JURNAL AR RO'IS MANDALIKA (ARMADA)
Journal website: https://ojs.cahayamandalika.com/index.php/armada

ISSN: 2774-8499 Vol. 6 No. 2 (2026)

Research Article

Transformation of Local Fish through Fermentation Technology for the Development of Functional Foods

Luthfiah

Politeknik Pertanian Negeri Pangkajene Kepulauan, Indonesia
Corresponding Author, Email: luthfiah@polipangkep.ac.id

Abstract

Local fish resources in Indonesia possess significant nutritional potential; however, their utilization remains largely limited to fresh or conventionally processed products with low added value. Fermentation technology offers a promising approach to transform local fish into functional foods with enhanced nutritional, health, and economic value. This study aims to analyze the role of fermentation technology in developing functional food products from local fish, focusing on nutritional enhancement, food safety, economic potential, and environmental sustainability. The research employed a qualitative method using a literature review approach, synthesizing data from peer-reviewed journals, academic books, and reputable scientific databases related to fish fermentation, functional foods, and food biotechnology. The findings indicate that fermentation improves protein digestibility, generates bioactive peptides, enhances antioxidant activity, and increases the presence of beneficial microorganisms such as lactic acid bacteria. Controlled fermentation using selected starter cultures was found to improve product safety by reducing biogenic amine formation while ensuring consistent quality. In addition, fermentation contributes to waste reduction and supports the circular bioeconomy by valorizing underutilized fish species and by-products. Overall, fermentation technology enables the sustainable transformation of local fish into high-value functional foods that integrate local wisdom with modern food biotechnology.

Keywords: Local Fish, Fermentation Technology, Functional Food.

INTRODUCTION

Fish is a rich source of high-quality animal protein, omega-3 fatty acids, vitamins, minerals, and various bioactive compounds beneficial to human health (Sarojnalini & Hei, 2019). However, the utilization of local fish in Indonesia remains largely limited to fresh or simple processed products, while its potential for development into high-value functional foods has not been fully optimized (Nikiforova, 2020). With the increasing awareness of healthy eating habits, the demand for functional foods derived from local resources continues to grow (Sun et al., 2022).

Fermentation is one of the oldest and most effective technologies proven to enhance the safety, flavor, and nutritional quality of food materials (Jung et al., 2022). The fermentation process generates new bioactive compounds such as bioactive peptides, organic acids, and antioxidants, which play an essential role in the development of functional foods (Belleggia & Osimani, 2023). Moreover, the use of probiotic microorganisms such as *Lactobacillus* and *Bifidobacterium* in fish fermentation has been shown to increase the functional value of the final product (Semjonovs et al., 2015).

In many Asian countries, traditional fermented fish products such as *jeotgal* in Korea and *ina sua* in Maluku have become integral parts of local culinary culture and natural sources of functional foods (Cha & Yu, 2024; Persulessy et al., 2020). These products are rich in free amino acids, polyunsaturated fatty acids, and beneficial microbes that contribute to gut health and immune system improvement (Narzary et al., 2021). Modern fermentation technologies allow for optimization of these traditional processes to meet industrial food safety and quality standards (Krotova et al., 2024).

Beyond nutritional aspects, fermentation also addresses the issue of fish waste, which often becomes an environmental concern. Utilizing fish by-products through fermentation can improve production efficiency while creating new economic value (Kutina & Korotkyh, 2021). Fermentation can be optimized using modern biotechnological approaches such as solid-state or enzyme-assisted fermentation (Bintari et al., 2021), potentially yielding high-quality, eco-friendly functional food products.

Transforming local fish through fermentation not only adds economic value but also supports national food security by diversifying food products based on local resources (Andriani et al., 2020). Moreover, this research is crucial for integrating local wisdom with modern technology to produce competitive functional foods for the global market (Sharma et al., 2022).

Numerous studies have shown that fish fermentation enhances sensory quality, extends shelf life, and produces bioactive metabolites beneficial for health (Belleggia & Osimani, 2023; Semjonovs et al., 2015). Additionally, integrating probiotic fermentation and local raw materials has been found to increase the bioavailability of functional compounds while providing antioxidant and antihypertensive effects (Jung et al., 2022).

This study aims to develop innovative fermentation methods utilizing local Indonesian fish to produce functional food products with high nutritional value, safety, economic potential, and environmental sustainability.

METHOD

This study employed a qualitative research approach with the type of literature study (literature review). This design was chosen because the main objective of the research is to review, analyze, and synthesize various previous studies related to the transformation of local fish through fermentation technology for the development of functional foods. A literature study approach enables the researcher to gain an in-depth understanding of concepts, theories, and empirical findings without conducting field data collection directly (Snyder, 2019).

Data Sources

The data in this research are secondary data, obtained from scientific publications such as peer-reviewed journal articles, academic books, research reports, and relevant conference proceedings. The inclusion criteria for data selection focused on publications discussing topics related to fish fermentation, food technology, probiotics, and the development of functional foods from local resources. Data were collected from reputable academic databases such as *ScienceDirect*, *SpringerLink*, *PubMed*, and *Google Scholar* to ensure validity and reliability of the information used (Booth et al., 2021).

Data Collection Technique

The documentation study technique was applied for data collection. This involved searching, reading, and recording relevant research findings that align with the focus of this study. Keywords such as *fish fermentation*, *functional food development*, *local fish*, and *biotechnology fermentation* were used to retrieve literature. Each publication was then evaluated based on its relevance, novelty, and methodological quality to ensure alignment with the research objectives (Xiao & Watson, 2019).

Data Analysis Method

The data were analyzed using content analysis, which involves coding, categorizing, and interpreting the contents of the collected literature to identify patterns, themes, and conceptual relationships. The analysis followed several stages:

1. Data collection of relevant literature;
2. Data reduction by selecting information aligned with the research focus;
3. Data presentation through thematic synthesis; and
4. Conclusion drawing based on theoretical and empirical findings.

This analytical approach allows the researcher to identify current trends, challenges, and innovations related to fish fermentation technology and its implications for functional food development (Bengtsson, 2016).

Through this methodological framework, the study aims to provide a comprehensive overview of the potential and challenges in transforming local fish into functional food products using fermentation technology. The synthesized literature findings are expected to serve as a scientific foundation for future experimental and applied research in food technology innovation.

RESULT AND DISCUSSION

Potential of Local Indonesian Fish as Raw Material for Functional Foods

Indonesia's rich ichthyofaunal diversity provides a vast range of fish species suitable for developing functional food products. Many local species, such as Oreochromis niloticus (tilapia), Pangasius sp. (catfish), and Rastrelliger sp. (mackerel), contain high-quality protein, omega-3 fatty acids, essential amino acids, and bioavailable micronutrients that make them excellent candidates for fermentation-based transformation (Narzary et al., 2021). These species are widely distributed in Indonesian freshwater and coastal ecosystems, yet much of their potential remains underutilized due to challenges in preservation, perishability, and lack of technological innovation in post-harvest processing (Atun et al., 2024).

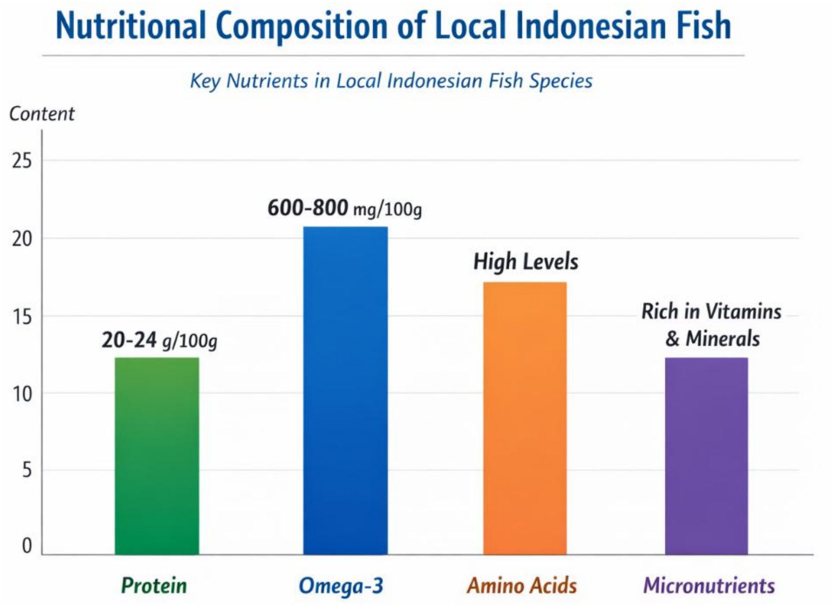

Figure 1. Nutritional Composition of Local Indonesian Fish for Functional Food Development

A prominent case study from Indonesia illustrating this potential is bekasam, a traditional fermented fish product originating from South Sumatra. Bekasam is typically produced using freshwater fish such as tilapia or catfish, mixed with salt and cooked rice, and allowed to ferment naturally for several days (Setiarto & Herlina, 2024). During this fermentation process, lactic acid bacteria (LAB) dominate, converting carbohydrates into lactic acid, reducing pH, and hydrolyzing fish proteins into free amino acids and peptides. These reactions not only improve flavor and texture but also enhance nutritional and functional value, yielding amino acids such as glutamic acid and aspartic acid that contribute to umami taste and increased digestibility.

From a biochemical standpoint, fermentation enriches fish-based foods with bioactive peptides, antioxidants, and beneficial microorganisms that can confer health benefits beyond basic nutrition. These bioactive compounds have been linked to antioxidant, antihypertensive, antimicrobial, and immunomodulatory effects, positioning fermented fish as a potential functional food (Atun et al., 2024). For instance, in traditional bekasam, peptides generated during fermentation have shown free radical scavenging activity, enhancing the antioxidant potential of the product.

However, the nutritional and microbiological qualities of fermented fish are highly dependent on fermentation conditions such as salt concentration, temperature, microbial strains, and fermentation duration (Narzary et al., 2021). Improper control may lead to excessive biogenic amine formation, compromising product safety. To address this, controlled fermentation using selected starter cultures—such as Lactobacillus plantarum and Pediococcus pentosaceus—has been recommended to improve product stability, safety, and reproducibility.

The bekasam case demonstrates how indigenous knowledge can be combined with modern biotechnology to develop standardized, safe, and market-ready fermented fish products that meet both local and international functional food standards. Moreover, utilizing underused local fish species through fermentation supports economic empowerment of rural fishing communities while reducing food waste and environmental impact.

Overall, local Indonesian fish possess significant potential for transformation through fermentation technology. With proper process optimization and scientific validation, traditional products such as bekasam could serve as a model for sustainable, culturally rooted functional foods that combine nutritional richness, food safety, and economic feasibility.

Innovative Fermentation Technologies for Fish Processing

In recent years, fermentation technologies for fish processing have shifted from traditional spontaneous methods toward controlled, scientifically optimized procedures that enhance nutritional, safety, and functional qualities of fermented fish products. Traditional fermentation relies on naturally occurring microbes and variable environmental conditions, which can result in inconsistent quality and safety risks due to uncontrolled microbial activity (Li et al., 2024).

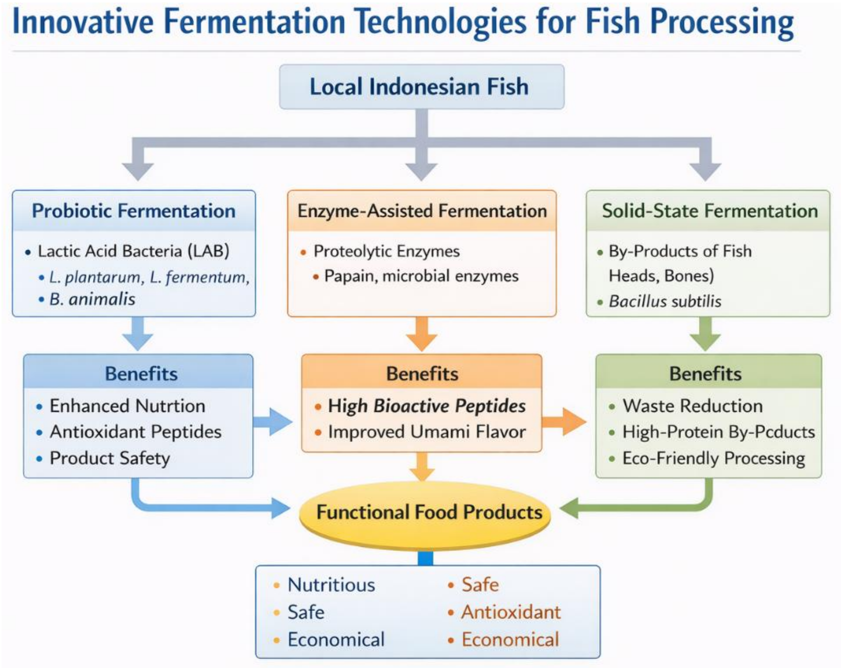

Figure 2. Innovative Fermentation Technologies in Fish Processing

One major advancement is the use of starter cultures of lactic acid bacteria (LAB) — such as Lactiplantibacillus plantarum and Latilactobacillus sakei — which can be inoculated to steer fermentation toward desirable outcomes. LAB-driven fermentation lowers pH, inhibits spoilage organisms, and promotes proteolysis, releasing peptides and free amino acids that contribute to nutritional enhancement, antioxidant capacity, and flavor improvement in fermented fish (Kim et al., 2022).

Case studies in traditional fermented fish, such as pla-ra and pla-som in Thailand, show that LAB species dominate the microbial community during fermentation and contribute significantly to product safety and quality. In inoculated fermentation trials, lactic acid bacteria populations reached high counts, leading to lower pH and increased soluble proteins, which are indicators of improved fermentation conditions and potential functional food attributes (Lin et al., 2024).

Another important advancement is the application of enzyme-assisted fermentation techniques. Research on fermented fish sauces such as budu and pekasam from Southeast Asia has identified bioactive peptides with significant antioxidant activity that are released during fermentation due to proteolytic action by microbes and enzymes. These peptides — such as LDDPVFIH and VAAGRTDAGVH — have been isolated from fermented anchovy and are linked to functional properties such as free radical scavenging activity, demonstrating the potential for generating health-promoting compounds through optimized fermentation (Najafian & Babji, 2019).

The review of global fermented fish products also indicates that fermentation increases the levels of free amino acids and bioactive compounds, including EPA and DHA omega-3 fatty acids, which contribute to cardiovascular health benefits. These functional components make salt-fermented fish not just a preserved food but also a nutrient-rich functional food, particularly when fermentation is guided by LAB and optimized for safety and health outcomes (Cha & Yu, 2024).

Emerging research highlights how fermentation technologies can be tailored to maximize both functional properties and safety profiles. For example, controlled fermentation can reduce hazardous biogenic amines — toxic compounds that can form in poorly controlled fermentation — while enhancing beneficial compounds.

Collectively, these innovations demonstrate that fermentation can transform local fish raw materials into high-value functional foods with enhanced nutrition (amino acids, peptides), sensory appeal (umami flavor), and potential health benefits (antioxidant, antihypertensive effects), while also offering greater reproducibility, safety, and economic potential than traditional fermentation methods.

1. Pla-ra and Plaa-som Fermentation in Thailand

   In Thailand, studies on pla-ra and plaa-som have applied LAB starter culture technology. The inoculated fermentation resulted in high LAB counts (up to 10 log CFU/g), lower pH, and desirable acid profiles compared to spontaneous fermentation. The presence of LAB increased soluble protein fractions, which are precursors to functional peptides, indicating that controlled fermentation can improve both nutritional and sensory quality of fermented fish (Lin et al., 2024).

2. Antioxidant Peptides from Budu and Pekasam

   Analytical studies on budu (Malaysian fermented fish sauce) and pekasam peptides reveal that amino acid sequences such as LDDPVFIH and VAAGRTDAGVH have significant antioxidant activity, which suggests potential for functional food applications beyond traditional culinary use. These peptides could be further explored as nutraceutical ingredients with health-promoting properties (Najafian & Babji, 2019).

Nutritional Enhancement and Functional Properties

Fermentation significantly enhances the nutritional and functional properties of fish-based products through complex biochemical reactions, including proteolysis, lipolysis, and microbial metabolism. During fermentation, proteolytic enzymes from both fish tissue and microorganisms hydrolyze fish proteins into bioactive peptides, which exhibit antioxidant, antihypertensive, antimicrobial, and immunomodulatory activities. These peptides are often short amino acid sequences—typically 2–20 residues—that are more bioavailable and can modulate physiological functions beneficial to human health. The production of such peptides transforms traditional fermented fish into a functional food capable of supporting preventive health strategies.

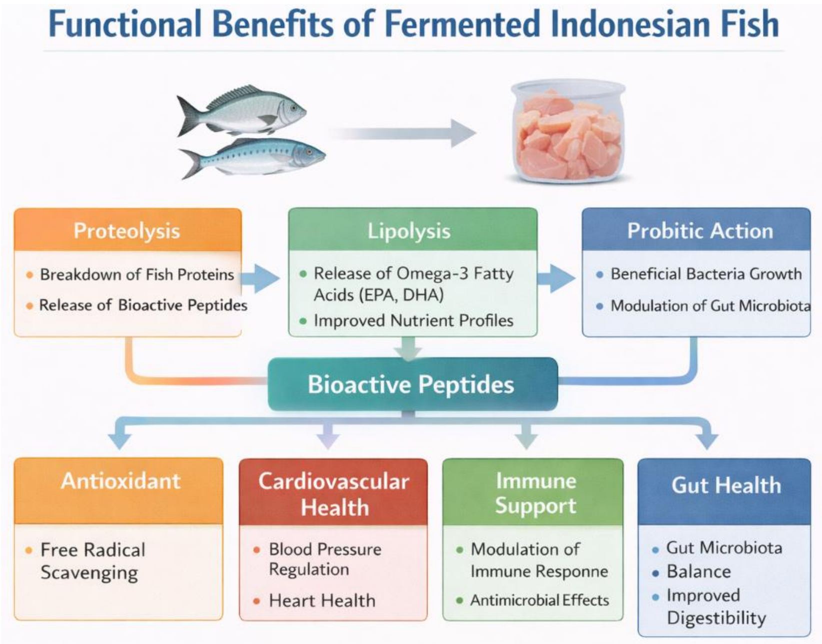

Figure 3. Functional Benefits of Fermented Local Fish Products

A central mechanism contributing to this enhancement is proteolysis, where protein degradation releases essential amino acids such as lysine, leucine, and glutamic acid, which not only improve nutritional quality but also influence flavor development through the formation of umami compounds (Cha & Yu, 2024). Lipolytic activity during fermentation also liberates polyunsaturated fatty acids (PUFAs), particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are known to contribute to cardiovascular and neural health. Furthermore, fermentation enhances the antioxidant capacity of fish products through the generation of peptides with radical-scavenging properties, helping to prevent oxidative stress-related diseases (Shahidi & Saeid, 2025).

A real-world case demonstrating these nutritional and functional improvements is found in the Indonesian fermented fish product bekasam. Studies have shown that bekasam fermentation using lactic acid bacteria (Lactobacillus plantarum) leads to increased levels of free amino acids and short-chain peptides, while also reducing lipid oxidation and spoilage potential (Putro, 1993). Similarly, in budu—a Malaysian fermented anchovy sauce—researchers identified peptides such as LDDPVFIH and VAAGRTDAGVH with strong antioxidant activity, confirming that optimized fermentation can yield bioactive compounds beneficial to human health.

Fermentation also positively affects gut health and immunity. The introduction of probiotic strains such as Lactobacillus casei and Lactiplantibacillus plantarum during fish fermentation enhances gut microbiota balance and immune modulation, which contributes to gastrointestinal well-being and disease prevention. Probiotics derived from fermented fish have been found to produce bacteriocins—natural antimicrobial peptides—that inhibit pathogens like Listeria monocytogenes and Staphylococcus aureus, improving both food safety and functional properties (Li et al., 2024).

Beyond human health benefits, the biochemical transformations during fermentation also improve digestibility and sensory appeal, making fermented fish both nutrient-dense and organoleptically desirable. Enhanced umami taste, soft texture, and reduced fishy odor are the result of controlled microbial and enzymatic processes that generate flavor-active compounds such as glutamic acid, succinic acid, and volatile esters (Cha & Yu, 2024). This combination of nutritional enrichment, health-promoting bioactivity, and improved sensory quality reinforces the positioning of fermented fish as a scientifically supported functional food.

In summary, fermentation of local fish species not only preserves raw materials but also biochemically transforms them into functional foods with higher nutritional value, better digestibility, enhanced sensory properties, and potential health-promoting bioactivity. This integration of traditional practices and modern biotechnology creates a sustainable pathway for improving food security, health outcomes, and local economic resilience in fish-producing regions like Indonesia (Li et al., 2024; Setiarto & Herlina, 2024).

Food Safety and Quality Assurance

Ensuring food safety in fermented fish products is a crucial prerequisite for their classification as functional foods. Fermentation inherently involves microbial activity, and while beneficial bacteria such as Lactiplantibacillus plantarum contribute to improved nutritional value and flavor, undesirable microorganisms that produce biogenic amines—including Morganella, Enterobacter, and Klebsiella—can also proliferate during uncontrolled fermentation, posing potential health risks to consumers (Visciano et al., 2020). Histamine, in particular, is a significant biogenic amine associated with scombroid poisoning when present at high concentrations.

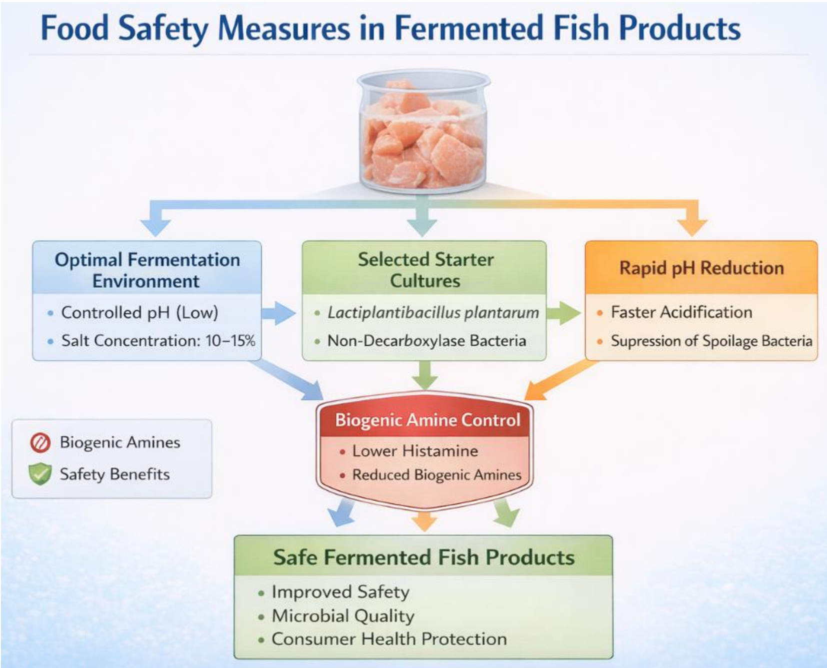

Figure 4. Food Safety Measures in Fermented Fish Production

One of the main safety challenges in fermented fish is the accumulation of biogenic amines such as histamine, tyramine, cadaverine, and putrescine, which are produced by microorganisms possessing decarboxylase enzymes (Turna et al., 2024). These compounds form through the decarboxylation of amino acids when fish is not properly handled or processed before and during fermentation. Consumption of high-histamine products can lead to symptoms such as headaches, flushing, and gastrointestinal distress, as histamine acts as a vasodilator and inflammatory mediator in the human body (Visciano et al., 2020).

To mitigate these risks, the use of selected starter cultures has been proven effective. Non–decarboxylase-producing starter cultures can suppress the growth of amine-producing bacteria while promoting safe and consistent fermentation. For instance, inoculation with Lactiplantibacillus plantarum or mixed-culture starters significantly reduces the accumulation of biogenic amines compared to spontaneous fermentation (Zhong-Yi et al., 2010).

An experimental study on Suan yu, a traditional Chinese fermented fish, demonstrated that inoculation with mixed starter cultures led to faster pH reduction, suppression of amine-producing bacteria, and significantly lower tyramine and putrescine levels compared to natural fermentation. This finding underscores that microbial management is key to improving the safety and hygiene of fermented fish products.

Moreover, in vitro studies have shown that using starter strains with amine oxidase activity can actively degrade histamine and other biogenic amines during fermentation, further enhancing food safety (Lee et al., 2016). These findings indicate that controlling the microbial ecosystem through inoculation strategies can transform traditional fermentation into a biotechnologically safe process.

In addition to microbial control, environmental factors such as initial pH, salt concentration, and fermentation temperature play significant roles in biogenic amine accumulation. Fermentations that achieve rapid pH reduction tend to suppress amine-producing bacteria while favoring lactic acid bacteria dominance (Turna et al., 2024). Thus, fine-tuning these parameters is essential for ensuring both microbiological stability and product safety.

Finally, beyond biogenic amine control, pathogenic bacteria such as Escherichia coli, Staphylococcus aureus, and Vibrio spp. remain concerns if poor sanitation and handling practices occur. Therefore, the integration of Good Manufacturing Practices (GMP) and Hazard Analysis Critical Control Point (HACCP) systems is strongly recommended in artisanal and industrial fish fermentation to achieve comprehensive safety assurance (Turna, 2024).

Economic Potential and Environmental Sustainability

Fermentation of local fish presents substantial economic potential and environmental sustainability advantages by transforming underutilized marine resources into high-value functional foods. From an economic standpoint, fermented fish products provide an avenue for value addition, particularly for small-scale fishers and coastal communities that often rely on low-priced or seasonal catches (Surya, 2024).

By applying fermentation technology, low-cost raw materials such as small pelagic fish (Sardinella spp., Stolephorus spp.) and freshwater species (Oreochromis niloticus) can be converted into nutrient-rich products with extended shelf life and premium market appeal (Tropea, 2022). This transformation not only boosts local income but also reduces post-harvest losses, a major issue in tropical fishery sectors where spoilage rates can reach up to 30–40% due to inadequate cold chain infrastructure (FAO, 2022).

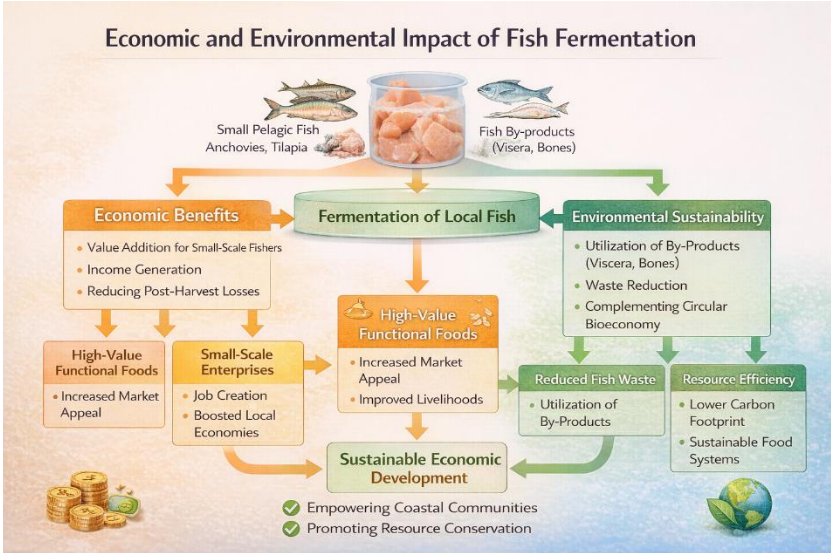

Figure 5. Economic and Environmental Impact of Local Fish Fermentation

Fermentation industries are also characterized by low energy requirements and minimal technological barriers, making them suitable for small and medium enterprises (SMEs) in developing countries. In Indonesia, for example, fermented products such as bekasam, peda, and wadi have been integrated into rural food enterprises, providing livelihood diversification while preserving local culinary heritage (Setiarto & Herlina, 2024). These enterprises rely on traditional knowledge but increasingly adopt standardized starter cultures and hygiene protocols to ensure market competitiveness. The commercialization of these products aligns with national strategies for blue economy development, which emphasize sustainable use of marine resources for food and employment (FAO, 2022).

From an environmental perspective, fermentation supports the principles of the circular bioeconomy by utilizing fish processing by-products—such as heads, viscera, and bones—that are typically discarded as waste (Tamasiga et al., 2022). Through controlled fermentation, these by-products can be converted into bioactive compounds, fish sauces, and enzymatic hydrolysates, which serve as valuable inputs in nutraceutical, cosmetic, and animal feed industries (Ananey-Obiri et al., 2019). For example, the fermentation of tuna viscera and anchovy residues has produced bioactive peptides with strong antioxidant and antimicrobial activities, demonstrating how waste valorization can simultaneously address food waste and resource efficiency.

A real-world example of this sustainable approach can be found in the fermented fish sauce industry in Southeast Asia, where manufacturers use small, low-market-value fish species and by-products from filleting operations to produce high-demand condiments such as nam pla (Thailand) and patis (Philippines). These industries provide employment for thousands of rural workers and generate significant export revenue while minimizing environmental waste through zero-discharge fermentation processes (Lopetcharat et al., 2001). Similarly, in Indonesia's coastal regions, small-scale fish processors have adopted fermentation of by-products into fish silage and fermented feeds, thereby reducing organic waste discharge into coastal ecosystems and promoting environmental resilience (Persulessy et al., 2020).

Fermentation also contributes to environmental sustainability by lowering carbon footprints compared to energy-intensive preservation methods such as freezing and canning. Lactic acid fermentation, in particular, requires no electricity for storage and utilizes natural microbial activity to preserve fish, aligning with climate-smart food production principles. Moreover, fermentation enhances food security by making seasonal fish harvests available year-round in shelf-stable forms, reducing dependence on imports and supporting local nutrition (FAO, 2022).

In summary, the fermentation of local fish for functional food development provides a holistic solution that integrates economic empowerment, food waste reduction, and environmental conservation. By valorizing local resources and adopting sustainable fermentation practices, developing countries can promote both income generation and ecological stewardship, positioning fermented fish as a key component of the blue and circular economy framework for the future of global food systems.

Integration of Local Wisdom and Modern Technology

The integration of local wisdom and modern fermentation biotechnology represents a vital pathway for the sustainable development of functional fish-based foods in Indonesia. Traditional fermented fish products such as bekasam (South

Sumatra), peda (Java), and ina sua (East Nusa Tenggara) are deeply rooted in Indonesian cultural and culinary heritage, serving as both nutritional sources and socio-economic pillars of coastal and inland communities (Setiarto & Herlina, 2024). These products, which rely on spontaneous lactic acid fermentation using natural microflora, exemplify community-based bioprocessing knowledge passed down through generations (Huda et al., 2020). However, despite their cultural and nutritional significance, these traditional methods often lack standardization and safety assurance, resulting in inconsistent product quality and limited commercial scalability.

Figure 6. Synergy Between Local Wisdom and Modern Technology in Fish Fermentation

Modern food biotechnology enables the optimization of these indigenous fermentation processes by introducing starter culture technology, microbial characterization, and process control to improve both safety and functionality (Narzary & Das, 2021). For example, through molecular identification techniques such as 16S rRNA sequencing, researchers have successfully isolated and characterized dominant Lactobacillus plantarum and Pediococcus pentosaceus strains from bekasam and peda fermentation, confirming their probiotic potential (Wulandari et al., 2020). By utilizing these identified beneficial strains as standardized starters, it becomes possible to ensure consistent acidification, flavor development, and inhibition of spoilage microorganisms—thereby upgrading traditional fermentation into a controlled, reliable bioprocess suitable for functional food production (Navarro-Peraza et al., 2020).

A practical example of this fusion of tradition and technology can be seen in the innovation of modernized bekasam, developed through the application of selected lactic acid bacteria to reduce histamine formation while enhancing antioxidant activity and sensory acceptance (Setiarto & Herlina, 2024). Similarly, in Thailand, traditional fish sauce (nam pla) fermentation has been refined through the introduction of Staphylococcus carnosus and Tetragenococcus halophilus starter cultures, resulting in shorter fermentation times and improved flavor uniformity. These cases demonstrate how modern microbiological control can enhance traditional fermented fish products, preserving their authenticity while meeting industrial and export standards.

From a socio-cultural perspective, the integration of local knowledge systems into modern production frameworks fosters community empowerment and inclusive innovation. Small-scale producers equipped with training in microbiological safety and process control can upgrade their artisanal production into certified micro-enterprises, improving livelihoods and strengthening rural economies. Additionally, partnerships between universities, research centers, and local cooperatives facilitate knowledge co-creation, where scientific validation complements indigenous practices rather than replacing them. This participatory approach ensures that modernization remains context-sensitive and aligned with local traditions.

The synergy between local wisdom and modern technology also contributes to product diversification in the functional food sector. Fermented fish peptides, enzymes, and probiotic strains isolated from traditional products are now being utilized in nutraceutical formulations, health supplements, and flavor enhancers. This biotechnological valorization not only enhances the commercial potential of traditional foods but also positions Indonesia as a key player in the growing global market for functional and fermented products.

Furthermore, embracing digital technologies such as Internet of Things (IoT)-based fermentation monitoring and blockchain traceability systems can improve product transparency, consumer trust, and export competitiveness. These technological integrations create a new paradigm of smart traditional food production, where the wisdom of heritage meets the precision of science.

In conclusion, integrating local wisdom with modern technology offers a holistic approach to functional fish product innovation—one that safeguards cultural authenticity, enhances food safety, empowers communities, and drives sustainable bioeconomic growth. This symbiotic relationship between tradition and science can serve as a global model for culturally rooted, technologically advanced food innovation.

CONCLUSION

This study concludes that fermentation technology plays a crucial role in transforming local fish into functional food products with improved nutritional quality, functional properties, and safety. Through biochemical processes such as proteolysis and microbial metabolism, fermentation enhances bioactive compound formation, extends shelf life, and increases the economic value of local fish resources.

From a practical perspective, the application of controlled fermentation using selected starter cultures can be adopted by small-scale producers to improve product consistency, safety, and market competitiveness. This approach also supports sustainable food systems by reducing post-harvest losses and promoting the utilization of underused fish species and processing by-products.

Future research is recommended to conduct laboratory- and pilot-scale experiments to optimize fermentation parameters, evaluate sensory acceptance, and assess the clinical health benefits of fermented fish products. Further studies integrating socio-economic analysis and consumer perception are also needed to support large-scale commercialization of fermented functional fish foods.

Bibliography

Ananey-Obiri, D., Matthews, L. G., & Tahergorabi, R. (2019). Proteins from fish processing by-products. In *Proteins: Sustainable source, processing and applications* (pp. 163–191). Elsevier.

Andriani, Y., Lili, W., Zidni, I., Wiyatna, M. F., & Risdiana, R. (2020). The effect of fermentation process on physical properties of organic material from domestic food waste. *Key Engineering Materials*, *860*, 345–350.

Atun, M. B., Julmohammad, N. B., Huda, N., Roslan, J. Bin, Shariff, A. H. M., & Nisa, F. C. (2024). Exploring the nutritional value, health benefits and concerns associates in selected fermented fish product in Southeast Asia: a review. *Canrea Journal: Food Technology, Nutritions, and Culinary Journal*, 94–112.

Belleggia, L., & Osimani, A. (2023). Fermented fish and fermented fish-based products, an ever-growing source of microbial diversity: a literature review. *Food Research International*, *172*, 113112.

Bengtsson, M. (2016). How to plan and perform a qualitative study using content analysis. *NursingPlus Open*, *2*, 8–14.

Bintari, S. H., Putri, M. F., & Saputro, D. D. (2021). Trends to the development of combined foods to create functional foods. *Journal of Physics: Conference Series*, *1918*(5), 52037.

Booth, A., James, M.-S., Clowes, M., & Sutton, A. (2021). *Systematic approaches to a successful literature review*.

Cha, Y.-J., & Yu, D. (2024). Health benefits and functions of salt-fermented fish. *Journal of Ethnic Foods*, *11*(1), 34.

Jung, S.-J., Chae, S.-W., & Shin, D.-H. (2022). Fermented foods of Korea and their functionalities. *Fermentation*, *8*(11), 645.

Kim, E., Won, J.-E., Yang, S.-M., Kim, H.-J., & Kim, H.-Y. (2022). Diversity of a lactic acid bacterial community during fermentation of gajami-sikhae, a traditional Korean fermented fish, as determined by matrix-assisted laser desorption/ionization time-of-flight mass spectrometry. *Foods*, *11*(7), 909.

Krotova, O., Tyulumdjieva, O., Vertiy, N., Ushakov, A., Isaeva, N., & Lodyanov, V. (2024). Fermentation biotechnology applied to byproducts of the fish processing industry: Nutrition and functionality information. *BIO Web of Conferences*, *113*, 3006.

Kutina, O., & Korotkyh, I. (2021). Recipe modeling and the study of the chemical composition of functional fish culinary products. *BIO Web of Conferences*, *30*, 1009.

Lee, Y.-C., Kung, H.-F., Huang, C.-Y., Huang, T.-C., & Tsai, Y.-H. (2016). Reduction of histamine and biogenic amines during salted fish fermentation by Bacillus polymyxa as a starter culture. *Journal of Food and Drug Analysis*, *24*(1), 157–163.

Li, H., Li, G., Bi, Y., & Liu, S. (2024). Fermented fish products: balancing tradition and innovation for improved quality. *Foods*, *13*(16), 2565.

Lin, S. S. M., Myint, M., & Chukeatirote, E. (2024). Improving Production and Quality of Fermented Fishery Products through Starter Culture Technology. *International Research Journal of Biological Sciences*, *13*(4), 17–24.

Lopetcharat, K., Choi, Y. J., Park, J. W., & Daeschel, M. A. (2001). Fish sauce products and manufacturing: a review. *Food Reviews International*, *17*(1), 65–88.

Najafian, L., & Babji, A. S. (2019). Purification and identification of antioxidant peptides from fermented fish sauce (Budu). *Journal of Aquatic Food Product Technology*, *28*(1), 14–24.

Narzary, Y., Das, S., Goyal, A. K., Lam, S. S., Sarma, H., & Sharma, D. (2021). Fermented fish products in South and Southeast Asian cuisine: indigenous technology processes, nutrient composition, and cultural significance. *Journal of Ethnic Foods*, *8*(1), 33.

Navarro-Peraza, R. S., Osuna-Ruiz, I., Lugo-Sánchez, M. E., Pacheco-Aguilar, R., Ramírez-Suárez, J. C., Burgos-Hernández, A., Martínez-Montaño, E., & Salazar-Leyva, J. A. (2020). Structural and biological properties of protein hydrolysates from seafood by-products: a review focused on fishery effluents. *Food Science and Technology*, *40*, 1–5.

Nikiforova, A. P. (2020). The use of fermentation for rational processing of fish: a review. *Limnology and Freshwater Biology*, 735–736.

Persulessy, C. B., Kusdiyantini, E., Ferniah, R. S., Agustini, T. W., & Budiharjo, A. (2020). Ina sua: the traditional food fermentation from Teon Nila Serua, Central of Maluku, Indonesia. *Journal of Ethnic Foods*, *7*(1), 24.

Putro, S. (1993). Fish fermentation technology in Indonesia. *Fish Fermentation Technology. United Nations University Press. Tokyo*, 107–128.

Sarojnalini, C., & Hei, A. (2019). Fish as an important functional food for quality life. *U: Functional Foods,(Lagouri, V, Ured)*, *2019*, 77–97.

Semjonovs, P., Auzina, L., Upite, D., Grube, M., Shvirksts, K., Linde, R., Denina, I., Bormanis, A., Upitis, A., & Ruklisha, M. (2015). Application of Bifidobacterium animalis subsp. lactis as starter culture for fermentation of Baltic herring (Clupea harengus membras) mince. *American Journal of Food Technology*, *10*(5), 184–194.

Setiarto, R. H. B., & Herlina, V. T. (2024). Exploring bekasam, an indigenous fermented fish product of Indonesia: original South Sumatra region. *Journal of Ethnic Foods*, *11*(1), 18.

Shahidi, F., & Saeid, A. (2025). Bioactivity of marine-derived peptides and proteins: a review. *Marine Drugs*, *23*(4), 157.

Sharma, R., Diwan, B., Singh, B. P., & Kulshrestha, S. (2022). Probiotic fermentation of polyphenols: Potential sources of novel functional foods. *Food Production, Processing and Nutrition*, *4*(1), 21.

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339.

Sun, W., Shahrajabian, M. H., & Lin, M. (2022). Research progress of fermented functional foods and protein factory-microbial fermentation technology. *Fermentation*, *8*(12), 688.

Surya, R. (2024). Fermented foods of Southeast Asia other than soybean-or seafood-based ones. *Journal of Ethnic Foods*, *11*(1), 27.

Tamasiga, P., Miri, T., Onyeaka, H., & Hart, A. (2022). Food waste and circular economy: Challenges and opportunities. *Sustainability*, *14*(16), 9896.

Tropea, A. (2022). Food waste valorization. In *Fermentation* (Vol. 8, Issue 4, p. 168). MDPI.

Turna, N. S., Chung, R., & McIntyre, L. (2024). A review of biogenic amines in fermented foods: Occurrence and health effects. *Heliyon*, *10*(2).

Visciano, P., Schirone, M., & Paparella, A. (2020). An overview of histamine and other biogenic amines in fish and fish products. *Foods*, *9*(12), 1795.

Wulandari, E., Yurmiati, H., Subroto, T., & Suradi, K. (2020). Quality and probiotic lactic acid bacteria diversity of rabbit meat Bekasam-fermented meat. *Food Science of Animal Resources*, *40*(3), 362.

Xiao, Y., & Watson, M. (2019). Guidance on conducting a systematic literature review. *Journal of Planning Education and Research*, *39*(1), 93–112.

Zhong-Yi, L., Zhong-Hai, L., Miao-Ling, Z., & Xiao-Ping, D. (2010). Effect of fermentation with mixed starter cultures on biogenic amines in bighead carp surimi. *International Journal of Food Science and Technology*, *45*(5), 930–936.