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Prawns and shrimps: review of the aquaculture, biology, microbes and preservation

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Abstract
Food, fish and other aquatic product’s insecurity in developing and underdeveloped countries has led to the evasion of some diseases attributable to the consumption of these products. Seafood however refers to all fresh or salt water organisms such as shellfishes, fin fishes, mollusks, crustaceans and all other forms of aquatic animal life. Shrimp continues to represent one of the safest forms of muscle protein consumed in the world. Actual reported illnesses or outbreaks are rare and usually involve mishandling or cross contamination in retail/food service settings or home. Seafood products are generally safe for consumption although, the bacterial load is high especially at the time of harvest due to the harvest techniques adopted. Poor post-harvest handling which may have removed the slime or protective covering on these aquatic species, poor processing techniques of such products also lead to an increase in the microbial load on these products. Therefore, this review is aimed at evaluating the culture, biological characteristics, microbial contaminations and ways of preserving Prawns and Shrimps from our water bodies.

Keywords: Prawns and shrimps, culture, micro-organisms, conservation, good health and well being

1. Introduction

On the bases of reported illnesses per volume consumed, shrimp among seafood is possibly the least problematic product. Microorganisms are very tiny one-celled organisms, viruses, fungi, and bacteria, they are found everywhere in the world. They are found in all living things, plants and animal. Some of these pathogens can be harmful and causes diseases, but there are some microorganisms that are needed for living things to survive [1].

The increasing complexity of food supply, technological innovations and ongoing globalization appears to drive new hazards into existence, or to reduce our capacity to manage the hazards that are known. Such new, unforeseen problems have been dubbed emerging risks. Government intervention in relation to food risks has often been reactive, whereas food safety incidents tend to build up rapidly. A more pro-active approach to risk prevention could prevent or make harmless the potential hazards before they have developed into problematic risks.

In Nigeria however, large numbers of these sea food processing plants are available but proper monitoring of foods and other edible items is not always carried out by institution or organizations concerned thereby, giving room to the fisher folks and sellers of other aquatic products to neglect the importance of hygiene practice on these products by exposing them to all sorts in the market place where consumers come to purchase and consume mostly without further processing such as washing, cooking or heating. Microbial contamination could also be due to unhygienic conditions in harvest areas like open toilets, use of untreated/wet organic manures such as cow dung, poultry manure, industrial effluents and sewage disposal into the water body in which the prawns inhabit [1].

Aquatic products or frozen foods consumed raw can endanger the health of the consumers due to the presence of microorganisms which are disease-causing pathogens such as bacteria, fungi, viruses, nematodes. These microorganisms are ubiquitous in nature (i.e. they are everywhere at every time), though occurring in various concentrations. Seafood however harvested from polluted waters also may carry bacteria and other pathogens gotten from human and animal waste.

A major source of microorganisms is the soil and they are then transferred to the prawns either through their contact with the gears, smoking kilns, hands or baskets. In order to ensure prawns good or hygiene for consumption, proper handling between capture and delivery to the consumer is a crucial element in ensuring quality of the final product. The standard of sanitation, handling method, time and temperature of holding the prawn also affect the prawn quality [1].

2. Aquaculture

Aquaculture has been celebrated globally and believed to usher in a viable alternative to capture fisheries. It is most welcomed especially now that the world population explosion has pushed the demand on fisheries products to worrisome limits. Shrimp farming is an area of aquaculture that has witnessed significant growth in recent years, contributing substantially to the global aquaculture production. However, intensification of shrimp aquaculture has come with unintended consequences such as wastewater management and other problems emanating from environmental impact of the wastewater. This study identified excess feed and fertilizer application, metabolite wastes, shrimp mortalities, oil spillage from farm machines, drug and chemical abuse as some of the activities contributing to wastewater generation in shrimp aquaculture farming. The impact of shrimp effluent water discharged has been observed to be socio-economic with both positive and negative dimensions. In attempt to overcome the overwhelming problems associated with shrimp effluent water and bring reassurances to its sustainability, a good number of new technological approaches have been identified including cavitation, high-rate algal pond system, use of nanomaterials, bio floc technology, Nano adsorbent and polymeric Nano adsorbents. Although all have been proven to be useful, none could boast of a complete and integrated approach that considers all the technological, legal, social, environmental, public health and institutional concerns. Unless modern and better ways of handling aquaculture operations are adopted, “tragedy of the commons” is inevitable as far as environmental impact is concerned. Undoubtedly, aquaculture poses as the fastest industry worldwide with enormous potential to arrest the ever-increasing wild fish demand thereby bringing a steady halt to overfishing. The consumption of fish is estimated to hit one million tons globally by 2030 [2].

2.1. Water Sources

Water pollution, biodiversity loss, disease outbreaks and habitat destruction resulting from the build-up and discharge of metabolites from the shrimp culture facilities are a major factors hampering high productivity in the system. These do not only affect productivity but also impact negatively on the environment thereby promoting clashes between shrimp aquaculture and other ventures. This has greatly undermined the sustainability of shrimp aquaculture and hence, a call for measures to mitigate this deterioration trend. Various attempts have been expressed to reduce the nutrient content of shrimp aquaculture wastewater at the laboratory and field scale. The wastewater treatment can be on-site bioremediation or out-site treatment [3]. On-site bioremediation refers to the natural wastewater treatment carried out at the point where it is generated. For instance, treatment of shrimp wastewater inside the pond during culture period; while out-site treatment entails the treatment of effluent water that has been moved out of the contaminated site. The urgent need to come up with useful advances to tame the serious negative impacts of shrimp aquaculture wastewater is compelling and can never be overemphasized. It has been reported that over 1.2 billion people are affected by poor water quality resulting to about 15 million death in children yearly over the world [3]. As a result of these staggering figures of death resulting from water pollution, many conventional methods have been advanced for shrimp aquaculture wastewater management. Some of these include coagulation, advanced oxidation process, membrane filtration process, adsorption, dialysis, phytocatalytic degradation and biological methods.

2.2. Activities leading to Wastewater Generation

In shrimp farming, wastewater may be generated during the full harvest stage. During production, shrimp feed, feces and dead organisms may significantly pollute the water. In another scenario, excessive use of chemicals in the culture system as well as disturbance of the pond bottom sediments can also pollute the upper layers of the pond water [4]. In addition, poor farm management practice such as littering of the farm with wastes resulting from dead shrimps can also add to the pollution load into the cultured water.

2.3. Metabolic Wastes

Feces are a major waste resulting from feed digestion in shrimps. The release of feces into the culture water, no doubt contributes to the pollution load of the water. Shrimp feces are rich in nitrogen and phosphorous which causes excessive algae growth, which potentially to cause algae bloom in water bodies receiving effluents from shrimp farms.

The heavy feed taken by shrimp in intensive culture system undergoes metabolism thereby releasing toxic nitrogenous substances into the culture water. These substances initiate series of reactions leading to products that add to the pollution level and deteriorate water quality. The major metabolic wastes reported in shrimp aquaculture wastewater are ammonia, urea and carbon dioxide [5]. As reported in the culture of *Peneaus monodon*, addition of these wastes into the culture water comes in two ways; either from the digestion and metabolism of egested feed or from unconsumed feed which make up about 11% of the total feed applied. Among the metabolic products reported from shrimp wastewater, ammonia has been identified as the most toxic and a major challenge in wastewater management. High total ammonia nitrogen has been reported to hamper shrimp production by lowering the water quality. To overcome this, regular water exchange is advised. However, apart from the laborious nature of water exchange, where to discharge the old water is often the problem. Therefore, a better way of handling such high ammonia level wastewater is to lower the ammonia level by chemical or biological treatment before discharge into the environment.

2.4. Impacts of Shrimp Aquaculture Wastewater on Environment

Shrimp aquaculture wastewater impacts the environment in many ways. In most cases, the negative impacts are the most projected. The management of shrimp effluent water yielded significantly to the production cost in terms of operational and extra capital cost [6]. Also, the cost for environmental protection to ensure good public health combines with the already compounded problems of shrimp aquaculture wastewater handling.

2.5. Impact of Shrimp Aquaculture Wastewater on Biodiversity

The incessant discharge of high nutrient shrimp aquaculture wastewater to the adjoining environment (Figure 1) affects the biodiversity of creeping, swimming and flying organisms of such areas. The nutrient rich and toxic effluent water destroys the breeding sites, nesting beds, roosting grounds and bird shelters [7]. In addition, more useful biota may be destroyed giving way to less important but more tolerant species of organisms. The toxic shrimp wastewater also impacts so much on the biota leading to the total extinction of some organisms.

Fig 1: Wastewater discharge from a shrimp farm

3. Prawn belong to the Kingdom----animalia, Phylum ----- arthropoda, Subphylum------crustacea, Class------ malocastraca, Suborder-----dendrobranchi.

The prawns are decapods crustaceans belonging to the suborder; dendrobrachiata.

Prawns are found worldwide and they include commercially significant species such as the white leg shrimp *(Litopaneausvannamer)* atlantic white shrimp *(Paneaussetiferus)*, Indian prawn (*Fenneropaneaindicus*) and tiger prawn (*Paneausmoodon*).

3.1. Characteristics of Prawn

Prawns are similar in appearance to other small swimming decapods such as shrimps (*Caridea*) and boxer shrimp (*Stenodidea)* but can be distinguished by the gill structure which is branching in prawns,(hence the name; *Dendrobranchia)*. One exception is the family *Luciferidea* which lack gills as adults. Prawns usually have claws on three pairs of their legs while shrimps have claws on only two. Prawns and shrimps belong to the same family as crabs and lobsters and are similar in a number of ways. They are a decapod crustacean, which means that they have 10 legs and a hard shell covering their body, although the shell that covers prawns and shrimps is much thinner than and not as hard as the shell of most other crustaceans. As with crabs and lobsters, shrimps and prawns must shed their shells in order to grow bigger. One of the main differences between prawns and shrimps and their relatives, the crabs and lobsters, is that prawns and shrimps primarily swim about, as opposed to crabs and lobsters that crawl. Prawns and shrimps also start their 4-year existence as males and then change into females for their final year of life. Unlike almost all other decapods, prawns do not brood their eggs on the pleopods but release the eggs into the water after fertilization.

Living prawns are divided among 7 families with 5 in the super family *Panaeoidea* and two in the Family *Sergestoidea* and collectively these include 540 extinct species and nearly 100 exclusively fossil species [1].

Freshwater prawns have a hard outer shell that must be shed regularly in order to grow. This process is called molting and because of this molting nature, growth occurs in increments rather than continuously. These further results in four distinct phases in their life cycle: egg, larvae, post larvae and adult. The females become sexually matured before six months of age. Mating in prawns occurs only between hard-shelled males and ripe females that have just completed their pre-mating molt and are soft-shelled. Adult males are larger than the females and the sexes are easily distinguishable [1].

3.2. History of Prawns

The earliest fossil prawns came from the rocks in Madagascar of permo-triassic age 250 million years ago [1]. There is a difference between prawns and shrimps although they are used interchangeably. The difference actually lies in their gill structure. Prawns have a branching gill structure while the gill structure of shrimps is lamella. Prawns are also similar to lobsters as they have two pairs of small pincers but due to the fact that they are similar in size to shrimps, they are sometimes confused. There are over 300 different species of prawns and shrimps which are found in most waters all over the world and a huge amount are found in waters of the pacific, Atlantic, gulf of Mexico, Indian and arctic ocean, although, they are also found in other parts of the world.

Prawns are either cold water or warm water and the cold water prawns are located in cold water oceans such as Atlantic and Arctic while warm water prawns are located in warm water oceans such as pacific and Indian ocean.

3.3. Nutritional Values of Prawns

Prawns are extremely good source of protein, yet are very low in fat and calories thereby, making them a very healthy choice of food. Meat and dairy are also good sources of protein but they tend to be very high in calories and saturated fat. Prawns also contain a lot of omega-3 fatty acids but these fatty acids are good and thus helps prevent against heart disease, circulatory diseases and many other types of illnesses. They have a high level of vitamin B12, zinc, iodine, phosphorus, potassium, selenium and iron but have smaller quantity of magnesium, calcium and sodium.

Many of these vitamins are essential for healthy skin, bones and teeth. The short supply of animal protein to a level almost beyond the reach of low income earners has thus led to an increase in the demand for prawns. Prawns (particularly the shell spine-prawn) on the average is composed of 9-35mg of glucose, 10-60mg of glycogen, 15-20% percentage protein, 1.5% extractives, 1.5% ash, 0.2% fat and 60-80% water [1].

4. Shrimps are crustacean (a form of shellfish) with an elongated body and a primarily swimming mode of locomotion – typically belonging to the Caridea or Dendrobranchiata of the decapod order, although some crustaceans outside of this order are also referred to as "shrimp".

Fig 2: The shrimp *Palaemon serratus* of the infraorder Caridea

More narrow definitions may be restricted to Caridea, to smaller species of either group or to only the marine species. Under a broader definition, *shrimp* may be synonymous with prawn, covering stalkeyed swimming crustaceans with long, narrow muscular tails (abdomens), long whiskers (antennae), and slender legs. Any small crustacean which resembles a shrimp tends to be called one. They swim forward by paddling with swimmerets on the underside of their abdomens, although their escape response is typically repeated flicks with the tail driving them backwards very quickly. Crabs and lobsters have strong walking legs, whereas shrimp have thin, fragile legs which they use primarily for perching.

Shrimp are widespread and abundant. There are thousands of species adapted to a wide range of habitats. They can be found feeding near the seafloor on most coasts and estuaries, as well as in rivers and lakes. To escape predators, some species flip off the seafloor and dive in to the sediment. They usually live from one to seven years. Shrimp are often solitary, though they can form large schools during the spawning season. They play important roles in the food chain and are an important food source for larger animals ranging from fish to whales. The muscular tails of many shrimp are edible to humans, and they are widely caught and farmed for human consumption. Commercial shrimp species support an industry worth 50 billion dollars a year, and in 2010 the total commercial production of shrimp was nearly 7 million tonnes. Shrimp farming became more prevalent during the 1980s, particularly in China, and by 2007 the harvest from shrimp farms exceeded the capture of wild shrimp. There are significant issues with excessive by catch when shrimp are captured in the wild, and with pollution damage done to estuaries when they are used to support shrimp farming. Many shrimp species are small as the term *shrimp* suggests, about 2 cm (0.79 in) long, but some shrimp exceed 25 cm (9.8 in). Larger shrimp are more likely to be targeted commercially and are often referred to as *prawns*, particularly in the Commonwealth of Nations and former British colonies [1].

4.1. Scientific Classification of Shrimps

Kingdom	:	Animalia
Phylum	:	Arthropoda
Subphylum	:	Crustacea
Class	:	Malacostraca
Order	:	Decapoda
Suborder	:	Pleocyemata
Infraorder	:	Caridea

4.2. Shrimp Habitat

Shrimp are widespread, and can be found near the seafloor of most coasts and estuaries, as well as in rivers and lakes. There are numerous species, and usually there is a species adapted to any particular habitat. Most shrimp species are marine, although about a quarter of the described species are found in fresh water. Marine species are found at depths of up to 5,000 metres (16,000 ft), and from the tropics to the polar regions. Although shrimp are almost entirely fully aquatic, the two species of *Merguia* are semi-terrestrial and spend a significant part of their life on land in mangrove.

4.3. Microbial Contamination in Shrimps and Prawns

Fresh and processed shrimps and prawns can harbour various types of microbes, including bacteria, viruses, and fungi. The specific microbial populations can vary depending on several factors such as the source of the seafood, handling and processing methods, storage conditions, and hygiene practices.

Here are some common microbes associated with fresh and processed shrimps and prawns:

4.3.1. Bacteria

Bacteria are the most common microorganisms found in seafood, including shrimps and prawns. The most common shrimp pathogenic bacteria belong to the genus Vibrio. Other Gram-negative bacteria such as *Aeromonas spp*, *Pseudomonas spp.*, and *Flavobacterium spp.*, are also occasionally implicated in shrimp diseases.

- **Vibrio spp.**

Several *Vibrio* species have been found to be causative agents in food-borne diseases. The genus *Vibrio* include Gram-negative, rod shaped, curved, non-spore forming, motile, and facultative anaerobic bacteria. They are more prevalent in estuarine and coastal areas, where they live freely in water, sediments, plankton, and nearly all flora and fauna found in coastal environment [7]. The pathogenic species which are most likely to infect human are *V. parahaemolyticus*, *V. vulnificus*, and *V. cholerae*.

These are major human health microbial hazards risks causing seafood-borne diseases in the people who consume raw or undercooked contaminated seafoods [8].

- **Aeromonas spp.**

Some minor seafood-borne outbreaks have also been observed in *Aeromonas* spp**.** in India and Bangladesh. *Aeromonas* spp. are responsible for Epizootic Ulcerative Syndrome (EUS) in different fish, resulting in significant damage to quality of seafood products. The contamination of seafoods may be due to the colonization of gut by this bacterium in marine environment [1].

- **Staphylococcus aureus**

Human beings are the main source of enterotoxigenic *S. aureus* and seafoods become contaminated during handling under poor hygienic conditions. Staphylococcal enterotoxins produced by this bacterium are the cause of its pathogenicity and virulence with reference to food safety. These enterotoxins can cause gastroenteritis characterized mostly by vomiting in the patients [9]. In addition to cases of food poisoning due to *S. aureus*, a problem linked to the presence of methicillin-resistant strains of *S. aureus* in food also is rising continuously [10, 11].

- ***Salmonella spp.***

Salmonella are rod shaped, and facultative anaerobic Gram-negative bacteria. These are usually motile having peritrichous flagella and they are oxidase-negative, catalase-positive, and a non-lactose fermenter [12]. They cause moderate to severe enteric inflammation and diarrhea; and the symptoms start 12 - 72 hours after eating contaminated food. *Salmonella* spp. are terrestrial bacterium that could be found in the intestine of animals such as poultry, cattle, reptiles, etc.; however, consumption of raw, and undercooked finfish, mollusks, and crustaceans can cause salmonellosis. Environmental factors such as water quality play a very important role in the occurrence of *Salmonella* in fish and pose a great risk for those consuming fish caught in contaminated waters without sanitary control [13, 14].

4.3.2. Fungi

Various types of fungi, including molds and yeasts, can grow on shrimp and prawns if they are not stored properly. While some molds are harmless, others may produce mycotoxins that can cause illness if consumed in significant quantities. An example of fungi associated with shrimps and prawns is *Fusarium sp.* (Fungus Disease) of Shrimp and Prawns.

4.3.3. Viruses

There are several viruses that can infect shrimp, causing mortality, slow growth, and deformations_[1]. The most important shrimp viruses include:

- Baculovirus Penaei (BP)
- Baculoviral Midgut Gland Necrosis Virus (BMN)
- Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV)
- Hepatopancreatic Parvo-like Virus (HPV)
- Monodon Baculovirus (MBV)

4.3.4. Parasites found on Shrimps

Shrimp parasites are a common problem for shrimp farmers and aquaculture owners because they can cause significant economic losses. Some parasites that affect shrimp include the trematode parasite, the fluke parasite, and the cestode parasite [1].

Other types of parasites which affect shrimps include:

1. Biotoxins – the shrimp has a parasite that produces cyanobacteria, which is toxic to humans.
2. Sapovirus – shrimp have a virus that causes diarrhea and vomiting.
3. Pseudofilter- this parasite attaches itself to the gills of the shrimp and prevents it from breathing properly, eventually killing it.
4. White spot syndrome- this disease causes white spots on the shrimp's body and they die prematurely as a result of it.
5. *Stichodactyla gigantea*– is a parasitic crustacean that burrows into the flesh of the shrimp and eats its insides out.

4.3.5. Parasites that can be found on prawns include:

- Cyanobacteria-producing parasite that is toxic to humans.
- Sapovirus, which causes diarrhea and vomiting.
- Pseudofilter, which attaches itself to the gills of the shrimp and prevents it from breathing properly, eventually killing it.
- Bopyrid isopod, a crustacean that hitches a ride on planktonic copepods to travel to new and far-flung mudflats in search of shrimp blood.

5. Microbes Associated with fresh Shrimps and Prawns

5.1. Pre-harvest contamination

The spoilage microflora of fresh ice-stored fish consist mainly of Gram-negative *Pseudomonas spp.* and H_2S-producing bacteria including *Shewanella putrefaciens. Acinobacter* and *Moraxella spp.* may comprise a portion of the spoilage microflora. It was reported that spoilage microflora was found on haddock fillets stored at refrigeration with abused temperatures showed Photobacterium phosphoreum to be the dominant spoilage microorganism [15]. Pseudomonas spp. and Shewanella putrefaciens were also present, being responsible for spoilage off-odors. The early stages of spoilage involve utilization of non-protein nitrogen, resulting in the formation and accumulation of fatty acids, ammonia and volatile amines. As proteolysis proceeds, spoilage becomes more evident. Hydrogen sulfide and other sulfur compounds, such as mercaptans and dimethyl sulfide, produced by *S. putrefacians* and some pseudomonads usually contribute to spoilage [1].

5.2. Post harvest Contamination

After harvesting from the fish farm or capture at sea, fish may either be stored in ice or fresh-frozen. The flesh of mollusks differs from that of crustaceans and free-swimming fish in that it contains an appreciable amount of carbohydrates in the form of glycogen. Even though microorganisms involved in mollusks' spoilage are the same as those encountered in fish and crustaceans (*Pseudomonas* and *Acinetobacter-Moraxella spp*.), spoilage of the former is primarily glycolytic (it contains 1–5% glycogen) rather than proteolytic, leading to a pH decrease from around 6.5 to 5.8. Under such conditions of acidity, enterococci, lactobacilli and yeasts dominate the later stages of spoilage.

On the other hand, crustaceans such as shrimp and prawns, in addition to their endogenous microflora, are subject to a more rapid microbiological spoilage due to usual contamination with bacteria from the mud trawled up along with these species following capture. Microbial spoilage of crustaceans occurs in a similar manner to fish flesh; however, the higher amount of free amino acids and other soluble nitrogenous compounds present leads to rapid spoilage and elevated levels of volatile basic nitrogen spoilage compounds [1].

5.3. Methods of preservation of Shrimps and Prawns

The flesh of fish is composed of macro constituents: moisture, proteins and fats, and micro constituents: minerals, vitamins and enzymes. In addition, crustaceans and mollusks contain carbohydrates in the form of glycogen. Due to their specific composition, seafood products are considered a very perishable commodity. The fact that fishing vessels gear seafood usually at large distances from the sites of consumption necessitates proper preservation to avoid product spoilage. This need is further driven by consumer demand for high-quality, lightly processed products with minimal changes in nutritional and sensory properties. This also applies to aquacultured seafood species which need to be properly preserved in order to be safely shipped to far away destinations. Besides traditional seafood preservation methods including chilling (at 0–1 °C), freezing (<1 °C), drying, smoking, salting, fermentation and canning, more recent methods of seafood preservation include (1) the use of natural preservatives, (2) high hydrostatic pressure treatment, (3) ozonation, (4) irradiation, (5) pulse light technology, (6) retort pouch processing and (7) packaging in combination with refrigeration or freezing [1].

5.3.1 Use of Natural Preservatives

Fresh seafood products are extremely perishable even when refrigerated and susceptible to microbial growth, autolytic activity and lipid oxidation. In order to maintain quality and extend seafood shelf life, preservatives may be added during product processing and storage. As a response to consumer demand for fresh, minimally processed foods containing no chemical additives, the food industry has turned to natural preservatives in order to maintain the quality and safety of consumed foods. Natural preservatives should be effective against a broad spectrum of bacteria and fungi, be active at low concentrations, be nontoxic, should not affect food sensory properties, should impart no flavor or color to food and, finally, should be cost-effective. Natural preservatives may be isolated from microorganisms, animals and plants. The main categories of natural preservatives used in seafood products include: organic acids, essential oils and plant/algal extracts, bacteriocins and chitosan [1].

5.3.2. High Hydrostatic Pressure

High hydrostatic pressure (HHP) is a non-thermal method of preserving food, in which the product is processed under very high pressure, leading to the inactivation of microorganisms and enzymes in the food. The first food products preserved by pressure entered the Japanese market in 1990. HHP has a similar effect on microorganisms and enzymes to high-temperature treatment. Pressures applied during treatment are usually in the range of 100–600 Mpa but may be as high as 1200 MPa for spore inactivation (sterilization). Microorganism inactivation is the result of cellular damage and biochemical changes resulting from food exposure to high pressures. It has been shown that fungi are more susceptible to damage by HHP, followed by Gram-negative and Gram-positive bacteria. Exposure to high pressure can also result in texture alteration of food products but such changes are reported to be reversible in the range of 100–300 MPa [1].

5.3.3. Irradiation of Seafood

Ionizing irradiation is used as a food preservation method by the seafood industry to (i) extend product shelf life (by effectively destroying spoilage microorganisms), (ii) improve food safety (by destroying pathogens responsible for foodborne illnesses), (iii) delay or eliminate sprouting or ripening and (iv) control insects and invasive pests. Irradiation is achieved using gamma rays, electron beams or X-rays. The supplied energy abstracts electrons (ionizes) from atoms in the targeted food. Independent research carried out by the World Health Organization and food regulatory agencies in the USA and EU has confirmed that irradiation is safe. Variations exist among different countries regarding regulations on which foods and at what doses can be irradiated. In numerous European countries, i.e., Austria, Germany and Greece, irradiation up to a dose of 10 kGy is only permitted for dried herbs, spices and seasonings. In contrast, in countries like Brazil and Pakistan, all foods are allowed to be irradiated. Irradiated food does not become radioactive (within the accepted energy limits, i.e., 10 MeV for electrons, 5 MeV for X-rays (US 7.5 MeV) and gamma rays from Cobalt-60), but irradiation can result in significant deterioration in the nutritional content and sensory properties of irradiated foods. Radiolytic products in the form of free radicals are another issue in food irradiation. The type of food and degree of treatment significantly affect changes in food quality and nutritional value caused by ionizing radiation [1].

5.3.4. Ozonation of Seafood

Ozone is a powerful disinfectant for bacteria, yeasts, molds, parasites and viruses. It causes extensive oxidation of (i) internal cellular proteins and (ii) unsaturated fatty acids in the cell envelope, resulting in rapid cellular damage. Research has also revealed gram-positive bacteria are more tolerant compared to gram-negative bacteria [16].

Vibrio parahaemolyticus can cause foodborne disease outbreaks especially involving seafood products. Feng *et al*. evaluated the following three parameters with regard to the efficacy of ozone treatment for the inactivation of *V. parahaemolyticus*: (i) aqueous O3 concentration; (ii) duration of treatment; and (iii) inoculated bacterial population. The most influential factor on the fate of the bacterium was shown to be the aqueous ozone concentration. Bacterial cell membranes remained intact at low O3 concentrations. On the contrary, at O3 concentrations above 1 mg/L, the functional integrity of bacterial membranes was compromised. Aqueous ozone penetrated the cells through leaking membranes, inactivating the enzymes and degrading the genetic material, eventually leading to cell death. Ozone treatment was also successfully used to control the bacterial load of commercial ice-producing machines by a factor of 10^4. Furthermore, no product flavor deterioration was noted using ozonated ice for preserving seafood.

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