri et al., 2022).

Furthermore, the transformation of by-products into innovative ingredients and products is essential for maximizing the economic value of fisheries. This approach minimizes economic waste, lessens environmental impact, and provides consumers with nutritious, affordable, and convenient food options with an extended shelf life (Monteiro et al., 2014; Fuchs et al., 2015; Penarubia et al., 2022). In India, the export of value-added fish products like Ready to Eat (RTE), Ready to Cook (RTC), and Ready to Serve (RTS) has significantly grown, contributing to rural entrepreneurship and enhancing economic value (Jeyanthi, 2023).

Moreover, marketing value-added products requires dynamic strategies, including conducting detailed market surveys, implementing innovative packaging, and engaging in direct sales through channels like supermarket chains. These strategies ensure that products are well-presented and meet consumer expectations for hygiene and health standards (Datta, 2015; Binsi et al., 2018; Viswanathan et al., 2023).

This article explores the importance of adding value freshwater fishes and discusses how value addition can enhance profitability. It also emphasises the potential of using by-products to develop non-food products from fish, providing additional income opportunities for small-scale producers and processors. Furthermore, the article also addresses the challenges within the competitive, evolving value-added fish products and outlines strategies to overcome these challenges in order to optimize resource utilization.

**Value addition and the importance in fishery industries**

Value addition, generally refers to any activity that alters a product to enhance its value at the point of sale. This involves adding ingredients or processes to raw or pre-processed food items to make them more appealing to buyers or easier for consumers to use. It is a strategy in production and marketing that is guided by customer needs and perceptions (CIFT). Value addition is particularly relevant in the fish processing sector, where demand for ready-to-eat and easy-to-prepare foods are becoming increasingly popular among consumers, where such products are perceived as having better quality and appeal, making them more desirable (Datta, 2015). It often includes additional ingredients like coatings or sauces, are presented in a consumer-friendly manner such as neatly prepared fillets, and offer enhanced convenience (Datta 2015; Binsi and Parvathy, 2021).

According to Palathra (2019), the drive for value addition in the fish industry stems from four main objectives: achieving higher profit margins, improving processing utilization, meeting evolving consumer demands, and diversifying the range of products available in the market. Although all fish are similar nutritionally, their market value can differ significantly. some fishes are considered premium and fetch higher prices, while others, less popular due to their lower market appeal, might be used for animal feed or discarded if not processed. Modern technology now has made possible by transforming such low-value fishes into acceptable edible product, enhancing their marketability and consumption after value-addition (Palathra, 2019; Datta, 2015).

Global trade in fish and fishery products are experiencing rapid growth every year (FAO, 2022). This trade often involves exports from developing to developed markets and vice-versa, covering thousands of miles to meet consumer demand across the globe. To maximize profitability, raw fish undergoes basic processing to maintain freshness and quality that appeals to consumers in distant markets. Ironically, while developing countries often exports raw fish, developed countries performs value adding process such as branding, and extending shelf life that significantly increase the products value. Unfortunately, developing countries frequently miss out on capitalizing fully on the potential value addition potential of their aquatic resources, forgoing significant economic benefits (egyankosh 2017).

**Fish products and value-addition of some fresh water fishes**

Freezing and storing whole fish, gutted fish, and fillets are effective methods for the long-term preservation of various freshwater species like rainbow Trout, Shellfish, Catla, Rohu, and Tilapia. These preservation techniques enhance shelf life for export to long distances, where they are sold in block frozen or Individual Quick Frozen (IQF) forms. These products are then transformed into different types of value-added products to reach global consumers (Binsi et al., 2018).

***Fillets***: The production of fish fillets, especially from species like tilapia, enhances market value and consumer appeal due to evolving consumer expectations and improvements in cold-chain logistics. These advancements have increased the popularity of fresh, pre-processed products like fillets that offer ease in processing and cooking, appealing to both consumers and producers (Peñarubia et al., 2022). However, filleting also generates significant by-products, such as fish heads, frames, and viscera, (Kumar et al., 2018) which are rich in high-quality proteins, omega-3 fatty acids, and essential micronutrients including vitamins A and D, riboflavin (B2), niacin (B3), and minerals like iron and zinc, selenium, and iodine (Olsen et al., 2014; Coppola et al., 2021; Ozogul et al., 2021). These nutritional by-products can be transformed into cost-effective, nutritious fish products, optimizing the utilization of the fish and minimizing waste, promoting a more sustainable use of fishery resources (Peñarubia et al., 2022).

***Surimi***: Surimi, a refined fish paste, traditionally made from deboned, minced marine fish like Alaska pollock, is gaining popularity with freshwater species due to overexploitation of marine resource and the need for sustainable alternatives. Freshwater fish such as bighead carp, grass carp, and tilapia are increasingly used due to their low cost and rapid growth, making them sustainable choices for surimi production (Yingchutrakul et al., 2022). In China, traditional surimi products like fish balls and fish cakes are commonly made from freshwater species such as bighead carp, grass carp, silver carp, and black carp (Li et al., 2021). Continued research in these fishes aims to enhance the gel properties essential for high-quality surimi (Chen et al., 2020; Gao et al., 2021). In India, successful surimi production has been demonstrated using species such as silver carp (Chowdhury et al., 2009), *Labeo calbasu* (Yathavamoorthi et al., 2010), and tilapia (Chakraborty et al., 2009), Innovative strides include the development of surimi powder from freshwater fish like tilapia, offering advantages such as ease of handling, reduced distribution costs, and no need for freezing, while retaining the functional protein properties necessary for homogeneous dry mixtures (Das et al., 2018). In India, the market for surimi and its derivatives is fast growing, with products ranging from block frozen surimi to shellfish analogues, making it a third largest surimi manufacturer (Binsi and Parvathy, 2021), catering to domestic and global market.

***Fish Roe***: In India, fish roe like fish egg is an underutilized food resource, despite it being a good source of protein and essential polyunsaturated fatty acids, including omega-3 and omega-5. To extend their shelf life and reduce spoilage risks efforts have been made to develop value-added, stable, and ready-to-eat products from these freshwater carp eggs. These processed products can be preserved for up to six months, allowing consumers to enjoy fish eggs even in the off-season (Sahu et al., 2012b). Researchers have successfully created a variety of fast-food products from carp eggs, including breaded and battered products that can be stored or deep fried and served immediately. Additionally, the breaded slice can be used as patties in fish egg burgers, or these egg slices or nuggets (Sahu et al., 2012b). Top of Form

***Deboned fish***: The "Boneless Whole Carp" technology, which preserves the fish's shape through a manual deboning process, has been developed to enhance the market value of carp (Das et al., 2018). Historically, carp has been less popular in the market due to its intramuscular bones (Sahu et al., 2012a; Li et al., 2021). This innovative technology has paved the way for products like spiced boneless carp, a ready-to-use item ideal for retail. Additionally, roasted whole carp has become a popular fast-food choice, perfect for take-home meals (Das et al., 2018). Responding to consumer demand for convenient options, a variety of boneless carp products have been developed, ranging from ready-to-cook items like fillets and nuggets to ready-to-serve fast foods such as battered and fried carp. The goal is to establish both a local and international market for these affordable, boneless, healthy, and ready-to-eat fish products that cater to consumer preferences (Binsi et al., 2018; Das et al., 2018; Ninan, 2021).

***Ready to serve fish items***: A wide variety of ready-to-serve fish products are available in the market, utilizing fish mince to create items such as battered and breaded fish fingers, fish balls, sausages, cakes, nuggets, patties, and cutlets. Domestic markets favor fish cutlets, while fish fingers are more popular in export markets. Adding soy protein to fish mince can improve the appeal and extend the shelf life of these products. Additionally, fish rolls made from the frame meat of fishes like rohu and tilapia can be developed with extended shelf life (Binsi et al., 2018; Binsi and Parvathy, 2021). Tilapia, with its odorless, lean, and white flesh, is particularly suited for creating diverse ready-to-serve products like fish curry, sandwiches, cutlets, burgers, and sticks for both domestic and international markets (Dhanapal et al., 2010). Moreover, a ready-to-eat fish sandwich spread made from low-cost tilapia mince and omega-3 fatty acid-rich fish oil can be thermally processed and packaged in retort pouches. This processing optimizes retorting conditions to enhance the nutritional value, texture, and oxidative stability of the spread, which has been shown to maintain its quality for up to 12 months without significant changes (Dhanapal et al., 2016; Das et al., 2018).

***Fish sausage***: Current research is exploring the commercial potential of Indian major carps for producing mince and value-added fish products, highlighting a growing interest in these freshwater species. While fish sausages have traditionally been prepared, on commercial scale from marine fish, there has been a shift towards investigating freshwater alternatives such as Indian major carps (de Oliveira Filho et al., 2012; Chattopadhyay et al., 2019; Gore et al., 2022). These carps are favourable for sausage production due to their white flesh and low fat. However, challenges such as high pin bone density, small size, and a characteristic muddy flavour limit their consumer appeal (Praneetha et al., 2015).

Mortadella, a large Italian sausage traditionally made from pork and chicken, is highly popular in the western world. Recently, mortadella made from minced tilapia is particularly well-received due to greater softness and more intense colour compared to pork and chicken counterparts (Alda et al., 2021; Jeronimo et al., 2021). Additionally, tilapia mortadella is considered nutritious and healthier than traditional mammalian and avian meat sausages due to higher content of polyunsaturated fatty acids (Feng et al., 2020). Efforts are also being made to explore the use of silver carp for sausage production to increase profitability and market appeal (Rahmanifarah et al., 2015; Pourashouri et al., 2020).

**Innovative uses of Fish by-products in various industries**

The utilization of fish by-products is becoming increasingly popular due to their sustainable source of valuable bio-compounds such as collagen, peptides, chitin, and polyunsaturated fatty acids (PUFAs). These compounds are ideal for biotechnological and pharmaceutical applications because of their safety, cost-effectiveness, and therapeutic benefits (Hemung, 2013; Gomez et al., 2020; Penarubia et al., 2022).Top of Form

Collagen and gelatin, traditionally derived from cow and pig skins, are now often sourced from fish by-products like scales and bones due to concerns over animal diseases and religious restrictions (Jafari et al., 2020; Senedheera et al 2020). These proteins are used extensively across various industries due to their biocompatibility and biodegradability (Pati et al., 2010; Huda et al., 2013; Senadheera et al., 2020; Ge et al., 2020). The growth in fish processing has led to increased by-product waste (Sricharoen et al., 2020; Islam et al., 2021), which can be repurposed to add value and enhance sustainability in the industry (Md Zin, 2019).

Research shows that fish collagen, especially from freshwater species like Rohu (*Labeo rohita*), Catla (*Catla catla*), Pangas catfish (*Pangasius pangasius*), Nile tilapia (*Oreochromis nilocitus*), Asian redtail catfish (*Hemibagrus nemurus*), Striped snakehead (*Channa striata*) catfish *Clarias gariepinus*, tilapia and *Cirrhinus mrigala* is preferred for its superior thermal stability and high amino acid content (Tian et al., 2021). This type of collagen is promising for biomedical Top of Formapplications such as wound dressings, burn treatments, and skin regeneration, (Coppola et al., 2021; Lima Verde et al., 2021; Zhao et al., 2021 Ibrahim et al., 2020; Liu et al.,2019).

Furthermore, about 50% of fish waste is discarded during processing but has potential for conversion into products like fish oil and biodiesel (Yahyaee et al., 2013). Fish oil rich in omega-3 fatty acids like eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) supports numerous biological functions is crucial for human health, contributing to a significant market value (Coppola et al., 2021). Additionally, fish wastes are also suitable material for biodiesel production, offering an eco-friendly fuel alternative due to low ash content, appropriate flashpoint, and suitable density (Jaiswal et al., 2022; Karkal et al., 2024).

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ish skin, considered a pollutant (Zilberfarb et al., 2023) is now being transformed into leather production through new technology (Bi et al., 2019). Tilapia leather, in particular, is valued for its thickness and tensile strength (Yoshida et al., 2016). This approach not only mitigates waste but also promotes a more dynamic economy in the fisheries sector (Godoy et al., 2010a).

Fish by-products such as carcasses and residual meat adhering to skin and bones can be processed into inexpensive yet nutrient-rich source for diverse applications (Vignesh et al., 2015). These by-products contain are rich in proteins and minerals like calcium (Fong et al., 2020). The fish flour, derived from these materials, is particularly useful for gluten-intolerant consumers (Stevanato et al., 2010; Monteiro et al 2014), and it significantly enhances the nutritional quality of various food items including soups, broths, pasta, and pizzas (Stevanato et al., 2007; Godoy et al., 2010b; Magalhães et al., 2019; Ahern et al., 2020; Verdi et al., 2020). Fish flour is also used in preparing breads, cookies, lasagnas (Franco et al., 2013; Kimura et al., 2017; Chambó et al., 2018). Additionally, fish soup powder, made from low -fat fresh-water fishes like tilapia, catla, rohu, and mrigal is valued for its richness in dietary proteins and minerals (Binsi et al 2018).

**Challenges and Strategies in Value Addition and Market Access for Fish Products**

The potential for adding value is significant, offering financial gains, enhanced food security, and improved nutrition. It optimizes utilization of greater percentage of fish for consumption. For instance, utilization from 30% to 60% substantially boost food availability. Additionally, non-fillet parts could be used to supplement micronutrients, although more research is needed to fully understand their nutritional profiles. The creation of value-added products from fish waste also demands careful consideration (Penarubia et al., 2022). It is imperative to understand the challenges in the competitive and evolving value-addition fish market, and develop appropriate strategies to overcome such challenges.

1. **High investment and advance technology**: The development of high-value products from bioactive compounds such as collagen, gelatin, and bioactive peptides requires significant capital investment and advanced technology, which may be out of reach for small-scale processors (Penarubia et al., 2022).
2. **Quality assurance**: Ensuring consistent quality and safety is critical, particularly as many value-added fish products are consumed directly. This necessitates rigorous quality assurance programs to prevent health risks and economic losses.
3. **Market viability**: Comprehensive market studies are essential before adopting new technologies or products to ensure consumer demand exists. Additionally, higher import duties and substantial investments in marketing and infrastructure can be prohibitive.
4. **Regulatory and tariff barriers**: In developing countries, exporting processed fish products can attract high tariffs compared to unprocessed fish, impacting profitability and export strategies (egyankosh 2017).
5. **Resource utilization**: Only about 30% of the fish is typically used for fillets, with the remaining 70% constituting by-products often underutilized, especially in smaller processing facilities that lack the necessary capital for equipment investments (Penarubia et al., 2022).

Strategies to overcome the above-mentioned challenges are

1. **Leveraging simpler technologies**: Implementing simpler technologies to transform by-products into food and feed at an artisanal level can increase the range of products and their market reach without the need for large capital investments (Penurbia et al., 2022).
2. **Strengthening quality assurance protocols**: Developing standard sanitary operating practices (SOPs), maintaining high-quality raw materials, and training a consistent workforce are essential steps to ensure product quality and safety.
3. **Enabling policy environment**: Governments can facilitate value addition by offering incentives for adopting new technologies and supporting local processing through subsidies or reduced tariffs (egyankosh 2017).
4. **Comprehensive economic analysis**: Conducting detailed cost/benefit analyses that consider both macro-economic and micro-economic factors helps determine the most effective strategies for utilizing fish by-products.
5. **Building export capabilities**: Control over more of the value chain can maximize revenue for exporting firms. Supportive policies from home governments can aid market access by incentivizing local processing and organizing trade associations.
6. **Product diversification and value addition**: Transforming a significant portion of fish into valuable products like fishmeal or utilizing skins for further processing can provide additional income streams, making operations more sustainable and economically viable, especially for larger facilities (Penarubia et al., 2022).

**Conclusion**Top of Form

In conclusion, the fisheries sector holds a critical role in global nutrition, food security, and economy. The perishable nature of the fish, which is a challenge for long-term storage, can be managed through innovative value addition techniques that extend shelf life, at the same time enhance market appeal. Such strategies not only boost profitability but also promote sustainable practice by utilizing the by-products and reducing waste. It is anticipated that finding alternative uses for freshwater fish beyond direct consumption could significantly enhance the local aquaculture industry. With the depleting sea fish resources, fish resources from fresh water and aquaculture offers tremendous opportunity to diversify and enrich the variety of fish products.

Embracing value addition facilities, the transformation of low-value by-products into high-value commodities like fishmeal, collagen, and fish flour are crucial for both environmental sustainability and economic enhancement. To fully capitalize on these opportunities, it is imperative for industry stakeholders to invest in quality assurance, engage in thorough market research, and advocate for supportive policies that facilitate local processing and market access. By doing so the fishery sector can continue to grow and provide nutritious, accessible, and affordable food options world-wide, thereby contributing to a healthier planet.

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