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Food Safety Strategies for Indian Fisheries Sector

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Preface

Fish is known to be an important nutritious and affordable source of protein, essential omega-3 fatty acids, and bioavailable micronutrients. Being one of the highly perishable food commodities, maintenance of safety and quality standards across the fish value chain assumes great significance. Food safety and quality may be potentially and irreversibly compromised in the aquatic value chain by bacterial contamination during poor handling processes or by improper storage and transportation conditions which might impair the safety, quality, and/or nutritional value of the downstream final product. At the consumer level, improper food preparation and traditional dishes prepared at low temperatures increase the risk of unsafe food. These factors along the value chain underpin the importance of implementing safety and quality assurance systems at the primary production stage during capture and harvest, and until the produce reaches the processing, retail, or trade level. The Food Safety and Standards Authority of India has notified the vertical standards for fish and fishery products which is a very important step regarding the safety and quality of products in the domestic market.

The fish and fish products form about 17% of India's agricultural exports. During 2022-23, India exported 1.73 million tonnes of marine products with a value of US$ 8.09 billion. Implementation of Hazard Analysis and Critical Control Point (HACCP) in the late 90's followed by a more comprehensive Food Safety Management Systems-Based certification (FSMSC) has completely restructured the seafood value chain in the country making the Indian Seafood Industry as one of the leading suppliers of quality seafood to over 100 countries across the globe.

Even though aquatic food has many health benefits, it is also linked to the increasing number of foodborne outbreaks around the globe. Aquatic food safety encompasses issues of global importance covering hazards of different origins. The potential food safety hazards can be of anthropogenic origin or natural. Frequent outbreaks have been reported due to hazards like different human pathogenic bacteria such as *Salmonella*, *Vibrio parahaemolyticus*, *E. coli* and *Listeria monocytogenes,* etc. which enter the food at any point during production, distribution, and preparation. Apart from these, chemical hazards due to residues of antibiotics, pesticides, heavy metals, etc. can also pose food safety issues. Also, the presence of pathogens, viruses, parasites, fish and shellfish poisonings, histamine, allergens, and microplastics have been recognized as major potential human health hazards due to aquatic food consumption. There are issues like the use of adulterants like formaldehyde and ammonia, unapproved additives, authenticity of the seafood, and emerging pathogens from the environment. Irrespective of stringent food safety regulations imposed by importing countries, there are frequent cases of rejection of aquatic food products due to the presence of pathogens, filth, residues of veterinary drugs, heavy metals, and histamine. Another major food safety issue over the past few decades has been the lack of intersectoral collaboration within the food production, processing, and supply chain. Therefore, it is imperative to have an interdisciplinary collaboration between different sectors either directly or indirectly involved in the aquatic food supply chain to ensure maximum food safety.

Safe aquatic food is a primary requirement of human health which is directly and indirectly linked to achieving many of the SDGs, especially those related to ending hunger & poverty and promoting good health & well-being. The WHO, FAO, UNEP, and WOAH have jointly considered food safety as part of their One Health Plan. There is a requirement for strong surveillance programmes and monitoring mechanisms to attribute the hazards concerning fish and fishery products. Strong interventions at the policy level to tackle the issues associated with seafood of capture and aquaculture origin will contribute to the improvement of the sector. Therefore, a fresh National approach to strengthening aquatic food safety systems is required to improve aquatic food safety. Against this background, the Brainstorming Session organized by the National Academy of Agricultural Sciences (NAAS) with Dr. G. Jeyasekaran as the Convenor is very timely. I am glad to note that most of the organizations involved in aquatic food safety participated in this Brainstorming Session. I would like to thank the Convenor, Dr. Jeyasekaran, and Editors Dr. V.K. Baranwal and Dr. Rakesh K. Jain of NAAS for bringing out this policy document.

March 2024 **(Himanshu Pathak)**
New Delhi

Food Safety Strategies for Indian Fisheries Sector

1. INTRODUCTION

Aquatic food is a very important food source providing proteins, micronutrients, minerals and polyunsaturated omega-3 fatty acids required by the human population (Fig. 1). Globally the aquatic food production in 2020 touched a level of 214 million tonnes, including 178 million tonnes of fish and shellfish (FAO, 2022), largely due to the growth of aquaculture accounting to higher production of 122.6 million tonnes, with a record value of 281.5 billion US$ (Table 1).

The amount of aquatic food meant for human consumption was 20.2 kg per capita. The value of aquatic food products traded globally in 2020 was 151 billion US$ (Table 1). The consumption of aquatic foods internationally has increased at an average annual rate of 3.0% since 1961, compared with a population growth rate of 1.6%. The aquatic foods provided about 17% of animal proteins and 7% of all proteins in 2019. The

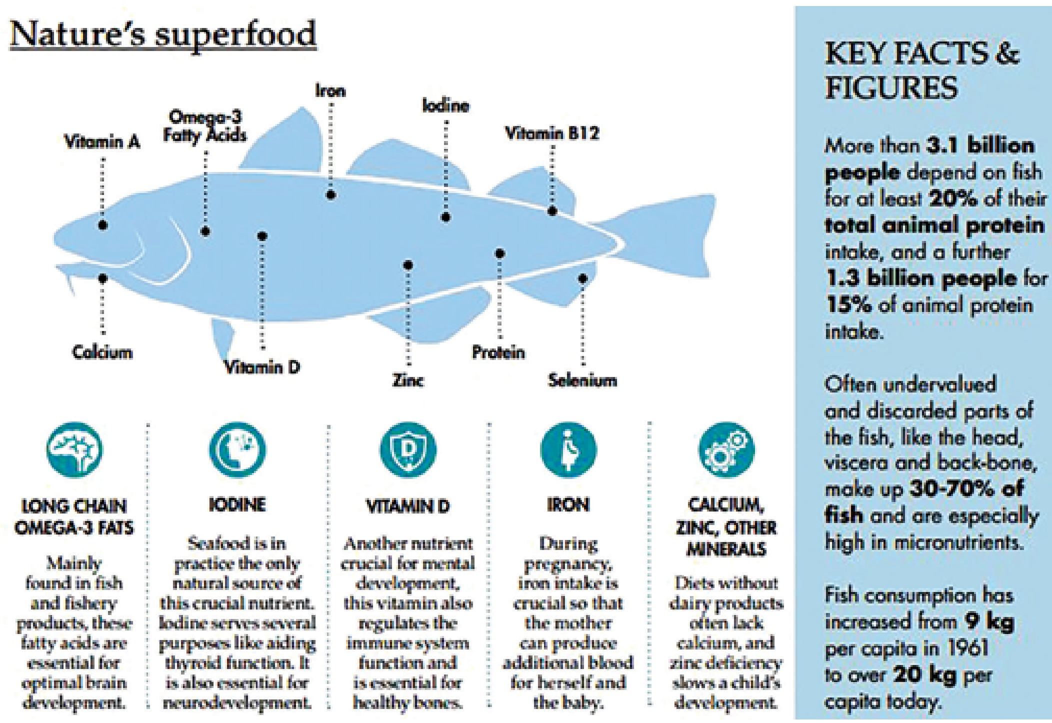

Fig. 1. Aquatic Food as Healthy Food (Source: FAO, 2017a)

Table 1. Global Production, Utilization & Marketing of Aquatic Foods (1990 to 2020)

Project Appraised	1990s	2000s	2010s	2018	2019	2020
	Average per year					
	Million tonnes (live weight equivalent)					
Production						
Capture:						
Inland	7.1	9.3	11.3	12.0	12.1	11.5
Marine	81.9	81.6	79.8	84.5	80.1	78.8
Total capture	88.9	90.9	91.0	96.5	92.2	90.3
Aquaculture:						
Inland	12.6	25.6	44.7	51.6	53.3	54.4
Marine	9.2	17.9	26.8	30.9	31.9	33.1
Total aquaculture	21.8	43.4	71.5	82.5	85.2	87.5
Total world fisheries and aquaculture	110.7	134.3	162.6	178.9	177.4	177.8
Utilization						
Human consumption	81.6	109.3	143.2	156.8	158.1	157.4
Non-food uses	29.1	25.0	19.3	22.2	19.3	20.4
Population (billions)	5.7	6.5	7.3	7.6	7.7	7.8
Per capita apparent consumption (kg)	14.3	16.8	19.5	20.5	20.5	20.2
Trade						
Exports – in quantity	39.6	51.6	61.4	66.8	66.6	59.8
Share of exports in total production	35.8%	38.5%	37.7%	37.3%	37.5%	33.7%
Exports – in value (USD 1 billion)	46.6	76.4	141.8	165.3	161.8	150.5

Source: FAO, 2022

aquatic food consumption is globally expected to increase by 15% in 2030 with a per capita consumption of 21.4 kg, due to the improvement in fish and shellfish post-harvest methods, rise in personal income with changes in dietary requirements, and increased urbanization.

In view of the continuous growth of aquaculture with a projection of 106 million tonnes in 2030, the global aquatic animal production in 2030 will touch a level of 202 million tonnes. Due to the improvement in management of aquatic stocks, utilization of underfished aquatic resources, continued reduction in waste, discards and losses, a 6% increase in global capture fisheries is also expected to touch a production level of 96 million tonnes in 2030. The value of traded aquatic products accounted for 11% of total agricultural trade, excluding forestry, and about 1% of total merchandise trade in 2020. Nearly 90% of the quantity of traded aquatic products, excluding algae, consisted of preserved products, mostly frozen (Fig. 2). Among the muscle foods, the contribution of aquatic food products to the export value is 49%. The faster rate of growth in value relative to quantity reflects the increasing proportion of trade in high-value species and products undergoing processing or other forms of value addition. China, Norway and Vietnam are the major exporters of aquatic foods. Though the EU is the single largest importer, the USA, China and Japan are the major importing countries of aquatic foods globally.

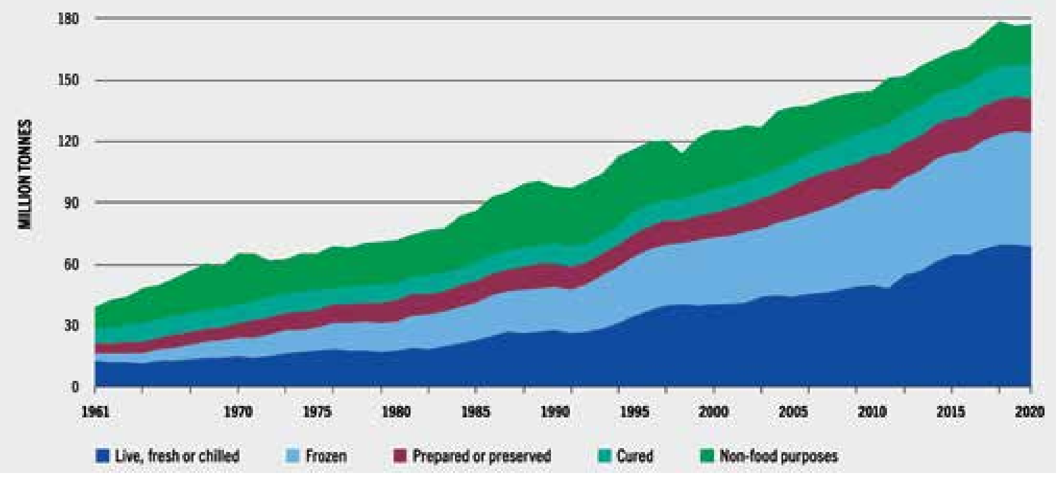

Fig. 2. Utilization of Aquatic Foods from 1961 to 2020 (Source: FAO, 2022)

Every year large quantity of aquatic food products is lost or nutritionally damaged though there is a continuous improvement in the facilities for processing and marketing. One of the SDGs of the UN considered food loss & waste is a major issue affecting the humanity, and thereby UN planned to reduce the food loss & wastage by 50% in 2030. The annual loss or waste in aquatic food is estimated to be about 35% of its production. Most of the loss in aquatic food is due to inefficient value chains in the supply of aquatic foods, as several developing countries around the World still have inadequate infrastructure facilities, poor services, and improper handling and processing practices. Many places where aquatic foods are landed, and marketed still lack proper power connections, roads connectivity, potable water facilities, ice production facilities, refrigerated transportation and cold storage facilities. A multidimensional & multi-stakeholder approach consisting of supportive policies and legislation coupled with necessary skills, knowledge, proper services, adequate infrastructure facilities and efficient technologies is needed for effectively reducing the loss & waste of aquatic food. The FAO Voluntary Code of Conduct for Food Loss and Waste Reduction (FAO,

2021) has identified the importance of these factors in relation to location, species, climate and culture, so as to find out an effective and sustainable solution.

India stands second in fish production in the World accounting for 7.56% of global fish production. The contribution of fisheries sector to overall Indian GVA is about 1.24%, and to the Indian agricultural GVA is over 7.28%. India's fish production in 2021-22 touched a value of 162.48 lakh tonnes with 121.21 lakh tonnes from inland and 41.27 lakh tonnes from marine sectors (DOF, 2022). The average growth rate was 10.34%, which is quite high. Of the total production, India exported 13.69 lakh tonnes fish worth Rs. 57,586.48 crore during 2021-22 to USA, Europe, Japan, China and Middle East Countries. The contribution of aquatic food to Indian Agricultural exports is 17%. Aquaculture contributes about 75% to the total Indian fish production. Among the States, Andhra Pradesh recorded the highest fish production followed by Karnataka, Odisha, and Gujarat (Table 2). Though India is exporting only about 10% of fish produced, it is earning a huge sum of foreign exchange through the export of aquatic foods. Since the importing countries like USA, Europe and Japan have been imposing stringent food safety regulations on the imported food, Indian food regulatory authorities involved in the certification of exported aquatic food products are continuously monitoring the quality and safety of the exported commodities, as otherwise our country will be losing the precious foreign economy and image. Even though about 90% of fish produced in India is available for domestic consumption, at times their quality and safety are not acceptable leading to loss of protein-rich food for humans.

The disposition of fish catch in 2020-21 showed that 105.64 lakh tonnes was utilized as fresh, followed by 18.49 lakh tonnes for freezing and 3.92 lakh tonnes for curing. Of the total fish production in India, about 77% is marketed as fresh, while 13% is utilized for freezing, and 3% for curing comprising drying, salting and smoking. Most of the frozen fish and fishery products are exported to different countries. Less than 1% is utilized for canning, and about 2% is subjected to reduction process for making fish meal, and fish oil. The implementation of Food Safety and Standards Act, and Food Security Act by the Govt. of India has brought some positive impact on the Indian food industries for providing safe food to the consumers. However, the aquatic foods marketed in India needs several food safety and quality interventions at policy level against the background of emerging aquatic foodborne pathogens, and usage of chemicals like formalin, ammonia, antibiotics, pesticides, heavy metal contaminants, and food additives in aquatic foods. The Joint FAO/WHO body, Codex Alimentarius Commission, has been at the forefront of bringing out global changes in food safety regulations. Similarly, the WHO, FAO, UNEP and WOAH have jointly considered food safety as part of their One Health Plan. The fish available for domestic consumption is from different water sources having varied environmental conditions like sea, reservoirs, lakes, rivers, ponds, etc. from cold from Kashmir to warm from Kanyakumari. Among the States, the per capita fish consumption was highest in Tripura (25.53 kg),

Table 2. Indian Fish Production (in lakh tonnes) (2015-16 to 2021-22)

State/UT's	2015-16		2016-17		2017-18		2018-19		2019-20		2020-21		2021-22	
	Inland	Marine	Inland	Marine	Inland	Marine	Inland	Marine	Inland	Marine	Inland	Marine	Inland	Marine
Andhra Pradesh	18.32	5.20	21.86	5.80	28.45	6.05	33.91	6.00	36.1	5.64	40.7	5.54	42.19	5.94
Arunachal Pradesh	0.04	0.00	0.04	0.00	0.04	0.00	0.05	0.00	0.05	0.00	0.05	0.00	0.05	0.00
Assam	2.94	0.00	3.07	0.00	3.27	0.00	3.31	0.00	3.73	0.00	3.93	0.00	4.17	0.00
Bihar	5.07	0.00	5.09	0.00	5.88	0.00	6.02	0.00	6.41	0.00	6.83	0.00	7.62	0.00
Chhattisgarh	3.42	0.00	3.77	0.00	4.57	0.00	4.89	0.00	5.72	0.00	5.77	0.00	5.91	0.00
Goa	0.05	1.07	0.04	1.14	0.06	1.18	0.05	1.15	0.04	1.01	0.05	1.06	0.05	1.11
Gujarat	1.12	6.97	1.17	6.99	1.38	7.01	1.42	6.99	1.58	7.01	1.57	6.83	1.86	6.88
Haryana	1.21	0.00	1.44	0.00	1.90	0.00	1.80	0.00	1.91	0.00	2.03	0.00	2.08	0.00
Himachal Pradesh	0.12	0.00	0.13	0.00	0.13	0.00	0.13	0.00	0.14	0.00	0.15	0.00	0.16	0.00
Jharkhand	1.16	0.00	1.45	0.00	1.90	0.00	2.08	0.00	2.23	0.00	2.38	0.00	2.57	0.00
Karnataka	1.69	4.12	1.59	3.99	1.88	4.14	1.98	3.9	2.29	4.03	2.61	3.47	4.85	5.89
Kerala	2.11	5.17	1.61	4.31	1.89	4.84	1.92	6.09	2.05	4.75	2.24	3.92	2.25	6.01
Madhya Pradesh	1.15	0.00	1.39	0.00	1.43	0.00	1.73	0.00	2.00	0.00	2.49	0.00	2.93	0.00
Maharashtra	1.46	4.34	2.00	4.63	1.31	4.75	1.00	4.68	1.18	4.43	1.25	3.99	1.57	4.33
Manipur	0.32	0.00	0.32	0.00	0.33	0.00	0.32	0.00	0.32	0.00	0.33	0.00	0.33	0.00
Meghalaya	0.11	0.00	0.12	0.00	0.12	0.00	0.13	0.00	0.14	0.00	0.16	0.00	0.18	0.00
Mizoram	0.07	0.00	0.08	0.00	0.08	0.00	0.07	0.00	0.07	0.00	0.05	0.00	0.05	0.00
Nagaland	0.08	0.00	0.09	0.00	0.09	0.00	0.09	0.00	0.09	0.00	0.09	0.00	0.09	0.00

Contd...

State/UT's	2015-16		2016-17		2017-18		2018-19		2019-20		2020-21		2021-22	
	Inland	Marine	Inland	Marine	Inland	Marine	Inland	Marine	Inland	Marine	Inland	Marine	Inland	Marine
Odisha	3.77	1.45	4.55	1.53	5.34	1.51	6	1.59	6.6	1.58	7.01	1.72	7.89	2.01
Punjab	1.20	0.00	1.33	0.00	1.37	0.00	1.35	0.00	1.51	0.00	1.65	0.00	1.90	0.00
Rajasthan	0.42	0.00	0.50	0.00	0.54	0.00	0.55	0.00	1.16	0.00	0.60	0.00	0.66	0.00
Sikkim	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tamil Nadu	2.43	4.67	1.97	4.72	1.85	4.97	1.7	5.20	1.74	5.83	1.75	5.48	2.12	5.95
Telangana	2.37	0.00	1.99	0.00	2.70	0.00	2.84	0.00	3.00	0.00	3.40	0.00	3.90	0.00
Tripura	0.69	0.00	0.72	0.00	0.77	0.00	0.70	0.00	0.78	0.00	0.82	0.00	0.82	0.00
Uttar Pradesh	5.05	0.00	6.18	0.00	6.29	0.00	6.62	0.00	6.99	0.00	7.46	0.00	8.09	0.00
Uttarakhand	0.04	0.00	0.04	0.00	0.05	0.00	0.05	0.00	0.05	0.00	0.06	0.00	0.06	0.00
West Bengal	14.93	1.78	15.25	1.77	15.57	1.85	16.19	1.63	16.19	1.63	16.69	1.55	16.52	1.91
Andaman and Nicobar Islands	0.00	0.37	0.00	0.39	0.00	0.39	0.00	0.40	0.00	0.40	0.00	0.43	0.00	0.44
Chandigarh	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Dadar and Nagar Haveli and Daman and Diu	0.00	0.23	0.01	0.23	0.00	0.24	0.00	0.28	0.00	0.32	0.00	0.30	0.00	0.30
Delhi	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00
Jammu and Kashmir	0.20	0.00	0.20	0.00	0.21	0.00	0.21	0.00	0.21	0.00	0.21	0.00	0.25	0.00
Ladakh	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.01	0.00
Lakshadweep	0.00	0.16	0.00	0.30	0.00	0.21	0.00	0.22	0.00	0.2	0.00	0.15	0.00	0.12
Puducherry	0.07	0.47	0.04	0.46	0.07	0.42	0.07	0.40	0.07	0.44	0.05	0.34	0.08	0.39
India	**71.62**	**36.00**	**78.06**	**36.25**	**89.48**	**37.56**	**97.2**	**38.53**	**104.37**	**37.27**	**112.48**	**34.77**	**121.21**	**41.27**

Source: Handbook on Fisheries Statistics 2022, DoF, Govt. of India followed by Manipur (18.25 kg), Kerala (17.93 kg), and Odisha (16.34 kg). However, the per capita fish consumption recorded for India was very low (6.3 kg) in 2020-21. On most of the occasions, fisheries sector is considered as an unorganised sector. Hence, the control of their quality and safety for domestic market right from fish capture/ landing is very much difficult and no agency is specifically involved in such activities. A clear policy on safety of domestic fish and fishery products is also lacking in India. It can be seen from the recent incidence of formalin contamination in fish sold in different fish markets of Delhi, Punjab, West Bengal, Andhra Pradesh, Kerala, Haryana, Goa, Bihar, Karnataka, Telangana, Maharashtra, Assam, Tamil Nadu, etc. Food safety issues are prevalent in fish and fishery products for domestic consumption in India as well as the problem of lower per capita fish consumption despite its healthy nature.

Humans across the world need safe, healthy, and nutritious aquatic food. It is the main duty of the Government that food safety standards are met by the aquatic foods available for human consumption. India, being a large country with varying food preferences by different states, has a difficult task in maintaining the aquatic food safety standards. The enormous changes occurred in the production, transportation and consumption of aquatic food during the last few decades lead to strengthening of aquatic food safety measures at national level with the active cooperation of different states of India in order to improve the aquatic food safety system. Though different stakeholders involved in aquatic food production and marketing are responsible for the aquatic food safety, the public confidence on the national competent authority for aquatic food safety system is lost when the available aquatic food is not safe for consumption, and there is a frequent occurrence of food safety issues. The national governments should adopt and implement robust aquatic food safety policies across the country, which will make the stakeholders to know and act properly for ensuring food safety. However, the acute differences in the strength of national aquatic food safety systems and complex dynamics within aquatic food systems coupled with economic disparities within and across states made aquatic food safety as a major issue to be solved in the interests of public health. Among hazards affecting the aquatic food safety, the microbiological and chemical hazards are most important. Besides food safety hazards, authentication of aquatic food is another key area that affect the safety of aquatic foods.

2. MICROBIAL HAZARDS AFFECTING THE SAFETY OF AQUATIC FOOD

Microorganisms play a very important role in the safety of aquatic food. The presence of human pathogens and the formation of histamine caused by spoilage bacteria make the control of both pathogenic and spoilage microorganisms critical for fish product safety. Sheng and Wang (2021) reviewed the outbreak and recall surveillance data obtained from government agencies from 1998 to 2018 and identified major safety concerns associated with both domestic and imported fish products. They have also reported the prevalence of major and emerging microbial pathogens including *Salmonella*, *Listeria monocytogenes*, *Aeromonas hydrophila, Vibrio cholerae, V. parahaemolyticus* and *V. vulnificus* in various aquatic foods including their survival under various conditions of storage, as well as the occurrence of antibiotic-resistant genes (ARGs) in antibiotic-resistant bacteria (ARB). They also observed that both the spoilage and pathogenic microbes including the ARGs from ARB can be transferred into aquatic foods.

Generally fish is considered a safe food, and the muscle of healthy fish is always regarded as sterile (Novoslavskij *et al*., 2016). The microorganisms are commonly present on fish surfaces, such as skin and gills, as well as inside of the fish in areas such as the digestive tract and internal organs. However, aquatic food products particularly raw or undercooked products have been involved in outbreaks associated with bacterial pathogens, biotoxins, histamine, viruses, and/or parasites (Galaviz-Silva *et al*., 2009). According to the U.S. Centre for Disease Control and Prevention, the most commonly implicated foods in foodborne outbreaks is the aquatic foods (CDC, 2018). During the recent years, aquatic foods contributed to about 8% of implicated in foodborne outbreaks, which is higher than that of beef and chicken. Higher food-borne outbreaks from aquatic foods showed that there exist greater food safety challenges in aquatic foods along with the necessity for efficient food control mechanisms. Even though most (above 90%) of the fish sold in the USA is imported, about 35% of fish is caught from the waters of US (NOAA, 2020). Pathogenic microbes are responsible for the recalls of large numbers of aquatic foods in the US markets. *Listeria monocytogenes*, *Salmonella*, and *Clostridium botulinum* are the main causative microbial agents for the recalls of aquatic foods including salmon products (FDA, 2020a), which highlighted the importance of food safety in imported as well as domestic aquatic foods.

Aquaculture and aquatic foods often contain antimicrobial resistant bacteria (ARB) that leads to antimicrobial resistance (AMR), which is a major food safety concern resulting in threat to public health and environmental pollution. The ARGs from bacterial pathogens can be rapidly disseminated due to plasticity of their communities through horizontal gene transfer to other bacterial communities. Schmieder and Edwards (2012) have reported that mobile genetic elements (MGEs) are crucial in ARGs dissemination via genetic transfer through horizontal means. The segments of DNA, including transposons, plasmids, & bacteriophages, are MGEs, which can be transferred within the genome as well as between the bacteria. Among the gene transfers, the plasmid-mediated conjugation is commonly involved in the horizontal transfer of resistant genes. Different mechanisms for the development of antibiotic-resistance in bacteria, that occur on the transfer of ARGs to the bacterium, include the modification of antibiotic receptors, reduction of membrane permeability to decrease influx, destruction or modification of the antibiotic itself, alternation of metabolic pathways, development of an active efflux system to pump the antibiotic out, and any other biological mechanism associated with the transfer of genetic materials.

3. CHEMICAL HAZARDS AFFECTING THE SAFETY OF AQUATIC FOOD

The Director-General of FAO, Dr. Qu Dongyu, on the Day of World Food Safety in 2020, stressed the importance of food safety & food security, as they are the basic rights of human beings. The 2030 Agenda of UN for achieving SDGs aims for the achievement in food security leading to end of hunger, and providing healthy food to all humans, as global goals. Chemical hazard refers to the intrinsic property of a chemical that cause adverse effects on human health, fish health and the environment. The occurrence of toxic concentrations of chemicals, and mass toxication with accidental exposure to toxic chemicals lead to chemical hazard. Sometimes the low level exposure to toxic chemicals for longer period also leads to diseases such as cancer, neurological disorders, and defects in birth. Hazards in aquatic system limit production and safe supply of food.

There are three types of chemical contaminants viz. Inorganic chemicals such as As, Cd, Pb, Hg, Se, & sulphites, Organic compounds such as polychlorinated biphenyls (PCBs), dioxins & insecticides, and Processing related compounds such as nitrosamines, antibiotics & hormones. Few metals such as Cu, Se, Fe & Zn are essential for fish. However, contamination occurs when mean level of the said metal increases. The problems of chemical contamination are nearly all man-made. They are due to ocean dumping of large quantity of chemicals from industries, accumulation of sludge from sewage treatment plants, drainage of chemicals from agriculture activities into the sea, and discharge of raw untreated sewage from large urban populations into the natural water systems. Through biomagnification, as in the case of predatory fishes, and bioaccumulation, as in the case of non-predatory fishes, these chemicals find their means of reaching the aquatic animals. The risk of chemical contaminants in wild caught fish is low. However, the fish caught in coastal waters & highly polluted waters, the risk of Hg, Se, dioxins, PCPs, ketone, chlordane, dieldrin & DDT is high. The organochlorine phosphates (OCPs) in fish intended for consumption is low probably below adverse human health. There is a potential concern for two groups of people, viz. populations that consume seafood as a major diet; and infants & young, who consume oily fish. Presence of chemical contaminants is dependent on the geographic location, species, fish size, feeding patterns, solubility of chemicals, and persistence of chemicals. The chemical hazards are mainly categorized into heavy metals, persistent organic chemicals, radiological contaminants, natural toxins, veterinary drugs, pharmaceuticals & PCPs, and allergens.

Emerging chemical hazards are pharmaceuticals (PhACs) like anti-inflammatory drugs such as diclofenac, ibuprofen; sedatives such as diazepam, sertraline; antibiotics such as azithromycin; analgesic, antipyretic, and salicylic acid; personal care products (PCPs) like synthetic musk such as galaxolide (HHCB), and UV filter in sunscreen such as 2-ethyl-ehxyl-4-trimethoxycinnamate (EHMC); brominated flame retardants (plastics, textiles, electricals) like polybrominated diphenyl ether PBDE99; perfluorinated compounds like fluorosurfactants (EU/EPA) in water resistant textiles, sprays, fire-fighting foams such as PFOA – perfluorooctanoic acid, and PFOS – perflourooctane sulfonate; plasticizers such as bisphenol A (BPA), phthalates, and PCBs; toxic elements such as inorganic arsenic, organic mercury, and cadmium; polyaromatic hydrocarbons such as burning coal, oil, petrol, rubbish, tobacco, wood, etc.; and detergents or disinfectants. The guidelines or standards are lacking for emerging chemical hazards like PhACs and PCPs; allergens in aquatic foods; heavy metals (Iodine, As and Cd) and marine toxins (palytoxin, domoic acid, ciguatoxins, and cyclic imines) in seaweed products; and chemical hazards in 3-D printed foods, and cell based fish meat.

The hazardous chemicals are contaminating a limited number of aquatic animals. However, the risks associated with PCBs, MeHg, PCB congeners, dioxins, and some OCPs are highly significant. Only few types of aquatic food poses risk on consumption, and so efforts to be made towards evaluation, education and control of chemical hazards in such foods. There is a need for improvement in the risk assessment procedures. Database for evaluating the safety of certain chemicals that find their way into aquatic food via aquaculture and processing is too weak. Principal recommendations include existing regulations to minimize chemical and contamination of the aquatic environment need to be strengthened and enforced;

Further research needs to be undertaken by government research organizations for determining the actual risks associated with the contaminated aquatic food as well as developing clear approaches for reducing such risks. Governmental Institutions need to increase the environmental monitoring of such risks. The central and state Governments have to be responsible for closure of sites of aquatic animals, and for issuing health and contamination advisories on specific consumption of aquatic foods. Food Safety Authorities like FSSAI needs to conduct a well-defined programme of public education on specific chemical hazards associated with aquatic foods.

The safety levels of biological agents, chemicals including animal drugs, toxins, and physical hazards in aquatic foods are given in the regulations and guidance of USFDA and USEPA (FDA, 2020b). As per the regulations, the furazolidone, chloramphenicol, diethylstilbestrol, fluoroquinolones, clenbuterol, dimetridazole, and glycopeptides residues are not permitted in aquatic food. The tolerance limit in fish muscle for residues of tetracyclines (a sum of tetracycline, oxytetracycline, and chlortetracycline) is fixed as 2 ppm. The muscle of catfish/ farmreared warm-freshwater finfish, and salmonids should contain less than 1 ppm of florfenicol residues. The muscle of catfish/ salmonids should not contain more than 0.1 ppm sulfadimethoxine. The public health is dangerous when the level of histamine in scombrotoxin-forming fish varieties (tuna & mahi mahi) is 500 ppm and above. The level of histamine in fish at 50 ppm and above indicates that the fish is decomposed irrespective of results of organoleptic evaluation. But, the threshold level for ciguatoxin contamination is 0.1 ppb, which is much severe than histamine poisoning (Dickey and Plakas, 2010). Most of the developing counties in the World do not have their own maximum residual levels (MRLs) for chemicals and toxins, while the MRLs vary among the developed countries (Okocha *et al*., 2018).

The EU Commission Regulation No. 37/2010 (EU, 2010) has set the MRL for the total of tetracyclines in fish muscle as 100 µg/kg (0.1 ppm), whereas the USA set the tolerance as 2 ppm, and the Codex Alimentarius Standards (FAO/WHO, 2018) as 200 µg/kg (only to OTC).

Sometimes foods are found to contain higher amounts of chemical contaminants like antibiotic & pesticide residues, heavy metals, and chemical additives such as food preservatives, and colouring agents. These chemicals are mostly used for controlling the microorganisms, insects and pests that are associated with environment and food. There is a suppression of human immune system leading to cancer due to the chemical contaminants including the biotoxins (mycotoxins, Paralytic shellfish toxin, Diarrhetic shellfish toxin, Azaspriacid shellfish toxin, Neurotoxic shellfish toxin and Amnesic shellfish toxin, Ciguatera toxin and Tetradotoxin) that enter into any stage of food chain from production to consumption. The use/ misuse of chemicals like antibiotics, disinfectants, pesticides & water conditioners in aquaculture systems for increasing the production and maintaining aquatic animal health may result in the development of antimicrobial resistance including multi-drug resistance in aquatic microorganisms, as well as affecting the non-target aquatic organisms. Besides, the aquatic animals also suffer from environmental contamination with plastics mainly from their degraded components such as nano & micro plastics. The recent development of Seafood Risk Tool (SRT) at global level leads to clear understanding of chemical and pathogen hazards in aquatic foods (Stentiford *et al*., 2022). The SRT assess the detailed profiling of the uncontrolled and controlled impact of hazards in the seafood supply chain, which is shown in Fig. 3. It uses a two-step semi-quantitative risk assessment schema to calculate impact as a multiple of scores for severity of harm caused and the likelihood of harm occurring; and it considers those hazards with potential for greatest impact on supply of seafood from different aquaculture sectors, and the interventions at various levels that may be required to mitigate such hazards.

4. AQUATIC FOOD AUTHENTICATION

The main aspect of seafood authentication is species authentication, which gives assurance on market transparency, thus avoiding fraud. Species authentication confirms that the commercial and scientific name provided on the label is the one that belongs to the species included in the product. Food authentication means establishing genuineness or validity of the material that contains nutritive and non-nutritive components, which when ingested and assimilated by an organism produce energy, stimulate growth and maintain life. As per FAO (2020), the important elements of food fraud are intention, deception, and undue advantage. Food fraud is complex and also a food safety concern. The eleven sins, as identified by Lawrence *et al*. (2022), that occur in aquatic food trade are species adulteration, species substitution, undeclared product extension, illegal processing, unauthorized international trade, IIU fishing, catch method fraud, animal welfare, modern day slavery, chain of custody abuse, and fishery substitution.

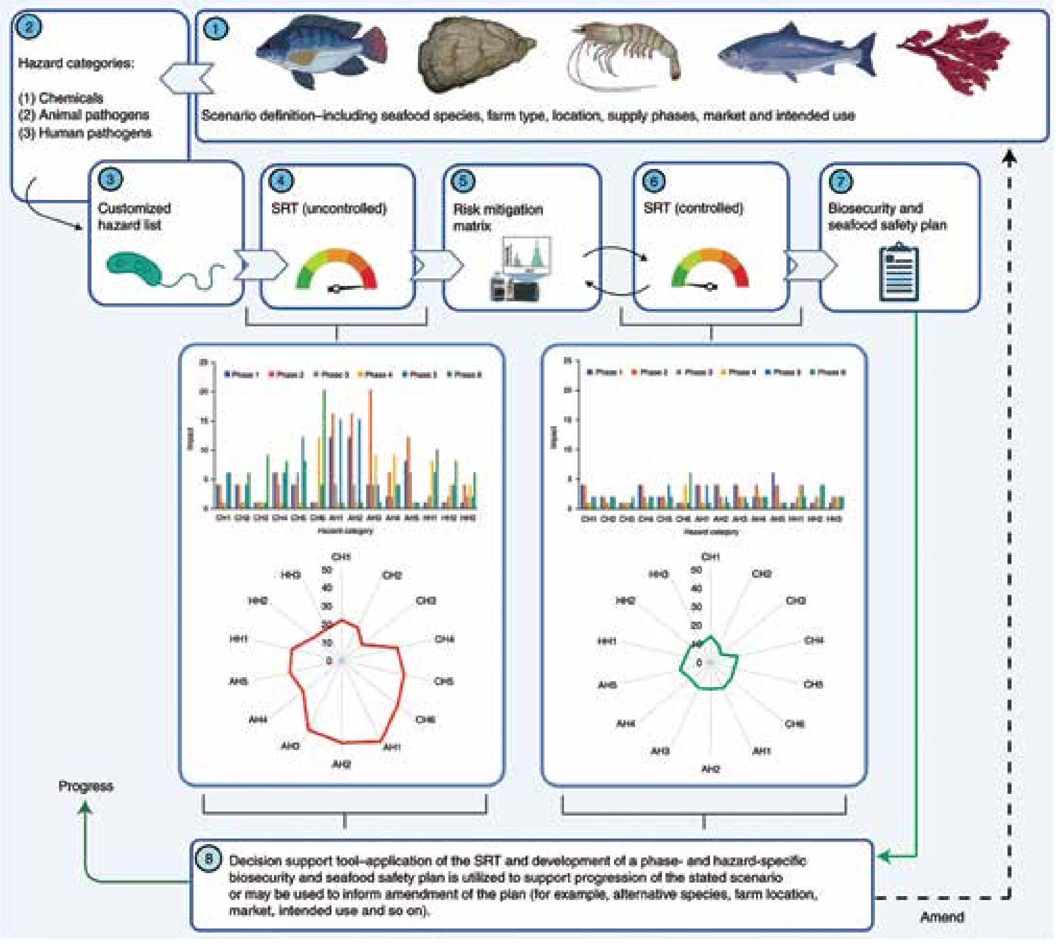

Fig. 3. Decision support system based on Seafood Risk Tool (SRT) (Source: Stentiford *et al.*, 2022)

Adulteration means making poorer in quality by addition. Provenance means Place of Origin/ Record of Ownership. Production & Distribution mean act of manufacturing and supply. Ethics & Environment mean moral principles and surroundings/ conditions. The authentication of aquatic food is required in order to protect consumer health, reduce economic loss, avoid cheating of consumer, and maintain effective conservation of aquatic environment. Prevention of food fraud must be cross-functional, and not just a food safety function issue, and should be implemented across businesses and supply chains. Food fraud training should be given to all departments, including procurement and operations. Food risk matrix includes food quality, food safety, food fraud, and food defence. Food security is a combination of food quality, and food safety. Food quality and food safety are unintentional, while food fraud, and food defence are intentional. Food fraud results in financial gains, that is economically motivated. It also results in harming public health, economic or terror funding that are ideologically motivated. Food fraud vulnerability assessment (FFVA) consists of Hazard Analysis and Critical Control Point (HACCP), Vulnerability Assessment and Critical Control Point (VACCP) and Threat Assessment and Critical Control Point (TACCP). VACCP is a method used to assess and mitigate vulnerabilities from food fraud/ authenticity and possible adulteration. The process is similar to HACCP and TACCP, although the latter is designed to protect against intentional adulteration for food defence purposes. The TACCP can be linked with VACCP to identify threats and vulnerabilities. The VACCP typically refers to raw material control, while TACCP typically refers to process, people, resource, and security controls. Food safety and food security, as identified by Balan *et al*. (2020), are inter-related. Food Integrity is the need of the hour as it combines food quality, food safety, and food authenticity. The response mechanism to food fraud, operating between the producer and consumer, consists of three levels viz. Self-Governance, Partner Governance, and Government Commitment.

The aquatic food commodity faces large proportion of food fraud in their entire logistical network due to an immense, often complicated and extremely opaque chains of supply from production to consumption. In order to implement efficient and practical countermeasures to detect and prevent food fraud, the FBOs, food regulatory authorities, and other actors involved in the supply of food should have in-depth knowledge on the risks and vulnerabilities associated with food supply chains. The aquatic food fraud occurred between 2010 and 2020, as reported by the European Union’s Rapid Alert System for Food and Feed, has shown that unauthorized veterinary drug residues were the most significant food safety concern particularly in farmed aquatic food originated from India, China, and Vietnam. For internationally traded goods, The EU border inspections of globally traded aquatic foods showed that the insufficient or fraudulent documentation is significant indicating that deceptive practices even occur along the aquatic food supply chain. Databases of EU indicated that aquatic food fraud means like species substitution, IUU fishing, fishery substitution, and species adulteration were less prevalent than that reported in different scientific publications. There is an urgent need to have a standardized rigorous dataset at the global level in order to detect and control aquatic food fraud.

Aquatic food is important for nutrition and food security and income generation, employment as well as for the livelihood of coastal communities across the World (World Bank, 2012). Due to the overexploitation of wild fish stocks coupled with the scarcity of fisheries resources at global level, increase in fish production for meeting the rising aquatic food demand, and the increase in income from fish business, there is a greater potential for the occurrence of food fraud in the aquatic food sector (FAO, 2017b). Young’s Seafood Limited outlined sins of aquatic food (Elliott, 2014) for describing nine food fraud types specific to the food sector. The nine food frauds are fishery substitution, species substitution, IUU substitution, catch method fraud, species adulteration, chain of custody abuse, undeclared product extension, animal welfare, and modern-day slavery (Fox *et al*., 2018). The timely detection as well as prevention of food fraud requires a deeper knowledge of food supply chains and individual business practices, along with a clear understanding of the vulnerability of food supply chain (FSA, 2021).

In different regions of the world, many fish species are often traded under different market names, and sometimes the low-valued fish is labelled with the name of high-valued fish. Most of the occasions, name labels on raw fish sold in retail shops and restaurants are incorrect. The fish consumers can recognise only a very few common names of the fish species like seabass, flatfish and snapper in the market. Since some of the common name of particular fish species like dragon fish is not appealing to the consumers, retail traders use different name for it, which leads to confusion in marketing as well as potential food safety risks for the consumers. The USFDA's Seafood List states that "The use of a misleading or false name prevents correct species identification of fish and thereby affecting the ability of fish processors and aquatic food consumers to make accurate assessments of the potential safety hazards associated with such fish species. Certain fish species pose hazards like scombrotoxins and allergenic proteins to human health, and hence accurate labelling is needed for the fish species.

For the identification of aquatic food species, the morphological characteristics can be used, whenever it is possible. Species-specific features, such as size, texture and colour, are used to differentiate species, often helped by guides with photographs, drawings and descriptions of what can be visually determined. When morphological characteristics are removed, which frequently occurs upon processing, visual identification of species becomes a difficult or impossible task to accomplish. Therefore, to verify the authenticity of aquatic food products and the compliance with the labelling legislation, several analytical methodologies have been developed. DNA-based methods have provided powerful tools for seafood species differentiation, being widely implemented regarding authentication purposes.

5. MANAGEMENT STRATEGIES FOR AQUATIC FOOD SAFETY

The export of aquatic food products accounts to 7.74 billion US dollar (13.70 lakhs metric ton) during the year 2022. Among that, 53.18% in quantity and 78.11% in dollar contributes in shrimp exports. USA accounted the major share (59.05%) followed by China 14.59%, EU 8.16%, Southeast Asia 4.78%, Japan 3.61%, Middle East 3.17%. The aquatic food products export from India is targeted to reach USD 14 billion by 2025. For ensuring the safety of exported food as well as domestic food, India has a food control programme, based on Codex and various International Standards, which has the essential components of legal framework, surveillance, monitoring and a certification process of foods throughout the food chain and taking proactive measure if food is deemed unfit for human consumption. The key elements of food control system for export are the protection of health of consumers and facilitation of trade. A farm to fork (food chain) approach of control system is followed from the primary production level to distribution. The confidentiality is maintained as the inspection and certification are transparent. The control system is also open for scrutiny from importing countries. The Food Business Operators (exporters), Competent Authority in India (Export Inspection Council), Consumers (importers) & Scientific Research Institutions have clearly defined roles and responsibilities as per the control system.

Food Control System in India has following provisions: Legislation/Regulation, Inspection, Testing, and Enforcement. The strategies for aquatic food safety can be proactive or reactive. There are several drivers of food safety (WHO, 2022). Consumers demand that foods are safe irrespective of whether they are imported or produced domestically. On failure to meet the food safety compliance, the food producers lose their high-valued export markets and reputation of their brands through rejections of their exported food products. The major drivers of food safety are demographic changes, environmental challenges, global food safety threats, demands for food safety, rise of new technologies coupled with digital transformation, impact of global changes on food supply chain, and changing behaviour of people on foods. Unsafe aquatic food threatens public health, produces inefficiencies in production systems, and creates trade barriers across the global aquatic food web. It is also considered as a major social cost. The Way Forward for Food Safety is to adopt the Block chain technology in improving traceability and transparency of food supply chains to avoid food fraud, conduct Risk assessment as per the category or variety and mitigation of the identified risks, utilize the Artificial Intelligence in food safety.

6. FOOD SAFETY STRATEGIES OF FAO & WHO

The FAO & WHO have identified five strategic priorities like strengthening National Food Control Systems, Identifying and responding to food safety challenges resulting from global changes and transformation of food systems, Improving the use of food chain information, scientific evidence and risk assessment in making risk management decisions, Strengthening stakeholder engagement and risk communication, and Promoting food safety as an important component in domestic, regional and international food trade. Each strategic priority has few objectives to achieve the food safety. The objectives of first strategic priority are the establishment of an institutional framework for coordinating the works of different competent authorities in the management of national food control systems; establishment of a harmonised, evidence-based modern framework of food legislation; establishment of food safety incidence records and emergency response systems; strengthening of surveillance and food monitoring programmes; development and implementation of appropriate food safety guidelines and standards; and strengthening of food safety compliance, verification and enforcement.

The objectives of second strategic priority are the identification of food safety challenges viz a viz response; identification and evaluation of food safety impacts; and adaption of suitable risk management practices to emerging foodborne hazards. The objectives of third strategic priority are the collection of comprehensive information along and beyond food chain for utilising these data for making appropriate risk management decisions; improvement on the use of food chain information, scientific evidence and risk assessment for taking suitable risk management decisions; making consistent and transparent risk management decisions for the establishment of food safety measures; collection of food safety information and risk analysis experiences beyond national borders for strengthening technical capacity and risk management decisions; and improvement on the generation and use of scientific evidence and risk assessment for establishment and review of food control strategies.

The objectives of fourth strategic priority are the establishment of appropriate platforms for consultation of stakeholders on national food safety agenda; establishment of framework for sharing verification of compliance with food safety regulatory authorities; improvement on stakeholder engagement and risk communication; facilitation on communication, education and engagement with consumers; facilitation on communication, capacity building and engagement with food business operators for inculcating food safety culture; and assessment on the importance of using non-regulatory schemes for enhancing food safety. The objectives of fifth strategic priority are strengthening of interaction between national agencies responsible for domestic food safety as well as for facilitating international fair trade practices; strengthening of food control systems and building capacity on food regulatory measures for domestic food; promoting food safety as a vital component in national and international food trade; strengthening the relationship between national competent authorities and international agencies and networks involved in establishing guidelines and standards for food; alignment of national food safety systems with the Codex Alimentarius Commission standards for the protection of public health and promotion of food trade at national and international levels.

The FAO has formed the Codex Alimentarius Commission, an International risk management body, responsible for developing food safety standards. The Codex Alimentarius Commission has brought out the General Principles of Food Hygiene, Codes of Practices for fish and fishery products, Guidelines for control of *Vibrio* spp., and Guidelines for control of *Listeria monocytogenes*. The Codex standards are science based. The necessary scientific advice for Codex standard development is provided by FAO/WHO through international expert committees viz. Joint FAO/WHO Expert Meeting on Microbiological Risk Assessment (JEMRA), Joint FAO/WHO Expert Committee on Food Additives (JECFA), and Joint FAO/WHO Meeting on Pesticide Residues (JMPR). The Smart Food Safety Initiatives identified for Aquatic Food Safety include the modernization of food supply chain with technology enabled traceability, establishment of an institutional network for seafood safety training, seafood safety laboratory network for supply chain management, outbreak investigation and pathogen tracking, and emphasis on the application of AI and machine learning in preventing aquatic food-borne outbreak of illness.

7. ONE HEALTH PLAN ON FOOD SAFETY

Nations design and implement their own regulatory control systems, policies, legislation and public services related to plant and animal health and food safety and quality (FAO, WHO, UNEP and WOAH, 2022), as per the main objective of One Health (OH) Plan of FAO, WHO, UNEP & WOAH, for global governance of food systems, and establishing a clear framework. Providing support for the adoption of international standards, providing scientific advice, and supporting public sector institutions for enhancing their capacity in the designing and implementation of better policies and regulatory frameworks, including capacities for risk-based food inspections, sampling and analysis, risk-communication and food safety management, antimicrobial resistance specifically awareness raising, capacity development for effective monitoring and mitigation of AMR risks, strengthening national and regional governance networks, action plans, and dissemination of good practices on use and control of antimicrobials, are the main areas of action on Food Safety and Quality, Plant Health, Animal Health. The main approach of One Health is for generation of evidence like mapping and assessing risks and challenges in the sectors along the food chain system, developing national policy and legal frameworks in line with International Plant Protection Convention (IPPC) norms, and developing capacity to reduce human health risks and ecosystems degradation.

The environmental footprints shall be made sustainable through improved aquatic food production for ensuring the health, societal and economical demands of the humans using the principle of One Health. This also optimizes the production, welfare measures & health of the ecosystem. The availability, accessibility, nutritional quality and safety of natural foods shall be compromised by increasing urbanization of humans coupled with population explosion. This can be alleviated to a greater extent in many of the developing countries through aquaculture systems that utilize locally available materials for farming aquatic animals. The aquatic food supply chain should be safe from production (farm) to consumption (fork) that protect the health of the public as well as ensure the monetary stability of the country. Since a variety of microorganisms exist in the aquatic environment, aquatic foods harvested from aquacultural systems often carry a reservoir of microbes including pathogens that may lead to public health hazard. Moreover, intensive farming of aquatic animals warrant the use of chemicals such as therapeutics, fertilizers, disinfectants, feeds resulting in public health issues associated with aquatic foods. Hence, One Health plan should comprise of aquatic food safety and aquatic environmental protection against various biosecurity issues.

8. FISHERIES EDUCATION AND TRAINING FOR SHAPING AQUATIC FOOD SAFETY STRATEGIES

The current educational programmes at the higher institutional level in India exclusively on aquatic food safety are: M.F.Sc. & Ph.D. in Fish Quality Assurance and Management offered by Tamil Nadu Dr. J. Jayalalithaa Fisheries University; and M.F.Sc. in Seafood Safety and Trade offered by Cochin University of Science and Technology. But, the M.F.Sc. & Ph.D. in Fish Processing Technology offered by ICAR-Central Institute of Fisheries Education, Central Agricultural Universities, State Agricultural Universities, State Veterinary Universities, and State Fisheries Universities are also having some provisions for fish quality and safety. Broad range of topics included in the PG programmes in Fish Post-harvest Technology are: Fish Quality Management/Certification/Trade Regulations, Microbiology/Biochemistry, Emerging Methods of Fish Processing/Packaging, Fishery products/By-products, and Waste Utilization/ Nutraceuticals. However, there is a specific need for Specialized Curricula on the following areas. They are Seafood safety management, Fish forensics to trace frauds, Surveillance and control programmes for seafood hazards, Artificial intelligence in seafood quality and safety assurance, Seafood nutrition & health, Eco(nomic)-friendly packaging, Novel methods of waste utilization, and Entrepreneurship development in fish processing. Various Levels of Food Safety Education in Fisheries sector is needed at University level for meeting the specific manpower requirements of the Industry, Policymaking bodies at the State and National levels, and Consumer Organizations. The educational efforts should involve university, regulatory & aquatic food industry personnel; industry-based internship for students & trainees; certification programme for plant workers; education on food safety hazards; expansion of academia-industry-regulatory interface; and involving public health and medical professionals in aquatic food safety training.

For improving the higher education on Aquatic Food Quality and Safety, the strategies to be adopted for education are: Modernization of course contents; Onsite Training infrastructure (Labs & Instrumentation); Specializations in Masters/Ph.D. courses; Certificate courses on HACCP, QMS; and Quality assurance & inspection programmes. In the case of basic and strategic research, the core areas are: Quality indicative smart tools; Rapid, field-based foodborne pathogens detection; Health-oriented food research; NGS application/metagenomics in aquatic food safety. The outreach programmes should include Seafood safety knowledge base; Changing seafood safety landscape; and Status and evolution of domestic safety standards. The Universities/ Institutes working on aquatic food safety should have efficient Industrial Collaboration on Problem-solving research; Industry led education in same pace; and Joint programmes. The Quality Management Programmes for accessing premium markets should include three components viz., HACCP in Aquaculture comprising of GMPs, Contamination control, Critical limits and monitoring requirements, International standards, and Safe fish-customer loyalty; Sanitation Training consisting of Food hygiene & sanitation programmes, Domestic & international standards for plants, and CGMP modernization; and the Concept of Processing from farm to kitchen, wherein the individual farmers are trained to process their own fish and supply to the customers directly. The new dimensions of Indian Education on Aquatic Food Safety should include the Importance of food safety in National Policy, Food safety management, Codex & allied food safety norms, Climate change & food safety challenges, Management of food safety emergencies, New tools for assessment & management of food safety risks, Food-borne outbreak investigation & surveillance mechanisms, Food safety risk assessment methodologies, Aquatic food traceability, and Consumer engagement & education.

9. RECOMMENDATIONS

The Brainstorming Session (BSS) deliberated the food safety issues involved in aquatic foods with respect to microbial hazards, chemical hazards, authenticity/ traceability, quality & safety management, role of WHO, FAO, UNEP & WAOH in aquatic food safety including one health plan, and the importance of education and research in implementing food safety strategies in Indian fisheries sector. The following are the major recommendations and actionable points:

- Creating technical manpower for dealing unique aquatic food safety issues through exclusive education and training on aquatic food safety
- Strengthening national aquatic food control systems as part of National Policy
- Identification of aquatic food safety challenges along with response, and strengthening engagement with stakeholders & risk communication
- Improvement on the usage of aquatic food chain information, scientific evidence, risk assessment for making right risk management decisions on aquatic food integrity
- Promotion of aquatic food safety as a vital component in domestic marketing of aquatic foods
- Establishing an All India Network Project on Aquatic Food Safety by ICAR on the similar lines of Aquatic Animal Health, as it is a One Health Concept
- Implementation of Blockchain technology to improve traceability and transparency of aquatic food supply chains and to avoid aquatic food fraud
- Artificial Intelligence in aquatic food safety for risk prediction & monitoring
- Studying the food safety challenges on the emerging cell-based aquatic food products in India

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Note: The designations and affiliations of the participants are as on the date of BSS.

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