



Review Article

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Food safety in fisheries: Application of One Health approach

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Fisheries comprise the fastest growing sector meeting the global protein requirements. Being an affordable enterprise, it is considered a safe source of food and the muscles of healthy fishes are almost sterile. However, a multitude of hazards (biological, chemical, and environmental) can be introduced into aquaculture throughout the production and supply chain. Also, it can originate from unsuitable farming practices, environmental pollution, and socio-cultural habits prevailing in various regions. Hence, with an increasing global population and demands for aquacultural products, assessment and regulation of food safety concerns are becoming significantly evident. 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. Here, we discuss the issues and challenges faced in the fisheries sector as a whole and the need for a One Health approach to overcome such hurdles.

Key words Aquaculture - fisheries - food-borne illness - food safety- One Health - organic pollution

Globally, an enormous increase in fish production was observed during the past 60 years. In 2018, nearly 179 million tons of fish production with a value of \$401 billion USD was reported¹. The per capita fish consumption across the globe has increased from 9.0 kg in 1961 to 20.50 kg in 2018¹. Fish being an affordable and rich source of animal protein is often regarded as a safe food. Moreover, the muscle of apparently healthy fish is almost sterile²⁻⁴. The microorganisms are often found on fish surfaces such as fish skin and gills, including internal organs such as the digestive tract, kidney, spleen, and liver. Additionally, outbreak reports associated with the microbial pathogens

(bacteria, viruses, and/or parasites), their toxins, and vasoactive histamines, due to the consumption of raw or uncooked fish and fish products are also available⁵. The pathogenic as well as spoilage flora can be introduced into aquaculture at any point throughout the value chain⁶. Besides, the role of the environment in regulating the microbiota of aquaculture has been unraveled⁷. Pathogens of public health importance as well as spoilage microbes are known to produce safety concerns and have been recovered from various points of aquaculture such as fish-rearing environments (water and sediment) and processing areas⁶. The presence of antibiotic-resistant genes (ARGs) among

such microbes has been a cause of concern⁸⁻¹⁰. Also, environment, storage, transportation, including hygiene issues of the processing plants and the persons involved in the production chain play a crucial role in food safety. Therefore, taken together, diverse sources and factors may contribute to the food safety issues throughout the production, processing as well as supply chain. To combat these food safety issues, it is important to understand the occurrence, ecology, concentration, and dynamics of various pathogenic and spoilage microorganisms present throughout the entire aquacultural production chain¹⁰. Another major food safety issue over the past few decades has been the dearth 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 this food supply chain to ensure maximum food safety. Here, we discuss the issues and challenges faced by the fishery sector as a whole and one health paradigm to overcome these issues and challenges.

Issues and challenges in food safety with special reference to aquaculture

The World Health Organization¹¹ estimated a global burden of nearly 600 million cases due to food-borne illnesses, which accounted for 4,20,000 deaths. Besides, 33 million years of healthy lives are lost due to the consumption of unsafe food, which is regarded to be an underestimate¹¹. The documented global foodborne outbreaks are primarily due to the consumption of contaminated food. While earlier outbreaks were accorded to the chemical contaminants (Minamata, Itai- itai and Yusho disease in Japan, mercury poisoning of Iraq, polychlorinated biphenyl poisoning of Taiwan, *etc.*), the recent ones were due to microbes (*Salmonella* Typhimurium DT 104 around the world, hepatitis-A outbreak in China, *E. coli* infection in Germany, paragonimiasis in North East India, listeriosis in South Africa, *etc.*)¹².

The available evidence of foodborne illnesses indicates that those fish species harvested from open oceans can be regarded as nutritious and safe, only if they are handled and stored properly and quickly. The risk of contamination by chemical as well as biological agents is also higher in fresh water and coastal belts as compared to the open seas. However, the possibility of food safety issues associated with the fisheries sector varies between different regions and habitats. Moreover, it varies according to the production and

management practices along with the associated environmental conditions.

The issues and challenges in food safety could be categorized broadly into microbial, chemical, personal, and environmental origin^{12,13}. The possible food-borne hazards in the aquaculture sector (infections, toxins, agrochemicals, residues, heavy metals) are briefly enlisted in the Table¹⁴⁻⁷². These hazards may originate from unsuitable farming practices, environmental pollution, and socio-cultural habits prevailing in various regions. Hence, with an increasing population and demands for aquacultural products, assessment and regulation of food safety concerns become important.

Microbial issues

Foods, particularly of animal origin (meat, milk, eggs, and fish) support the growth of microbes (bacteria, viruses, and parasites) that can serve as potential sources of food-borne illnesses. Although viruses are grossly accounted for the majority of food-borne illnesses, but hospitalisation and mortality rates are associated either due to bacterial agents or their toxins. The illnesses may range from mild gastroenteritis to neurological, hepatic, and renal syndromes. It has been reported that more than 90 per cent of food-borne illnesses are due to various species of *Staphylococcus aureus*, *Escherichia coli*, *Salmonella* spp., *Listeria*, *Vibrio*, *Clostridium*, and *Campylobacter*^{12,73}.

In aquaculture, bacteria, viruses, and trematodes are the major biological hazards⁷³. The bacterial agents of public health importance that can contaminate aquaculture and its products are broadly divided into two *viz.*, indigenous microbiota *i.e.*, those which are naturally present in the aquaculture environment (*C. botulinum*, *V. parahaemolyticus*, *V. cholerae*, *Aeromonas*, *Listeria*) and non-indigenous microflora *i.e.*, those introduced into the environment by way of excreta (*Salmonella* spp. and *E. coli*). Intensive aquaculture practices have promoted the growth of several bacterial infections (*E. coli*, *Salmonella* spp., *Shigella* spp., *Aeromonas hydrophila*, *V. parahaemolyticus*, *V. cholerae*, *V. vulnificus*, *Plesiomonas shigelloides*, *Edwardsiella tarda*, and *Streptococcus iniae*), which would lead to increased use of antimicrobials¹⁴⁻²². However, it is not easy to determine the levels of antimicrobial usage in aquaculture as the quantum and compounds put in practice differ significantly among countries. Consequently, antimicrobials would be employed in aquaculture therapeutically, prophylactically, and

Table . Food safety hazards in aquaculture products

Food safety hazards	Species involved	Region	Reference
Bacterial agents			
<i>Salmonella</i> (<i>S.</i> Aberdeen; <i>S.</i> Stanley; <i>S.</i> Wandsworth; <i>S.</i> Typhimurium)	Mussels, Fish Shrimp, Shellfish	China	45
<i>Salmonella</i> (<i>S.</i> Weltevreden; <i>S.</i> Newport; <i>S.</i> Senftenberg)	Seafood, Blue anchovy, freshwater fish	USA	46
<i>Salmonella</i> (<i>S.</i> Typhimurium, <i>S.</i> Anatum, <i>S.</i> Weltevreden)	Shrimp, freshwater fish	Vietnam	47
<i>Salmonella</i> spp.	shrimp	Imported to USA	20
<i>Shigella</i> spp.	Fish	Winam Gulf of Lake Victoria, Kenya	48
	Seafood	Imported to Jordan	19
<i>S. dysenteriae</i>	Fish	India	49
<i>S. dysenteriae</i>	Fish	Zimbabwe	50
<i>Escherichia coli</i> O157:H7	Carps	India	51
<i>E. coli</i> O157:H7	Farm fishes	Turkey	22
<i>Vibrio cholerae</i>	Fish samples	India	21
<i>V. cholerae</i>	Fish, crabs, bivalves	Haiti	52
<i>V. parahemolyticus</i>	Oysters	Alaksa	53
<i>V. parahemolyticus</i>	Shellfish and sea food	US Atlantic coast	54
<i>V. parahemolyticus</i>	Shrimp	Spain	18
<i>V. vulnificus</i>	Raw oysters	USA	55,56
<i>V. vulnificus</i>	Raw oysters	Japan	16
<i>Listeria monocytogenes</i>	Salmon	Norway	57
<i>L. monocytogenes</i>	Tilapia	Taiwan	58
<i>L. monocytogenes</i>	Fish, shrimp, and ready-to-eat seafood	Iran	17
<i>Clostridium botulinum</i> Type- E	Fish from trout farms	Finland and Sweden	59
<i>C. botulinum</i> Type- E	Tilapia	USA	60
<i>C. botulinum</i> Type- E	European river lamprey	Finland	14
<i>Mycobacterium marinum</i>	Rainbow and brown trout	Italy	15
Viruses			
Norovirus	Seafood (shellfish, oyster)	China	34,44
Hepatitis A virus	Shellfish, raw clams	Spain; Shanghai, China	35,61
Hepatitis E virus	Shellfish	Scotland	36
Parasites			
Nematodes: Anisakiosis	Sardine	Italy	33
Anisakiosis	Squids	Central and western North Pacific Ocean	62
Capillariosis	Black porgy	Shikoku Island, Japan	30
Gnathostomosis	Raw seafood	Southeast Asia and Latin America	32
Cestodes: Diphyllbothriosis	Trouts	Chile, Russia, Finland, Ireland, Scotland, USA	28
Trematodes: Chlonorchosis	Freshwater fishes	Pearl River Delta region of China, Taiwan, South Korea and North Vietnam	27,28
Opisthorchosis	Fish	Thailand, Lao, Cambodia and Central Vietnam	31

Contd...

Food safety hazards	Species involved	Region	Reference
Parasites			
Paragonimosis	Freshwater crabs or crayfish	China, Liberia, Nigeria, Venezuela, Japan, Northeastern India	29,63
Biological toxins			
Scombrototoxin	Fish (Mackerel, Tuna, mahi-mahi, Spearfish, Scad, Oilfish <i>etc.</i>)	USA	64
Ciguatoxin	Fish	USA, Spain	64,65
Brevetoxin	Shellfish	Gulf of Mexico, Southeast US coast, New Zealand	65,66
Domoic acid	Mussels	New England	67
Tetradotoxin	Bivalve shellfish, Marine pufferfish	English Channel, Japan, China, Taiwan	66,68
Yessotoxin	Scallop	Spain, Italy	69,70
Cyanobacterial toxins (microcystin).	Freshwater fish	China, Dhaka, Bangladesh	71,72
Agrochemicals			
Fertilisers, water treatment agents, flocculants, pesticides <i>etc.</i>	Shrimp, Salmon	North Eastern Australia, North Pacific American coast, Atlantic Ocean	37,38
Veterinary and aquaculture drug residues			
Antibiotics, parasiticides, growth promoters (hormones), feed additives	Fish, Shrimp	India, Bangladesh, Nigeria, Iran	23-26
Heavy metals			
Lead, Cadmium, Mercury	Freshwater fish, White shrimp	Indonesia, India, Zhanjiang Harbour Bay	41-43
Persistent organic pollutants			
Dioxins and polychlorinated biphenyls (PCBs)	Farmed Scottish and European salmon, Shrimp	Europe, Central Java coast	39,40

metaphylactically not only to manage the infections but also to promote growth²³.

The surge in the food-borne infections caused by drug-resistant bacteria was correlated with the antibiotic usage in food animals and the emergence of resistant infections among humans and animal pathogens. Such drug-resistant pathogens could be directed to the human food chain either by way of direct contact (aquatic biota or drinking water), or through the consumption of contaminated seafood. Furthermore, the antibiotic selection pressure alters the biodiversity of the aquatic environment and commensal flora of aquatic biota²³⁻²⁶. Additionally, the exchange of genetic material may take place between the aquatic and terrestrial bacterial pathogens on exposing the terrestrial bacteria in the aquatic environment to residual antimicrobials and biofilm. This fact could be evidenced by the sharing of genetic

material and resistance determinants for antibiotics such as beta-lactamases, tetracyclines, and quinolones between aquatic bacteria, fish pathogens as well as human pathogens⁷³.

The concern over antimicrobial usage in aquaculture could be aggravated with the incidence of antimicrobial residues in aquatic species. The antibiotics could accumulate as residues in tissues, even before these are metabolised wholly or excreted from the system. This can occur when the aquatic species are harvested for consumption while on medication or before the appropriate withdrawal period. Such cases of residues in aquaculture products have been reported from countries like India²³, Bangladesh²⁴, Nigeria²⁵, and Iran²⁶. The occurrence of antimicrobial residues has raised apprehensions over the recent years owing to public health concerns (drug resistance, hypersensitivity, mutagenicity, carcinogenicity,

teratogenicity, aplastic anaemia, and dysbiosis of commensal gut flora) among seafood merchandise²³⁻²⁶.

Besides bacteria, a wide range of fish species harbour parasites; some of them are highly pathogenic and are transmitted by way of consumption of raw and inadequately cooked fish. In general, fish serves as intermediate hosts for these parasites; humans act as a definitive host when the infectious stages are consumed. Such parasitic infections are more often prevalent in those communities which prefer eating raw or undercooked fish, mainly in eastern and southern Asia^{27,28}. Freshwater fisheries are commonly associated with parasitic infections; little is known about the role of farmed aquaculture species. The two major genera of medical importance include *Clonorchis* and *Opisthorchis*; *Paragonimus*, *Heterophyes*, and *Metagonimus* are of lesser importance²⁷⁻³².

Apart from bacterial and parasitic infections, viruses (commonly norovirus, and hepatitis viruses types- A and E) are also associated with disease outbreaks³⁴⁻³⁶. Contamination of aquaculture species, especially the bivalves occur from the discharges of sewage effluents, urban runoff, and wastes from boats and through animal sources. Viral contamination is regarded as a public health hazard and hampers sustainable aquaculture practices. The issue attains complication as the current risk assessment and regulations rely only on bacterial indicators (predominantly, coliforms, *E. coli*, and faecal streptococci) for the detection of faecal pollution in aquaculture. Such bacterial indicators could not represent the public health risk of aquaculture from enteric viral pathogens^{34-36, 44}.

Chemical issues

Chemical additives (colourants and preservatives) and contaminants (heavy metal, pesticide, and antibiotic residues) have been found plentiful in foods. These agents often used to eradicate and control vermins, are found in the foods and associated environment. Besides, biotoxins such as mycotoxins, marine biotoxins, cyanogenic glycosides can enter the food chain causing impairment in the immune system and can lead to cancer^{37,38}.

In countries where aquaculture forms the backbone, a plethora of chemicals (antibiotics, pesticides, disinfectants, and water conditioners) are employed to sustain the production. Such strategies would not only lead to the emergence of antimicrobial resistance, particularly, multi-drug resistance but also

tend to infect the non-target species. Such chemicals could turn out to be disruptive and find their way into the natural ecosystem that would eventually lead to irreparable damage to the aquatic system³⁸. Plastics (often micro- and nano- plastics) resulting from the degradation and fragmentation of larger plastic items may enter the aquatic matrices (surface, sediments, beaches, etc.). Even though removal of the gastrointestinal tract of seafood would alleviate the risk of microplastics in humans, consumption of these aquatic species (bivalves and small fish) wholly may result in microplastic exposure. However, their fate in the human gastrointestinal tract is not completely understood¹.

Environmental hygiene issues

The most important element determining the aquacultural microflora is its environment⁷. Improper disposal and recycling facilities in food-producing and processing plants would lead to an increased risk of the pest as well as insect population, resulting in food spoilage and contamination. The water temperature, harvesting techniques, season, and processing methods may also influence the spoilage. The predominant bacterial spoilage agents are located on the slime layer of the skin, gills, and intestine. As the tissues of fish contain higher levels of non-protein nitrogenous (NPN) compounds (trimethylamine oxide, free amino acids, and creatinine), proteins, and peptides, the growth of microbes results in the decomposition of proteins and production of metabolites which would result in spoilage.

Waste thrown away from the food industries into the environment is a cause of public health concern. Besides routine chemicals (antimicrobials, pesticides, hormones, pigments, minerals, vitamins), persistent organic pollutants (POPs) such as dioxins and polychlorinated biphenyls (PCBs) are found in the environment abundantly and accumulate in animal food chains^{39,40}. Similarly, heavy metals (lead, cadmium, mercury) could pave their way in foods mainly through pollution of air, water, and soil⁴¹⁻⁴³.

Inappropriate aquacultural practices could result in environmental degradation; eutrophication and organic pollution constitute common adverse impacts. Together with chemical pollution, these could deplete oxygen, reduce water quality, coral death, and habitat disruption of water bodies. Such a hostile environment would sustain the growth of harmful microbes to aquatic life⁷³.

Personal hygiene issues

Inadequate personal hygiene of the handlers poses significant occupational as well as a public health risk. Alike, clean water and water body, harvest equipment, and containers would suffice the public health risks, if any, that would culminate in foodborne illnesses. Since the disease outbreaks of public health concern could seldom be correlated to the disease manifestation in fishes, intervention approaches for assuring food safety in aquaculture practices are quite difficult to be determined. Therefore, quantitative risk assessment is considered to be the best method for identifying pathogens. The quantitative risk assessment criteria employed for the pathogen identification involve the formulation of the problem, assessment of exposure as well as health effects, and finally, the risk characterization. Often, stochastic techniques such as Monte Carlo modelling could also be devised as suitable microbial quantitative risk assessment methods⁷⁴. The data thus generated, could be used in arriving at decisions during risk management, and employed for effective implementation of hazard analysis and a critical control point (HACCP)- based food safety assurance programmes. Although the concept of ‘farm-to-fork’ has progressed in the aquaculture processing sector, yet its application in farming to ensure food safety remains still in infancy¹².

Role of One Health in the fisheries sector

The issues and challenges connected with the food safety, food security, and production systems ensuring a holistic sustainable development could collectively qualify as a societal and wicked impasse. Hence, ensuring safe, secure, affordable, and quality food for all is pragmatically difficult. However, developing a One Health (OH) lens would suit a better outlook to these nagging challenges⁷⁵. The further extension of OH principle beyond the scope of zoonoses can successfully address food safety, especially in aquaculture practices. The OH principle would thereby facilitate improved production of aquatic species to ensure sustainable environmental footprints for meeting the local socio-economic demands⁷⁵.

Human health

In general, food production systems can provide a wide range of public health as well as socio-economic benefits. The OH principles can achieve investment and optimization towards productivity, welfare concerns, and ecosystem health. Practically, the market preferences or societal goals to tolerate health will

play a crucial role. The ever-increasing population, as well as urbanising trends in the human population, may compromise the accessibility and nutritive quality of natural foods; therefore, the processed foods are of utmost importance. Aquaculture enterprises can solve this issue to a greater extent by providing locally available nutritious foods mainly in low- and middle-income countries (LMICs), thereby opening up employment avenues to many^{12,76}. In short, scope for trade, opportunities for better employability, quality diet and better infrastructural facilities determine the success metrics of aquaculture. Moreover, a safe supply chain (farm- to- fork) is imperative to alleviate the burden of public health impacts and to enhance the economic stability of the society and nation. Hence, access to an optimum quantity of safe and nutritive food is pivotal for the sustenance of life, promoting better health and thereby stabilising the economy⁷⁵.

While public health threats are emerging, early evaluation of such risks is essential to uphold the OH principles. For instance, the escalating international trade has impacted the bivalve mollusc production ever since the 1950s, the dearth in the framework, availability of the origin, occurrence, and characterized data of those pathogens of public health significance in the aquatic ecosystems have underestimated the supply chain demands and exports from LMICs⁷⁵.

Organism health

Food production involves complex socio-ecological systems within an environment with a wide variety of species habitat. Farmed macrobiotic communities interact often with a wide range of eukaryotic as well as prokaryotic microbes inside the aquatic environment. Within the aquatic ecosystem involves a variety of known and unknown pathogens that may produce infection and disease. Hence, the crop-growing water bodies are regarded as artificial ecosystems that can act as a conducive environment for rapid propagation of pathogens and emergence of public health outbreaks⁶. It is therefore, important to consider the stock management in terms of public health aspects, particularly biosecurity, zoonoses, therapeutic and/or interventional impact on the limited aquatic environment.

The intensive aquacultural practices have necessitated the use of chemicals (pond fertilizers, biocides, chemotherapeutics, and formulaic feeds) for improving stock performance. On the research front, microbial identification and hazard profiling employing sophisticated technologies such as metagenomic

analysis or next-generation sequencing of water bodies, feed, and host tissues are attracting wide momentum. Such technological advancements could not only identify the biosecurity risks associated with aquaculture but also prevent the pathogen spillover to the adjoining environment and wildlife *per se*^{75,76}.

Environmental health

The majority of aquaculture enterprise is fresh water-based, and the rest is based on marine and brackish habitats. However, drastic climatic changes have resulted in the heating up of water bodies and the expansion of hypoxic zones affecting the marine ecosystem⁷⁷. Culture platforms for aquatic species (bivalves and seaweeds) enact as home grounds for natural biodiversity and lift the efficiency to maintain nutrient and microbial levels within the water column. On the other hand, onshore aquaculture systems provide a better possibility for environmental control, biosecurity measures, and a smaller environmental footprint in comparison with open systems. Besides, sustainable management on the pressing environmental sanitation issues (pollution and effluent discharge) needs to be given special attention in those areas where petite or sparse freshwater regulatory measures exist⁷⁵.

In order to ensure food safety and thereby preventing food-borne illnesses, rapid and reliable detection of pathogens and/or toxins is required. The farm managers, food producers, processors, distributors, handlers, and vendors bear the primary responsibility, whereas the consumers shall remain attentive. The governing agencies must enforce and implement pragmatic food safety regulations to safeguard public health. Medical practitioners need to remain enthusiastic to prevent such illnesses and treat those diseases with a safe diet under proper supervision. Veterinarians, aquaculturists, and agriculturists shall shoulder collaboration with all their stakeholders in the light of chemical and pathogen spillover with an ultimate aim to ensure food safety in the larger interest of the society.

Conclusion and perspectives

Seafood being one of the most merchandized global supplies, the unaccounted international burdens of socio-economic practices require special consideration within the aquaculture enterprise. The achievement of success metrics in the aquaculture sector at national levels, together with the international collaboration

would form a firm foundation for the adoption of OH principles in practice.

The food safety has now become a pressing and burning global issue. Hence, stakeholders from diverse domains (government agencies, industry experts, researchers, academicians, and the community) should involve themselves to simplify the food systems to uncouple the public health benefits of consuming good quality aquatic protein sources from adverse impacts on the environment, organism, and the society. Integration of good aquacultural practices with the existing regulations may deliver encouraging impacts. The convergence of various sectors in a holistic pattern under 'One Health umbrella' would facilitate increased production of aquaculture species for effective food production and sustainable environmental footprints meeting the regional socio-economic demands.

Taking leads from this approach and the past successes involved in various other domains like zoonotic infections, it is the need of the hour to inculcate a OH approach in food safety, especially the fisheries sector with an ultimate aim of achieving health and well-being for humans, co-existing non-humans and their communal environment for achieving planetary health.

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