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Value Addition of Freshwater Fish: Processing Technologies, Product Development and Sustainable Utilization

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Abstract

Freshwater fish are valuable sources of high-quality protein, essential amino acids, minerals, vitamins and beneficial lipids, contributing significantly to food and nutritional security. However, their high moisture content, endogenous enzymatic activity and susceptibility to microbial spoilage make them highly perishable. Poor post-harvest handling, inadequate cold-chain facilities and dependence on fresh fish marketing can cause substantial quality and economic losses. Value addition offers an effective strategy to extend shelf life, enhance convenience, increase economic returns and diversify fish utilization. Conventional methods such as chilling, freezing, drying, salting and smoking can be integrated with modern technologies including modified-atmosphere packaging, high-pressure processing, surimi production and protein recovery. Species such as tilapia, rohu, catla, common carp, silver carp and catfish can be processed into fillets, mince, fish fingers, cutlets, sausages, powders and ready-to-cook products. Processing by-products can also be converted into fish meal, oils, hydrolysates, collagen, gelatin and fertilizers, supporting circular bioeconomy and sustainable fisheries development.

Keywords: Freshwater Fish, Value Addition, Fish Processing, Fish Powder, Surimi, Ready-To-Cook Products, By-Products, Sustainability

Introduction

Freshwater fish are important components of aquatic food systems, comprising capture-fisheries and aquaculture species such as Indian major carps, common carp, tilapia, catfish and freshwater prawns. They provide highly digestible protein, essential micronutrients and other nutrients while supporting employment, rural livelihoods, income generation and nutritional security. However, fresh fish is highly perishable due to its high moisture content, near-neutral pH, endogenous enzymatic activity and microbial load. Consequently, immediate icing, hygienic handling, efficient transportation and appropriate processing are essential for maintaining quality and minimizing post-harvest losses (Venugopal, 2006).

Value addition encompasses processing operations that enhance the economic, nutritional, functional or convenience value of fish. These range from cleaning, dressing,

filleting and portioning to advanced processes such as mincing, drying, protein extraction, surimi production, packaging and ready-to-eat product development. Value-added processing can improve profitability, market access and resilience within fish value chains (Venkatappa et al., 2025). For freshwater fish, diversification is particularly important because many species are marketed mainly as whole fresh fish. Development of value-added products can expand consumer choices, utilize underused species, reduce post-harvest losses and create opportunities for small-scale processors and entrepreneurs.

Freshwater Fish: From Perishable Commodity to Value-Added Product

The first step in value addition is proper post-harvest handling. Harvested fish should be protected from contamination and temperature abuse and rapidly cooled using ice or refrigerated systems. Poor handling before processing can reduce the quality and shelf life of the final product, regardless of the sophistication of the subsequent technology.

Freshwater fish can then be converted into a hierarchy of products ranging from minimally processed chilled fish to highly formulated ready-to-eat foods. The selection of processing technology should depend on species characteristics, muscle composition, size, fat content, intended market, available infrastructure and consumer preferences. Processing technologies should therefore be viewed as a continuum rather than isolated methods.

Chilling and Freezing

Chilling is one of the simplest and most important preservation methods for freshwater fish. Storage under ice slows microbial growth and enzymatic reactions while maintaining the characteristics of fresh fish. Chilled fish can be marketed as whole fish, dressed fish, steaks or fillets.

Freezing provides substantially longer storage than chilling and allows processors to decouple production from immediate consumption. Individually quick frozen (IQF) fillets, steaks, portions and minced fish products are particularly suitable for organized retail and institutional markets. Rapid freezing generally produces smaller ice crystals and can help preserve muscle structure compared with slower freezing methods (Venugopal, 2006).

Modern packaging technologies can further improve frozen-product quality. Vacuum packaging and modified-atmosphere packaging can reduce exposure to oxygen and help control oxidation and quality deterioration. Effective temperature control throughout storage and transportation remains essential because repeated temperature fluctuations can negatively affect texture and product quality.

Drying and Dehydrated Products

Drying is among the oldest fish preservation technologies and remains relevant for freshwater fish, particularly where refrigeration facilities are limited. Reduction of moisture and water activity inhibits microbial growth and slows many deterioration reactions. Traditional sun drying can be economical but is vulnerable to contamination, insects, rainfall and fluctuations in temperature and relative humidity.

Improved solar dryers, mechanical hot-air dryers and hybrid drying systems provide greater control over drying conditions. Dried freshwater fish can be sold as whole dried fish, flakes, powder or as an ingredient in soups, snacks and composite foods.

Fish powder is particularly promising because it converts a perishable raw material into a shelf-stable ingredient. A study on tilapia and silver carp demonstrated that fish powders could contain approximately 63.63% and 73.58% protein, respectively, while also supplying minerals such as calcium, phosphorus, iron and zinc (Kabir et al., 2022).

Fish powders can therefore be incorporated into bakery products, soups, extruded foods, instant mixes, noodles, snacks and complementary foods. They can also be particularly useful in regions where consumers require convenient protein-rich ingredients.

Salting and Smoking

Salting reduces water activity and produces characteristic sensory properties. Depending on salt concentration and processing conditions, salted freshwater fish can be marketed as whole fish, fillets or other forms. Appropriate hygienic practices and controlled salt levels are important because excessive salting may negatively affect consumer acceptance and nutritional considerations.

Smoking combines preservation with flavor development. Traditional smoking remains important in many communities, while improved smoking kilns can provide better control of temperature, smoke exposure, hygiene and fuel consumption. Smoked tilapia, carp and catfish products have potential for both domestic and specialty markets.

Mince-Based and Ready-to-Cook Products

One of the most promising approaches for freshwater fish is conversion into mince-based products. Mechanical separation of edible flesh from frames and bones can increase flesh recovery and provide a standardized raw material for product development.

Fish mince can be converted into:

- fish fingers and nuggets;
- fish cutlets and patties;
- fish balls;

- fish sausages;
- burgers;
- kebabs;
- spreads and pastes; and
- ready-to-cook coated products.

These products are particularly attractive to urban consumers because they reduce preparation time and minimize the inconvenience associated with bones. They also provide an opportunity to utilize smaller fish or portions that may have lower value in conventional fresh-fish markets.

Tilapia has considerable potential in this area. Research has shown that tilapia processing by-products and mechanically recovered flesh can be used for development of minced products and surimi, creating additional nutritional and economic value (Peñarubia et al., 2023).

Surimi and Gel-Based Products

Surimi is a concentrated myofibrillar protein preparation produced by repeated washing and subsequent processing of fish muscle into a functional paste. Its excellent gel-forming properties make it suitable for fish balls, imitation seafood, fish cakes and other structured products.

Freshwater fish such as silver carp and tilapia have received increasing attention as alternative surimi raw materials. Silver carp possesses white muscle and favorable gel-forming characteristics, while recent research has emphasized the importance of seasonal variation in muscle proteins and processing conditions for surimi quality (Zou et al., 2024).

Recent research has also demonstrated the potential of Nile tilapia as a sustainable alternative raw material for surimi. The species is attractive because of its aquaculture availability and stable production, although consumer acceptance, infrastructure and market development remain important considerations.

Fish Protein Concentrates and Functional Ingredients

Protein recovery represents an important avenue for freshwater fish value addition. Fish protein concentrates and powders can serve as nutrient-rich ingredients in bakery products, soups, extruded snacks, pasta and nutritional formulations. Tilapia protein concentrate, for example, has demonstrated approximately 75% protein content, highlighting its potential as a functional food ingredient (Shanavas et al., 2021). Protein recovery can also utilize processing by-products through drying, enzymatic hydrolysis, filtration and related technologies. Such approaches improve protein utilization, create new markets for underutilized fish and

processing side streams, enhance the nutritional value of formulated foods, and contribute to sustainable and efficient freshwater fish processing.

Utilization of Freshwater Fish Processing By-Products

Processing inevitably generates heads, frames, bones, skin, scales, viscera and trimmings. Historically, these materials were frequently discarded or directed toward low-value uses. Today, they are increasingly regarded as valuable resources within a circular bioeconomy.

Depending on species and processing method, by-products can represent a substantial proportion of the original fish mass. FAO has reported that processing by-products can reach up to about 70% of processed fish in some circumstances, emphasizing the importance of their timely collection, preservation and utilization.

Potential products include:

- **Fish meal and feed ingredients:** Protein-rich fish residues can be converted into fish meal or other feed ingredients after suitable processing.
- **Fish oil:** Lipid-rich materials can be processed to recover oils containing valuable fatty acids.
- **Protein hydrolysates:** Enzymatic hydrolysis can convert fish proteins into peptides with nutritional and functional applications.
- **Collagen and gelatin:** Skin, bones and connective tissues can serve as raw materials for collagen and gelatin recovery.
- **Mineral-rich products:** Bones and scales contain calcium and phosphorus and can potentially be processed into mineral ingredients.
- **Fertilizers and biofertilizers:** Low-value residues that are unsuitable for food applications can be converted into agricultural products.
- **Bioenergy:** Organic residues may also be utilized for anaerobic digestion and other energy-recovery processes.

Recent literature emphasizes that technologies such as hydrolysis, filtration, ultrasound, microwave treatment, supercritical-fluid extraction and pulsed electric fields are being investigated to improve recovery of valuable components from fish-processing residues (Coppola et al., 2024).

Packaging, Food Safety and Shelf-Life Management

Processing alone cannot ensure product quality; food safety must be maintained throughout the value chain through Good Manufacturing Practices (GMP), sanitation, hygienic handling, water-quality control, temperature management and HACCP-based systems. Appropriate packaging protects products from oxygen, moisture, light, contamination and

mechanical damage. Vacuum, modified-atmosphere and high-barrier packaging can improve the stability of dried, frozen and ready-to-cook products. For powdered products, moisture-resistant packaging is essential to prevent water-activity increase, caking, microbial growth and chemical deterioration. Emerging non-thermal technologies, including high-pressure processing, offer further potential for enhancing safety and quality while minimizing undesirable effects associated with conventional thermal processing (Venugopal, 2006).

Sustainable Utilization and Circular Economy

The future of freshwater fish processing depends on efficient raw-material utilization through circular and cascading approaches. Different fish fractions can be directed toward suitable products, including fillets, mince, protein powders, hydrolysates, mineral products, feed, fertilizers and bioenergy. Such valorization improves resource efficiency, reduces food waste and environmental impacts, and enhances economic returns. This approach is particularly relevant for small and medium-scale enterprises, where improved drying, fish powder production, mince-based products and hygienic packaging require comparatively lower investment. Technology selection should be based on raw-material availability, energy requirements, technical expertise, market demand and anticipated product value. Thus, integrated by-product utilization can contribute significantly to sustainable aquatic-food systems, employment generation and improved nutritional and economic outcomes.

Future Opportunities

The future of freshwater fish value addition will focus on consumer convenience, nutritional functionality, sustainability and product innovation. Ready-to-cook and ready-to-eat foods, protein powders and functional ingredients offer strong market potential. Digital marketing, traceability, improved cold chains and women-led enterprises can further strengthen value chains. Emerging technologies such as high-pressure processing, advanced drying, membrane separation and enzymatic hydrolysis can enhance product quality and resource recovery. However, technology selection should consider energy use, investment, processing scale and market economics.

Conclusion

Value addition transforms perishable freshwater fish into nutritious, convenient and economically valuable products through chilling, freezing, drying, smoking, mincing, surimi, powders and ready-to-cook foods. Sustainable utilization of heads, bones, skin and viscera for fish meal, oils, protein hydrolysates, collagen, gelatin, fertilizers and bioenergy supports circular bioeconomy principles. Integrating hygienic processing, cold-chain management,

suitable packaging and food-safety systems can strengthen value chains, reduce environmental impacts, generate income and enhance food security, livelihoods and sectoral resilience.

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