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Review Article

Seafood: processing, preservation, nutrition, marketing, and policy

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Abstract: Seafood is an essential component of the global diet and economy, with diverse species and products contributing to the nutrition and well-being of populations worldwide. This paper provides a comprehensive review of key aspects related to seafood, including processing, preservation, nutrition, marketing, and policy. The processing of seafood involves traditional techniques such as frozen and ultracold, and some new techniques such as high pressure, plasma, pasteurization, which are crucial for maintaining product quality and extending shelf life. Furthermore, the nutritional value of seafood, rich in proteins, omega-3 fatty acids, vitamins, and minerals, is discussed in detail, highlighting the health benefits associated with seafood consumption. The marketing of seafood products involves strategies for promoting and distributing these products to consumers, addressing consumer preferences, trends, and sustainability concerns. Finally, the paper explores the policy aspects related to seafood, including food safety standards, and sustainability initiatives, emphasizing the importance of policy frameworks in ensuring the responsible management of seafood resources.

Keywords: seafood; preservation; nutrition; marketing

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1 Introduction

The "*2024's World Fisheries and Aquaculture Status Report*" showed that the total production of 2022's global fishery resource was increased to 223 million tons with 4.4% increase, compared with 2020 year[1]. Aquatic animal production reached 185.4 million tons, and marine algae production was 37.8 million tons. In addition, in 2021, the global aquatic animal utilization exceeded 160 million tons with the nearly double growth rate than that of 1961's global population. Moreover, in 2022, the per capita demand for aquatic food reached 20.7 kg. Seafood is an important part of aquatic food, and compared to freshwater fish, marine fish is widely accepted by consumers due to their lack of muddy taste and fewer little fish bones. The role of seafood processing industry is pivotal in driving national economic growth. In recent years, since 2018, the Blue Economy Report of 2021 revealed that approximately 4.5 million direct job opportunities have emerged within sectors linked to the marine economy in the EU. Seafood sales had generated around €650 billion in revenue, and the total value-added turnover stands was €1.76 billion.

As we all know, seafood plays an important role in promoting public health and wellness, because it is rich in proteins, omega-3 fatty acids, minerals, vitamins and other bioactive substances such as taxanthin, riboflavin, steroids and sterols[2]. Seafood is mainly available fresh or processed products (e.g., minced products, ball products, dried products, seaweed, *et al.*) (Fig. 1)[3]. While, during processing, a large amounts of processing by-products (heads, bones, skins, and viscera) are also produced[4]. Numerous studies have shown that these processing by-products are rich in nutrients. For example, fish intestines contain plenty of fish oil, especially for the abundance of omega-3 fatty acids. These fatty acids have been demonstrated as very important roles in maintaining heart and eye health, regulating mood, reducing inflammation symptoms, and offering other beneficial effects. Fish skins are rich in large-molecule collagen, which can be used to produce bio-active peptides that inhibit the formation of melanin. Shrimp shells are also a good source of chitosan, which positively enhance the body's immunity and improve cell activity. Besides, some marine sponge animals also contain sterol-like substances, which have strong inhibitory effects on the growth of cancer cells. Many research focuses on the extraction technology of bioactive, their identification and biological activity evaluation. These research greatly promote the high-quality development of modern aquatic industry. However, in the underdeveloped countries, aquatic by-products (e.g., discarded shells, heads, bones, viscera,

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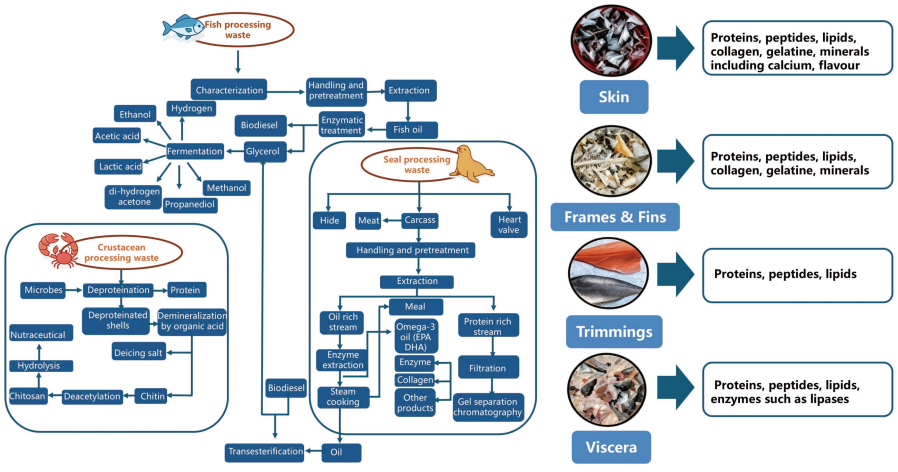


Figure 1 Solid seafood waste biorefineries and the processing byproducts of different categories of solid seafood waste[3].

fins and skins) are normally discarded or be processed into low commercial value products (fish meal, fodder), showing the lower processing rate, compared with the developed countries[5]. Therefore, it is necessary to determine effective and safe strategies to promote the high-quality development of the marine food industry in the underdeveloped countries to efficiently utilize these marine resources.

In recent years, the developments of globalization and digitalization have driven marketing innovation of marine food, e.g., online sales, direct supply platforms and traceability labels. Moreover, the sustainable fisheries and environmental protection also attract increasing attention, with governments committed to making more sustainable and feasible management policies. Thus, it is essential for us to work together to promote the innovation of processing and preservation technologies, sustainable development technology, and global cooperations to ensure we and our descendants can continue to enjoy high-quality, safety and delicious marine products.

Thus, this paper aims to present a comprehensive strategy for the conservation and sustainable utilization of marine organisms, as well as the development of novel functional foods, to better predict the development of seafood and by-products in the food industry.

2 Preservation and processing

The quality changes of most aquatic products are closely related to the actions of microorganisms and endogenous enzymes. According to the data of World Health Statistics, foodborne diseases cause approximately 600 million infections and 420,000 deaths every year[6]. Among them, the pathogenic *Vibrio*, *Listeria monocytogenes*, *Clostridium botulinum*, and histamine-producing bacteria, which are mainly found in the deteriorated fishery products and regarded as main contributors. Aquatic products are easily to be spoilage, because of its high water, nutrient, microorganisms and endogenous enzymes. Thus, preservation technology is very important.

2.1 Low temperature

Refrigerated (4 °C) and super-chilling (−3 °C) could guarantee the quality of fish fillets with low pH, total volatile base nitrogen (TVB-N), tricarboxylic acid cycle (TCA)-soluble peptides and nucleotides. However, in the daily life, common low-temperature preservation is usually achieved using refrigerators or freezers, which consume about 35%–50% of the total energy, and produce 1% CO_2 emission of the total global. In contrast, some novel cold or frozen processing preservation technologies have been successfully developed to overcome these disadvantage[7].

2.2 High-pressure processing

High-pressure processing (HPP) has been considered as a non-thermal processing technology that can inactivate spoilage bacteria and endogenous enzymes, delay food quality deterioration while retaining their nutritional and sensory characteristics. Li *et al.*[8] reported that high pressure (> 300 MPa) can deactivate the polyphenol oxidase (PPO) activity of shrimp bodies, delaying the formation of melanosis.

2.3 Irradiation preservation

Food irradiation, known as “cold pasteurization”, is a cost-effective cold processing method that could be used for food preservation. The irradiation sources for food preservation include *γ*-rays, X-rays, or electron beams. These irradiation sources can effectively break down cellular components (proteins and membranes) and kill bacteria and pathogens at sufficient energy levels, reducing biological hazards during the distribution of seafood processing and marketing, guaranteeing the seafood safety[9]. Long *et al.*[10] pointed out that a combination of 7 kGy of gamma irradiation and modified atmosphere packaging (MAP) (50% CO_2, 45% N_2, and 5% O_2)had a synergistic effect on reducing TVB-N, hardness and chewiness of shrimp, extending its shelf life by at least 6 days. Though many researchers have demonstrated that the irradiated food is safe, it still causes consumer less acceptance, especially after Japanese nuclear sewage discharged into the sea.

2.4 Cold treatment technology

The pulsed electric field (PEF) and cold plasma (CP) are new non-thermal preservation technologies that have been widely investigated for seafood preservation[11,12] (Fig. 2A), due to their low temperature and short processing time, as well as they can effectively extend the shelf life of some fresh marine foods such as fish and cephalopods[13]. Besides, the combinations of novel antibacterial agent, cryoprotectant and antioxidant also have been used to preserve the aquatic products. For example, Nikoo *et al.*[14] reported that extracted proteins and chitin hydrolysates from various fish, crustaceans and cephalopods could be used as cryoprotectants (Fig. 2B). They contain hydrophilic amino acids and polar groups can stabilize the bound water in myofibrillar

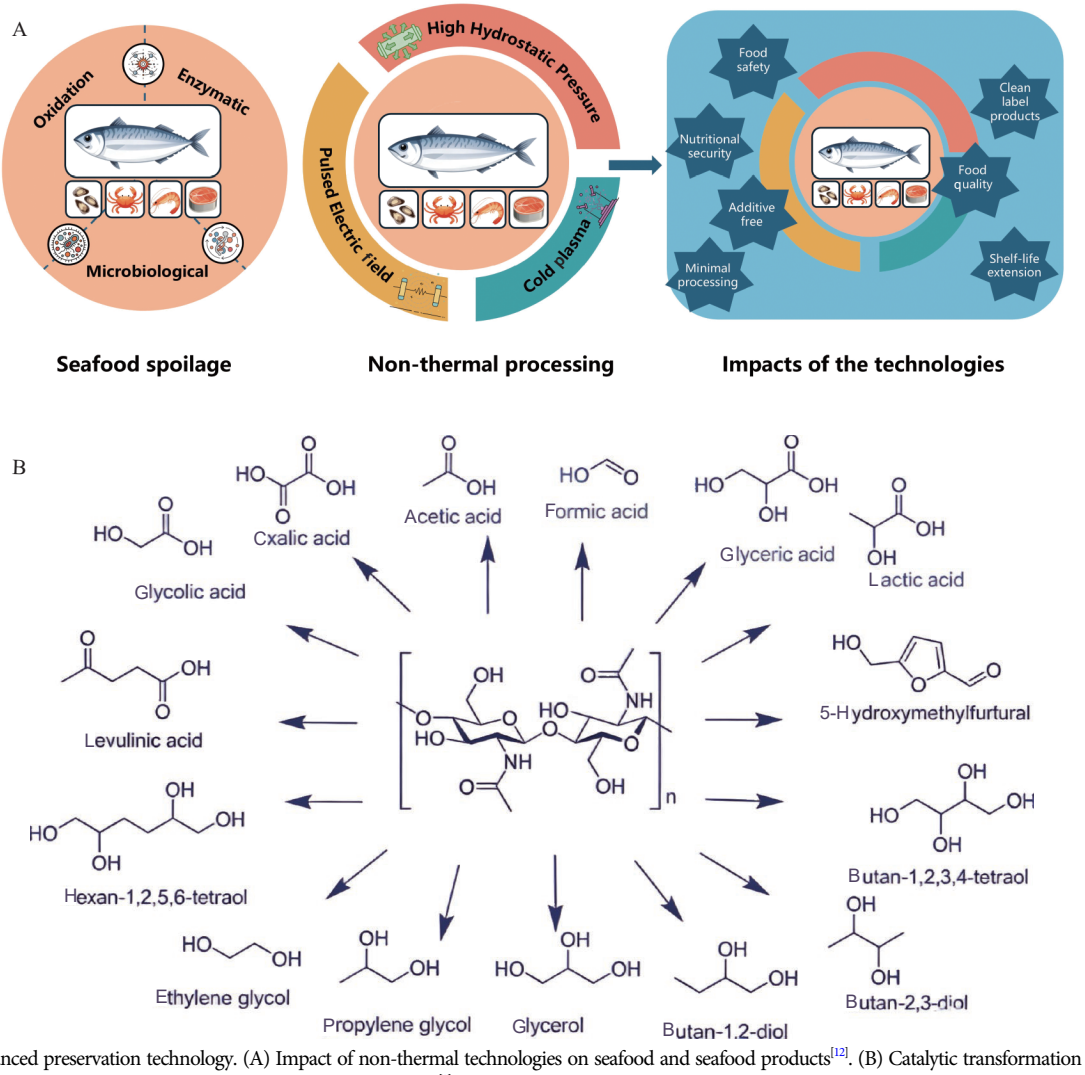


Figure 2 Advanced preservation technology. (A) Impact of non-thermal technologies on seafood and seafood products[12]. (B) Catalytic transformation of chitin and its derivatives into. alcohols, organic acids, and 5- hydroxymethylfurfural[3].

proteins, reducing structural damages of proteins during frozen storage.

There are lots of research focusing on the applications of preservation technologies of marine food to improve its processing efficiency, ensure its nutritional value and enhance the economic value. However, the seafood processing normally generates wastewater and processing by-products, causing environmental pollution, which is one of the urgent global challenges that should be further addressed. Besides, it is still necessary to develop new preservation and processing technologies to enhance seafood product quality and diversity, reducing nutrient loss, decreasing environmental pollution and improving seafood economy.

3 Nutrition

The nutrients of seafood typically consist of protein, fat, polysaccharides and minerals, and they play the crucial roles in fulfilling the human body's daily nutritional requirements. For instance, the protein and fat contents of salmon contains were approximately 20–25 and 10–20 g/100 g, respectively. The omega-3 fatty acids content of salmon is 1–2 g/100 g. Furthermore, seafood contains plenty of vitamin D, vitamin B_{12}, calcium, phosphorus and iron etc. which are also essential for human health.

3.1 Marine fish collagen

Many studies have demonstrated that marine protein exhibit high bioavailability in the human body due to their optimal proportion of essential amino acids. Marine proteins and peptides could regulate the key metabolic pathways of body, facilitating the synthesis of biological substances, and are indispensable for bodily growth and development, aiding in tissue repair and maintenance. For instance, the sardines protein could reduce the insulin resistance and tumor necrosis factor (TNF)-α levels, decreasing the risk of hyperglycemia[2]. Furthermore, numerous marine organisms have been investigated as potential sources of collagen (Fig. 3). Marine collagen could be extracted from fish, sponges and jellyfish, and they offer several advantages over bovine collagen in terms of extraction ease, water solubility and excellent physico-chemical stability. And the marine collagen and collagen based products have attracted lots of interests and showing high economical and human health benefits[15].

3.2 Essential fatty acid

Due to the presence of long-chain polyunsaturated fatty acids (PUFAs), including omega-3 fatty acids such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), lipids play a crucial role in enhancing the nutritional value of fish. Marine lipid is

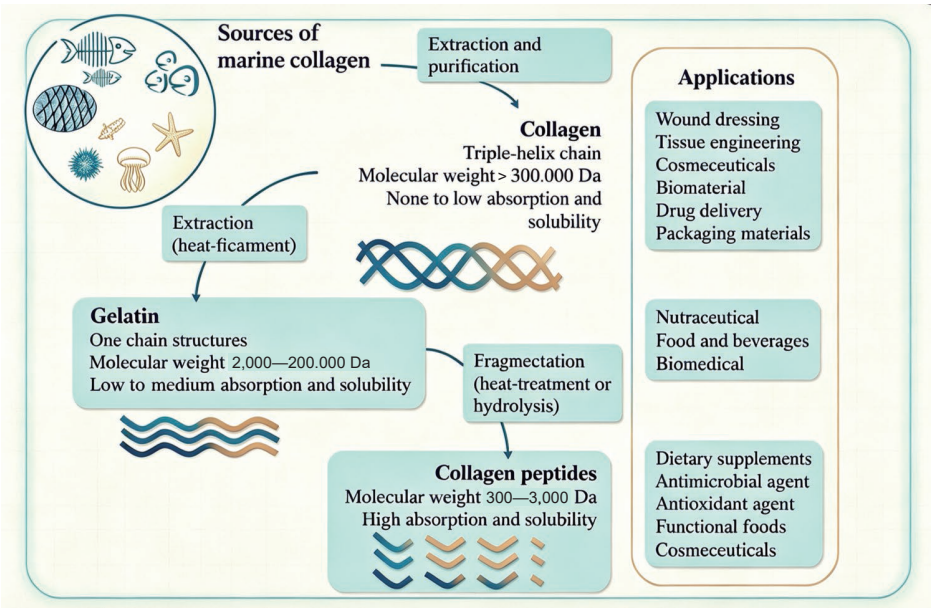


Figure 3 Structural diagram of collagen in fish by-products and its practical applications[15].

another very important substance that is beneficial to human health, especially in terms of reducing the risk of coronary heart disease and cardiovascular diseases, decreasing inflammatory diseases such as arthritis, and preventing cancer, especially for the long-chain omega-3 PUFAs[15]. Among of them, DHA is crucial for optimal development of brain and nervous system in children, as well as, it has been extensively demonstrated could prevent cardiovascular diseases, hypertension, and idiopathic oligospermia in adults. Moreover, for the aged person, it helps prevent dementia, age-related macular degeneration, Alzheimer's disease and mood disorders. EPA and DHA also have anti-inflammatory properties by influencing prostaglandin synthesis. For pregnant women, breastfeeding mothers and reproductive-age women, fatty acids also play a critical role in membrane-mediated processes such as osmoregulation, nutrient assimilation and transportation.

3.3 Marine animal polysaccharide

Marine animal polysaccharides are a class of significant bioactive compounds, including hyaluronic acid and chitosan. They can enhance drug release in the human body through specific reactions, showing high application values as nano-materials in biomedicine and biotechnology. Furthermore, marine polysaccharides also exhibit physiological functions such as anti-obesity, anti-oxidation and improvement of metabolic syndrome[16]. Normally, marine polysaccharides can ameliorate inflammatory bowel disease (IBD) by inhibiting pro-inflammatory factor activity, enhancing anti-inflammatory factor activity and regulating the expression of other cytokines. For example, Jia *et al.*[17] found that sulfated polysaccharide of pacific abalone (AGSP) could directly intervene in IBD by regulating the NF-κB signaling pathway and directly controlling the expression of IBD-associated cytokines (Fig. 4).

3.4 Sterols

Besides, research also indicated that marine animals possessed different species and contents of sterol (e.g., cholesterol, phytosterols and cyclosterol) of different species of seafood. Generally, marine animals obtain sterols primarily through dietary intake within the food chain or *via* internal synthesis. Abdul *et al.*[18] reported that focusterol has the potential to inhibit the catalytic activity of aldose reductase (RLAR) in rats and may play a role in the treatment of diabetes. They noted that incorporating focusterol into medicinal dietary supplements has positive effects on diabetes (Fig. 5). Meinita *et al.*[19] reported that extracted fucosterols from brown algae could exert the anti-inflammatory effects under lipopolysaccharide-stimulated conditions.

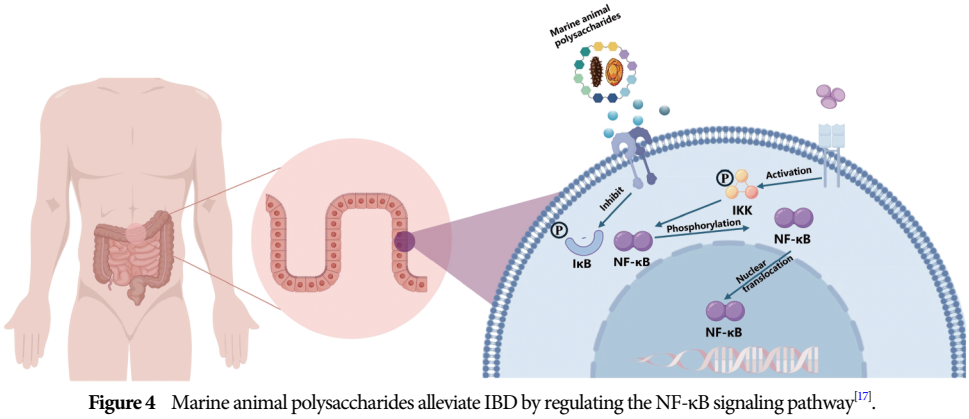


Figure 4 Marine animal polysaccharides alleviate IBD by regulating the NF-κB signaling pathway[17].

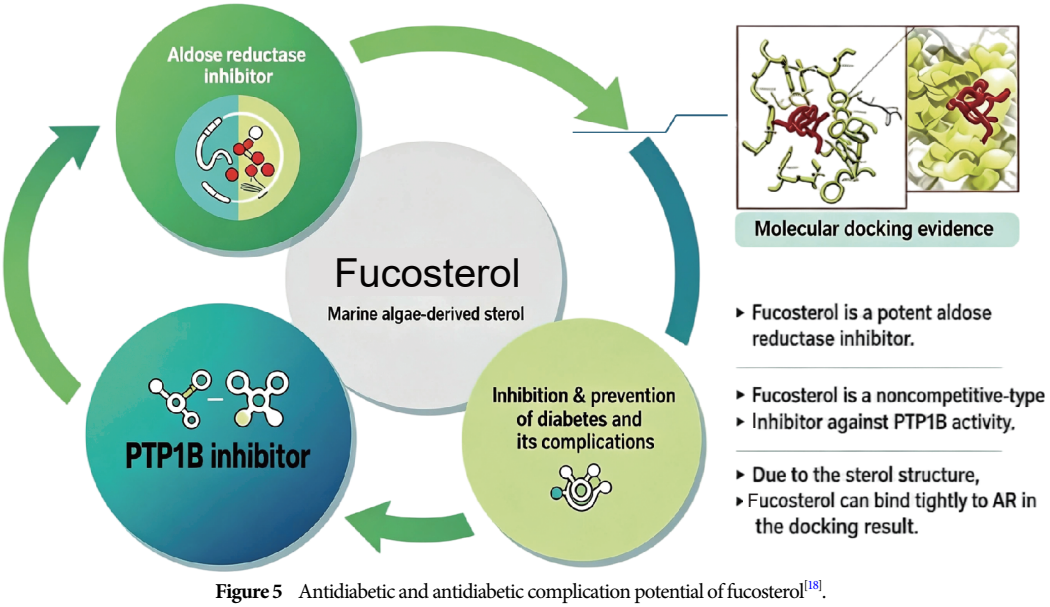


Figure 5 Antidiabetic and antidiabetic complication potential of fucosterol[18].

3.5 Other marine source active substances

Regarding the correlation between medicine and food, in marine mollusks, bivalves (oysters, scallops, mussels, and clams), cephalopods (octopus, squid, and cuttlefish), and gastropods (whelks, conchs, abalones, and snails) are important economical seafood. Many mollusk species (shells, soft tissues, bases, secretions, etc.) are used in production of medicine to treat gastrointestinal diseases, cancer, inflammation, aging, and other ailments around the world. For example, extracted lipids and amino acids from mussels are associated with anti-inflammatory properties for various ailments like hypertension, osteoarthritis (OA), skin burns, asthma, or wound healing. In terms of nutritional supplements, the recommended daily intake of chondroitin sulfate, glucosamine sulfate and hyaluronic acid is 20 mg/(kg·day), 1,200 mg/day and 50–100 mg/day, respectively. These substances can be extracted from chondrocytes in marine organisms and their combination has high curative effect for treating OA and alleviating joint pain, and they have been widely used as dietary supplements. Squalene is another well-known active substance, which could be extracted from the livers of deep-sea sharks, with an average of 2,300–8,400 mg of squalene per 100 g of shark liver oil. Squalene has been widely used as a dietary supplement in soft gel capsules and helps balance hormone levels by participating in the production of steroid hormones, aiding in the improvement of premenstrual syndrome, menopausal issues, and even fertility[20].

However, there are numerous toxic substances present in marine organisms, such as methylmercury, polychlorinated biphenyls, dioxins, organochlorine pesticides, and other environmental pollutants, which cause health risk to consumers. For example, mercury is mainly present in the form of methylmercury, which is considered as neurotoxic, and even low levels of mercury exposure over the long term can lead to cardiovascular, reproductive, developmental, neurological, renal, immune toxicity, and carcinogenic effects. Thus, it is necessary to develop rapid and convenient detection technologies to monitor above safety factors of seafood, guaranteeing consumers' safety.

4 Marketing

In general, the circulation of seafood primarily consists of fresh and processing products (dry, salted, smoked, cured, canned, *et al.*). With the continuous development and application of cold chain logistics technology, the freshness of seafood has been better guaranteed. Fresh sales are crucial for high-end catering and seafood restaurants, particularly for premium varieties such as shark fin and sea cucumber, meeting consumers' dual pursuit of quality and appearance. Processing seafood is also favored by many consumers for its unique flavor and nutritional value. For instance, in 2020, the United States imported 2,760,859 metric tons of canned seafood products along with 9,850 metric tons of smoked products and 27,194 metric tons of cured products, making significant contributions to the market demand of seafood imports from countries including Asia (58%) in the international market[21].

In recent years, thanks to the advancements of processing technology, the utilization ratio of seafood processing by-products is growing. Fish oil and peptide products attract consumers' interests, and these products have different applications. For example, for the fish oil products, they have soft gels, liquid formulations, or additives to other products. Furthermore, sustainable biotechnologies have emerged as cost-effective solutions that contribute to establishing a circular bioeconomy by recovering bioactive substances from seafood waste using microorganisms and enzymes. Peptide, fish protein hydrolysate (FPH), which is derived through enzymatic or chemical processes from processed fish or fish by-product, showing high antioxidant, anticancer, antibacterial and antihypertensive properties[22]. For example, ACE inhibitory peptides have antihypertensive activity, and it has become a primary method for converting fish by-product into valuable pharmaceutical and food industry products[23]. Though we can find lots of processed marine or marine based products, novel technologies are still required to develop new high quality value-added healthy products.

5 Policy

In the past decade, policymakers, economists, politicians, environmentalists, and scholars have closely focused on the concept of a circular economy, aiming for long-term sustainability and catalytic transformation of seafood waste and its derivatives, presenting an effective pathway towards carbon neutrality. In

recent years, new processing technologies have been emerged, which mainly focus on the microbial fermentation and enzymatic hydrolysis to improve the seafood market values by producing high quality products, reducing energy requirements and environment pollution, improving the production and processing efficiency. In 2022, due to the increased initiatives and legislation, the bio-economy accounted for 9% of the entire economy in terms of employment and income.

The chemical catalytic transformation of seafood processing waste can significantly increase its market value, providing an effective approach to tapping into resource potential and converting waste into valuable materials. Chitins and proteins, for example, can be chemically or biologically separated from shellfish waste (Fig. 6). These approaches could not only increase their bioavailability, but also address a key global challenge: the conversion of seafood waste to sustainable chemicals[4].

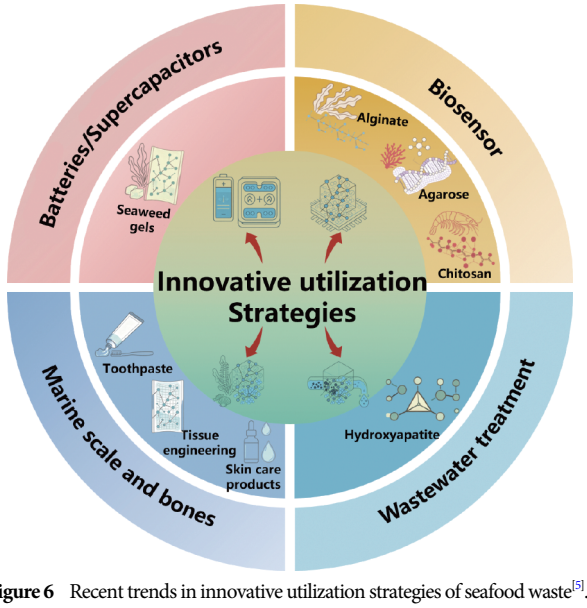


Figure 6 Recent trends in innovative utilization strategies of seafood waste[5].

Nevertheless, the Japanese government still needs to devote themselves to clearly solve the impact of nuclear radiation on the safety of world marine food. After the Fukushima nuclear accident in 2011, the marine ecosystem suffered severe contamination, and marine food was also subjected to varying degrees of radiation pollution. On August 24, 2023, the Japanese government officially decided to discharge radioactive contaminated water into the ocean, triggering global concerns and controversies. Until now, the lack of transparency and information disclosure by the Japanese government on this issue has sparked controversy, caused mountains of concerns and worries about the safety of marine food. This is because that the discharge of nuclear wastewater could have long-term negative effects on the safety of marine food, because it could enter the every corner of the world. Radioactive substances and toxic chemicals may be absorbed by marine organisms and finally enter the food chain, ultimately it could significantly affect human health through intake of the polluted marine food, water and other polluted food resource. Moreover, this action shows a long-term threat to the sustainable utilization of marine resources, health and integrity of marine ecosystems, threatening the sustainability of marine resources. This unilateral action, conducted at the expense of the interests of neighboring countries and the international community, imposes serious harm to shared international values. If Japan continues to discharge hazardous substances into the ocean, it will seriously undermine the common values of the international community[24].

In conclusion, marine food policies have become increasingly important with the increase of global population and food safety issues. The development of marine food policies should require consideration of the sustainable utilization and protection of marine resources, ensuring availability of sufficient food resources for human use from the ocean and preserve the integrity of marine ecosystems. In order to achieve this goal, many countries and international organizations have formulated a series of marine food policies. For example the European Commission encourages each country to develop a multi-year national plan detailing its aquaculture development strategy to focus on the sustainability of marine source[25]. However, the utilization and protection of marine resources are still one of the biggest global challenges, requiring international cooperation and coordination. In the future, close international collaboration should be performed to promote the transboundary management and protection of marine resources, contributes to ensure the sustainable utilization and distribution of marine food resources.

6 Conclusion

In conclusion, as technological advancements progress and our understanding of marine-derived foods deepens, contributing to increase these products market. Nevertheless, regulatory constraints necessitate that newly discovered marine-based functional foods undergo rigorous clinical trials to validate their efficacy and safety before being introduced to consumers. Ethical and moral considerations often limit the acceptance of certain experimental outcomes, rendering the process both resource-intensive and challenging. Despite these hurdles, the vast potential of marine by-products presents numerous opportunities for the future growth of the food industry.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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