DOI: https://doi.org/10.62985/j.huit_ojs.vol25.noS1_ICA.246

ZERO-WASTE APPROACH IN TUNA FISH PROCESSING INDUSTRY

Nguyen Cong Binh[1*], Nguyen Minh Xuan Hong[2]

[1]*Ho Chi Minh City University of Industry and Trade*

[2]*Nong Lam University Ho Chi Minh City*

*Email: *binhnc@huit.edu.vn*

Received: 2 May 2025; Revised: 25 May 2025; Accepted: 6 June 2025

ABSTRACT

A high fraction of the food materials in fish processing is discarded and this waste can pose threats to the environment. Therefore, many researchers and food producers currently focus on food waste reduction to minimize environmental footprint, decrease production costs, enhance profit, and head to sustainable development. This paper explores the tuna fish processing industry throughout main streams and its by-products. Approximately 50% of tuna fish becomes by-product during filleting, including heads, organs, bones, and skin. These by-products can be converted into more valuable products such as tuna oil, collagen, hydroxyapatite, and fish sauce by traditional methods as well as conventional technologies. The transformation of by-products from tuna fish processing reduces not only waste but also the greenhouse gas emissions and contributes to both environmental and economic benefits.

Keywords: Tuna fish, processing, by-product, zero waste, sustainable development.

1. INTRODUCTION

Food production is evolving rapidly to meet the demands of sustainability, efficiency and consumer preferences. Some of the key trends shaping the food manufacturing industry today include low-emission technologies and recycling of by-products.

Low-emission technologies include renewable energy in food processing and carbon capture in production. According to the United Nations, one of the main causes of climate change is global warming. Since climate change is becoming a more serious danger, all industries have had to immediately reduce their greenhouse gas (GHG) emissions [1]. As the food system accounted for more than one-third of GHG emissions in 2015 [2], the food production industry needs to take appropriate action to address this issue. The food manufacturing sector must set climate objectives and monitor its emissions since it is a significant source of GHG emissions. When establishing emission targets, it is crucial to take into consideration and incorporate emissions from the whole value chain in addition to their own emissions [3]. Despite this important contribution, the majority of food scientists are still ignorant about the carbon issue, and there hasn't been much focus on how the food sector can address it. To reduce emissions, the food manufacturing industry widely applies process optimization as a strategy to reduce energy consumption, using various methods such as adjusting production schedules, streamlining production times, improving equipment control, and applying continuous processing methods [4]. By implementing basic process optimization techniques such as insulation testing and regular maintenance, the baking industry has the potential to save nearly 30 percent of its energy consumption, highlighting the effectiveness of adopting advanced thermal management strategies and waste heat recovery as an approach to reducing energy consumption [5], [6]. Furthermore, cutting-edge methods of food processing technologies like microwave heating and highpressure processing have a lot of potential for increasing food processing effectiveness and lowering energy usage. In particular, it has been demonstrated that microwave heating works well for pasteurization, thawing, and dehydration [7], [8].

A very important aspect that cannot be ignored in the current food processing technology industry is recycling by-products to achieve zero waste, which is both sustainable and good for the environment. There are many definitions of food waste (FW) by international organizations such as the Food and Agriculture Organization of the United Nations (FAO) but there is still no consensus between food loss and food waste. A recent European project, Fusions, proposed the following definition: “Food waste is any food and inedible parts of food removed from the food supply chain for recovery or disposal (including compost, plowed/unharvested crops, anaerobic digestion, bioenergy production, cogeneration, incineration, sewerage, landfill, or marine discharge).”[9]. According to estimates from the Food and Agriculture Organization (FAO) of the United Nations, approximately 1.3 billion tons, or one-third, of the food produced for human use is lost or wasted worldwide [10].

The proportion of food' by-products recycled globally varies significantly depending on sector and region. According to a report by the Food and Agriculture Organization of the United Nations (FAO) (2011), about 30-40% of all food produced globally is lost or wasted, but only a small fraction is properly recycled. It is estimated that only about 16% of food waste is recycled or reused as animal feed, compost or energy sources (such as biogas) [11].

In the meat and poultry processing industry, nearly 95% of by-products in some countries such as the United States and European countries are reused for secondary purposes such as pet food, gelatin, and biofuel [12].

In the fruit and vegetable processing industry approximately 25-30% of by-products are reused, mainly as animal feed, compost or in value-added products [13].

Nearly 20% of the world's food supply comes from the seafood processing sector, which also produces 6–8 million tons of garbage a year, or around 50–70% of all seafood raw materials. Crab shells, shrimp, shrimp shells, crustacean shells, fish scales, fins, skin, and viscera, among other inedible portions of marine animals, are produced as trash that is high in chitin and other organic materials [14]. In developed countries (Norway, Iceland, etc.), more than 90% of fish by-products are recycled into valuable products (e.g. fishmeal, fish oil, collagen, gelatin). But in developing countries, the utilization rate can be less than 30-50%, with most of it being discarded as waste [15].

By-products from tuna fillet processing account for 50% of raw materials, including 18% fish head, 14% skin and remaining meat, 8% bones, 2% fins and 8% gills and viscera [16]. Vietnam's tuna exports have grown significantly. In December 2024, exports reached nearly 86 million USD, up 17% over the same period in 2023. Total export turnover in 2024 reached about 989 million USD, up 17% over the same period last year [11]. The global tuna fish market was valued at USD 43.14 billion in 2024 and is projected to grow to USD 54.51 billion by 2032, exhibiting a Compound Annual Growth Rate of 3.02% during the forecast period [17].

The above studies show that the amounts of by-products in the fruit and vegetable processing and seafood processing industries that are reused is still very limited. This shows that research to reuse by-products in these two industries is very potential. To develop sustainably and effectively as well as limit environmental pollution, it is necessary to research technology and solutions to move towards zero waste.

Current studies mainly use by-products of the seafood processing industry to extract bioactive compounds or produce value-added products [18], [19]. Very few publications are based on the technological process of production and identify all by-products generated from that process, thereby resolving all these by-products into value-added products and reducing waste to the environment.

In this study, the by-products generated in the tuna processing industry and their composition are analyzed. In addition, the technology for the reuse of by-products is proposed and the impact of value-added products from by-products on the economy and the environment is discussed.

2. BY-PRODUCTS FROM THE TUNA FISH PROCESSING INDUSTRY AND THEIR COMPOSITION

Tuna is currently processed in two main forms: frozen tuna fillets and canned tuna. The processing steps that create the main by-products are shown in Figure 1. Both processing processes have the same steps to create by-products such as Bleeding & Washing1; Head removal & Gutting and Washing 2. For the tuna fillet production process, the Filleting & skinning step creates by-products similar to the Separate with muscle meat step in the canned tuna production process. In addition, the trimming step of the frozen tuna fillet production process also creates broken meat.

There are differences in the chemical composition of tuna by-products such as fish blood, head, viscera, skin, bones, dark muscle and broken meat. The composition of each by-product varies depending on the species of fish and the season. The chemical composition of tuna by-products is presented in Table 1.

Table 1. The chemical composition of tuna by-products

Tuna by-products	Chemical composition	References
Blood	Water (75-85%); Proteins (10-15%); Lipids (1-5%); Carbohydrates (<1%): Mainly glucose and glycogen.	[20], [21]
Head	Water (50-70%); Proteins (15-25%); Lipids (5-25%); Ash (Minerals) (5-10%)	[22], [23]
Viscera	Water (60-80%); Proteins (10-20%); Lipids (5-25%); Ash (Minerals) (1-5%)	[24], [16]
Bone	Water (40-50%); Proteins (15-25%); Lipids (1-5%); Ash (Minerals) (30-50%)	[25], [26], [27],[28]
Skin	Water (50-65%); Proteins (25-35%); Lipids (2-10%); Ash (Minerals) (1-5%)	[29], [30], [31]
Dark muscle	Water (60-75%); Proteins (20-30%); Lipids (3-6%); Ash (Minerals) (1-4%)	[32], [33], [34]
Broken meat	Water (60-75%); Proteins (20-30%); Lipids (2-10%); Ash (Minerals) (2-5%)	[35], [36]

Results in Table 1 show that tuna by-products are a high source of protein, lipids, and minerals. With by-products accounting for 50% of the total annual tuna catch, this is a significant source of raw materials for the production of value-added products.

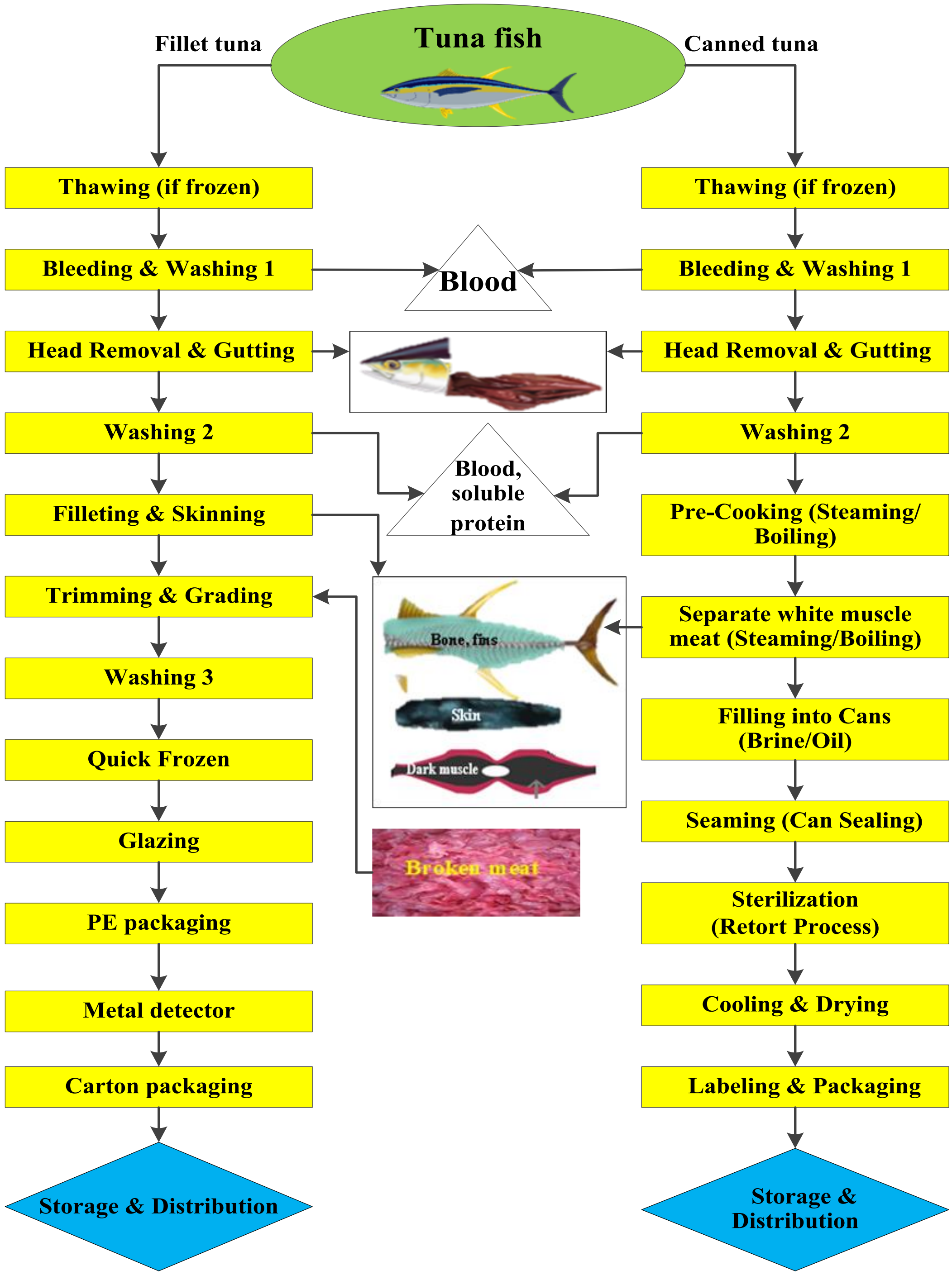

Figure 1. Flow chart of production process of fillet tuna, canned tuna and their by-products

3. TRANSFORMATION OF BY-PRODUCT FROM THE TUNA FISH PROCESSING INDUSTRY

The transformation of tuna by-products into goods with additional value has numerous advantages, including lowering greenhouse gas emissions associated with garbage, promoting the development of sustainable industries, and lowering pollution levels in the environment. By-products of tuna can be processed to create fish protein hydrolysates, fish sauce, hydroxyapatite, tuna oil, tuna collagen and gelatin, and tuna digestive enzymes.

3.1. Tuna oil

Tuna oil is a value-added product from tuna by-products. Refined tuna oil is a pale yellow, odorless substance made from tuna by-products from canned tuna processing technology or frozen tuna fillet processing technology. Normally, tuna oil is made only from heads, meat, bones and trimmed meat. Oil produced from tuna by-products can be produced by conventional pressing, solvent extraction or more advanced methods such as supercritical CO_2 extraction. However, to limit the variability of tuna oil, the method of using protease enzymes to hydrolyze tuna by-products and obtain 3 products at once is also very valuable, which are fish oil, hydrolyzed protein and hydroxyapatite (Fig.2)

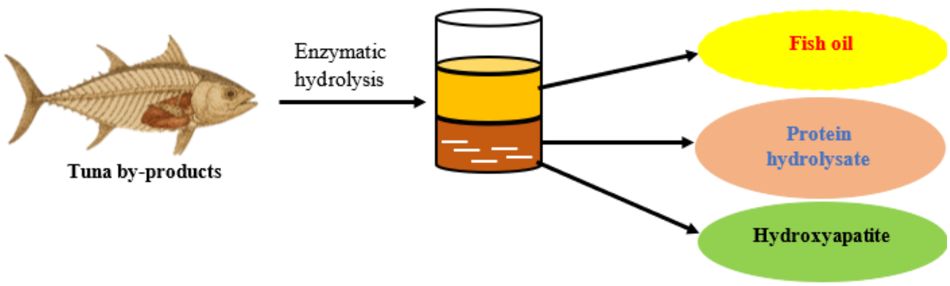

Figure 2. Enzymatic hydrolysis of tuna by-products

Polyunsaturated fatty acids (PUFAs) are found in tuna oil, especially the omega-3 fatty acids DHA (docosahexaenoic acid, C22:6n3) and EPA (eicosapentaenoic acid, C22:5n3). Typically, the oil contains 5.7% EPA and 18.8–25.5% DHA [37]. Because PUFAs can increase immunity, reduce the risk of coronary heart disease, and prevent some types of cancer, they are essential for human nutrition and health. Omega-3 fatty acids can be conveniently supplied by oil and water emulsions [38].

3.2. Fish protein hydrolysate

Hydrolysis is defined as the breakdown of proteins into peptides of various sizes. The degradation process can be carried out by chemical methods such as acids or bases or biological methods using enzymes. The use of acids and bases for chemical hydrolysis aims to break the peptide bonds of proteins [39]. Although the chemical process produces products with varied chemical compositions and functional properties, this process is preferred by industries over the biological process because it is inexpensive and simple. However, with reduced nutritional quality and poor functionality, chemically produced products have many limitations when used in food ingredients.

One more efficient and environmetal-friendly method to obtain hydrolysates from fish protein by-products is through enzymatic hydrolysis [40]. Bioactive peptides can subsequently be extracted from these hydrolysates using chromatographic techniques and membrane separation. Mass spectrometry can then be used to identify the peptides' molecular properties. Fish hydrolysates and peptides are promising nutraceutical ingredients for use in food because of their many biological actions, which include antioxidative, lipid homeostasis regulation, anti-inflammatory, anticancer, neuroprotective, and antihypertensive effects. Additionally, they frequently exhibit gelling, foaming, and emulsifying qualities, making them potentially appropriate as multifunctional additives. Fish waste byproducts could therefore be transformed into functional substances with additional value that are intended to treat chronic illnesses [41]. In another study, the effective use of fish waste, particularly viscera, has been proved to be critical to the aquatic food industry's financial sustainability [42]. Enzymatic hydrolysis is a highly efficient technique for obtaining valuable proteins from fish viscera while preserving their nutritional value. The protein hydrolysate made from skipjack tuna viscera utilizing Alcalase in this work had a high protein content. As such, it can be utilized in a variety of medicinal agents, dietary supplements, and food additives [43]. Hydrolysis of tuna blood (TB) by Neutrase enzyme is suitable for the production of peptides with high antioxidant and antihypertensive properties and potential applications in food, pharmaceutical and functional food products [44].

3.3. Hydroxyapatite from tuna bone

Collagen makes up the organic portion of fish bone, which makes up 30% of the total [45]. Calcium phosphate and hydroxyapatite make up the majority of the inorganic materials that make up the remaining 60% to 70%. As a result, fish bones are a good source of essential inorganic compounds with a calcium-phosphorus balance that can be utilized as a dietary supplement [46]. However, fish bones are still mainly used as animal feed.

There are currently many studies on the production of bioactive hydroxyapatite (Hap) from tuna bones. According to Venkatesan & Kim (2010), tuna bones have been extracted and characterized for use in biomedical applications. Based on the analysis, it can be concluded that varying the isolation temperature between 600–900 °C has tremendous impact on the production of HAp from *Thunnus obesus* with required properties [47]. Another study, using the precipitation process, hydroxyapatite was created from skipjack tuna bone. To investigate hydroxyapatite's biocompatibility, pre-osteoblast cell cultures were used. Different hydroxyapatite concentrations of 200 µg/mL, 100 µg/mL, and 5 µg/mL were applied to the cells. The cultures were examined for viability 24 hours, 48 hours, and 72 hours after being incubated with 5% CO_2 at 37 °C. Optical density was the reported result. According to the study, skipjack tuna bone generated roughly uniformly sized granular particles. In the center, the surface material seemed to clump and develop pores. For hydroxyapatite derived from skipjack tuna bone, the weight percentage Ca/P ratio was 1.94. According to these findings, hydroxyapatite from skipjack tuna bones may be used as a biomaterial for bone engineering [48].

3.4. Tuna collagen and gelatin

In the food, cosmetic, biomedical, and pharmaceutical industries, collagen and its derivatives have found extensive usage as materials [49], [50]. Although cows and pigs are the primary source of collagen and gelatin utilized in commercial products, mammalian illnesses like foot/mouth disease and bovine spongiform encephalopathy pose safety concerns due to the possibility of disease transmission to humans. Furthermore, using products from cows and pigs is forbidden in several religions. Fish collagen and gelatin, on the other hand, have a low danger of spreading viruses and don't conflict with Islamic dietary regulations or Hindu/Buddhist religious sensitivities.

Collagen and gelatin can be obtained from the skin, bones, and fins of fish. Despite being discarded as garbage, they produce a very large amount of collagen (about 36–54%) [51]. In addition, hydrolyzed collagen has also been studied and produced from yellowfin tuna skin, resulting in a product with good biological activities and physical properties such as antibacterial ability, antioxidant ability, foaming ability, and very good antifreeze ability [52]. Collagen, gelatin and hydrolyzed collagen are commonly extracted using enzymatic agents and are considered to be effective in the food industry in terms of economy, environmental friendliness, versatility and desirable properties of the resulting products [53], [54].

3.5. Tuna digestive enzymes

Fish viscera are one of the most important by-products of the fishing industry. These organs are rich sources of digestive enzymes, such as pepsin and trypsin and chymotrypsin [55]. Many scientists have isolated and refined the enzymes from the internal organs of tuna, including the yellowfin tuna's spleen [56] and and the stomach of albacore tuna [57]. Recently, Proteinases from albacore tuna spleen are extracted and recovered, which greatly helps to enhance the amounts of valuable products from albacore tuna processing wastes and lessen the local pollution issue. Additionally, the properties of the resulting enzyme can be applied to the food, detergent, pharmaceutical, leather, and silk sectors [58].

3.6. Fish sauce

Fish sauce is a processed food produced through the fermentation of fish or fish waste as raw materials. Traditionally, fish sauce is produced by mixing fish with salt at a prescribed concentration and then incubating at room temperature (±30 °C) for 6-12 months or longer [59]. Sometimes fermentation is carried out through a combination of salt, enzymes and bacteria [60]. Fish sauce is popular in South Asian countries and is used as a condiment as well as a source of protein. The nitrogen content in fish sauce can reach 20 g/L, of which 80% consists of amino acids [61]. During the fermentation process, fish meat is hydrolyzed into short-chain amino acids, which are considered to contribute to the unique flavor, aroma, texture and taste of fish sauce [62]. Fermentation increases the total amount of soluble nitrogen and food quality because it not only produces essential amino acids but also minerals such as sodium (Na), calcium (Ca) and magnesium (Mg) [59]. According to Wenno & Loppies (2019), it was demonstrated that the addition of 5% papain enzyme and 20% salt to tuna loin waste (cut-off) produced tuna fish sauce with good physicochemical properties [63]. The fish sauce had a purple color, viscosity of 9.58 cp, salt content of 26.57%, volatile base nitrogen (TVBN) content of 26 mgN%, total acid concentration of 0.11%, protein content of 11.3% and moisture content of 59%. Glutamic acid was the predominant amino acid present in the produced tuna fish sauce.

4. CONCLUSION

In the global fisheries business, tuna is a vital commodity. It is widely marketed globally and produced in large quantities. The majority of the tuna companies, including those that can tuna and make sashimi, only use white meat, which leads to a large amount of waste or by-products. These by-products are rich in protein and have a good nutritional value overall. These by-products have been transformed by researchers into fish protein hydrolysate, hydroxyapatite, fish meal, fish oil, pet food, gelatin, extracts of digestive enzymes, and fish sauce.

Converting by-products from tuna fillet production into high-value solutions is not only a step forward in resource optimization but also brings great benefits in a low-emission context. Instead of letting them go to waste or being disposed of in polluting ways, utilizing these by-products to produce food supplements, animal feed, organic fertilizers or even high-value industrial products has demonstrated the potential for sustainable development of the aquaculture industry.

By applying advanced technologies such as molecular biology, microbial fermentation, and low-energy processing, the tuna value chain can be expanded without significantly increasing environmental pressure. This contributes to reducing greenhouse gas emissions through reducing food waste, maximizing the use of biological resources, and replacing fossil-based products. At the same time, this also promotes innovation and creates additional economic value for the fisheries sector, especially in coastal countries.

Overall, the conversion of tuna by-products not only solves the environmental problem but also opens a new direction for the circular economy, highlighting the important role of the fisheries sector in the context of globalization and the transition to a low-emission economy.

REFERENCES

1. Hansen A.D., Kuramochi T., Wicke B. - The status of corporate greenhouse gas emissions reporting in the food sector: An evaluation of food and beverage manufacturers. Journal of Cleaner Production **361** (2022) 132279. https://doi.org/10.1016/j.jclepro.2022.132279
2. Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F. N., Leip, A. - Food systems are responsible for a third of global anthropogenic GHG emissions. Nature Food **2** (3) (2021). https://doi.org/10.1038/s43016-021-00225-9
3. Reavis, M., Ahlen, J., Rudek, J., & Naithani, K. - Evaluating greenhouse gas emissions and climate mitigation goals of the global food and beverage sector. Frontiers in Sustainable Food Systems **5** (2022). https://doi.org/10.3389/fsufs.2021.78949
4. González-Ramírez, J. E., Leducq, D., Arellano, M., & Alvarez, G. - Energy consumption optimization of a continuous ice cream process. Energy Conversion and Management **70** (2013). https://doi.org/10.1016/j.enconman.2013.03.015
5. Muster-Slawitsch, B., Brunner, C., & Fluch, J. - Application of an advanced pinch methodology for the food and drink production. Wiley Interdisciplinary Reviews: Energy and Environment **3** (6) (2014). https://doi.org/10.1002/wene.117
6. Pask, F., Sadhukhan, J., Lake, P., McKenna, S., Perez, E. B., & Yang, A. -Systematic approach to industrial oven optimisation for energy saving, Applied Thermal Engineering **71** (1) (2014). https://doi.org/10.1016/j.applthermaleng.2014.06.013
7. Galanakis, C. M. - Innovation Strategies in the Food Industry: Tools for Implementation. Academic Press (2016). https://doi.org/10.1016/C2015-0-00303-3
8. Atuonwu, J.C., Leadley, C., Bosman, A., Tassou, S.A., Lopez-Quiroga, E., & Fryer, P.J. - Comparative assessment of innovative and conventional food preservation technologies: Process energy performance and greenhouse gas emissions, Innovative Food Science and Emerging Technologies **50** (2018) 174-187. https://doi.org/10.1016/j.ifset.2018.09.008
9. FUSIONS - Retrieved May 2018, from Food Waste Definition (2016). https://www.eu-fusions.org/index.php/about-food-waste/280-food-waste-definition
10. Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., & Meybeck, A. -

Global food losses and food waste: extent, causes and prevention. International Congress: FAO (2011).

11. VASEP - Tuna exports recover and face new challenges, https://vasep.com.vn/san-pham-xuat-khau/ca-ngu/xuat-nhap-khau/thang-2-2024-xuat-khau-ca-ngu-phuc-hoi-va-doi-mat-voi-thach-thuc-moi-33056.html

12. Ricci, A., Allende, A., Bolton, D., Chemaly, M., Davies, R., Herman, L., Koutsoumanis, K., Lindqvist, R., Nørrung, B., Robertson, L., Ru, G., Sanaa, M., Simmons, M., Skandamis, P., Snary, E., Speybroeck, N., Kuile, B. Ter, Threlfall, J., Wahlström, H., Fernández Escámez, P. - Evaluation of the application for a new alternative processing method for animal by-products of Category 3 material (ChainCraft B.V.). EFSA Journal **16** (6) (2018) https://doi.org/10.2903/j.efsa.2018.5281

13. Kumar, H., Bhardwaj, K., Sharma, R., Nepovimova, E., Kuča, K., Dhanjal, D. S., Verma, R., Bhardwaj, P., Sharma, S., & Kumar, D.- Fruit and vegetable peels: Utilization of high value horticultural waste in novel industrial applications. Molecules **25** (12) (2020). https://doi.org/10.3390/molecules25122812

14. Yan, N., & Chen, X.- Sustainability: Don't waste seafood waste. In Nature **524** (2015) 155-157. https://doi.org/10.1038/524155a.

15. European Commission: Directorate-General for Maritime Affairs and Fisheries and EUMOFA - Blue bio-economy – Situation report and perspectives, Publications Office of the European Union, 2018. https://data.europa.eu/doi/10.2771/053734

16. Gamarro, E., Orawattanamateekul, W., Sentina, J., & Gopal, S. - By-products of tuna processing. GLOBEFISH Research Programme FAO 112 (2013).

17. Fortune Business Insights - Tuna Fish Market Size, Share & Industry Analysis, By Species (Skipjack, Albacore, Yellowfin, Bigeye, Bluefin, and Others), By Type (Canned, Fresh, and Frozen), and Regional Forecast (2025) 2025-2032.

18. Hsu, K.C. - Purification of antioxidative peptides prepared from enzymatic hydrolysates of tuna dark muscle by-product, Food Chemistry **122** (1) (2010). https://doi.org/10.1016/j.foodchem.2010.02.013.

19. Estiasih, T., Ahmadi, K., & Nisa, F. C. - Optimizing conditions for the purification of omega-3 fatty acids from the by-product of tuna canning processing. Advance Journal of Food Science and Technology **5** (5) (2013). https://doi.org/10.19026/ajfst.5.3120.

20. Tansukkasem, S., Kaewpathomsri, P., Jonjaroen, V., Payongsri, P., Lertsiri, S., & Niamsiri, N. - Production and characterization of heme iron polypeptide from the blood of skipjack tuna (*Katsuwonus pelamis*) using enzymatic hydrolysis for food supplement application. Foods **12** (17) (2023). https://doi.org/10.3390/foods12173249

21. Mongkonkamthorn, N., Malila, Y., Yarnpakdee, S., Makkhun, S., Regenstein, J. M., & Wangtueai, S. - Production of protein hydrolysate containing antioxidant and angiotensin-i-converting enzyme (Ace) inhibitory activities from tuna (katsuwonus pelamis) blood. Processes **8** (11) (2020) 1–22. https://doi.org/10.3390/pr8111518

22. Li, W., Liu, Y., Jiang, W., & Yan, X. - Proximate composition and nutritional profile of rainbow trout (*Oncorhynchus mykiss*) heads and skipjack tuna (*Katsuwonus pelamis*) Heads. Molecules **24** (17) (2019). https://doi.org/10.3390/molecules24173189

23. Rani, P., Vijay Kumar, P., Rushinadha Rao, K., PPN Vijay Kumar, C., & Shameem, U. - Seasonal variation of proximate composition of tuna fishes from Visakhapatnam fishing harbor, East coast of India. IJFAS **4** (6) (2016) 308-313.

24. Banze, J. F., da Silva, M. F. O., Enke, D. B. S., & Fracalossi, D. M. - Acid silage of tuna viscera: Production, composition, quality and digestibility. Boletim Do Instituto de Pesca **43** (2017). https://doi.org/10.20950/1678-2305.2017.24.34
25. López-Álvarez, M., Souto-Montero, P., Durán, S., Pérez-Davila, S., Vázquez, J. A., González, P., & Serra, J.- Valuable Ca/P sources obtained from tuna species' by-products derived from industrial processing: Physicochemical and Features of Skeleton Fractions. Recycling **9** (6) (2024) 1–14. https://doi.org/10.3390/recycling9060109
26. Toppe, J., Albrektsen, S., Hope, B., & Aksnes, A. - Chemical composition, mineral content and amino acid and lipid profiles in bones from various fish species. Biochemistry and Molecular Biology **146** (3) (2007) 395-401. https://doi.org/10.1016/j.cbpb.2006.11.020
27. Benjakul, S., Mad-Ali, S., & Sookchoo, P. - Characteristics of biocalcium powders from pre-cooked tongol (*Thunnus tonggol*) and yellowfin (*Thunnus albacores*) tuna bones. Food Biophysics **12** (4) (2017). https://doi.org/10.1007/s11483-017-9497-0
28. Nemati, M., Huda, N., & Ariffin, F. - Development of calcium supplement from fish bone wastes of yellowfin tuna (*Thunnus albacares*) and characterization of nutritional quality. International Food Research Journal **24** (6) (2017) 2419-2426.
29. Devita, L., Nurilmala, M., Lioe, H. N., & Suhartono, M. T. - Chemical and antioxidant characteristics of skin-derived collagen obtained by acid-enzymatic hydrolysis of bigeye tuna (*Thunnus obesus*). Marine Drugs **19** (4) (2021). https://doi.org/10.3390/MD19040222
30. Nguyen, B. C., Nguyen, H. M. X., Nguyen, K. H. N., & Kha, T. C. - Optimization of treatment conditions for non-collagen removal from yellowfin tuna skin (*Thunnus albacares*). Chiang Mai University Journal of Natural Sciences **19** (3) (2020), 548–562. https://doi.org/10.12982/CMUJNS.2020.0036
31. Suseno, S. H. - Proximate, fatty acid, amino acid and mineral composition of tuna (*Thunnus* sp.) by-product from West Sumatra Province, Indonesia. Pakistan Journal of Nutrition **14** (1) (2015). https://doi.org/10.3923/pjn.2015.62.66
32. Unnikrishnan, P., Kizhakkethil, B. P., George, J. C., Aliyamveetil Abubacker, Z., Ninan, G., & Chandragiri Nagarajarao, R. - Antioxidant peptides from dark meat of yellowfin tuna (*Thunnus albacares*): Process optimization and characterization. Waste and Biomass Valorization **12** (4) (2021). https://doi.org/10.1007/s12649-020-01129-8
33. Kannaiyan, S. K., Bagthasingh, C., Vetri, V., Aran, S. S., & Venkatachalam, K. - Nutritional, textural and quality attributes of white and dark muscles of little tuna (*Euthynnus affinis*). Indian Journal of Geo-Marine Sciences **48** (2) (2019).
34. Nguyen, T.B., Mueni, L.M., Bui, T.N.T.V., Bao, H.N.D., Thi Kim Cuc, N., & Nicolai, T. - Characterization of tuna dark muscle protein isolate. Journal of Food Processing and Preservation **46** (8) (2022). https://doi.org/10.1111/jfpp.16753
35. Sahubawa, L., Ustadi, Heliana, L. S., & Rosdiana. - Increased value added of tuna flakes (by-product) from steak processing through development of halal commercial food products (Tuna Topping Spaghetti). Journal of Food and Pharmaceutical Sciences **9** (2) (2021) 431-442. https://doi.org/10.22146/jfps.1911
36. Sayana, & Sirajudheen. - By-products from Tuna processing wastes an economic approach to coastal waste management. Proceedings of the International Seminar on Coastal Biodiversity Assessment (2017).
37. Chantachum, S., Benjakul, S., & Sriwirat, N.- Separation and quality of fish oil from

precooked and non-precooked tuna heads. Food Chemistry **69** (3) (2000). https://doi.org/10.1016/S0308-8146(99)00266-6

38. Shen, Z., Rusli, J. K., Sanguansri, L., & Augustin, M. A.- Retention of propanal in protein-stabilised tuna oil-in-water emulsions. Food Chemistry **101** (2) (2007). https://doi.org/10.1016/j.foodchem.2006.02.029
39. Pasupuleti, V. K., & Braun, S.- State of the art manufacturing of protein hydrolysates. In Protein Hydrolysates in Biotechnology (2010). https://doi.org/10.1007/978-1-4020-6674-0_2
40. Pasupuleti, V. K., & Demain, A. L.- Protein hydrolysates in biotechnology. In Protein Hydrolysates in Biotechnology (2010). https://doi.org/10.1007/978-1-4020-6674-0
41. Gao, R., Yu, Q., Shen, Y., Chu, Q., Chen, G., Fen, S., Yang, M., Yuan, L., McClements, D. J., & Sun, Q.- Production, bioactive properties, and potential applications of fish protein hydrolysates: Developments and challenges. Trends in Food Science and Technology 110 (2021) 687–699. https://doi.org/10.1016/j.tifs.2021.02.031
42. Nikoo, M., Regenstein, J. M., & Yasemi, M.- Protein Hydrolysates from Fishery Processing By-Products: Production, Characteristics, Food Applications, and Challenges. In Foods **12** (24) (2023). https://doi.org/10.3390/foods12244470
43. Klomklao, S., & Benjakul, S.- Utilization of Tuna Processing Byproducts: Protein Hydrolysate from Skipjack Tuna (Katsuwonus pelamis) Viscera. Journal of Food Processing and Preservation **41**(3) (2017). https://doi.org/10.1111/jfpp.12970
44. Mongkonkamthorn, N., Malila, Y., Yarnpakdee, S., Makkhun, S., Regenstein, J. M., & Wangtueai, S. -Production of Protein Hydrolysate Containing Antioxidant and Angiotensin -I-Converting Enzyme. Processes **8** (11) (2020) 1–22. https://doi.org/10.3390/pr8111518
45. Nagai, T., Izumi, M., & Ishii, M.- Fish scale collagen. Preparation and partial characterization. International Journal of Food Science and Technology **39** (3) (2004). https://doi.org/10.1111/j.1365-2621.2004.00777.x
46. Yoon, G. A., Kim, Y. M., Chi, G. Y., & Hwang, H. J.- Effects of tuna bone and herbal extract on bone metabolism in ovariectomized rats. Nutrition Research **25** (11) (2005). https://doi.org/10.1016/j.nutres.2005.08.005
47. Venkatesan, J., & Kim, S. K.- Effect of temperature on isolation and characterization of hydroxyapatite from tuna (thunnus obesus) bone. Materials **3** (10) (2010). https://doi.org/10.3390/ma3104761
48. Wardani, S. C., Sujuti, H., Mustamsir, E., & Hapsari, D. N.- Synthesis and potential of skipjack tuna bone hydroxyapatite as bone tissue engineering biomaterial. Journal of Physics: Conference Series **1665** (1) (2020). https://doi.org/10.1088/1742-6596/1665/1/012032
49. Cheng, F. Y., Hsu, F. W., Chang, H. S., Lin, L. C., & Sakata, R.- Effect of different acids on the extraction of pepsin-solubilised collagen containing melanin from silky fowl feet. Food Chemistry **13** (2) (2009) 563–567. https://doi.org/10.1016/j.foodchem.2008.08.043
50. Liu, X., Zheng, C., Luo, X., Wang, X., & Jiang, H. (2019). Recent advances of collagen-based biomaterials: Multi-hierarchical structure, modification and biomedical applications. Materials Science and Engineering C, 99, 1509–1522. https://doi.org/10.1016/j.msec.2019.02.070

51. Nagai, T., & Suzuki, N.- Isolation of collagen from fish waste material - Skin, bone and fins. Food Chemistry **68** (3) (2000). https://doi.org/10.1016/S0308-8146(99)00188-0
52. Nguyen, B. C., Kha, T. C., Nguyen, K. H. N., & Nguyen, H. M. X. -Optimization of enzymatic hydrolysis of collagen from yellowfin tuna skin (*Thunnus albacares*) by response surface methodology and properties of hydrolyzed collagen. Journal of Food Processing and Preservation **45** (4) (2021).. https://doi.org/10.1111/jfpp.15319
53. Wang, B., Wang, Y. M., Chi, C. F., Luo, H. Y., Deng, S. G., & Ma, J. Y.- Isolation and characterization of collagen and antioxidant collagen peptides from scales of croceine croaker (Pseudosciaena crocea). Marine Drugs **11** (11) (2013). https://doi.org/10.3390/md11114641
54. Ren, J., Zhao, M., Shi, J., Wang, J., Jiang, Y., Cui, C., Kakuda, Y., & Xue, S. J.- Purification and identification of antioxidant peptides from grass carp muscle hydrolysates by consecutive chromatography and electrospray ionization-mass spectrometry. Food Chemistry **108** (2) (2008) 727–736. https://doi.org/10.1016/j.foodchem.2007.11.010
55. Haard, N. F., & Simpson, B. K. - Digestive Proteinases from Marine Animals. In Seafood Enzymes (2020). https://doi.org/10.1201/9781482289916-11
56. Klomklao, S., Benjakul, S., Visessanguan, W., Kishimura, H., & Simpson, B. K.- Proteolytic degradation of sardine (*Sardinella gibbosa*) proteins by trypsin from skipjack tuna (*Katsuwonus pelamis*) spleen. Food Chemistry **98** (1) (2006). https://doi.org/10.1016/j.foodchem.2005.05.047
57. Nalinanon, S., Benjakul, S., Visessanguan, W., & Kishimura, H. - Partitioning of protease from stomach of albacore tuna (*Thunnus alalunga*) by aqueous two-phase systems. Process Biochemistry **44** (4) (2009). https://doi.org/10.1016/j.procbio.2008.12.018
58. Poonsin, T., Sripokar, P., Benjakul, S., Simpson, B. K., Visessanguan, W., & Klomklao, S. - Major trypsin like-serine proteinases from albacore tuna (*Thunnus alalunga*) spleen: Biochemical characterization and the effect of extraction media. Journal of Food Biochemistry **41** (2) (2017). https://doi.org/10.1111/jfbc.12323
59. Lopetcharat, K., Choi, Y. J., Park, J. W., Daeschel, M. A. - Fish sauce products and manufacturing : A review, Food Reviews International **17** (1) 65–88. https://doi.org/10.1081/FRI-100000515
60. Saisithi, P. - Traditional fermented fish: fish sauce production. In: Martin, A.M. (eds) Fisheries Processing. Springer, Boston, MA (1994). https://doi.org/10.1007/978-1-4615-5303-8_5
61. Mizutani, T., Kimizuka, A., Ruddle, K., & Ishige, N. - Chemical components of fermented fish products. Journal of Food Composition and Analysis **5** (2) (1992). https://doi.org/10.1016/0889-1575(92)90031-E
62. Jiang, J. J., Zeng, Q. X., Zhu, Z. W., & Zhang, L. Y. - Chemical and sensory changes associated Yu-lu fermentation process - A traditional Chinese fish sauce. Food Chemistry **104** (4) (2007). https://doi.org/10.1016/j.foodchem.2007.03.024.
63. Wenno M. R. & Loppies C. R. M. - Physico-chemical characteristics and amino acid profile of fermented sauce made from tuna loin by-product, in IOP Conference Series: Earth and Environmental Science **370** (2019) 012006. https://doi.org/10.1088/1755-1315/370/1/012006

TÓM TẮT

TIẾP CẬN THEO HƯỚNG KHÔNG CHẤT THẢI TRONG NGÀNH CHẾ BIẾN CÁ NGỪ

Nguyễn Công Bỉnh[1*], Nguyễn Minh Xuân Hồng[2]
[1]*Trường Đại học Công Thương Thành phố Hồ Chí Minh*
[2]*Trường Đại học Nông Lâm Thành phố Hồ Chí Minh*
*Email: *binhnc@huit.edu.vn*

Một lượng lớn nguyên liệu trong quá trình chế biến cá là phụ phẩm và chất thải này có thể gây ra mối đe dọa cho môi trường. Do đó, nhiều nhà nghiên cứu và nhà sản xuất thực phẩm hiện đang tập trung vào việc giảm thiểu chất thải thực phẩm để giảm tác động đến môi trường, giảm chi phí sản xuất, tăng lợi nhuận và hướng tới phát triển bền vững. Bài báo này khám phá quy trình công nghệ biến cá ngừ và các sản phẩm phụ của nó. Trong quy trình sản xuất cá ngừ fillet đông lạnh thì lượng phụ phẩm tạo ra khoảng 50% so với nguyên liệu bao gồm đầu, nội tạng, xương và da. Những phụ phẩm này có thể được chế biến thành các sản phẩm có giá trị gia tăng như dầu cá ngừ, collagen, hydroxyapatite và nước mắm bằng các phương pháp truyền thống cũng như các công nghệ thông thường. Việc chuyển đổi các sản phẩm phụ từ quá trình chế biến cá ngừ không chỉ làm giảm chất thải mà còn giảm lượng khí thải nhà kính và góp phần mang lại lợi ích về mặt môi trường và kinh tế.

Từ khóa: Cá ngừ, chế biến, sản phẩm phụ, không chất thải, phát triển bền vững.