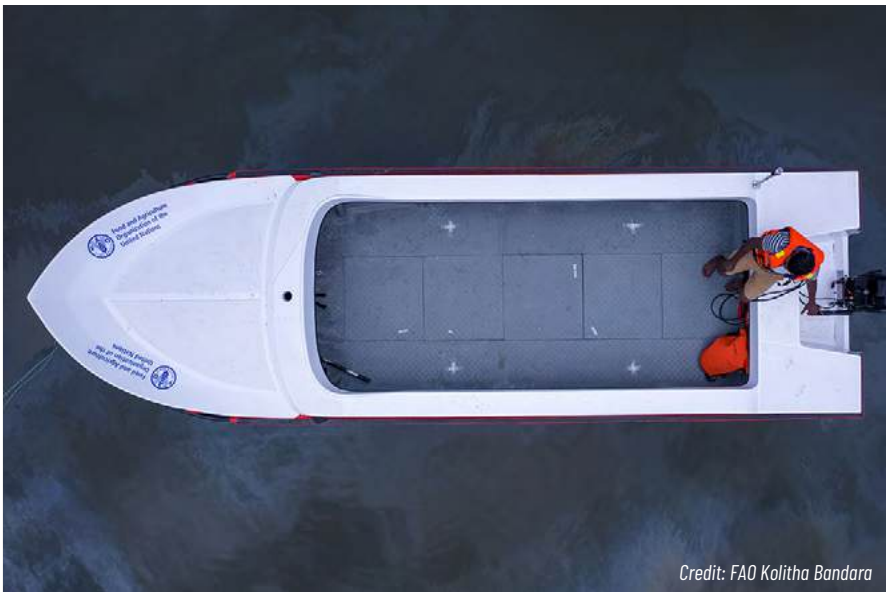
INNOVATIONS ALONG THE SEAFOOD TRADE AND VALUE CHAINS: THE WAY FORWARD

By Sujit Krishna Das

Aquatic products will continue to be highly traded, boosted by increased global consumption and production, improved storage, preservation, transportation and liberalisation of policies. Such trends have facilitated the emergence of complex supply chains in which fish and fish products often cross several national boundaries before final consumption. Innovations along the seafood trade and value chains can leverage market access, while value-addition and diversification of markets and products can help countries to remain resilient during adverse situations. Partnerships and investments are necessary to develop required infrastructures. Meanwhile, appropriate policies to modernise the seafood supply and value chains (farm to fork and boat to table) at the country level; and embracing eco-friendly approaches and introduction of technologies will ensure the sustainability of the sector. Economic returns will be improved, aquatic value chains will be strengthened; and transparency and responsibility will be maximised; along with reduced food loss and waste and enhanced food safety.



FAO-designed climate-resilient boat, Sri Lanka

Global fisheries and aquaculture production attained an all-time record high of 185 million tonnes in 2022, of which 94 million tonnes were from aquaculture (51 percent) and 91 million tonnes from capture fisheries (49 percent). The total farmgate sale value was estimated as USD 452 billion, USD 296 of which was from aquaculture, with Asia contributing significantly (70%).[1]

Meanwhile, the 36th session of the FAO Committee on Fisheries (COFI) which was held this past July, underscored the importance of sustainable fisheries and aquaculture in meeting current and future food security and sustainable growth needs, while achieving sustainable and resilient agrifood systems. COFI36 also welcomed global initiatives to promote sustainable aquatic foods from marine and inland waters, including by addressing food loss and waste. The Session strongly supported Blue Transformation as a Programme Priority Area and adopted the Guidelines for Sustainable Aquaculture (GSA), while requesting for FAO's technical assistance and support for their implementation.[2]

Aquatic foods with their low environmental footprint, great diversity and capacity to supply critical nutrients to sustain healthy diets are one of the seven priorities for ending hunger (Von Braun *et al.*, 2021).[3] In 2021, FAO launched Blue Transformation vision (FAO, 2022),[4] considering three core components: aquaculture, fisheries, and value chains. It also emphasised sustainable fisheries management, increased and responsible aquaculture production, reduced food waste; and enhanced marine habitat protection and circularity along the seafood value chains to maximise the opportunities offered by aquatic food systems with a view to enhance food security, improve nutrition, eradicate poverty and support the achievement of the 2023 Agenda for Sustainable Development.

Global seafood trade outlook[5]

The bulk of fisheries and aquaculture production is used for human consumption and this share is projected to remain broadly stable, reaching 90% by 2033. Overall, the fish available for human consumption is projected to increase by 21 million tonnes (live weight equivalent) by 2033, reaching 186 million tonnes.

Global fish production, encompassing both capture fisheries and aquaculture, is anticipated to rise from 185 million tonnes during the base period to 206 million tonnes by 2033. Global fish production is expected to expand by 12% (or 22 million tonnes) over the next decade compared with 21% (or 32 million tonnes) during the previous decade. Aquaculture will drive the deceleration of growth, while still maintaining its role as the primary force for the overall expansion of global fish production. By 2033, aquaculture is expected to account for 55% of global fish production, compared with a share of 51% during the base period.

[1] *1.a, 1.b & 1.c. FAO. 2022. In Brief to The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. Rome, FAO. https://doi.org/10.4060/cc0463en*
[2] *FAO. 2024. The State of World Fisheries and Aquaculture 2024 – Blue Transformation in action. Rome. https://doi.org/10.4060/cd0683en*
[3] *Von Braun, J., Afsana, K., Fresco, Louise O. & Hassan, M. 2021. Food systems: seven priorities to end hunger and protect the planet. Nature, 597: 28–30. https://doi.org/10.1038/d41586-021-02331-x*
[4] *FAO. 2022. Blue Transformation – Roadmap 2022–2030: A vision for FAO's work on aquatic food systems. Rome. https://doi.org/10.4060/cc0459en*
[5] *OECD-FAO Agricultural Outlook 2024-2033OECD/FAO (2024), OECD-FAO Agricultural Outlook 2024-2033, OECD Publishing, Paris/FAO, Rome. https://doi.org/10.1787/4c5d2cfb-en.*

Aquatic products will continue to be highly traded, boosted by increased consumption, improved storage, preservation, transportation and liberalisation policies. Such trends have facilitated the emergence of complex supply chains in which fish and fish products often cross several national boundaries before final consumption. About 35% of total fisheries and aquaculture production is expected to enter international trade (31% excluding intra-EU trade) in the form of products for human consumption or for non-food purposes by 2033. A share of this trade consists of repeated trading of products in different processing stages among countries and regions. World exports of fish for human consumption are projected to total 45 million tonnes live weight by 2033, up 4.0% (or 1.7 million tonnes) on the base period.

Trends in utilisation and processing of seafood products

Of the 185.4 million tonnes (live weight equivalent) of aquatic animals harvested globally in 2022, about 89 percent (164.6 million tonnes) was used for direct human consumption. The remaining 11 percent (20.8 million tonnes) was destined for non-food purposes, of which about 83 percent (17 million tonnes) was reduced to fishmeal and fish oil, while the rest (about four million tonnes) was largely utilised as ornamental fish, in aquaculture (e.g. as fry, fingerlings or small adults for on-growing), as bait, in pharmaceutical applications, for pet food, or as raw material for direct feeding in aquaculture and for the raising of livestock and fur animals.

In 2022, of the 165 million tonnes destined for human consumption, live, fresh or chilled accounted for about 43%. This continues to represent the preferred and most high-priced form of aquatic food products, followed by frozen (35%), prepared and preserved (12%) and cured (10%). Freezing is the main method of preserving aquatic foods, accounting for 62% of the 93 million tonnes of processed aquatic animal production for human consumption (i.e. excluding live, fresh or chilled). Significant differences exist in the utilisation and processing methods across continents, regions and countries, and even within countries. Preservation and processing may vary due to differences between species related to their characteristics, composition, size and shape. Aquatic species can be prepared using a wide range of methods, from manual to fully-automated. An industrialised fishery often has different processing requirements from a small-scale artisanal fishery. Products can be packaged and commercialised in a wide variety of ways depending on the location, scale of operation, country's infrastructure and market demand.

FAO Trade Policy Briefs. No. 52, Lem *et al.,* 2023[6], provided three key messages: i) aquatic products are among the most widely-traded food items worldwide; (ii) trade of aquatic products significantly contributes to economic growth in the developing countries; and (iii) small-scale fisheries (SSF) have a big contribution to the national economy.

The Policy Brief also suggested actions to address these key challenges:

- Diversify markets, including evaluating opportunities in neighbouring countries, to mitigate the adverse effects of eventual shocks and disruptions that affect trade.
- Increase awareness about the nutritional and macronutrient benefits of aquatic products as an affordable and easily accessible animal protein.
- Implement knowledge-sharing actions to facilitate the market access of the small-scale fisheries sector (SSF) to international markets.

This article discusses the key innovations and technological developments along the seafood trade and value chains to leverage market access and diversify markets and products. It also provides policy recommendations to develop necessary infrastructures; and reform policies prioritising small scale fisheries and action plans to ensure the sustainability of this sector. Thus, the trade and economic returns from the sector will be improved, aquatic value chains will be strengthened, transparency and responsibility will be maximised, and socio-environmental impacts will be minimised through reduced food loss and waste as well as enhanced food safety.

Importance of innovations along the seafood trade and value chains

Innovations might bring quite a few advantages for the fisheries and aquaculture sectors:

- Ensure more Public-Private Partnerships (PPPs) to attract investments and drive technological developments;
- Build awareness on the nutritional and macronutrient benefits of fishery products, and increase access to affordable and accessible animal protein;
- Improve access to markets and sustainable fish trade;
- Improve end-to-end cool chain management and distribution systems;
- Promote compliance, traceability and seafood safety issues;
- Reduce Food Loss and Waste (FLW) along the seafood value chains while promoting a circular economy; and
- Encourage considerations on environmental, social and aquatic animal welfare issues.

Interventions along the seafood trade and value chains also help to:

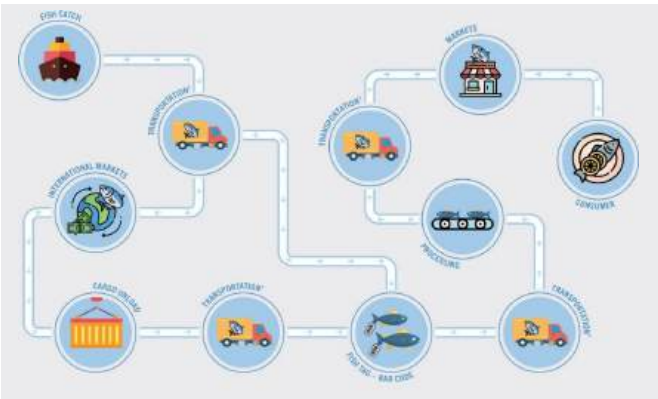
- Boost production through integration of different trophic levels;
- Generate employment and improve livelihoods;
- Bridge the gaps between standard-setting, trade and technology;
- Reduce competition among land, water and energy use while promoting energy-efficient and alternative use of resources;

[6] *Lem, A., Castro de Souza, M. & Griffin, W. 2023. The importance of international trade for fisheries and aquaculture products. Trade policy briefs, No. 52. Rome, FAO. https://doi.org/10.4060/cc9061en https://www.fao.org/documents/card/en/c/cc9061en*

- Lessen the burden of water, spaces and labour utilisation;
- Develop a competitive, transparent and integrated value chain; and
- Address social and environmental issues including climate change, fish and crustacean welfare etc.

According to FAO, the value chain is the full range of activities that are required to bring a product or service from its conception to the final consumers. Value chains (Figure 1) include local, regional and global markets. Key activities in an aquaculture value chain can include design, production, processing, transport, wholesale, retail marketing and consumers.

Figure 1: Typical framework for fisheries and aquaculture value chains



Credit: FAO

Over time, FAO has taken several initiatives to minimise the gaps between trade and technological development while maximising the standard-setting and traceability. FAO, 2016[7]; Blaha, Vincent and Piedrahita, 2023[8] identified the major gaps and inconsistencies in traceability specific to aquatic foods, as follows: standard gap, awareness gap, commitment gap, implementation gap, technology gap and economic gap. Meanwhile, FAO conducted online and regional consultations (FAO, 2022)[9] to finalise the development of a guidance document (Blaha, Vincent and Piedrahita, 2023) on end-to-end traceability in capture fisheries and aquaculture to address these gaps. Furthermore, to offer solutions to address these standard-setting and technology gaps in fisheries, FAO is leading a pilot initiative to develop the Global Record of Stocks and Fisheries (GRSF). FISH4ACP is another FAO initiative that unlocks the potential of sustainable fisheries and aquaculture in Africa, Caribbean and the Pacific.

The following ways (a-j) should be explored along the seafood value chains to improve trade and economic returns; gain better market access; strengthen traceability and standard-setting; and build awareness among the key stakeholders.

[7] *FAO. 2016. Data needs for blue growth. In: The State of World Fisheries and Aquaculture 2016 – Contributing to food security and nutrition for all, pp. 108– 113. Rome.* https://www.fao.org/3/i5555e/i5555e.pdf

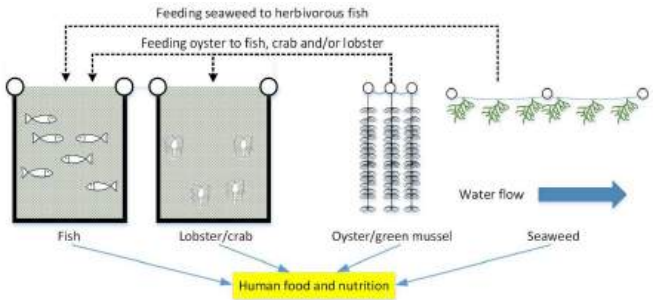
[8] *Blaha, F., Vincent, A. & Piedrahita, Y. 2023. Guidance document: Advancing end-to-end traceability – Critical tracking events and key data elements along capture fisheries and aquaculture value chains. Rome, FAO.* https://doi.org/10.4060/cc5484en

[9] *FAO. 2022d. Report of the regional consultations on advancing end-to-end traceability in fish value chains – Virtual meetings, September 2021 to January 2022. FAO Fisheries and Aquaculture Report, No. 1378. Rome.* https://doi.org/10.4060/cc0307en

a) Nature-based, combined and integrated production systems

The combination and integration of different trophic levels such as Low Trophic Aquaculture and Integrated Multi Trophic Aquaculture (Figure 2); species (fish, shellfish and seaweed, etc.) or nature-based solutions; the introduction of land-water-energy efficient farming techniques (combined recirculating aquaculture systems and biofloc, offshore farming and aquaponics, etc.); and utilisation of solar power and locally-available resources (aquasilviculture, permaculture, etc.) might contribute to production which is not harmful to nature. Nature-based farming of aquatic animals not only provides value through ecosystem benefits such as carbon sequestration and nutrient absorption; but it also adds value to the total aquaculture production. At the same time, development of climate-resilient and disease-resistant seeds; and alternative sources of animal protein and group certification will strengthen the sustainability of the aquatic producing and growing systems.

Figure 2: Example of Integrated Multi Trophic Aquaculture (IMTA)



Credit: Philip Gu and Dao Huy Giap, 2023

Innovative concepts like aquasilviculture, pescatourism and aquavillages, marine parks, fish museums or cultural centres not only generate income for the fishing community but also promote their cultural heritage. Excursions to aquavillages, for example, help visitors to explore local delicacies, culinary dishes and take up accommodation offered by the fishing community, all of which will contribute towards the income and livelihoods of small communities.

b) Smarter supply chain management using blockchain

With the help of blockchain technology, customers can source seafood products, and trace and track their origin. It ensures that supply chains of aquatic food systems are more traceable and responsible.

Figure 3: Application of blockchain

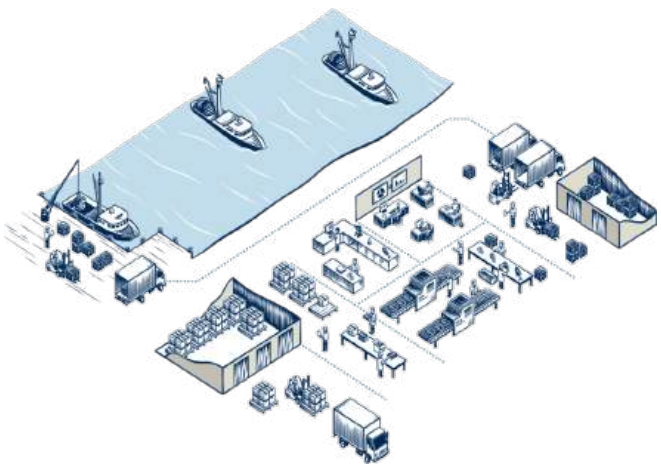
Credit: Wholechain, USA

Blockchain companies are developing new ways for smarter and sustainable supply chain management combining blockchain (Figure 3) with RFID (Radio Frequency Identification), NFC (Near Field Contact) sensors, and QR codes. [10]

c) Responsible value chain management using AI and ML

There are some good examples of the application of Artificial Intelligence (AI) and Machine Learning (ML) along seafood value chains to ensure transparency and accountability. These include technology for species identification (e.g. FishFace); quality inspection of tuna (e.g. TunaScope); electronic monitoring of fishing activity (e.g. SnapIT) in fisheries; counting sea lice and monitoring salmon growth (e.g. AquaByte); counting shrimp PL and predicting growth (e.g. XpertSea); and improving farm management and productivity (e.g. Aquaconnect).

Figure 4: Digital workflows in the seafood industry



Credit: ThisFish, Canada

In 2020, Eric Enno Tamm, CEO, ThisFish[11], highlighted some of the practical insights regarding application of AI and ML in the seafood industry which are useful till today:

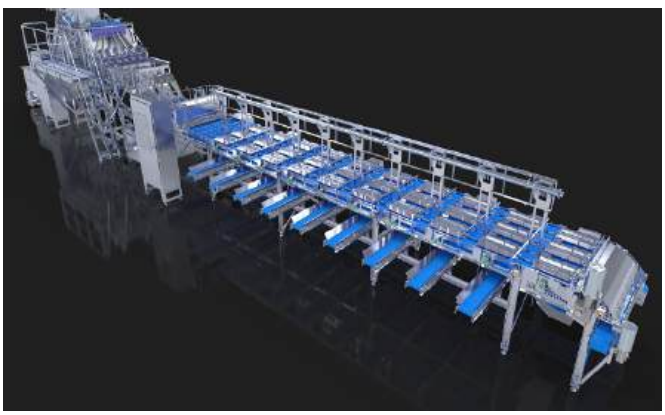
- Most companies recognise that digitisation is inevitable (Figure 4), but some are slow to change. As AI is about extracting more value from existing data, it could help drive digitisation in the seafood industry by boosting the return on investment;
- Seafood has more natural variability than most food commodities. Species, fish size, seasonality, sexual maturity, catch method and storage time: all these factors affect quality and yields. As a result, it is often hard to accurately predict production and quality outcomes. That is a perfect problem for machine learning, whose core strength is its ability to take an incomprehensible number of variables to accurately make predictions; and
- For AI to work, you need clean, comprehensive and complete data. False or inaccurate data will undermine AI's ability to make good predictions. AI motivates companies to ensure that their suppliers are sending them accurate data, thus improving supply chain traceability. Technologies such as blockchain don't solve the "garbage-in, garbage-out" data dilemma. AI does.

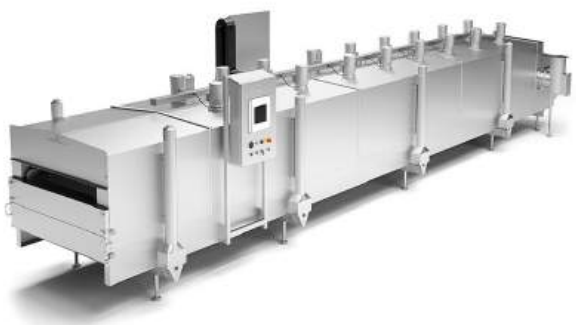
Also important to mention is elemental profiling technology, which helps importers, customs officials, retailers, and others trace globally-traded seafood back to its source, which can shed light on production practices with critical environmental and social implications. Elemental profiling is the process of analysing a set of the elements that make up a material or species.[12]

d) Disruptive equipment and supplies for handling and processing

Handling and processing of seafood products is multifaceted and diversified. The equipment and supplies (examples in Figure 5) used to process products depend on the following considerations: (i) types of species; (ii) variety of products; (iii) targeted market; (iv) production volume; (v) manpower and time; (vi) access to finance; (vii) willingness to adopt change; and (viii) customer demand. Furthermore, there are also variations along the key handling and processing steps, such as farm to processing plant; and processing plant to consumers.

Figure 5: (top) SMART Shrimp Grader, Laithram Machinery USA; (bottom) Cryogenic Tunnel Freezer, Air Products, USA





[10] https://supplychaindigital.com/technology/combining-blockchain-nfcrfid-technologies-smarter-supply-chains

[11] *How is Artificial Intelligence going to disrupt the seafood industry? Eric Enno Tamm, 2020. Post in LinkedIn.* https://www.linkedin.com/pulse/how-artificial-intelligence-going-disrupt-seafood-industry-tamm?utm_source=share&utm_medium=member_android&utm_campaign=share_via

[12] *Li et al. 2017. Assessment of elemental profiling for distinguishing geographic origin of aquacultured shrimp from India, Thailand and Vietnam. Food Control Volume 80, October 2017, Pages 162-169.*https://www.sciencedirect.com/science/article/abs/pii/S0956713517302402

e) Value-addition, market diversification and market access

Value-addition and product diversification are two sides of the same coin, and we must diversify our exports by the addition of newer species through aquaculture. There is an increasing need for safe and healthy seafood products with high sensory quality (Gonçalves, 2011)[13]. However, the taste, texture and flavour of seafood; and the attitude, beliefs, behaviour and traditions of consumers are also important to penetrate a new market. Dependency on certain markets does not benefit the economy in the long term, as was demonstrated during the COVID-19 pandemic period. Hence, improving domestic markets; and enabling market access and diversification of markets are the key for sustainable seafood business.

Access to developed markets requires product certification by national regulatory agencies. It is worth thinking about a small-producer aquaculture standard in the form of a national certification standard which could be similar to, but less rigorous than, VietG.A.P. [14]

Figure 6. Value-added shrimp products available in ASEAN countries as per consumer demand

f) Biodegradable and sustainable packaging

Consumers are increasingly aware of the negative impacts of plastic pollution, giving room for growth of bioplastic packaging made from seaweeds and other ocean materials. Nowadays, entrepreneurs prefer responsibly-sourced packaging materials with the ability to provide traceability information on the label (e.g. a QR code).

Innovations are necessary to improve seafood product packaging and labelling (Figure 7). Generally, seafood packaging is done to: (i) prevent moisture leakage; (ii) preserve quality and safety; and (iii) provide traceability information. Over time, the concept of biodegradable and sustainable packaging has gained wider acceptance. Different startup companies are now developing biodegradable packaging made from seaweed and other ocean-sourced materials. These types of packaging are not only useful for nature and people, but also promote the circular economy.

Figure 7. Examples of improved shrimp packaging

g) Ensuring food safety and public health

A multitude of hazards (biological, chemical, and environmental) can be introduced into aquaculture throughout the production and supply chain. They can also originate from unsuitable farming practices, environmental pollution, and the socio-cultural practices prevailing in various regions. Ensuring safe, secure, affordable, and quality food for all in a global context is pragmatically difficult. In this context, it is quite imperative to understand the ecology and dynamics of these hazards throughout the entire production chain in a One Health approach.[15] Considering public health needs, it is urgent to ensure food safety at the national level while linking it directly to food and nutritional security as well.

Due to increasing seafood demand, the occurrence of food fraud is also rising. To prevent this malpractice, equipment such as the Micro-X-ray fluorescence (ITRAX) appears to be a useful tool.[16]

[13] *Gonçalves, A.A 2011. Value-added Products from Aquaculture: A Global Trend. Article in World Aquaculture . January 2011. WORLD AQUACULTURE 43:4 pp 48-52,67. https://www.researchgate.net/publication/267509864*

[14] *Melissa, M. and Ann, W., 2014. Is certification a viable option for small producer fish farmers in the global south? Insights from Vietnam, Marine Policy Volume 50, Part A, December 2014, Pages 197-206. https://doi.org/10.1016/j.marpol.2014.06.010*

[15] *Jess Vergis, Deepak B. Rawool, Satya Veer Singh Malik and Sukhadeo B. Barbuddhe. 2021. Food safety in fisheries: Application of One Health approach. Indian J Med Res 153, March 2021, pp 348-357 DOI: 10.4103/ijmr.IJMR_573_21*

[16] *Patrcia. S.G, Karthik, G., Jesmond, Samut., Neil, S., Jagoda, C., Debashish, M., 2018. Itrax micro X-ray fluorescence (μXRF) for soft biological tissues. Methods X, Volume 5, p1267-1271 . https://methods-x.com/article/S2215-0161(18)30157-2/fulltext*

h) Consumer awareness and demand-oriented marketing

Entrepreneurs and startup companies can enhance consumer awareness by disseminating information on the health benefits of regular consumption of seafood through social media like Facebook, TikTok, X, Instagram and LinkedIn etc. Social media plays a vital role in reaching a huge customer base within a short time. On the other hand, the application of various mobile apps by food delivery service providers (Grab, Food Panda, etc.) added a new avenue for SMEs in e-commerce; this is one of the best examples of demand-oriented marketing in the seafood sector.

i) Minimise food loss and waste and maximise socio-environmental benefits

Utilisation of seafood by-products and co-products {fish scales, fish maws, fish skins, crustacean shells, fish meal and fish oil, fish protein hydrolysate (FPH), pituitary glands, collagen, gelatin, chitosan, pet food, biofertilizer, handicrafts made from fish scales and mollusc shells, etc.} also offers significant social and environmental benefits along with the economic value. By utilising these fishery by-products and co-products, the seafood industry can directly contribute to SDGs by reducing environmental hazards and increasing economic benefits through circular economy.

j) The following policies are being highlighted below to ensure inclusive and sustainable development along the seafood trade and value chains:

Clearly, to improve seafood trade and value chains, countries need to adopt industry-oriented, stakeholder-focused and inclusive policies at national, regional and international levels. The following policies are highlighted below for developing an inclusive and sustainable seafood sector.

j.1.) At national level (producers, suppliers, traders and consumers)

- Promote 'cluster-based farming' among small-scale producers to reduce competition for water, space and energy, and to grow shared responsibility;
- Improve end-to-end cool chain management by enabling sufficient and affordable handling, transport, preservation facilities to ensure farm-to-fork distribution;
- Harness innovative technologies (such as IoTs, AI, Machine Learning and blockchain etc) to improve transparency and responsibility along the seafood value chains;
- Introduce improved processing and freezing techniques; and alternative packaging to ensure quality and safety of the seafood products; and
- Create widespread awareness that it is essential to grow an adequate amount of responsible seafood rather than produce a huge amount of seafood by following an unsustainable approach.

j.2.) At regional and international level (competent authorities)

- Regional and international coordination and collaboration are required to ease market access and trade barriers;
- Public-Private-Partnerships are required for consistent funding in the research and development of new technologies and innovative approaches;
- Capacity-building programs through training and piloting appropriate technologies are required to transfer cost-effective innovations in the small-scale sector;
- Benchmarking and governance are needed for the sustainability of the fisheries and aquaculture-related technologies; and
- There should be a common platform to update and share the relevant information among the key stakeholders.

Conclusion

Necessity is the mother of all inventions and demand drives innovation. Investments and partnerships are the key drivers in the development and replication of cost-effective and appropriate technologies. Adoption of inclusive policies, strengthening awareness on the nutritional and macronutrient benefits of aquatic foods; as well as improved market access will ensure a sustainable fish trade. Meanwhile, the utilisation of smarter supply chains and ensuring responsible value chains will safeguard the sustainability of the seafood sector.

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