International Journal of Food Sciences and Nutrition Innovations
Volume 1, Issue 1, 38-49.
e_ISSN: xxxx-xxxx
https://e-journal.gomit.id/ijfsni

Innovative Manufacturing of Fish-Enriched Instant Noodles: A Perspective of Circular Economy and Sustainability Approach

Irem Kılınç [1*]
Izmir Kâtip Çelebi University, TURKEY

Riya Liuhartana Nasyiruddin [2]
University of PGRI, INDONESİA

Adityas Agung Ramandani [3]
Yuan Ze University, TAIWAN

Berna Kılınç [4]
Ege University, TURKEY

*** Corresponding author:**
Irem Kılınç, Izmir Katip Celebi University, TURKEY, kilincirem75@gmail.com,

Article Info

Article history:

Received: April 01, 2025
Revised: May 08, 2025
Accepted: June 01, 2025

Keywords:

Circular economy
Fish-enriched noodles
Food waste valorization
Functional foods
Sustainable food systems
Water and carbon footprints

Abstract

Background of Study: Innovative food solutions are essential for low- and middle-income countries facing food insecurity, malnutrition, and environmental degradation. The high consumption of instant noodles in Indonesia, especially among low-income and nutritionally vulnerable populations, presents a strategic opportunity to enhance nutritional quality by utilizing underutilized fish resources and seafood by-products.

Aims and Scope of Paper: This study aims to evaluate the development potential of fish-enriched instant noodles within the framework of circular economy and sustainability. It covers the nutritional enhancement, food waste reduction, and environmental impacts of such innovations, particularly focusing on the feasibility of industrial-scale implementation in the Indonesian context.

Methods: A multidisciplinary approach was employed, combining nutritional science, food technology, and sustainability principles. The production process involved the selection of fish-based ingredients and by-products, dough formulation, processing through steaming and energy-efficient drying, and the use of biodegradable packaging. The innovation was assessed in terms of nutritional improvement, environmental impact, and industrial scalability.

Result: The results demonstrated that fish-enriched instant noodles significantly improve protein content, omega-3 fatty acids, calcium, and micronutrients compared to conventional instant noodles. Moreover, the adoption of renewable energy, water recycling systems, and eco-friendly packaging effectively reduced the carbon footprint and waste associated with production. This innovation aligns with several United Nations Sustainable Development Goals (SDGs), including Goal 2 (Zero Hunger), Goal 3 (Good Health and Well-being), Goal 12 (Responsible Consumption and Production), and Goal 14 (Life Below Water).

Conclusion: The development of fish-enriched instant noodles offers a functional food solution that not only enhances community nutrition but also reduces food waste and supports sustainable food systems. Despite its promising potential, challenges remain, including limited regulatory frameworks, technological readiness, and low consumer awareness of the benefits of circular economy-based foods. Cross-sector collaboration is essential to achieve broader implementation of this innovation on an industrial scale.

To cite this article: Kılınç et al. (2025). Title. *Journal of Food Sciences And Nutrition Innovations, 1*(1), 38-49.

INTRODUCTION

Global food systems are under unprecedented strain due to the combination of fast population expansion, urbanization, and accelerating climate change, making it difficult for them to maintain environmental sustainability and food security (Niu et al., 2024). Undernutrition, food insecurity, and environmental degradation frequently cross in low- and middle-income countries, making these compounding pressures particularly prevalent worldwide (Kunlere, 2025). The creation of novel, reasonably priced, nutrient-dense, culturally acceptable, and ecologically conscious food products must therefore be given top priority in these nations (Turner et al., 2020). One practical method to alleviate micronutrient deficiencies and enhance public health outcomes on a large scale is to reformulate frequently consumed convenience foods with functional additives (Meenakshi & Quisumbing, 2025).

In Southeast Asia, instant noodles are consumed in large quantities, especially in Indonesia, where they are a staple food. Significant health, financial, and environmental advantages could result from improving their nutritional composition with marine-based ingredients (Prakoso et al., 2019); World Aquaculture (Society, 2024). One of the most vibrant and extensive areas of the world food system is the noodle industry. Growing urbanization, time constraints, and consumer demand for reasonably priced, shelf-stable meals are the main factors driving its popularity (Prakoso et al., 2019); (Simanjuntak & Lingga, 2024). The Asia-Pacific area accounted for more than 80% of the world's consumption in 2023, with 121.2 billion servings consumed worldwide, according to the World Instant Noodles Association (2024). According to (Simanjuntak & Lingga, 2024), with a total demand of 45,070 million servings (MS), Indonesia (14,260 MS), Vietnam (8,480 MS), India (7,580 MS), and Japan (5,980 MS) are in second and third place, respectively. Demand is increasing in regions outside of Asia, including the US, Brazil, Nigeria, and Russia. The expansion of e-commerce and urban middle-class consumer bases are expected to support the worldwide noodle market's 6.5-7.3% compound annual growth rate (CAGR) from 2025 to 2034 (Instant Noodles Global Market Report (2025)). Instant noodles are a popular dish in Indonesia, per a 2016 analysis on food product consumption profiles published by MARS Indonesia. 92.4% of people in seven major Indonesian cities who participated in the survey said they eat instant noodles. MARS Indonesia ascribed this high consumption rate to the fast-paced lifestyles of Indonesians, which have been greatly impacted by their eating habits due to expanding employment prospects and increased client demands (Rahmatika & Indayani, 2022).

Numerous studies conducted in Indonesia have investigated fortifying noodles with marine ingredients. One such product is "Indofishme," which is made from processed marine resources such fish, seaweed, shrimp waste, and CMC (carboxymethyl cellulose), which lowers gluten levels and increases nutritious content (Nelas et al., 2022). Another study utilized catfish (*Pangasius* sp) bone to fortify noodles with calcium, demonstrating the usefulness of fish processing by-products as functional ingredients (Panjaitan et al., 2023). Additionally, (Litaay et al., 2022) formulated dry instant noodles using sago flour as a wheat alternative, enriched with skipjack tuna (*Katsuwonus pelamis*) to enhance protein content. Research by (Nawaz et al., 2021) established that incorporating 15–20% fish meat maintains the chemical composition and physical integrity of instant noodles, suggesting this as an optimal inclusion rate. Fish is a rich and bioavailable source of high-quality protein and essential micronutrients—including long-chain omega-3 fatty acids (EPA and DHA), vitamin D, vitamin B12, selenium, and iodine—that are vital for cognitive development, immune regulation, and cardiovascular function (Noreen et al., 2025). In this context, it seems that seafood-enriched formulations are a good source to encourage healthy eating generations.

Access to essential nutrients is still restricted in many low-income groups, and regular intake of processed foods lacking in nutrients exacerbates health inequities even more (Turner et al., 2020). Additionally, by promoting low-cost or/and underutilized fish species, and seafood processing by-products (such as bones, viscera, skins, and fish oil) as affordable, nutrient-dense inputs, this functional food innovation also adheres to the principles of the circular economy (Cooney et al., 2023) ; (Zhao et al., 2022) Despite having a high nutritional content, these materials are frequently thrown away or reduced to animal feed. By using them in the production of human food, food waste is decreased and a more robust and sustainable food system is promoted. This contributes to multiple United Nations Sustainable Development Goals (SDGs):

- Goal 2: Zero Hunger
- Goal 3: Good Health and Well-being
- Goal 12: Responsible Consumption and Production
- Goal 14: Life Below Water (Hasselberg et al., 2024)

As consumers' awareness of sustainability increases, reducing the carbon footprint of the sector, environmentally friendly packaging and evaluation of fish by-products have gained importance (Cooney et al., 2023), and the inclusion of alternative protein sources such as legumes and algae in food formulas (Mosibo et al., 2024) has gained importance in terms of improving human nutritional value and protein diversity. This article focuses on encouraging the production of new value-added, nutritious products from fish waste and by-products within the scope of sustainability and circular economy.

Gap Analysis

Even though several functional noodle prototypes have been developed, mainly within Indonesia, there are still a lot of unanswered questions regarding the field's research and application. Current research frequently concentrates on product creation or nutritional enhancement isolated, without including regulatory frameworks, circular economy analysis, or more comprehensive sustainability criteria. Data on consumer perception, industrial scalability, and the long-term effects of such breakthroughs on public health are likewise scarce. Furthermore, a thorough assessment of industrial-scale processing, waste valorization, and regulatory consequences is limited, despite the testing of specific components such as fish flour or bone powder. Consequently, there is still a gap between advances at the pilot stage and commercial manufacturing methods.

To strengthen the circular economy in the food sector, fish-enriched instant noodles present a valuable opportunity for integrating underutilized marine biomass into a high-demand consumer product. Large volumes of fish processing waste (i.e., heads, bones, skins, and viscera) are often discarded or used for low-value applications such as animal feed or fertilizers. Through innovative processing such as enzymatic hydrolysis, drying, or extrusion, these by-products can be transformed into functional ingredients rich in protein, calcium, and omega-3 fatty acids for noodle formulations (Mathew et al., 2022). This not only adds nutritional value to the product but also contributes to SDG 12.3, which targets halving per capita global food waste at the retail and consumer levels by 2030 (Okadera et al., 2025). Furthermore, embedding circular design in the supply chain, such as sourcing fish by-products from local fish markets or processors helps reduce transportation emissions and supports regional economic development. Applying circular strategies also means rethinking packaging, water reuse during noodle processing, and energy-efficient drying techniques. Advanced models of circular marine food systems have shown that using fish by-products for human consumption can yield significantly higher environmental and economic returns compared to their use in bioenergy or livestock feed chains (Fadeeva & Van Berkel, 2023). These models emphasize traceability, regulatory compliance, and multi-stakeholder collaboration elements still underdeveloped in the Indonesian context.

To operationalize zero food waste goals, technological innovation must be supported by data-driven tools such as Life Cycle Assessment (LCA) and Material Flow Analysis (MFA). These methodologies enable the identification of hotspots in resource use and emissions along the noodle production value chain. When applied to fish-enriched products, such tools can quantify avoided waste, GHG emission reductions, and nutrient recovery efficiencies from upcycled ingredients (Ruge, 2023).These metrics are crucial for both regulatory reporting and consumer communication. Additionally, behavioral strategies such as eco-labeling and consumer education on circular food benefits can improve public trust and product acceptance, addressing SDG 12.8 which emphasizes awareness for sustainable lifestyles. From a policy perspective, integrating the fish-enriched noodle innovation into broader food system reform will require alignment with national food waste reduction strategies, investment incentives, and public-private partnerships. Governments can promote the use of fish processing residues in human food through tax incentives, quality certification schemes, and pilot funding. Universities and research institutions can support this transition by developing low-cost, scalable processing technologies and assessing nutritional bioavailability of fish waste-derived ingredients. Ultimately, the success of this innovation lies in aligning product development not only with market demand but also with ecological responsibility and SDG-aligned performance indicators.

Rationale of the Study

The integration of nutrient-rich marine ingredients into instant noodle formulations is both a culturally appropriate and economically viable strategy to address persistent malnutrition in Indonesia. Given the ubiquity of noodle consumption, especially among low-income and nutritionally vulnerable groups—this intervention offers high reach and impact potential. With over 14 billion servings consumed annually in

Indonesia alone, the reformulation of even a fraction of this volume can lead to substantial nutritional improvements at the population level (Society, 2024). Simultaneously, the valorization of underutilized marine resources supports environmental goals and circular economy principles, reducing waste and optimizing existing value chains. By aligning with multiple SDGs, this innovation contributes to national and global development agendas (Solarte-Toro & Cardona Alzate, 2021)

This study aims to investigate the development and industrial potential of fish-enriched instant noodles within the Indonesian context, through the lens of circular economy and sustainability. The research is designed to evaluate the feasibility, health implications, and environmental advantages of this functional food innovation. Specific objectives:

- To evaluate the nutritional enhancement of instant noodles fortified with fish meat and marine by-products.
- To assess the environmental impact of utilizing underutilized fish species and seafood waste streams.
- To identify key regulatory, technological, and process factors influencing adoption in Industrial scale.
- To analyze the industrial scalability and economic viability of fish-enriched noodle production.

Hypothesis

Incorporating marine-based proteins and by-products into instant noodle formulations can significantly improve nutrient intake, reduce food waste, and foster sustainable food system transformation in Indonesia and similar low- and/or middle-income countries.

METHOD

Research Design

This study employed a product development experimental design integrating food technology, nutritional science, and sustainability engineering to formulate fish-enriched instant noodles within a circular economy framework (Jenser, 1986); (Shikha et al., 2020).

Population and the Methods of Sampling; Instrumentation

The population consisted of various low-cost, nutrient-dense fish species and seafood by-products, including anchovy (*Stolephorus spp.*), sardine (*Sardinella spp.*), catfish (*Clarias spp.*), silver carp (*Hypophthalmichthys molitrix*), tuna, and sea bass (Litaay et al., 2022); (Mpalanzi et al., 2023); (Shikha et al., 2020); (Ainsa et al., 2021).A purposive sampling approach was applied, selecting ingredients based on nutritional value, local availability, and sustainability. The instruments used included texture analyzers, nutritional analysis tools, and sensory evaluation forms (Nogueira et al., 2019); (Chen & Chen, 2025).

Instrument

The research utilized a combination of processing equipment such as mixers, steamers, and dryers for noodle production. Analytical instruments were employed to determine the proximate composition, including protein, fat, and moisture content. Texture and color analyzers were used to evaluate the physical properties of the noodles, ensuring consistency and quality (Obadi et al., 2022). Additionally, sensory evaluation protocols involving trained panels were conducted to assess taste, texture, and overall acceptability of the fish-enriched instant noodles (Eteng et al., 2023); (Hossain et al., 2024).

Procedures and Time Frame

The production process began with the careful selection and preparation of fish ingredients through processes such as mincing, hydrolysis, and drying to ensure quality and stability (Xin et al., 2022); (Dai et al., 2024). Following this, the fish powder was incorporated into dough formulations, typically in concentrations ranging from 5% to 20%, using a blend of wheat flour and other composite flours to optimize texture and nutrition (Nogueira et al., 2019). The dough was then sheeted, cut into strands, and steamed to achieve the desired gelatinization and protein denaturation (Chen & Chen, 2025). Subsequent drying or the use of non-frying methods helped reduce fat content and enhance shelf life (Obadi et al., 2022). Finally, flavoring, seasoning, and eco-friendly packaging were applied to the finished product to ensure both consumer appeal and environmental responsibility (Misron et al., 2025). This stepwise production process is illustrated in Figure 1.

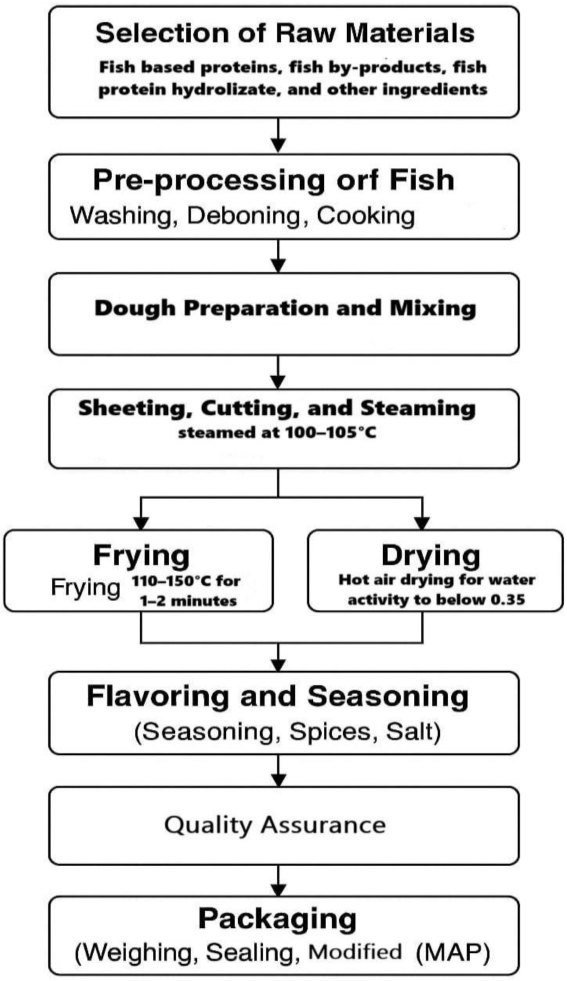

Figure1. The production process of fish instant noodle

Analysis Plan

The data analysis in this study involved the use of descriptive statistics to assess the nutritional content of the fish-enriched noodles, including measurements of protein, fat, and energy levels. A comparative analysis was conducted to evaluate differences between the developed noodles and conventional instant noodle products, referencing prior works by (Monteiro et al., 2016) and (Nawaz et al., 2021). To measure environmental impacts, a Life Cycle Assessment (LCA) was applied, providing insight into resource use and emissions associated with the production process (Ciacci & Passarini, 2020); (Obadi et al., 2022). Additionally, sensory evaluation using hedonic scales was employed to gauge consumer acceptance of taste, texture, and overall quality (Eteng et al., 2023). No advanced statistical methods were used beyond these standard comparative and descriptive analyses.

Scope and/or Limitations

This study was confined to the development of prototypes at a laboratory scale and did not extend to industrial-scale production trials. One major limitation is the absence of consumer perception studies and assessments of market readiness, which are essential for commercial success. Another challenge lies in the regulatory uncertainties concerning the incorporation of seafood by-products into food intended for human consumption, which could impede widespread application (Coppola et al., 2021). Additionally, the results obtained may not be directly transferable to different geographical or demographic settings. To address these constraints, future research should focus on conducting field trials and comprehensive economic feasibility studies to validate the scalability and market potential of this innovation.

RESULTS AND DISCUSSION

RESULTS

Effects Related to Food Structure, Processing and Consumption

Incorporating fish and fishery-derived ingredients into pasta and noodles presents a compelling opportunity to develop functional foods with enhanced nutritional profiles. Recent studies highlight both the advantages and disadvantages of this approach, as detailed below.

Advantages:

- **Nutrient Enrichment and Functional Food Development:** The fish industry's byproducts are rich in nutrients, making their inclusion in pasta an interesting option for creating functional foods (Ainsa et al., 2021).
- **Benefits for Specific Dietary Needs:** Gluten-free pasta enriched with fish can serve as a nutritious and convenient option for individuals with celiac disease, enabling them to benefit from fish consumption, particularly the intake of Ω-3 fatty acids (Aínsa et al., 2021)
- **Marketability and Consumer Preference:** Studies suggest that fish protein-enriched noodles, such as those made from bighead carp, can be marketable. Consumers have indicated a preference for noodles with higher nutritional value, and fish protein-enriched noodles can maintain a taste comparable to commercial pasta (Pascual, 2016)
- **Improved Nutritional Value:** The inclusion of fish protein concentrate significantly increases the nutritional value of pasta. For instance, fresh pasta fortified with up to 30% tilapia protein concentrate showed an increased nutritional value (Reis et al., 2015). Similarly, pasta containing tuna and sea bass by-products demonstrated a higher fatty acid content in tuna pasta, resulting in a more nutritious product (Ainsa et al., 2021)
- **Presence of Beneficial Fatty Acids:** Tuna pasta, incorporating tuna by-products, exhibited a higher fatty acid content compared to sea bass pasta, contributing to a more nutritious final product (Ainsa et al., 2021)

Disadvantages:

- **Sensory and Textural Changes:**
    - **Rougher Surface:** The addition of fish gelatin hydrolysates to gluten-free functional noodles (GFN) based on rice and cassava flour resulted in a slightly rougher surface (Wangtueai et al., 2020)
    - **Impact on Hardness and Breakability:** Tissue profile analysis (TPA) of fish pasta showed lower hardness and breakability compared to control pasta (Ainsa et al., 2021).
    - **Changes in Cohesion and Brightness:** Cohesion was higher in tuna pasta, while sea bass pasta was brighter (Ainsa et al., 2021).
    - **Cooking Properties:** Fish incorporation led to a decrease in weight gain and swelling index, along with an increase in cooking losses (Ainsa et al., 2021).
    - **Sensory Acceptance Thresholds:** While tilapia protein concentrate increased nutritional value, sensory results indicated that 20% tilapia protein concentrate was the maximum recommended level due to potential sensory impacts (Reis et al., 2015).
    - **Aroma and Taste:** Sensory analysis revealed differences in homogeneity, typical aroma, fish aroma, fish smell, and elasticity in fish-incorporated pastas. It was concluded that the tuna content should be reduced (< 3%) to improve its sensory profile (Ainsa et al., 2021).

Given these findings, it's clear that incorporating fish by-products into pasta/noodles offers a promising avenue for creating nutritionally enhanced functional foods, with various studies exploring different fish sources and concentrations to optimize sensory acceptance and technological properties while leveraging valuable nutrients like protein and omega-3 fatty acids. Table 1 provides an overview of the predicting average nutritional composition of fish-based instant noodles, compared with traditional formulations based on fish enriched instant soup (Islam et al., 2018); fish meat noodles (Nawaz et al., 2021); fish flour fortified pasta (Monteiro et al., 2016).

Table 1. Average Nutritional Composition of Fish-Enriched vs. Conventional Instant Noodles (per 100 g, dry weight)

Nutrient	Fish-Enriched Noodles	Conventional Instant Noodles
Energy (kcal)	390–420	450–480
Protein (g)	12–18	6–8
Total Fat (g)	10–14	16–20
Saturated Fat (g)	3–5	7–9
Carbohydrates (g)	50–55	60–65
Sugars (g)	<1	<1
Sodium (mg)	700–900	1,200–1,600
Calcium (mg)	100–250	<30
Iron (mg)	4–7	1–2
Zinc (mg)	2–4	<1
Vitamin D (IU)	80–150	<10
EPA + DHA (mg)	100–250	Negligible

* Note: Values are average estimates based on prototype products and published literature; actual values vary based on species used, enrichment method, and processing conditions.

Economic & Environmental Aspects

Traditional fried instant noodles have lower energy costs but higher oil usage and carbon emissions(Adejunwon et al., 2019); (Obadi et al., 2022). Fish-based noodles using drying (non-frying) methods are more sustainable, reduce fat content, and are marketable as "healthy premium options" (Obadi et al., 2022). Life Cycle Assessment (LCA) shows that most emissions are from energy for drying and raw material transportation, thus local sourcing and renewable energy are key (Ciacci & Passarini, 2020).

The sustainable production of fish instant noodles integrates environmentally conscious strategies across all stages—from raw materials to final packaging and waste management. Sourcing fish such as mackerel, tilapia, tuna, or salmon from local, MSC-certified fisheries reduces overfishing risks and transportation-related carbon emissions (Saleh et al., 2022). Core ingredients like wheat flour and starch are optimized using organic farming and biodegradable, renewable sources, limiting pesticide use and agricultural runoff. The processing stage adopts energy-efficient technologies such as high-efficiency mixers, steam recovery systems, and solar-assisted drying to cut down CO_2 emissions and fossil fuel dependency (Sovacool et al., 2021). Air-drying is favored over traditional deep frying to reduce oil waste and carbon footprint. Greywater recycling and drain-water heat recovery systems further lower energy and freshwater consumption by up to 50% (Dallemand & Gerbens-Leenes, 2013); (Kordana-Obuch et al., 2023). Waste valorization is implemented through the conversion of fish by-products like skin, scales, and bones into valuable resources such as fish oil or fertilizer, contributing to industrial symbiosis models (Coppola et al., 2021). Packaging is addressed using biodegradable PLA or PHA films for primary packs and FSC-certified recycled cardboard for secondary cartons, significantly minimizing environmental load. Labor and overhead practices promote social sustainability by ensuring fair wages and safe working conditions, while utilities are managed through renewable energy integration and water reuse systems. Finally, obtaining eco-labels such as organic, non-GMO, or carbon-neutral certifications not only boosts marketability and consumer trust but also reinforces the environmental integrity of the product through verified life-cycle assessments (Reichert et al., 2020). Together, these integrated measures make fish instant noodle production more sustainable, economically viable, and aligned with global environmental goals.

Recommendations for Sustainable Scale-Up

A multifaceted strategy that integrates social, economic, and environmental factors throughout the whole value chain is needed to accomplish sustainable scale-up of fish-enriched noodle production. The following suggestions are essential for expanding on the current findings:

- Prioritise Energy-Efficient Processing and Renewable Energy Integration: In line with the finding that "Fish-based noodles using drying (non-frying) methods are more sustainable, reduce fat content" (Obadi et al., 2022), non-frying methods should be adopted by consistently investing in and optimising air-drying or other non-frying technologies for noodle production. This directly reduces oil usage and associated carbon emissions. Furthermore, since "most emissions are from energy for drying," it is imperative that processing facilities be powered by renewable energy sources (such as solar-assisted drying, direct solar energy for heating, and geothermal), which includes high-efficiency mixers and steam recovery systems. This is because "most emissions are from energy for drying" (Ciacci & Passarini, 2020). In addition to helping to "lower energy and freshwater consumption by up to 50%" (Dallemand & Gerbens-Leenes, 2013); (Kordana-Obuch et al., 2023). expanding the use of greywater recycling and drain-water heat recovery systems is essential for resource efficiency on a greater scale.
- Optimize Raw Material Sourcing for Reduced Environmental Impact: Expanding partnerships with local, MSC-certified (Marine Stewardship Council) fisheries for sourcing fish species like mackerel, tilapia, tuna, or salmon is recommended, as this strategy directly addresses "reducing overfishing risks and transportation-related carbon emissions" (Saleh et al., 2022). Concurrently, ensuring that core ingredients like wheat flour and starch are sourced from suppliers committed to organic farming practices and biodegradable, renewable sources will minimize pesticide use and agricultural runoff as production volumes increase. Finally, systematizing and scaling the "conversion of fish by-products like skin, scales, and bones into valuable resources such as fish oil or fertilizer" will contribute to industrial symbiosis models and minimize waste (Coppola et al., 2021), effectively turning a waste stream into an economic and environmental asset.

Discussion

Implications

The development of fish-enriched instant noodles has significant implications for improving nutritional status, particularly in developing countries such as Indonesia, which face persistent challenges related to malnutrition and food security. This innovation not only enhances the intake of protein, omega-3 fatty acids, calcium, and essential micronutrients but also contributes to food waste reduction by utilizing underused fish resources and seafood by-products. Additionally, by integrating the principles of circular economy and environmental sustainability, this innovation aligns with several Sustainable Development Goals (SDGs), including SDG 2 (Zero Hunger), SDG 3 (Good Health and Well-being), SDG 12 (Responsible Consumption and Production), and SDG 14 (Life Below Water). The innovation also creates new opportunities for the food industry to deliver eco-friendly, nutritious products while supporting the economic well-being of coastal communities.

Research Contribution

This study makes a valuable contribution to scientific knowledge by presenting a multidisciplinary approach to the development of marine-based functional foods, combining nutritional science, food technology, and environmental sustainability analysis. It advances the understanding of how fishery by-products can be transformed into high-value food ingredients, while also proposing a production model that incorporates energy efficiency, renewable energy use, and biodegradable packaging. Furthermore, the study highlights the importance of integrating product innovation with industrial policy and consumer education to ensure broader adoption and acceptance of such innovations at both industrial and community levels.

Limitations

Despite its potential, this study has several limitations. First, most of the findings remain conceptual and prototype-based, with limited testing in actual industrial-scale applications. Second, there is insufficient empirical data on consumer perceptions, market readiness, and taste preferences, which could impact the broader acceptance of the product. Third, regulatory challenges regarding the use of seafood by-products in human food may pose significant barriers to large-scale development and commercialization. Additionally, further research is needed to assess the long-term health impacts and environmental effects of such innovations.

Suggestions

For future development, it is recommended that further research conduct industrial-scale trials to evaluate the technical and economic feasibility of fish-enriched instant noodle production. Moreover, consumer behavior studies and market acceptance research should be prioritized to ensure successful commercialization. Efforts should also be made to explore and clarify regulatory frameworks and food safety standards for the use of fish by-products in food production. Finally, enhancing cross-sector collaboration among governments, the food industry, research institutions, and local communities is essential to accelerate the sustainable and inclusive adoption of this innovation.

CONCLUSION

Fish-enriched instant noodles represent a high-impact, scalable innovation at the intersection of nutrition, environmental sustainability, and the circular economy. In Indonesia—where instant noodles are a dietary staple, particularly among low-income and nutritionally vulnerable populations—the reformulation of these products with underutilized fish species and seafood by-products offers a culturally appropriate and economically feasible strategy to combat malnutrition. These marine-based ingredients not only enhance the nutritional content of noodles by increasing levels of protein, omega-3 fatty acids, calcium, iron, and other essential micronutrients, but also reduce food waste by valorizing parts of the fish typically discarded or downgraded in the supply chain. From an environmental perspective, the integration of sustainable sourcing, renewable energy systems, greywater recycling, and biodegradable packaging significantly lowers the overall carbon footprint of production. The application of circular economy principles—such as reusing by-products, reducing dependency on synthetic inputs, and optimizing local value chains—further supports a zero-waste approach to food manufacturing. These strategies not only align with broader environmental and public health objectives but also respond to growing consumer demand for ethical, sustainable, and nutrient-rich food options. Despite the potential, the transition from prototype development to industrial-scale implementation remains limited. Current gaps include insufficient regulatory guidance on the use of marine by-products in food, lack of consumer awareness, limited technological infrastructure among small and medium enterprises, and weak integration between fisheries and food processing sectors. Addressing these challenges is essential for mainstreaming sustainable noodle innovation in both national and global markets.

ACKNOWLEDGMENT

Acknowledgements are extended to all those who have provided support, assistance, and contributions throughout the course of this research. Whether in the form of academic guidance, data provision, facilities, or moral support, every form of help has been invaluable to the smooth progress and success of this study. Special thanks are also given to the co-authors for their unwavering support and significant contributions to the review paper process. All forms of involvement are deeply appreciated as essential components in achieving the results of this review paper.

AUTHOR CONTRIBUTION STATEMENT

Irem Kılınç: Processing and evaluation of fishery products, research on food production-industrial systems. Evaluation of production of fish-enriched noodles.
Riya Liuhartana Nasyiruddin: Evaluation of the noodle industry, production-consumption balance, analysis of nutritional content of fish-enriched noodles.
Adityas Agung Ramandani: Evaluation of the system in terms of industrial and circular economy
Berna Kılınç: Evaluation of the system in terms of sustainability and waste management.

REFERENCES

Adejunwon, O. H., Jideani, A. I. O., & Falade, K. O. (2019). Quality and public health concerns of instant noodles as influenced by raw materials and processing technology. *Food Reviews International*, *36*(3), 1–42. https://doi.org/10.1080/87559129.2019.1642348

Ainsa, A., Honrado, A., Marquina, P. L., Roncalés, P., Beltrán, J. A., & Calanche M., J. B. (2021). Innovative development of pasta with the addition of fish by-products from two species. *Foods*, *10*(8), 1889. https://doi.org/10.3390/foods10081889

Aínsa, A., Vega, A., Honrado, A., Marquina, P., Roncales, P., Gracia, J. A. B., & Morales, J. B. C. (2021). Gluten-free pasta enriched with fish by-product for special dietary uses: Technological quality and sensory properties. *Foods*, *10*(12), 3049. https://doi.org/10.3390/foods10123049

Chen, J., & Chen, Z. (2025). New insights into how the structure of starch synergistically affects the digestibility, texture, and cooking properties of instant rice noodles incorporated with starch–lipid complexes. *International Journal of Food Science and Technology*, *60*(1), vvae031. https://doi.org/10.1093/ijfood/vvae031

Ciacci, L., & Passarini, F. (2020). Life Cycle Assessment (LCA) of environmental and energy systems. *Energies*, *13*(22), 5892. https://doi.org/10.3390/en132205892

Cooney, R., de Sousa, D. A. B., Fernández, A., & Clifford, E. (2023). A circular economy framework for seafood waste valorisation to meet challenges and opportunities for intensive sustainability. *Journal of Cleaner Production*, *392*, 136283. https://doi.org/10.1016/j.jclepro.2023.136283

Coppola, D., Lauritano, C., Palma Esposito, F., Riccio, G., Rizzo, C., & de Pascale, D. (2021). Fish waste: From problem to valuable resource. *Marine Drugs*, *19*(2), 116. https://doi.org/10.3390/md19020116

Dai, W., He, S., Huang, L., Lin, S., Zhang, M., Chi, C., & Chen, H. (2024). Strategies to reduce fishy odor in aquatic products: Focusing on formation mechanism and mitigation means. *Food Chemistry*, *444*, 138625. https://doi.org/10.1016/j.foodchem.2024.138625

Dallemand, J. F., & Gerbens-Leenes, P. W. (2013). *Bioenergy and water*. Publications Office of the European Union. https://doi.org/10.2790/94637

Eteng, O. E., Bassey, N. O., Nelson, V. A., & Udosen, E. O. (2023). The effect of instant noodles formulated with natural spice and noodle seasoning on hemato-biochemical parameters and body weight changes in albino rats model. *UMYU Scientifica*, *2*(2), 120–127. https://doi.org/10.56919/usci.2322.013

Fadeeva, Z., & Van Berkel, R. (2023). *Towards Circular Economy of Food Systems: An Explorative Appraisal of Opportunities in Fish, Seafood Value Chains BT - Sustainable Food Value Chain Development* (pp. 61–86). Springer. https://doi.org/10.1007/978-981-19-6454-1_4

Hossain, M. J., Alam, A. N., Lee, E. Y., Hwang, Y. H., & Joo, S. T. (2024). Umami characteristics and taste improvement mechanism of meat. *Food Science of Animal Resources*, *44*(3), 515–532. https://doi.org/10.5851/kosfa.2024.e29

Instant Noodles Global Market Report (2025). (2025). In *The Business Research Company*. https://www.thebusinessresearchcompany.com/report/instant-noodles-global-market-report

Islam, M., Sarker, M. N. I., Islam, M. S., Prabakusuma, A. S., Mahmud, N., Fang, Y., Yu, P., & Xia, W. (2018). Development and quality analysis of protein enriched instant soup mix. *Food and Nutrition Sciences*, *9*(6), 610–618. https://doi.org/10.4236/fns.2018.96050

Jenser, B. R. (1986). *Fish noodles (SAFIS Extension Manual Series No. 33)*. Southeast Asian Fisheries Development Center. https://repository.seafdec.org/handle/20.500.12066/5982

Kordana-Obuch, S., Starzec, M., Wojtoń, M., & Słyś, D. (2023). Greywater as a future sustainable energy and water source: Bibliometric mapping of current knowledge and strategies. *Energies*, *16*(2), 934. https://doi.org/10.3390/en16020934

Kunlere, A. S. (2025). Strategies to address food insecurity and improve global nutrition among at-risk populations. *International Journal of Science and Research Archive*, *14*(02), 1657–1680. https://doi.org/10.30574/ijsra.2025.14.2.0564

Litaay, C., Indriati, A., & Mayasti, N. K. I. (2022). Fortification of sago noodles with fish meal skipjack tuna (Katsuwonus pelamis). *Food Science and Technology*, *42*, e46720. https://doi.org/10.1590/fst.46720
Mathew, J., Blossom, L., Gopal, T. K. S., & Thomas, A. (2022). Nutritional and Quality Properties of Pasta and Noodles Incorporated with Fish/ and Fishery-Derived Ingredients Using Extrusion Technology- A Review. *Critical Reviews in Food Science and Nutrition*, *62*(4), 1002–1023. https://doi.org/10.1080/10498850.2022.2120376
Meenakshi, J. V, & Quisumbing, A. (2025). Diet quality and micronutrient intakes in nutritional value chains: A synthesis and suggestions for further research. *Food Policy*, *130*, 102789. https://doi.org/10.1016/j.foodpol.2024.102789
Misron, A., Che Musa, N., Salleh, M. S., & Zandi, G. (2025). Sustainable labelling on packaging: Does it impact purchase behavior? *International Review of Management and Marketing*, *15*(2), 240–253. https://doi.org/10.32479/irmm.17716
Monteiro, M. L. G., Mársico, E. T., Soares Junior, M. S., Magalhães, A. O., Canto, A. C. V. C. S. C., Costa-Lima, B. R. C., Alvares, T. S., & Conte Junior, C. A. (2016). Nutritional profile and chemical stability of pasta fortified with tilapia (Oreochromis niloticus) flour. *PLoS ONE*, *11*(12), e0168270. https://doi.org/10.1371/journal.pone.0168270
Mosibo, O. K., Ferrentino, G., & Udenigwe, C. C. (2024). Microalgae proteins as sustainable ingredients in novel foods: Recent developments and challenges. *Foods*, *13*(5), 733. https://doi.org/10.3390/foods13050733
Mpalanzi, V., Chaula, D., & Ngungulu, A. W. (2023). Textural, cooking quality and sensory acceptability of noodles incorporated with moringa leaf and sardine powders. *European Journal of Nutrition & Food Safety*, *15*(10), 1–20. https://doi.org/10.9734/ejnfs/2023/v15i101341
Nawaz, A., Li, E., Khalifa, I., Irshad, S., Walayat, N., Mohammed, H. H. H., Zhang, Z., Ahmed, S., & Simirgiotis, M. J. (2021). Evaluation of fish meat noodles: Physical property, dough rheology, chemistry and water distribution properties. *International Journal of Food Science and Technology*, *56*(2), 1061–1069. https://doi.org/10.1111/ijfs.14761
Nelas, M. H., Sumartini, R., Nabila, N., Hutapea, E., Fitriana, E., & Saputra, N. (2022). The effect of thickers on the quality of "Indofishme" instant noodles as nutrition rich instant noodles based on fish (Scomberomorus Commerson and Seaweed (E.Cottonii). *Procedia of Social Sciences and Humanities*, *3*, 192–200. https://doi.org/10.21070/pssh.v3i.157
Niu, H., Li, Z., Zhang, C., & Li, M. (2024). Sustainable food systems under environmental footprints: The delicate balance from farm to table. *Science of The Total Environment*, *954*, 176761. https://doi.org/10.1016/j.scitotenv.2024.176761
Nogueira, A. D. C., Oliveira, R. A. D., & Steel, C. J. (2019). Protein enrichment of wheat flour doughs: Empirical rheology using protein hydrolysates. *Food Science and Technology*, *39*(2), 488–493. https://doi.org/10.1590/fst.06219
Noreen, S., Hashmi, B., Aja, P. M., & Atoki, A. V. (2025). Health benefits of fish and fish by-products—A nutritional and functional perspective. *Frontiers in Nutrition*, *12*. https://doi.org/10.3389/fnut.2025.1564315
Obadi, M., Li, Y., & Xu, B. (2022). Identifying key factors and strategies for reducing oil content in fried instant noodles. *Journal of Food Science*, *87*(10), 4329–4347. https://doi.org/10.1111/1750-3841.16301
Okadera, T., Tsuchiya, K., & Hanaoka, T. (2025). Synergy between SDGs 12.3 and 2.1 in lower-middle-income countries through the lens of food waste and energy imbalance. *Scientific Reports*, *15*, 17956. https://doi.org/10.1038/s41598-025-01579-x
Panjaitan, P. S. T., Tanjung, A., & Sopha, D. (2023). Production of instant noodles with the addition of catfish bone (Pangasius sp.). *PELAGICUS: Jurnal Iptek Terapan Perikanan Dan Kelautan*, *4*(2). https://doi.org/10.15578/plgc.v4i2.12724
Pascual, D. M. (2016). Utilization and acceptability of noodles enriched with different levels of fish protein from bighead carp (Aristichthys nobis). *International Journal of Sciences: Basic and Applied Research*, *25*(1), 389–401.
Prakoso, S. G., Satria, R., Kinanti, N. C., & Puspitasari, R. (2019). Analysis of Samyang instant noodle's market in Indonesia using the impact of uncertainty avoidance by Hofstede's cultural dimensions. *Insignia Journal of International Relations*, *6*(2), 123. https://doi.org/10.20884/1.ins.2019.6.2.1557
Rahmatika, F. A. Y., & Indayani, L. (2022). The influence of brand image, product quality and price on purchase decisions for Beauty Glow Skincare in Sidoarjo. *Indonesian Journal of Law and Economics Review*, *17*. https://doi.org/10.21070/ijler.v17i0.799
Reichert, C. L., Bugnicourt, E., Coltelli, M.-B., Cinelli, P., Lazzeri, A., Canesi, I., Braca, F., Martínez, B. M., Alonso, R., Agostinis, L., Verstichel, S., Six, L., Mets, S. D., Gómez, E. C., Ißbrücker, C., Geerinck, R., Nettleton, D. F., Campos, I., Sauter, E., & Schmid, M. (2020). Bio-based packaging: Materials, modifications, industrial applications and sustainability. *Polymers*, *12*(7), 1558. https://doi.org/10.3390/polym12071558
Reis, E. S. G., Souza, M. L. R. D., Michka, J. M. G., Kimura, K. S., Lara, J. A. F. D., Delbem, A. C. B., & Gasparino, E. (2015). Fresh pasta enrichment with protein concentrate of tilapia: Nutritional and sensory

characteristics. *Food Science and Technology Campinas*, 1–7. https://doi.org/10.1590/1678-457X.0020
Ruge, D. (2023). *School meals and food systems - : Rethinking the consequences for climate, environment, biodiversity, and food sovereignty BT - School meals and food systems - : Rethinking the consequences for climate, environment, biodiversity and food sovereignty* (p. 102). London School of Hygiene & Tropical Medicine. https://doi.org/10.17037/PUBS.04671492
Saleh, N. E., Wassef, E. A., & Abdel-Mohsen, H. H. (2022). *Sustainable fish and seafood production and processing BT - Sustainable fish production and processing* (pp. 259–291). https://doi.org/10.1016/B978-0-12-824296-4.00002-5
Shikha, F. H., Hossain, M. I., & Farzana, L. (2020). Development of noodles with low cost Silver carp fish (Hypophthalmichthys molitrix) mince. *Bangladesh Journal of Fisheries*, *32*(1), 107–114. https://doi.org/10.52168/bjf.2020.32.12
Simanjuntak, D., & Lingga, D. (2024). Product differentiation in food-product markets: Evidence from the Asian instant noodles industry. *Agris On-Line Papers in Economics and Informatics*, *16*(2), 75–95. https://doi.org/10.7160/aol.2024.160206
Society, W. A. (2024). Indonesia: Emerging as a leader in aquaculture. *World Aquaculture Magazine*. https://www.was.org/articles/Indonesia_Emerging_as_a_Leader_in_Aquaculture.aspx
Solarte-Toro, J. C., & Cardona Alzate, C. A. (2021). Biorefineries as the base for accomplishing the sustainable development goals (SDGs) and the transition to bioeconomy: Technical aspects, challenges and perspectives. *Bioresource Technology*, *340*, 125626. https://doi.org/10.1016/j.biortech.2021.125626
Sovacool, B. K., Bazilian, M., Griffiths, S., Kim, J., Foley, A., & Rooney, D. (2021). Decarbonizing the food and beverages industry: A critical and systematic review of developments, sociotechnical systems and policy options. *Renewable and Sustainable Energy Reviews*, *143*, 110856. https://doi.org/10.1016/j.rser.2021.110856
Turner, C., Kalamatianou, S., Drewnowski, A., Kulkarni, B., Kinra, S., & Kadiyala, S. (2020). Food environment research in low- and middle-income countries: A systematic scoping review. *Advances in Nutrition*, *11*(2), 387–397. https://doi.org/10.1093/advances/nmz031
Wangtueai, S., Phimolsiripol, Y., Vichasilp, C., Regenstein, J. M., & Schöenlechner, R. (2020). Optimization of gluten-free functional noodles formulation enriched with fish gelatin hydrolysates. *LWT*, *133*, 109977. https://doi.org/10.1016/j.lwt.2020.109977
Xin, X., Essien, S., Dell, K., & Zhao, X. (2022). Effects of spray-drying and freeze-drying on bioactive and volatile compounds of smoke powder food flavouring. *Food and Bioprocess Technology*, *15*(4), 785–794. https://doi.org/10.1007/s11947-022-02779-3
Zhao, Z., Li, Y., & Du, Z. (2022). Seafood waste-based materials for sustainable food packing: From waste to wealth. *Sustainability*, *14*(24), 16579. https://doi.org/10.3390/su142416579