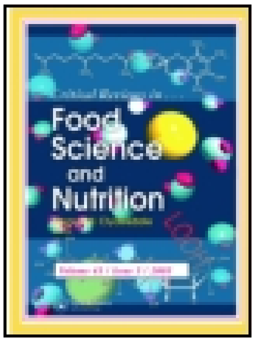

Critical Reviews in Food Science and Nutrition

ISSN: 1040-8398 (Print) 1549-7852 (Online) Journal homepage: https://www.tandfonline.com/loi/bfsn20

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CRITICAL REVIEWS IN FOOD SCIENCE AND NUTRITION
https://doi.org/10.1080/10408398.2020.1749024

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REVIEW

Possible food safety hazards of ready-to-eat raw fish containing product (sushi, sashimi)

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ABSTRACT
It is undeniable that with the popularity of sushi and sashimi over the last decade the consumption of raw fish has extremely increased. Raw fish is very appreciated worldwide and has become a major component of human diet because of its fine taste and nutritional properties. Possible hazards concerning fish safety and quality are classified as biological and chemical hazards. They are contaminants that often accumulate in edible tissue of fish and transmit to humans via the food chain affecting the consumer's health. Although their concentration in fish and fishery products are found at non-alarming level of a daily basis period, they induce hazardous outcome on human health due to long and continuous consumption of raw fish. Regular sushi and sashimi eaters have to be aware of the contaminants found in the other components of their dish that often add up to acceptable residue limits found in fish. Hence, there is the urge for effective analytical methods to be developed as well as stricter regulations to be put in force between countries to monitor the safety and quality of fish for the interest of public health.

KEYWORDS
Ready-to-eat food; biological risks; micro-organisms; environmental contaminants; marine biotoxins; toxic chemicals

Introduction

Fish and seafood have wide-ranging nutritional benefits due to their natural components. They contain not only n-3 polyunsaturated fatty acid (PUHA), but proteins with high nutritional value, essential amino acids (cysteine, glutamine, hydroxyproline, proline, taurine), bioactive peptides, different essential minerals (e.g. calcium, selenium, iron, zinc), and also water- and fat-soluble vitamins (B_3, B_6, E, D) can be found in them (Daschner 2016).

The high nutritional values and health benefits associated with the consumption of sushi cannot be denied because of the nature of its components.

Although sushi and sashimi production was originally a preservation method for fish products in Southeast Asia since the 7th century, with globalization, a circulating global commodity is accessible to the masses regardless of social class. While sushi consists of vinegared cooked rice dressed with different vinegared ingredients such as raw or cooked seafood, marine fish, vegetables, meat, cooked egg that can be wrapped or not in seaweed sashimi is made up of raw-only marine fish or seafood products. However, the word "sushi" is commonly used to refer to both sushi and sashimi. The number of sushi restaurants in the United States was over 5000 meaning and is popular gourmet as fast food chain in the UK (Hsin-I Feng 2012). Sushi restaurants are distributed worldwide showing increasing pattern with 30–50% compared to the results of the previous study conducted, and over the five years (2024), the Sushi Restaurants industry is expected to continue its expansion (Anonym 2020).

Fish fat and oils are notably beneficial to human health in long period. Unsaturated fats found in fish are rich in omega-3 fatty acids which are extremely important for a healthy functioning central nervous system as well as crucial in reducing inflammatory response and reducing the risk of cancer and heart related diseases such as strokes. Omega-3 fatty acid such as eicosapentaenoic acid and docosahexaenoic acid (DHA), typically found in tuna, salmon and herring, which are typical sushi fish, have been claimed to reduce coronary heart disease (Daschner 2016; Gibson 2018). In fact, The National Fisheries Institute (NFI) advises a fish intake of two servings per week for a healthy heart. Wasabi, the ingredient used to add flavor and disinfect raw fish used for sushi has been proven to be an immune system enhancer due to its antibacterial properties and its action against latent pathogens because of its high content of beta-carotenes, glucosinolates and various isothiocyanates. It also acts as a bactericidal for bacteria such as *E. coli* and *Staphylococcus*. Studies on congestive disorders and asthma have praised the action of wasabi on reducing excess chest and nasal cavities mucus which worsen asthma conditions. Nori, a special seaweed used in sushi, consists of a high amount of iodine, iron, calcium, sodium, magnesium and phosphorus. Crucial vitamins such as vitamin A, B_1, C and E as well as substances important to fight cancer can also be found in nori. On top of all its benefits nori has a unique capacity that is the removal of radioactive strontium and other heavy metals from the body (Hsin-I Feng 2012).

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Cultural globalization changes the diet of populations worldwide and would increase the consumption of a certain type of food. The consumption of fish in western cultures and across the world has not only increased due to the widespread and commercialization of sushi but also because fish is considered a brain food and has strongly been proven as a healthy food by experts. However, despite being a food that promotes a healthy function of human body regular raw fish consumers such as in the case of sushi and sashimi are at risk of incurring a series of health detriments. It is important that consumers understand the health hazards associated with raw fish consumption due to the increasing demand for fish meat.

In the present review, the food safety hazards of ready-to-eat raw fish containing, e.g. sushi and sashimi, such as biological and chemical contaminants, and their impact on human health will be discussed and explained as well as the respective regulations put in force by important food administrations such as the European Food Safety Authority (EFSA), the Food and Drug Administration (FDA), the Seafood Hazards Analysis and Critical Control Point (HACCP), the Hong Kong Food and Environmental Hygiene Department's (FEHD) Sushi Surveillance Guidelines, the World Health Organization (WHO) and its special committee the Joint Food and Agriculture Organization of the United Nations/World Health Organization (FAO/WHO) Expert Committee on Food Additives (JECFA) will be highlighted.

Biological hazards

Biological hazards include zoonotic parasites and microorganisms such as bacteria and viruses that may induce food-borne infections in humans. Zoonotic agents are transmitted directly or indirectly via the consumption of contaminated foodstuffs or through direct contact with animals. A variety of biological agents are responsible for food-borne diseases. The European Food Safety Authority (EFSA) defines a food-borne disease as a result from the consumption of drinking water, raw and basic materials and products of food of animal and plant origin, or the animals themselves and even the feed for animals contaminated with pathogenic microorganisms which include viruses, bacteria, parasites, and fungi, many of which are zoonotic and will cause mild gastrointestinal symptoms to life- threatening human health conditions (EFSA (European Food Safety Authority) 2018b). Unfortunately, the consumption of sushi may expose consumers to possible food-borne zoonotic infections. In order to conserve the typical characteristics and integrity of sushi and sashimi, the high-heat cooking process, by which the majority of zoonotic pathogens can be killed is not used when preparing them (Hsin-I Feng 2012; Lee et al. 2006). As a result, the zoonotic bacteria and parasites present in these foods may pose a potential health risk to the consumers. Even though the correct deep-freezing process of fish will kill infectious parasites, the constant direct hand contact with fish during the preparation of sushi predisposes consumers to biological contamination.

Parasites

Parasites in their larval stage may pose a health hazard if ingested in non-cooked, undercooked, or unfrozen seafood (Han, Huang, and Mahunu 2017). Cestodes (tapeworms), trematodes (flukes), nematodes (roundworms) and recently Myxosporidia are the four major types of parasites responsible for raw fish and seafood zoonotic food-borne infections (Daschner 2016). Fish parasitic zoonoses have always been particularly found in Asia because of the importance of raw fish in their diet, but with aquaculture and the spread of aquatic foods to international markets as a result of culinary globalization, those parasitic zoonoses have emerged and are present passed the Asian continent (Chai, Darwin, and Lymberly 2005; Dorny et al. 2009; Liu et al. 2008).

Diphyllobothrium species are the most widely distributed parasitic tapeworms in fish responsible for zoonotic infections in humans countries throughout the world with prevalence in Russia, South Korea, Japan, South and North America, France, Italy, Switzerland, Sweden, Finland and Estonia (). Infection occurs with ingestion of raw or undercooked fish that contains the infective larval stage called plerocercoid. *D. latum and D. nihonkaiense* are the most common species with *D. latum* dwelling in freshwater fish such as perch, char, and pike whilst *D. nihonkaiense* is found almost exclusively in salmon (Daschner 2016; Dorny et al. 2009). Epidemiology for the *Diphyllobotrium* tapeworm has unquestionably transformed from rural to urban regions due to a fast development of fresh fish transportation system in order to meet the demands for seafood in healthy diets (Arizono et al. 2009). Although the worm can reach a surprisingly big size, infections in general tend to be without symptoms and if symptoms are present they will be mild and include diarrhea, abdominal pain, discomfort, weight loss, asthenia, megaloblastic anemia, immunosuppression, and can be cured without difficulties (Daschner 2016; Dorny et al. 2009; Vuylsteke et al. 2004).

The most important trematodes (flukes) affecting humans via consumption of raw or undercooked infected fish are *Clonorchiasis* and *Opisthorchiasis* species. They are transmitted through snails to freshwater fish from which it reaches humans or other mammals following their consumption (Daschner 2016; Dorny et al. 2009). Presence of trematodiosis was specific to areas where the first and second intermediate hosts cohabit. Endemic areas are countries in the east of Asia, however, an emergence of the disease has been observed in the past few years in countries throughout the world in which there is an increased consumption of traditional fish dishes such as sushi, sashimi, ceviche and carpaccio based on raw or undercooked fish meat due to the expansion of the international trade in fish (WHO 2002). Symptoms of clonorchiosis occur mainly due to heavy infections and include jaundice, ascites, cholangitis, choledocholithiasis, pancreatitis and even cholangiocarcinoma as well as formation of gallstones (Daschner 2016; Dorny et al. 2009). Intestinal trematodes are more common and are actually the most common in humans, their infection will result in abdominal pain, diarrhea and lethargy (Chai et al. 2009). Another important fish-borne trematode infection is caused by *Paragonimus westermani* that colonizes the lungs. It is mainly seen in Asia but due to globalization, travel and a change in the diet of people it may be present in different countries worldwide and is caused by ingestion of infected freshwater crustaceans mostly crabs and crayfish. Symptoms tend to be unexplained fever, cough, pleural effusion, hemoptysis and eosinophilia and the worms can also be seen in uncommon parts in the body such as the brain and the heart (Daschner 2016; Diaz 2013).

Some nematodes cause zoonotic infection and these include *Anisakid* nematodes, *Eurostrongylides* and *Gnathostoma* worms (Ljubojevic et al. 2015). The most important and common species affecting humans via fish and fish products are *Anisakid* nematodes including *Anisakis simplex*, *Pseudoterranova decipiens* and *Contracaecum osculatum*. *Anisakid* nematodes occur as third-stage larvae in marine fish from which they infect humans after ingestion of raw or undercooked fish productsInfective larvae of *A. simplex* are found in the body cavity, muscles and organs of the fish whilst *P. decipiens* is mainly in the muscles and *C. osculatum* is mostly in the liver, cecum, mesenteries and body cavity (Buchmann and Mehrdana 2016; Dorny et al. 2009). Anisakiosis has dramatically prevailed throughout the world over the last two decades with a greater preponderance in north of Asia and western Europe countries such as The Netherlands, Germany, France and Spain (Ljubojevic et al. 2015). Although all anisakids will either cause severe gastrointestinal infections in humans or will simply be passed out in the feces or manifested via vomiting some symptoms will tend to be specific to a species. *A. simplex* is responsible for most of the observed anisakiosis cases (Buchmann and Mehrdana 2016). Its symptoms often include abscess or eosinophilic granuloma, epigastric pain, vomiting, diarrhea and nausea whilst an infection with *P. decipiens* causes a tickling sensation in the throat of the infected person who will cough up larvae and in some cases vomiting is seen. *C. osculatum* causes infection in the gastrointestinal tract, however, infection related to this species is less common. Eurostrongylides have been known to cause gastritis and intestinal perforation in humans after ingestion of raw or undercooked fish or fish products (Ljubojevic et al. 2015). *Gnathostoma* nematodes are usually found in South-East Asia and Latin America, however, with the intensification of international travels and a change in the eating habits of people worldwide the disease has emerged in non-endemic countries. After ingestion the infective larvae enter the gastric mucosa to later reach the abdominal cavity and migrate in organs (larva migrans). Symptoms will be mainly cutaneous in the infected person but sometimes visceral ones can be seen, too. The most common cutaneous symptom is subcutaneous erythematous edema. Although rare, visceral symptoms can be seen in the eye, lungs, central nervous system, digestive tract and genito-urinary tract. Nonspecific symptoms such as fever, urticaria, nausea, vomiting and epigastric pain may be seen 24–48 h following ingestion of the larvae (Leroy et al. 2017).

Bacteria

Bacteria can rapidly reproduce under optimum temperature and environment. Cooking and irradiation are the most viable way of getting rid of bacteria in fish or fish product so consuming raw or undercooked fish greatly exposes the consumer to infections (Hsin-I Feng 2012). While some spoilage and pathogenic bacteria are part of the indigenous microbes that are naturally present in food products and they can nonetheless cause illnesses in consumers by ingestion of a naturally infected fish or by ingestion of contamination that resulted from mishandling. Many bacterial species are responsible for spoilage in the fish and fish products (Daschner 2016; Ghaly et al. 2010). The spoilage microbiota of a fish will mainly depend on the processing and preservation methods used, however, that of newly caught fish will depend on the microbial contents of the water it came from. *Pseudomonas* spp. and *Shewanella putrefaciens* are the most frequent spoilage bacteria of iced fresh fish (Gram and Huss 1996). Fish or fish products affected by spoilage bacteria has a bad smell, and an unpleasant taste and texture. Although spoilage bacteria generally do not cause illness, when ingested in very high concentrations they can cause gastrointestinal discomfort that is, however, usually self limiting (Blackburn 2006; Daschner 2016). Pathogenic bacteria will be responsible for bacterial infection and contrarily to spoilage bacteria they do not alter the color, taste or texture of the infected fish or fish product which makes it difficult to recognize a contaminated food. Food poisoning resulting from pathogenic bacteria can be classified into two main types of illnesses: food intoxication and food infection. Food intoxication results from the consumption of bacterial toxins produced in the food while food infection results from the consumption of bacteria that will then produce toxins in the digestive tract. Bacteria responsible for toxin production are *Staphylococcus aureus* and *Clostridium botulinum*. Botulism bacterium is found in the digestive tract of the fish where it produces a virulent lethal nerve toxin. Cases of botulism food intoxication are most of the time due to inadequately cold smoked, salt cured or fermented fish products. *Clostridium perfringens* will cause diseases by releasing toxins in the gut after consumption of a large number of vegetative cells (Han, Huang, and Mahunu 2017). Scombroid poisoning also called histamine fish poisoning occurs after a large production of biogenic amines due to bacterial decarboxylation of histidine in some particular fish that have high amounts of amino acid and those are tuna, mackerel, bonito, and more. This can also happen in nonspecific fatty and migrating fish. Histamine producing bacteria are found on the gills and gut of the fish and the process usually occurs in the captured fish (Daschner 2016). Bacteria responsible for food poisoning are *E. coli*, *Salmonella* spp., *Listeria monocytogenes, Staphylococcus aureus, Bacillus cereus, C. perfringens, Campylobacter* spp., *Shigella* spp., *Streptococcus* spp., *Vibrio cholera* (O1 and non-O1), *V. parahaemoliticus, V. vulnificus, Yersinia enterolitica and Y. pseudotuberculosis*. The common symptoms caused by them are abdominal pain, profuse watery diarrhea, vomiting, and nausea (Böhme et al. 2012). *Vibrio cholera* causes cholera whilst *V. vulnificus* is more dangerous and should be avoided at all costs. It has a virulent strain that causes high fever, decreased blood pressure, septicemia, and skin and flesh damage and frequently will cause death to those infected with it (McGee 2004).

Viruses

Unlike parasites and bacteria there are not many types of viruses responsible for viral food-borne illness arising from the consumption of raw or undercooked fish or fish products, however, they are nonetheless of importance. During the process of food making viruses are transmitted from individual to individual, from individual to food, or via fomites (NRA (National Restaurant Association) 2017). When it comes to fish, fish products and seafood most of the diseases are caused by a virus, especially the Norwalk virus an intestinal virus that is also called the norovirus. The norovirus is transmitted by food or water contaminated with feces. It is known to be the most common cause of human viral gastroenteritis in the world. The virus damages the small intestinal lining which then leads to vomiting and diarrhea in the affected person (Daschner 2016; Hsin-I Feng 2012). Transmission of the norovirus occurs during handling or preparation of seafood, fish or fish products as a result of bad personal hygiene such as improper hand-washing after the use of the bathroom and can affect people of all ages (Centers for Disease Control and Prevention 2015; NRA (National Restaurant Association) 2017). Hepatitis A is the second virus after the Norwalk virus that is commonly found in seafood fish or fish products and causes the most common type of hepatitis with distinctive symptoms being a sudden onset of fever, nausea, vomiting, fatigue and abdominal pain followed by several days of jaundice. It can also cause a long-lasting damage to the liver. As the Norwalk virus, the Hepatitis Virus originates from feces and sewage (Daschner 2016; Hsin-I Feng 2012).

Chemical hazards

In addition to biological hazards, chemical hazards can be, and it is often the case, present in our foodstuffs and this is particularly true for raw fish and seafood. Their presence can arise from natural sources, migration of chemicals, veterinary drug residues, deliberate or non-deliberate contamination (Krska et al. 2012). Heavy metals, fish biotoxins, pesticides and drug residues are the main chemical hazards associated with the consumption of raw fish, fish product and seafood based dishes.

Heavy metals

Presence of heavy metals in the fish is due to the soil geochemistry, erosion of the geological matrix, and different anthropogenic activities such as industrial mining wastes emptied in waters (Clarke et al. 2015; Yusà et al. 2008). The main ones associated with edible fish and seafood are lead (Pb), cadmium (Cd), arsenic (As), chromium (Cr) and mercury (Hg) (Maldonado-Simán et al. 2018). Prolonged exposure to these heavy metals can seriously deteriorate human health so with their fast-growing pollution in aquatic ecosystem they are of a major problem and concern worldwide (Gupta, Khan, and Santra 2008; Malik et al. 2010). Due to their high toxicity and their ability to cumulate in the food chain they have carcinogenic and other deleterious effects on the human health as a result of the biomagnification that occur with time (Has-Schön, Bogut, and Strelec 2006; Malik et al. 2010). Destructive effects include cancers and damage to the nervous system (Han, Huang, and Mahunu 2017).

Inorganic arsenic compounds have carcinogenic properties. According to human epidemiological data, the inorganic arsenic compounds occurring in foods and the drinking water increase the probability of development of skin, lung and urinary bladder tumors. This is directly attributable to genotoxic and epigenetic effects exerted by arsenic and its methylated metabolites (ATSDR (Agency for Toxic Substances and Disease Registry) 2007).

The concentration of arsenic in foodstuffs is usually low ($<0.25\,\mu g/g$). However, in aquatic ecosystem the arsenic content of marine fish and live bivalve mollusks is <2–$170\,mg/kg$ and in freshwater fish is <0.1-$3\,mg/kg$ but it incorporated into organic molecules such as arsenobetain, arsenocholine and arsenic derivatives of sugars and, therefore, their arsenic content may be high (IPCS (International Programme on Chemical Safety) 2001; Stoeppler 2004). These organic arsenic compounds, however, give much less cause for concern from food safety aspects, as they are less toxic and are rapidly eliminated from the human organism. According to relevant surveys, within the often-high total arsenic content of fish and shellfish the proportion of organic derivatives is usually $\geq 95\%$, whereas that of the more toxic inorganic arsenic compounds is only 2–5%. (EFSA (European Food Safety Authority) 2009)

The PTWI value of arsenic established by the WHO was previously $15\,\mu g/kg$ (JECFA-776776 1989; JECFA-959959 2011). It was withdrawn by WHO and has not yet created a new one. There is no established PTWI for organic derivatives, which may be ingested by people regularly consuming large quantities of fish in amounts as high as 300–$350\,\mu g$ per week.

Fish and shellfish may contain much higher concentrations of mercury than other species, in $>90\%$ of the cases in the form of methylmercury. It is due to the fact that, after being released into surface waters (lakes, seas), the inorganic mercury compounds of mostly industrial origin undergo biomethylation as a result of microbial activity in the aquatic environment, and the methylmercury thus produced then accumulates in lower aquatic organisms that serve as food for shellfish and fish (ATSDR (Agency for Toxic Substances and Disease Registry) 1999; IPCS (International Programme on Chemical Safety) 1986, 2003). As methylmercury undergoes biomagnification in the aquatic food chain, it may reach especially high concentrations in predatory fish that are at the top of the chain. The usual concentration of methylmercury in fish is $<0.4\,mg/kg$ but in predatory fish species it may be several times higher than that. Majority of people eat maximum 20–30 g of fish per day, but in certain regions the daily consumption of fish may reach 400–500 g. Accordingly, methylmercury intake with food may vary between ≤0.2 and 3–4 µg/kg (Costa et al. 2016; EFSA (European Food Safety Authority) 2012).

Chromium exists in different valence states. Among them the trivalent form (Cr III) can occur naturally and is essential dietary element to normal glucose, protein and fat metabolism, but this and the hexavalent chromium (Cr VI) can enter the environment due to various industrial anthropogenic activities (e.g. steel, leather and textile manufacturing) (ATSDR 2012; Coetzee, Bansal, and Chirwa 2020; Leita et al. 2009). The trivalent form much less toxic than the hexavalent form. However, oral uptake of chromium (6+) is insignificant because it converts to trivalent chromium in the environment. If hexavalent chromium is consumed this conversion is also realized in the stomach. Chromium (3+) is poorly absorbed from the intestine due to the poor membrane permeability but consumption of high amount of hexavalent form can induce stomach pain, vomiting and hemorrhages. Other health problems (lung cancer, allergic reaction, skin rash, nose irritation, ulcer, depressed immune system, damage of lung, kidney and liver) are also due to chromium (6+) (Choppala, Bolan, and Park 2013; Coetzee, Bansal, and Chirwa 2020; Dayan and Paine 2001). The human consumers can be exposed to chromium (mainly Cr III) by the food, drinking water and air resulted in <0.2–0.4 µg, 2.0 µg and 60 µg, respectively. The chromium content of human food sources is generally low (<0.10 mg/g) (EFSA (European Food Safety Agency) 2014a, 2014b). In aquatic ecosystem the trivalent and hexavalent chromium can exist together with little organic matter, however, chromium (6+) is generally predominant in marine water. In contaminated water the chromium is not taken up orally by the fish from the water but it is particularly accumulated on the gills which is generally not an edible tissue of the fish. Based on the scientific literature chromium is not biomagnified in the aquatic food chain. Its bio-concentration factor is 1 in rainbow trout (*Salmo gairdneri*), and is 100 in oyster (*Crassostrea virginica*), blue mussel (*Mytilus edulis*) and soft shell dam (*Mya arenaria*). The concentration of the hexavalent form is the highest in the gill followed by liver, skin and muscles in decreasing amount (ATSDR 2012; Bakshi and Panigrahi 2018). The recommended daily intake of chromium (3+) is 50–200 µg/day for adults. The Tolerable Daily Intake of trivalent chromium is 300 µg/kg b.w./day and of hexavalent chromium is 0.9 µg/kg b.w./day, respectively (EFSA (European Food Safety Agency) 2014b).

Polychlorinated substances

Dioxins and dioxin-like substances like PCB (polychlorinated biphenyl) are highly persistent in the environment and have tendency to accumulate in the animal and human organism and to undergo biomagnification in the food chain. PCBs containing 3 or more chlorine atoms in benzene rings are relatively stable, persistent and highly lipophilic substances in the environment. The less chlorinated derivatives are more easily degraded. The more chlorinated isomers selectively accumulate in adipose tissue, while the less chlorinated isomers are more likely to be hydroxylated in the body and thus more easily eliminated. In aquatic ecosystems, the highly chlorinated congeners are accumulated in the sludge, while less chlorinated substances are decomposed by microbial action (Henry 2015; Jepson and Law 2016). Therefore, in fish, predominantly congeners containing 4–6 chlorine atoms or more tend to accumulate. In fish and other aquatic organisms, the concentration of PCBs can be up to 75,000 times that in water (EFSA (European Food Safety Authority) 2010a; Uekusa et al. 2017).

The most prominent lesions are due to damage to the skin, liver, kidney, hematopoietic organs and immune system. In the skin, predominantly in humans, chloracne is observed, which includes hyperkeratosis of the affected area, proliferation of sebaceous epithelial cells, appearance of keratinocysts and edema of the eyelids. Severe necrosis can be developed in the liver resulted in biliary excretion and porphyrinaemia followed by photosensitivity. Prolonged exposure may result in damage to the hematopoietic organs and blood vessels thus pancytopenia and hemorrhages can be manifested throughout the body. All animal species are characterized by thinning due to general metabolic disorders. Disturbing of the immune system is prone to bacterial and viral infections. Dioxins are highly teratogenic in the embryo and have carcinogenic effect predominantly in the liver. They are typically not mutagenic compounds but may amplify the effect of other, mutagenic compounds (so-called 'co-mutagens') (ATSDR (Agency for Toxic Substances and Disease Registry) 2000; Lauby-Secretan et al. 2013; Rysavy, Maaetoft-Udsen, and Turner 2013).

The Tolerable Weekly Intake (TWI) of dioxins and PCBs of dioxin-like effect is 14 pg TEQ (toxic equivalency)/kg. The maximum tolerable level of dioxins is 4–6 pg TEQ/g in fish. The total tolerable limit for dioxins and dioxin-like PCBs combined is usually 1.5–2 times the values applying to dioxin alone (EFSA (European Food Safety Authority) 2015, 2018a; JECFA 2004).

According to Western European surveys, the average dioxin content of fish was <0.5 pg/g. The dioxin contamination of environmental origin, however, may be much higher than that in some fish species (e.g. herring, salmon) living in certain areas such as the Baltic Sea (EFSA (European Food Safety Authority) 2010a; Piskorska-Pliszczynska et al. 2012).

Radioactive compounds

The presence of the radioactive elements in the environment and in the food-producing animals is generally due to anthropogenic "activity" such as accident of nuclear power plant. During it artificial radioactive substances (e.g. iodine, cesium, plutonium) can be released into the environment such as ^{131}I, ^{134}Cs, ^{137}Cs, ^{239}Pu and ^{240}Pu. Among them the radiocesium elements are the most important due to their highest concentrations and long half-life i.e. 2.07 years for

^{134}Cs and 30.07 years for ^{137}Cs, respectively (Malek, Nakahara, and Nakamura 2004).

The recommended maximal permitted concentrations of ^{137}Cs in foodstuffs is 100-1250 Bq/kg, however, it is modified with special limits if the import food originated in or consigned from Japan after Fukushima accident. Based on the latter regulation, the products shall comply with the maximum level for the sum of ^{134}Cs and ^{137}Cs such as 10 Bq/kg for mineral water and similar drinks and tea brewed from unfermented leaves, 50 Bq/kg for foods for infants and young children and milk and milk-based drinks, and 100 Bq/kg for other foods including fish and fishery products (Commission Regulation 2016).

Radiocaesium, particularly ^{137}Cs can accumulate in the marine food chain including marine organisms, however, they can be detected in freshwater fish. Based on the scientific literature freshwater fish can contain 100-times higher concentration of ^{137}Cs than the marine fish because the radiocaesium is more highly accumulated in the water, soil and organisms of terrestrial ecosystem than in coastal area and marine environment (Arai 2014a; Buesseler et al. 2012; Yasunari et al. 2011). The fish and other aquatic organisms can take ^{137}Cs up directly from the water and due to their nutrition, resulted in high concentration in the flesh of marine animals. Thus, the consumption of contaminated fish and fishery products may be important health risk to human consumers. Due to the internal exposure by ingestion of contaminated food, the ^{137}Cs is distributed in the soft tissues reaching 75% of it in the muscle, resulted in increase of cancer risk (Nielsen et al. 1999).

In the last century, due to Chernobyl disaster in 1986, the ^{137}Cs level was above the health standard in fish captured in Barent Sea that has been reduced below 1 Bq/kg, e.g. 0.7 Bq/kg in cod (*Gadus callarias*). Further reduction was observed to 2017 (0.07 Bq/kg) but brown trout (*Salmo trutta*) still contains radiocaesium more than 20 years after the accident (Brittain and Gjerseth 2010; Mizuno and Kubo 2013). Due to the Chernobyl accident the fish in the Baltic Sea similarly can still contain radioactive cesium measured in herring (*Clupea harengus*), flounder (*Platichthys flesus*) and plaice (*Pleuronectes platessa*). The level of ^{137}Cs is the highest in the predatory fish e.g. in cod (*Gadus callarias*) and pike (*Esox lucius*) (Zalewska and Suplińska 2013). Based on the assessment the "good status" will be reached till about 2020–2025 if the radioactivity of 137Cs is <2.5 Bq/kg for herring and 2.9 Bq/kg for flounder and plaice, respectively (HELCOM 2018).

However, a newer nuclear accident was occurred in 2011 at Fukushima Daiichi Nuclear Power Plant due to a natural catastrophe resulted in releasing of radioactive substances into terrestrial and aquatic ecosystem in East Japan. During a three-year period (2011–2014) the concentration of radiocaesium (total Cs, ^{134}Cs, ^{137}Cs) have been gradually decreased from 202 to 18700 Bq/kg to 3.8–600 Bq/kg but the detected levels of them were above the regulated limit such as 100 Bq/kg in several fish species (e.g. ayu [*Plecoglossus altivelis*], Japanese dace [*Tribolodon hakonensis*], Japanese silver crucian carp [*Carassius langsdorfii*], Japanese white crucian carp [*Carassius cuvieri*], masu salmon [*Oncorhynchus masou*], sockeye salmon [*Oncorhynchus nerka*], white-spotted char [*Salvelinus leucomaenis*]) (Arai 2014b).

Fish biotoxins

Food-borne diseases caused by fish biotoxins increase in occurrence and prevail in food poisoning incidents worldwide and are responsible for acute and chronic diseases in humans (Brett 2003). Diseases caused by fish biotoxins are characterized by cardiovascular, neurological and/or gastrointestinal disturbances (Aristoy et al. 2009). These biotoxins are either produced by bacteria or come from toxic algae, they are resistant to damaging temperatures of usual cooking and processing and are non-organoleptic (Brett 2003). The most important fish biotoxins are scombroid toxins, ciguatoxin, and tetrodotoxin (TTX), whilst less common nonetheless, dangerous ones are marine algal toxins such as amnesic shellfish poisoning (ASP), azaspiracid, diarrheic shellfish poisoning (DSP), neurotoxic shellfish poisoning (NSP), and paralytic shellfish poisoning (PSP) (Brett 2003; Gibson 2018; Han, Huang, and Mahunu 2017; Lehel, Lányi, and Laczay 2017a, 2017b).

Scombroid toxins have already been mentioned when biological hazards were previously discussed, however, they will be elaborated here as part of chemical hazards because even though they are a product of a living microorganism they are not living organisms themselves. Scombroid poisoning, commonly referred to as histamine fish poisoning is caused by the consumption of contaminated fish, usually from the Scombridae families, which contain high amounts of histamine (Brett 2003; Hungerford 2010; Lehel, Lányi, and Laczay 2017b). Fish belonging to the Scombridae families include tuna, mackerel, skipjack and bonito, however, some non-scombroid fish such as sardines, anchovies, herrings, blue fish, mahi-mahi, amberjack and pilchards are known to also cause the intoxication (Chen et al. 2008). These scombroid fishes have very high levels of free histidine that is naturally present in their muscles and which will be transformed into histamine by the bacterial enzyme histidine decarboxylase under conditions that are favorable to both bacterial growth and synthesis of that enzyme (Joshi and Bhoir 2011). Following ingestion of the spoiled fish symptoms will appear rapidly, and in some cases instantly. Fortunately, the intoxication usually causes a mild illness with rapidly resolving symptoms which are mainly sweating, headache, vomiting, diarrhea, flushing, rash of the face, neck and upper chest, tingling and itching of the skin. Other symptoms such as dizziness, palpitation, nausea, burning sensation in the mouth, and abdominal pain can also be experienced. Most of the time the intoxication resolves within 24 h, however, severity of the condition can vary according to the sensitivity of the individual to histamine. Treatment for severe cases consists of administration of an antihistamine drug (Brett 2003; Chen et al. 2010; Gibson 2018; Lehel, Lányi, and Laczay 2017b).

Ciguatera poisoning is a type of marine fish poisoning with different environmental origins and has prolonged effects on the human health (EFSA 2010b; Gibson 2018). Ciguatoxin is produced by algae of the tropical coral reefs and are found in high concentration in the fishes living in that environment that are parrot fish, mullet, snappers, moray eels, and groupers (Daranas, Norte, and Fernandez 2001; Scogging 1998; Yasumoto 2001). Symptoms are gastrointestinal, cardiovascular and neurological disturbances such as diarrhea, vomiting, itching and muscle pain and would appear from a few minutes to 30 h following consumption of the contaminated fish but are generally known to be felt under 6 h (Boada et al. 2010; Brett 2003; EFSA 2010b; Lehel, Lányi, and Laczay 2017b; Lewis 2006). Although death is rare, neurological symptoms may last up to years and will be stimulated by stress and substances that have a ciguatoxin mimicking effect, e.g. alcohol (Yasumoto 2001). The intoxication which used to be an issue of importance to regions of the Pacific Ocean, Western Indian Ocean and the Caribbean Sea only, is now of global importance due to the increased seafood consumption worldwide and globalization of the seafood trade (Han, Huang, and Mahunu 2017).

Tetrodotoxin (TTX) is mainly found in puffer fish, xanthid crabs, the blue-ringed octopus, toadfish, marine gobies, newts, horse-shoe crabs and their eggs, and is amongst the most potent and lethal marine poisonings (Gall et al. 2011; Hwang and Noguchi 2007; Isbister and Kiernan 2005). It is frequent in Southeast Asia as well as in Taiwan and Japan, however, the disease has been also reported in the United States (How et al. 2003). Due to its level of toxicity no cure or antidote is available and therefore, the mortality rate is high. It is however reassuring to see a decline in occurrence of the intoxication due to enforcement of regulations and legislations by governments worldwide in regard to the marketing of nontoxic fish. The onset of the symptoms has been reported to begin 2–3 h following consumption of the fish and include numbness of the orofacial region, muscle weakness, acroparesthesia, hypotension, hypoxemia, breathing failure, and mild hypercapnia. However, the onset of the signs may be delayed from 6 to 20 h after ingestion, thus the hospitalization of patient for intensive monitoring is highly recommended within short time to prevent the serious consequences, full cardiac arrest and then death (How et al. 2003; Lehel, Lányi, and Laczay 2017b).

About 40 species of marine algae produce toxins that are dangerous to humans. The toxins get in the food-chain through carnivorous gastropods, crustacean and some fish. Toxicity in some shellfish can be so high that they are able to be dangerous to consumers (Daranas, Norte, and Fernandez 2001; Lehel, Lányi, and Laczay 2017a). These toxins are of importance today due to the increasing appearance of harmful algae caused by intensive aquaculture, transportation of cysts attaching to ships and eutrophication of coastal waters (Brett 2003). Symptoms caused by ASP, domoic acid that are usually present within 24 h, are headache, dizziness, confusion, short-term memory loss, difficult respiration and coma. Neurological symptoms tend to occur within 48 h and the short-term memory loss can be permanent. Domoic acid is found on the coastal waters of Portugal, Spain, France, the UK, Canada and the USA and is present in high amounts in king scallops and at non-negligible levels in blue mussels, queen scallops, crab and razor fish. Other fish such as sardine and mackerel can also be a source of contamination (Brett 2003; Hess et al. 2001; Lehel, Lányi, and Laczay 2017a). Azaspiracid poisoning reported in Italy, France and England mainly results from the consumption of Irish mussels and results in gastrointestinal symptoms such as nausea, vomiting, severe diarrhea and stomach cramps. Symptoms appear 6–18 h after ingestion and can last for up to 5 days (James et al. 2002; Lehel, Lányi, and Laczay 2017a). DSP is caused by four toxins: dinophysis toxins, okadaic acid, pectenotoxins and yessotoxins. The toxins are found globally and are present in a lot of shellfish such as mussels, cockles, whelks and green crabs, oysters, and scallops. Symptoms appear within 30 min post ingestion and tend to be acute affecting the gastrointestinal tract causing diarrhea, nausea, vomiting and abdominal cramps and will resolve within 3 days. At high concentrations okadaic acid and dinophysis toxins are tumor promoters whilst yessotoxins and pectenotoxins have a hepatotoxic effect (Brett 2003; Lehel, Lányi, and Laczay 2017a). NSP is caused by brevetoxins that are found in shellfish such as cockles and mussels of New Zealand, oysters and whelks in the USA. The toxins have similar gastrointestinal and neurological symptoms as ciguatera poisoning, however, they are not as severe and resolve completely within a few days. The symptoms occur within 1–3h and include numbness in the mouth and of extremities, abdominal pain, vomiting, and diarrhea (Brett 2003; Daranas, Norte, and Fernandez 2001; Lehel, Lányi, and Laczay 2017a). PSP is caused by saxitoxins found globally in mussels, scallops, crabs, clams, oysters, abalone, and lobsters. The onset of symptoms is from 15 min to 10 h post ingestion inducing numbness of the lips, face, neck, prickling sensation in the fingertips, headache, fever, nausea, vomiting, and diarrhea. In severe cases respiratory failure followed by death can be seen (Brett 2003; Lehel, Lányi, and Laczay 2017a).

Pesticides

Because of their effectiveness in protecting agricultural produces and controlling pests and pest associated diseases the use of pesticides has increased worldwide in the recent past years. In fact, it is believed that 23 million kg of pesticides are used yearly in the agriculture sector. However, due to their uncontrolled disposal in the environment and their inappropriate use as well as their ability to contaminate soils, water and biota humans often unconsciously consume them. Misuse of pesticides facilitates their passage in the food chain. In fact, from all the pesticides used humans end up consuming 44% of insecticides, 30% of herbicides, 21% of fungicides and 5% of other pesticides (Carvalho 2017; EFSA (European Food Safety Authority) 2017; Pimentel 2009; Pimentel and Burgess 2013). Furthermore, fish and shellfish can accumulate high amounts of pesticide residues that are often more than the amount found in their waters.

Moreover, fish feed contaminated by pesticides will end up being a risk to the human consumer (Han, Huang, and Mahunu 2017). Fish are a non-negligible source of contamination for humans and pesticides will cause damage to the human health irrespective of the time exposure for this reason, it is important to acknowledge the presence of pesticides in fish and the risk encountered by consumers (Abhilash and Singh 2009; Ledoux 2011). Suppression of the immune system, increase incidence of cancer, chronic kidney disease, endocrine diseases, male and female sterility, and neurological and behavioral disorders of children have been associated with chronic pesticide poisoning. Mild headaches, flu, blurred vision, skin rashes and more severe damages such as paralysis and death can also occur (Abhilash and Singh 2009).

Drugs

Over the years, aquaculture has become the main source of fish to meet the demands of the market for human consumption. For greater productivity and to be able to treat and prevent diseases, control parasites and undesirable microorganisms, reproduction, weight gain and to sedate the fish (such as for weighing) various drugs are used in fish farming worldwide and for this reason, drugs residue in the tissues of edible fish has now become of an important concern regarding the consumer's safety. Undeniably, the use of unauthorized drugs and the misuse of authorized drugs in aquaculture can be dangerous for the human health. The chemical compounds of these drugs may be allergenic, carcinogenic, toxic, can interfere with vaccination or the intake of other drugs in humans and may also cause an antibiotic resistance in pathogens. Many drugs are used of which fluoroquinolones (FQs), chloramphenicol (CHPC) and Malachite green (MG) are the most common and known to have irreversible dangerous effects (Papich 2016; Quesada, Paschoal, and Reyes 2013; Wen, Wang, and Feng 2006).

Efficient against gram negative and gram positive bacteria, FQs are broad spectrum antibiotics that are very often used for the treatment of bacterial diseases in humans and animals. Because of their improper and uncontrolled intensive use in fish farming, the presence of residues and the increasing microbial resistance is of concern. With their concentration dependent mode of action and their pronounced post antibacterial effect, FQs have been reported to cause chromosomal damage, micronuclei formation, unwanted DNS synthesis, and breakage of DNA strands. Furthermore, damage of articulation cartilages, changes in the bone growth and tendons in young animals and children have been seen. Despite their ban in aquaculture by some authorities such as the US FDA, other governments such as the EU still allow their use with set maximum residue limits (MRLs) from 100 to 600 ng/g in the muscle and skin for danofloxacin, difloxacin, enrofloxacin, oxolinic acid and flumequine. Because of its ability to penetrate and kill intracellular bacteria, CHPC is a broad spectrum antibiotic of choice in aquaculture. It is often used for prophylaxis and disinfection to prevent diseases. Although rare, the side effects caused in humans are nonetheless very serious. Dose related reversible depression of the bone marrow and non dose related irreversible severe leukemia as well as inhibition of protein synthesis have been reported. For this reason, CHPC use in animal feed and food-producing animals has been banned in several countries such as Japan, China, the EU and the USA. However, due to its availability and cheap prices it is still widely illegally used and therefore, bypasses official rules, which is a serious problem for the consumer's health (Han, Huang, and Mahunu 2017; Papich 2016).

Originally used in the textile industry as a dye, MG has found its way into the fish farming industry because of its ectoparasiticidal, fungicidal and antiseptic properties. Its low cost, availability and efficiency have led it to be used intensively as a first-choice medicine in fish farming worldwide. Reported to have potential carcinogenic, genotoxic, mutagenic and teratogenic effects the European Commission, the USA, China and a few countries has ban its use in aquaculture, however, MG residues have nonetheless been detected in some EU Member States, which indicates that the substance is still in use (Han, Huang, and Mahunu 2017).

Regulation and legislation

Safety of the consumers concerning raw fish, seafood, and their products is achieved through official systems and governing bodies working together of which the Seafood Hazard Analysis and Critical Control Points (HACCP), the European Commission (EC), the Food and Drug Administration (FDA), and the Hong Kong Food and Environmental Hygiene Department's (FEHD) Sushi Surveillance Guidelines are the most prominent and effective ones. Regulations and measures are in force in order to control raw fish, seafood and their products at their place of harvest, throughout their journey, and at the receiving end weather it is a place of marketing or in restaurants. Checks are official and performed by the competent authorities, the official veterinarian, as well as trained employees of the concerned business. Safety measures involve physical examination and laboratory tests undertaken for the safety of consumers (Hsin-I Feng 2012). Targeting directly the irresponsible use and misuse of drugs in food-producing animals powerful international organizations such as Food and Agriculture Organization (FAO), World Health Organization (WHO) and Office International des Epizooties (OIE) work together with governments of different countries to strongly regulate the use of medicines in farmed aquaculture species. To achieve this, maximum residue limits (MRLs) for the use of antimicrobials in aquaculture have been established and implemented. By definition, the MRL is the maximum acceptable amount of a substance present in the edible tissues of an animal that will not be of a health risk when ingested by the consumer. Edible tissues include honey, milk, eggs, muscle, liver, kidney, and fat. MRLs are used only for the drugs approved to be used in food producing animals. The accepted maximum amount aims to be in accordance with the accepted daily intake (ADI), expressed in mg/kg body weight, that is the amount of a substance ingested daily throughout lifetime and that will therefore not be a health threat. The FAO/WHO Experts Committee on Food Additives (JECFA), a committee that advises the Codex Alimentarius, sets the ADI and MRLs standards for the use of veterinary drugs in food producing animals. Those standards that are then used by the Codex Alimentarius Commission, a resource that provides a collection of internationally recognized guidelines and others, regarding food production and its safety. Countries will then use the Codex Alimentarius as a standard to establish sanitary measures. Unfortunately to this day, only a few governments have set MRLs standards concerning aquaculture. In the EU the body in charge of setting the MRLs is the Working Group on the Safety of Residues (WGSR) that is part of the Committee for Veterinary Medicinal Products (CVMP). Table 8 shows the MRLs set for the use of fluoroquinolones in aquaculture in different regions of the world. Prohibited or unauthorized substances without MRLs are used according to minimum required performance limits (MRPLs), established by the European Community, via the Commission's Decision 2002/657/EC (Commission Decision 2002). The European Community, Canada, and Norway have approved some antibiotics for specific use in aquaculture. Regulations put in place specifies the types of antibiotic drugs that can be used, the species for which they can be used, the diagnosis, the dosage, the duration of the treatment and the treatment interruption period to be respected (called the withdrawal period), in order to allow excretion of the drug before slaughter. This ensures effective excretion of the drug before slaughter as well as the amount of residues to be below the MRL, and also decreases the risk of pathogen resistance. In the European Union, the USA and Canada, approved antibiotic drugs are obtained by prescription only, and with the supervision of a qualified person (Quesada, Paschoal, and Reyes 2013).

The basic legal regulations regarding contaminants occurring in foods including fish, fishery products and live bivalve mollusks are contained in Commission Regulation (EC) No 1881/2006 setting maximum levels for certain contaminants in foodstuffs. It involves maximum limits for industrial contaminants such as dioxin and combined level of dioxin and PCB (4 pg/g and 8–12 pg/g for fish, fishery products), benz(a)pyrene (2–5 μg/kg for fish and fishery product, 5–10 μg/kg for live bivalves), and heavy metals (cadmium, lead, mercury) (Table 3) (Commission Regulation 2006).

In order to protect the health of consumers, tolerable daily, weekly or monthly intakes are determined for the most important contaminants (the tolerable monthly intakes are used for substances prone to bioaccumulation). These tolerable intakes are levels that would not cause adverse health effects even in the case of continuous, lifelong intake. In the case of contaminants, these quantities are designated tolerable daily, weekly and monthly intake (TDI, TWI and TMI, respectively). On the basis of the available data, the international organization responsible for risk assessment and for establishing the tolerable intake levels (Joint FAO/WHO Expert Committee on Food Additives, JECFA) can often establish provisional (P) TDI, TWI and TMI values (PTDI, PTWI and PTMI, respectively). The Committee periodically revises and, if necessary, modifies these provisional values in the light of the new toxicological and epidemiological data (Herrman and Younes 1999; JECFA 2004; JECFA-940940 2007; JECFA-959959 2011; JECFA-960960 2010; JECFA-983983 2013).

Incorporated in the seafood industry in 1990, the HACCP is a risk assessment system used by governing bodies to achieve their goal. The HACCP sushi-specific production guide includes the following main points:

1. All seafood comes from an identifiable approved source. Recreational fishermen are not approved and no fish from unapproved sources can be used in the production of sushi;
2. All seafood, including eggs (roe) and surimi must come from a source that functions following a HACCP plan;
3. Because of the risk of parasites some fish need to be frozen by the supplier or retail operation before being served as a raw ready-to-eat;
4. All other components of the sushi dish such as vegetables, nori, vinegar and spices must come from approved and identifiable sources;
5. Commercially prepared pre-acidified rice must be obtained from approved and identifiable sources under a HACCP plan with records for the rice production;
6. Potentially hazardous foods are delivered at or below 5 °C or solid frozen;
7. It is the responsibility of a retail establishment to have a program for routine inspection of the incoming approved products, their condition, temperature, integrity of the packaging and correct labeling information as well as documents on accepted and rejected products and the person taking that decision and other necessary comments.

Through its regulations the European Commission provides high level of food safety for European countries by working both within Europe and with third countries importing to Europe. Regulation (EC) No 854/2004 lays down the rules for official controls with respects to fishery products and bivalve mollusks intended for human consumption (Commission Regulation 2004c). In case of live mollusks, production places are constantly monitored and classified A, B, C or prohibited area according to the Most Probable Number (MPN) of *E. coli* per 100 g of flesh and intravalvular liquid. Samples are taken to control presence of chemical and fecal contaminants, toxin producing planktons, biotoxins and microbiological quality of the bivalve. Periodic toxicity tests are made and if results show a potential threat to human health closure of the concerned place is done until the acceptable criteria are met. Controls are performed not only on products harvested in classified areas but also on those outside classified areas such as in third countries. Fishery products are subject to official controls of production and placing on the market which include regular check on the hygienic conditions of landing, carrying vessels, handling methods, storage and transportation. Fishery products undergo organoleptic examinations throughout all the stages of production, processing and distribution in order to determine the freshness of the products. The presence of the previously mentioned biological and chemical hazards are checked for in compliance with the Community legislation and in case of test failure products are classified unfit for human consumption. Poisonous fish and fishery products containing biotoxins dangerous to the consumer's health such as ciguatera are removed from the market. Furthermore, all imports are done with official certificates bearing an official stamp (Commission Regulation 2004b). Regulation (EC) No 853/2004 lays down specific hygiene rules regarding the production and marketing of live bivalves and fishery products. Controls of live bivalve mollusks are undertaken by the competent authority to ensure that unacceptable amounts of biotoxins are not present and that requirements for harvesting and specific hygienic handling methods are met for dispatch and purification centers. Maximum accepted levels of marine biotoxins can be seen in Table 5. In accordance with the HACCP system, vessels transporting fishery products are also subject to meticulous controls about their hygiene, temperature, and way of operation in order to prevent cross contamination and spoilage of the products. A specific way of how they should be built and equipped for such merchandise is described in the regulation. Establishments handling fishery products and live bivalve mollusks are also strictly controlled according to the requirements laid down by regulations. Health standards for fishery products are done in accordance with Regulation (EC) No 852/2004, and include an organoleptic examination in compliance with the freshness criteria, a check on the acceptable amounts of histamine and total volatile nitrogen, and a visual examination to detect parasites (Commission Regulation 2004a).

The FDA is a federal agency in the United States responsible for the protection and the promotion of public health (FDA (Food and Drug Administration) 2018b). Its goals in regards to the seafood industry are as follow:

1. Ensuring the safety of seafood through an effective and efficient system;
2. To increase the confidence of the consumer;
3. To implement HACCP preventive controls for seafood;
4. To ensure continuous access of the United States to world markets where HACCP controls are the norm.

The FDA continuously publishes sushi food handling guides for operators and consumers, and consumption recommendations about seafood products in order to minimize the risk of contamination and protect people with a compromised immune system. In that regards, the agency advises anyone with an ill functioning autoimmune system to have safe seafood practices and to avoid the consumption of sushi and sashimi. The main points in their handling guides are:

1. Employees should not have any outwear on but clean clothes and should at all times wear head caps;
2. Never should employees smoke, eat, or play with their hair;
3. Never should employees be sick or have open wounds;
4. Employees should wear at all times disposable gloves when handling food and change them; after handling raw food and after doing non-food tasks;
5. The fish should not have any darkening around its edge or any brown or yellow discoloration (Hsin-I Feng 2012).

With the Sushi Surveillance Guideline the Hong-Kong FEHD aims to raise people awareness in food safety and public hygiene regarding the consumption of sushi (FEHD (Food and Environmental Hygiene Department) 2018). Under their program, retailers who want to manufacture and sale sushi and sashimi, and vendors who just want to sell but not manufacture such food have to hold a specific permit in order to engage in their business. Additionally, samples of sushi and sashimi are collected by food inspectors who send them to the Public Health Laboratories, Pathology Service of the Department of Health for microbiological examination. The assessment is done in two parts of which the first one consists of measuring the level of indicator micro-organism such as aerobic plate count (APC) and *E. coli* and specific pathogens such as *Salmonella* spp., *Shigella* spp., *Staph. aureus*, and *V. parahaemoliticus*. High levels of indicator micro-organisms reveal non-satisfactory hygienic practice during the processing of the product from its source to the plate of the client, whilst high levels of APC are an indication of contamination and inappropriate time/temperature during storage. Through the scheme, guidance is given on how and whom from to buy the raw products, the optimal temperature that should be applied, the cleaning frequency and the method to be applied to clean utensils used for the preparation of sushi and sashimi, the hygienic practice that is to be carried out by employees, and the conditions in which the products are to be kept. Additionally, a specific and comprehensive guide for "How to Wash your Hands" is given to employees. Furthermore, guidance is given directly to the public on how to choose legitimate sushi restaurants and how to select optimum seafood for human consumption (Hsin-I Feng 2012).

Methods used for detection of hazards

The Codex Alimentarius defines a contaminant particle as any substance not voluntarily added to any food, during its primary production, processing activities, packaging, and distribution, as result of environmental contamination (Maldonado-Simán et al. 2018). Generally, the chemical contamination of foodstuffs with potential health threats the consumers mainly happen on the farm, during primary production. Contamination is caused by sources such as parasites, pathogenic microorganisms, heavy metals, biotoxins, pesticides, and fishery drug residues (Laczay 2014; Han, Huang, and Mahunu 2017; Maldonado-Simán et al. 2018). However, the main purpose for intensive fish farming is to meet the increasing demands of the consumers whilst producing products that are safe for consumption, in order to protect consumers from fish food-borne disease. Safety is achieved by controlling and reducing veterinary drugs residues and other contaminants (Cooper et al. 2015). For this reason, MRLs and other maximum limits of different contaminants in food have been established by international organizations and several analytical methods have been developed for the detection of harmful factors in fish and fish products to measure the safety of the edible tissue (Han, Huang, and Mahunu 2017; Maldonado-Simán et al. 2018). Furthermore, programs to encourage organic production systems are being elaborated in order to significantly decrease the use of veterinary drugs in food producing animals (Cooper et al. 2015).

Detection of biological hazards

Parasites present in fish are responsible for much of the fish-borne related diseases. For a long time, their detection has only been based on candling and manual inspection. The process consists of placing the fish fillet sample onto a white light table to identify the parasites and remove them manually. However, these methods only allow to spot 75% of the parasites as those embedded deeper than 6 mm into the sample tissue would often be missed, even with a trained eye and thorough inspection. For this reason, additional techniques have been used as complementary tools and they include enzyme linked immunosorbent assay, immunofluorescent antibody analysis, and polymerase chain reaction techniques. Complementary methods are particularly useful in the case of plerocercoids, *Giardia, Opisthorchis,* and *Anisakis* spp., which live deep in the tissues. Imaging spectroscopy has been found particularly efficient for detection of cod nematodes, however, it is still yet to be applied for industrial samples (Han, Huang, and Mahunu 2017).

Food provides a good environment for the development of microorganisms because of its physio-chemical properties and its biological factors (Laczay 2014). Microorganisms, especially fish bacteria have been the source of many food-borne diseases worldwide. Various methods are used in the fish industry in order to detect those bacteria and prevent possible health issues in consumers. Tables 1 and 2 show the accepted limits of some bacteria present in fish and seafood regarding food safety and process hygiene, respectively. Traditional microbiological examinations consist of measuring the total viable count (TVC), spoilage bacteria and pathogenic bacteria. TVC is the number of bacteria in a food able to reproduce and form visible colonies on a culture medium at specific temperature. It is important to understand that TVC is not the total bacteria present in a food but just a fraction of it. Plate count agars (PCA) have been used for the culture and examination bacteria present in fish and fishery products. However, this technique requires long incubation periods, specific culture medium and proper temperatures. Quicker methods to determine TVC in food have been developed which include, electronic nose, hyper-spectral imaging technique, ATP luminescence method, infrared spectroscopy and fiber spectroscopy. However, conventional methods are culture and bacterial colony counting methods, polymerase chain reaction (PCR), and the immunology-based method involving antigen-antibody interactions (Han, Huang, and Mahunu 2017).

Colony counting method is the main conventional technique used for bacterial identification. It involves the use of qualitative tests to establish the absence or presence of the pathogenic bacteria, and quantitative tests to determine the number of viable cells. To grow the bacteria either direct plating onto a selective agar plate, or incubation of the fish product extract in enrichment followed by plating onto a selective agar is used. Direct plating includes either standard plate count and surface count techniques. Standard plate count is done to determine the number of viable colony forming units whilst surface count technique is used for the determination of heat sensitive psychotrophic bacteria. Direct plating is mostly used for strict aerobes and micro-aerophillic bacteria. Bacterial growth induced by incubation with enrichment is mostly used for opportunistic pathogenic and pathogenic bacteria, such as *Salmonella*, *Clostridia* and *Listeria* spp.

PCR is a common laboratory technique used for *in vitro* exponential DNA amplification and due to its specificity, accuracy, sensitivity, and rapidity, is a powerful and widely used tool for bacteria as well as virus detection (Kalendar et al. 2017). PCR techniques for the detection of bacteria include real-time PCR, multiplex PCR, and reverse transcriptase PCR. Multiplex PCR is preferred over other PCR techniques as it can identify several variables simultaneously and amplify them (Han, Huang, and Mahunu 2017). Quantification of target sequences by real-time quantitative PCR (RQ-PCR) is the most important technique used for the detection of viruses. In contrast to these methods such as qualitative PCR approaches, RQ-PCR detects the targeted genome in real time and its work is not affected by the concentration of reagent or other variables, such as cycling conditions. However, commercial RQ-PCR assays are only available for a few numbers of viruses (Akkaya et al. 2017; Edin et al. 2015; Hasan et al. 2019; Jung et al. 2018; Rajapaksha et al. 2019; Sea-Liang et al. 2019; Siow et al. 2016; Stone and Mahony 2014; Tanchou 2014; Teranishi and Ouch 2014; Wang et al. 2019; Yoshii et al. 2017; Zauli 2019).

Immunology-based methods are used for the detection of bacterial cells, spores, viruses and toxins. The methods are based on antigen-antibody bindings and are widely used for the detection of food-borne pathogens and are often used for *E. coli*, *Salmonella*, *Campylobacter* spp., *L. monocytogenes*, and Staphylococcal enterotoxins. An array of immunological detection techniques are used and they include enzyme immunoassay, enzyme-linked immunosorbent assay, flow injection immunoassay, enzyme-linked fluorescent assay, bioluminescent enzyme immunoassay, radio immunoassay, immuno-magnetic separation, enzyme-linked immuno-magnetic chemiluminescence, immuno-chromatography strip test, immuno-precipitation assay, agglutination test, western blot test, and modified western blot test. Immunological methods are less time consuming than any

Table 1. Accepted limits of some bacteria in fish and seafood regarding food safety (Commission Regulation 2005).

Food category	Microorganisms	Sampling plan	Limits (n and M)	Stage where criteria apply
Live bivalve mollusks, echinoderms, tunicates and gastropods	*Salmonella*	n = 5 c = 0	0/25 g	Products placed on market during their shelf-life
Cooked crustaceans and molluskan shellfish	*Salmonella*	n = 5 c = 0	0/25 g	
Live bivalve mollusks, echinoderms and gastropods	*E. coli**	n = 1** c = 0	230 MPN/100 g flesh and intravalvular liquid	

**E. coli* indicating feacal contamination;
** Sample of at least 10 individuals.

Table 2. Accepted limits of bacteria in fish and seafood regarding process hygiene (Commission Regulation 2005).

Food category	Microorganisms	Sampling plan	Limits	Stage where criteria apply
Shelled and shucked products prepared from cooked crustaceans and mollusks	*E. coli*	n = 5 c = 2	m = 1 cfu/g M = 10 cfu/g	Improvement of production hygiene
Shelled and shucked products prepared from cooked crustaceans and mollusks	Coagulase- positive *Staphylococci*	n = 5 c = 2	m = 100 cfu/g M = 1000 cfu/g	

Table 3. Accepted maximum levels for heavy metals in fish (Commission Regulation 2006).

	Concentration of heavy metals (mg/kg wet weight)		
Foodstuffs	Lead	Cadmium	Mercury
Muscle meat of fish	0.30	0.05*	0.50**
Crustaceans, except brown meat of crab, head and thorax meat of lobster, and similar large crustaceans	0.50	0.50	0.50
Bivalve mollusks	1.50	1.00	–
Cephalopods (without viscera)	1.00	1.00	–

*Muscle meat of swordfish has a cadmium maximum accepted level of 0.30 mg/kg wet weight. Muscle meat of anchovy, bonito, common two-banded seambream, eel, gray mullet, horse mackerel or scad, louver, sardine, sardinops, tuna and wedge sole has a cadmium maximum accepted level of 0.10 mg/kg wet weight.
**Muscle meat of anglerfish, Atlantic catfish, bonito, eel, emperor, grenadier, halibut, marlin, megrim, mullet, pike, plain bonito, poor cod, portuguese dogfish, rays, redfish, sail fish, scabbard fish, seabream, pandora, shark, snake mackerel or butterfish, sturgeon, swordfish and tuna has mercury maximum accepted level of 1.0 mg/kg wet weight.

other methods, however, they are less sensitive, and a low affinity of the antibody to the pathogen and results can easily be affected by contaminants (Han, Huang, and Mahunu 2017).

Detection of chemical hazards

The accumulation of heavy metals in the food chain and their residues in fish edible tissue is of concern for the human health due to their non-biodegradable nature. With their carcinogenic effects and their ability to biomagnify with time, tracing them in the environment, food, and drinking water is crucial for preserving the sustainability of the environment as well as the health of consumers (Has-Schön, Bogut, and Strelec 2006; Malik et al. 2010). The main detection techniques used include atomic absorption spectroscopy, inductively coupled plasma-atomic emission spectrometry, inductively coupled plasma-mass spectroscopy, and ultraviolet visible spectroscopy. However, sample preparation for these methods are time consuming, requires expensive equipment and professional handling. Therefore, despite the specificity and sensitivity of these methods, new innovated simpler yet reliable methods are needed. Recently developed analytical methods include electrochemical sensors, biosensors, quartz crystal microbalance, and optical methods. Sensing elements have been created with the use of biomolecules, conjugated polymers, liquid crystal, and nano materials (Han, Huang, and Mahunu 2017). Table 3 shows the maximum levels for heavy metals in fish. No maximum limit has yet been established for arsenic in the European Union, however, detection methods are being worked upon (Food Safety Authority of Ireland 2009). However, the maximum limit of inorganic arsenic in rice is regulated, it is between 0.10 and 0.30 mg/kg depending on the types of rice products (Commission Regulation 2015).

Recently, to separate the different arsenic species (organic and/or inorganic derivatives) in various samples (soil, water, air, terrestrial and marine organisms, plant) combined methods are applied such as e.g. high performance liquid chromatography coupled to hydride generation and atomic fluorescence spectrometry (HPLC-HG-AFS) or using cold or cryogenic trapping in conjunction with hydride generation to detect the volatile derivatives. Furthermore, HPLC–ICP-MS, ion exchange chromatography coupled to inductively coupled plasma-mass spectrometry (IEC–ICP-MS), flow injection hydride generation atomic absorption spectrometry (FI-HG-AAS) completed with additional analytical methods e.g. X-ray absorption spectroscopy (XAS), electrospray mass spectrometry (ESI–MS) are applied to confirm and/or identify the exact arsenicals. Capillary electrophoresis (CE) can also be used as a separation method in combination with different detection system. However, there is no such

Table 4. Accepted maximum limit of histamine in fish samples for European countries (Commission Regulation 2005).

Foodstuffs	Sampling	Limit of histamine (mg/kg)	Stage where the criterion applies
Fishery products from fish linked to high amount of histidine*	n = 9 c = 2	m = 100 M = 200	Products placed on market during their shelf-life
Fishery products that have undergone enzyme maturation treatment in brine, manufactured from fish species linked to high amount of histidine*	n = 9 c = 2	m = 200 M = 400	

*Mackerel, herring, anchovy, dolphinfish, bluefish, bluefish, and queenfish.

hyphenated technique that can be sued alone or in combination to detect all types of arsenic species because it can be influenced by the physico-chemical properties of the derivatives, extraction procedures etc. (Ardini, Dan, and Grotti 2020; Fiamegkos et al. 2015; Francesconi and Kuehnelt 2004; Jeong et al. 2017; Leufroy et al. 2011; Nearing, Koch, and Reime 2014; Pizarro et al. 2003).

Recently, to differentiate the individual mercury species (organic, inorganic derivatives, total mercury) in different matrices (e.g. soil, seafood) HPLC method (partition or ion chromatography) and/or GC method are widely used completed with suitable extraction procedures. These techniques combined with sensitive detectors such as e.g. atomic fluorescence spectrometry (AFS), electrothermal atomic absorption spectrometry (ET-AAS), inductively coupled plasma-optical emission (ICP-OES), ICP-mass spectrometry (ICP-MS) offer the analyst a reliable and suitable system for mercury speciation. However, the different mercury species can be detected with combined methods such as e.g. isotope dilution gas chromatography inductively coupled plasma mass spectrometry (ICP-MS) to achieve suitable analytical method with low detection limit, and to confirm and/or identify the exact individual or total mercurial (Kubáň et al. 2009; O'Connor et al. 2019; Senila et al. 2018; Taylor, Jackson, and Chen et al. 2008). As a newer method the thermal decomposition, amalgamation and atomic absorption spectrometry (TDA AAS) is achieved for direct analysis of trace amounts of total mercury in various biological samples (e.g. blood, urine, hair, seafood) (Lech and Turek 2019; Torres et al. 2012).

With its potent biological action, histamine is naturally found in high concentration in certain fish species. Through the action of histidine decarboxylase enzyme, free histidine is transformed into histamine (Laczay 2014). Numerous reports of scromboid toxin (histamine) poisoning highlight how important the detection and control of the substance in fish and fishery products is. Regulation level of histamine is established in most countries in order to preserve the safety of consumers. Maximum accepted limits of histamine set by these regulations can be seen in Table 4. Several analytical methods are used as tools for the detection of histamine in aquaculture produces. Simple and cheap layer chromatography to resource-intensive powerful liquid chromatography-mass spectrometry method (LC-MS) is available. Although colorimetric and fluorometric analytical methods can be used, chromatography is widely used due to its high performance and its possibility of being coupled with detectors for a better reliability, sensitivity and selectivity. In fact, LC is in most countries, the official analytical method used for the detection and regulatory purposes of histamine in fish and fishery products. However, just like most reliable methods, liquid chromatography is an expensive method and the need for non-expensive yet reliable and easily managed techniques are needed. For this reason, new analytical techniques based on electrochemical methods, immunoassay methods, and molecularly imprinting methods have been innovated (Han, Huang, and Mahunu 2017).

Many detection methods for ciguatoxins in fish are used today of which mouse bioassay, cell bioassay, LC-MS, LC-MS/MS, and immunoassay are the usual ones. However, there are some disadvantages associated with these methods. For instance, mouse bioassay requires high concentration of toxins, is time consuming and has often been reported to have poor specificity. Cell bioassay and immunoassays often give unreliable results due to the different structures of ciguatoxic congeners or sodium channel activators; false positive or false negative results are not uncommon. Liquid chromatography-mass spectroscopy and liquid chromatography-mass spectroscopy-mass spectroscopy require complicated sample preparation and expensive equipment. Due to the lack of new high performance and reliable techniques these analytical methods remain the best options for the detection of ciguatoxins in fish but cannot unfortunately be used at a commercial level because of their costs (FAO (Food and Agriculture Organisation) 2017; Han, Huang, and Mahunu 2017). Furthermore, there is insufficient scientific information concerning the toxin therefore, accepted maximum levels of ciguatoxins related to the edible tissue of fish or mollusk are yet to established (FAO (Food and Agriculture Organisation) 2017).

Tetrodotoxin is amongst the most potent and lethal marine poisonings (Gall et al. 2011; Han, Huang, and Mahunu 2017). Analytical methods appropriate for its detection in fish and fishery products currently involve mousse bioassay, heterologous receptor binding assay, chemosensors selective assay, high performance liquid chromatography, liquid chromatography-mass spectrometry, liquid chromatography-mass spectrometry-electrospray ionization assay, immuno-affinity chromatography assay, in vivo and in vitro genotoxicity assays, monoclonal antibody-based immunoassay, and gold nanoparticle probe-based immunoassay (Han, Huang, and Mahunu 2017). No accepted maximum amount of tetrodotoxin has been established yet, so the techniques are used to make sure that contaminated fish and fishery products are not placed on market for human consumption (EC (European Commission) 2016). Table 5 below shows the maximum accepted levels of the main marine biotoxins.

Table 5. Maximum accepted levels for the major marine biotoxins (Commission Regulation 2004c).

Biotoxin	Maximum accepted levels regarding fish meat and mollusks
Paralytic Shellfish Poisoning toxins (PSP)	800 µg/kg
Amnesic Shellfish Poisoning toxins (ASP)	20 mg of domoic acid/kg
Okadaic acid, dinophysistoxins, and pectenotoxins together*	160 µg of okadaic acid equivalent/kg
Yessotoxins*	1 mg/kg
Azaspiracids*	160 µg/kg

*Toxins of Diarrhetic Shellfish Poison (DSP)

Table 6. Tolerated levels of environmental chemical contaminants and pesticides in the edible portion of fish and seafood (mg/kg wet weight) (FDA (Food and Drug Administration) 2018a).

Compound	Maximum tolerated level in edible tissue (mg/kg)	Food commodity
Carbaxyl	0.25	Oysters
Diquat	2	Fish
	20	Shellfish
Diuron and its metabolites	2	Farm raised, freshwater finfish
Endothall and its mono methyl ester	0.1	All fish
Fluridone	0.5	Finfish and crayfish
Glyphosate	0.25	Fish
	3	Shellfish
2,4-D	0.1	Fish
	1	Shellfish

Table 7. Action levels of environmental chemical contaminants and pesticides in the edible portion of all fish (mg/kg wet weight) (FDA (Food and Drug Administration) 2018a).

Compound	Level in edible tissue (mg/kg)
Aldrin and dieldrin*	0.3
Chlordane	0.3
Chlordecone	1.3
DDT, TDE, DDE**	5.0
Methylmercury	1.0
Heptachlor, heptachlorepoxide***	0.3
Mirex	0.1

*residues of the pesticides individually or in combination. However, if calculating a total, the amounts of aldrin or dieldrin found at below 0.1 mg/kg are not counted.

**residues of the pesticides individually or in combination. However, if calculating a total, the amounts of DDT (Dichloro-diphenyl-trichloroethane), TDE (tetrachloro-dyphenylethane), and DDE (dichloro-diphenyl-dichloroethyl) found at below 0.2 mg/kg are not counted.

***residues of the pesticides individually or in combination. However, if calculating a total, the amounts of heptachlor and heptachlorepoxide found at below 0.1 mg/kg are not counted.

Pesticides are intensively used in agriculture. To decrease misuse in order to be compliant with good agricultural practices (GAP), and to ensure health and safety of consumers MRLs have been set by governments (Tables 6 and 7), and can therefore be controlled with analytical methods. Analysis of pesticides MRLs is done with gas chromatography using selective detectors of which flame photometry, pulse flamed photometry, nitrogen-phosphorous, and electron-capture are the main ones. Gas chromatography is also often combined with mass spectrometry. For the detection of specific pesticides such as nonvolatile and/or thermally unstable and/or polar pesticides, liquid chromatography with diode array and fluorescence detection is used. Lately, liquid chromatography coupled with either mass spectrometry or tandem mass spectroscopy has been used as efficient analytical methods to identify and quantify pesticide residues in food. Just like for the previously mentioned chemical hazards, chromatography is an excellent analytical method, however, it is time consuming, requires professional handling due to its complexity, and is expensive to run therefore, not suitable to be used at an industrial level. Simpler and efficient methods have been introduced for large scale samples and these include enzyme-linked immunosorbent assays, electrochemical immuno-sensor, fluorescence polarization immunoassay, and surfaced-enhanced Raman spectroscopy (Han, Huang, and Mahunu 2017).

Recently, rapid multiresidue analytical methods using QuEChERS (quick, easy, cheap, effective, rugged, safe) sample preparation method have been developed. The QuEChERS extraction procedure has been extensively validated thus it can be used to prepare and screen different biological samples (food of plant and animal origin) using GC-MS and LC-MS/MS to detect wide range of pesticides (EN-15662 2008; Ledoux 2011; Lee et al. 2013; Lehotay 2007; Nasiri et al. 2016; Štajnbaher and Zupančič-Kralj 2003; Urkude, Kochhar, and Dhurvey 2015; Wilkowska and Biziuk 2011).

With intensified production and farming, comes the increased risk of disease emergence and spreading which inevitably leads to an intensified used of drugs for prophylactic, therapeutic, and/or metaphylactic purposes (Quesada, Paschoal, and Reyes 2013). The most drug residues in food are due to the administration of drugs to fight the emergence of animal diseases (Cooper et al. 2015). Various methods have been elaborated for their detection (Han, Huang, and Mahunu 2017). The topic focuses on the detection of prominent fishery drugs that are fluoroquinolones, chloramphenicol and malachite green.

The common use of fluoroquinolones in food producing animals and especially in fish has raised concerns because of slow elimination of the drug by the fish organism therefore, leading to accumulation of residues in the fish edible tissue, which poses the issue of pathogen resistance to fluoroquinolones in consumers. The current methods used for the detection of fluoroquinolones are based on liquid chromatography using fluorescence, ultraviolet, diode array detection or mass spectrometry (Han, Huang, and Mahunu

Table 8. Maximum residue limits established for the use of fluoroquinolones in aquaculture in different regions of the world (Quesada, Paschoal, and Reyes 2013).

	MRL (μg/kg)		
Fluoroquinolone	Europe	Japan	Asia
Flumequinine	600	50	500
Oxolinic acid	300	100, 60	50, 100
Difloxacin	300	–	–
Enrofloxacin	100	–	100
Danofloxacin	100	500, 40, 600	–
Sarafloxacin	30	100, 100	–

2017). Liquid chromatography methods, especially mass spectrometry liquid chromatography, are known to be modern effective analytical methods for the detection of fishery drugs in fish due to their high selectivity and detectability, as well as their analyte identity confirmation (Quesada, Paschoal, and Reyes 2013). However, because of the time consuming and complex clean-up procedure involved, and the need for sophisticated analytical equipment, these methods are not suitable for the control of a large number of samples. Therefore, development of better analytical techniques is needed. At the time being, efficient new techniques such as microbiological assays, immunoaffinity chromatography, enzyme-linked immunosorbent assay, molecular methods or PCR assay are being used (Han, Huang, and Mahunu 2017).

Chloramphenicols can be detected by using HPLC, gas chromatography-mass spectrometry (GC-MS), LC-MS and LC-MS/MS. However, the latter method is the most efficient one due to its high sensitivity and specificity. As for fluoroquinolones, however, the time consuming and complex instruments requirements for this analytical method do not make it be an effective method for the sampling of commercial amounts of samples. More recent methods that include the use of sensors are currently more and more used; sensors used are electrochemical, gravimetrical, and optical. A more specific analytical method developed to particularly detect chloramphenicols has surface plasmon resonance sensors; with this particularity, high sensitivity and low detection limits are possible (Han, Huang, and Mahunu 2017). Because of its detrimental effects to the human health, the Codex Alimentarius advises that there is no safe level of residues of the substance or its metabolites in edible food tissue. Therefore, no residues are allowed, banning the use of chloramphenicols in food producing animals (Codex Alimentarius 2018).

The characteristics of malachite green make the drug be a perfect match for the use of chromatographic methods; with a strong chromophore at 618 nm and a positive charge, residue detection schemes based on liquid chromatography with visible absorbance or mass spectrometric detection are used. However, despite the sensitivity and specificity of the methods, the use of chromatography for sampling large quantity of samples at industrial levels is not so adequate due to its financial and timely cost. An attempt to ameliorate the techniques of sampling has resulted in the development of newer methods such as surface-enhanced Raman spectroscopy, enzyme-linked immunosorbent assay, and RNA-Aptamer-Based assay (Han, Huang, and Mahunu 2017). Similarly to chloramphenicols, the use of malachite green in food producing animals is banned, so no residues of the substance is allowed to be found; such findings condemn the product to destruction (Codex Alimentarius 2018).

The QuEChERS extraction procedure is recently recommended for detection of veterinary drugs from different classes in various matrices (e.g. food: porcine, chicken, fish muscle, milk, shrimp; water) beside pesticides (Anastassiades et al. 2003; Urkude, Kochhar, and Dhurvey 2015). However, it is not suitable for recovery of polar veterinary drugs (e.g. penicillins, tetracyclines, quinolones). This sample preparation method may be combined with appropriate detection techniques such as e.g. liquid chromatography time-of-flight mass spectrometry (LC–TOFMS) to detect mebendazole, sulfonamides, malachite green, matrix solid-phase dispersion and high performance liquid chromatography with diode array detection (MSPD–HPLC–DAD) to determine fluoroquinolones, sulfonamides, tetracyclines, macrolides, or solid-phase extraction with liquid chromatography tandem mass spectrometry (SPE–LC-MS/MS) to measure anthelmintics (Habibi et al. 2019; Imamoglu and Olgun 2016; Machado et al. 2013; Mooney et al. 2019; Shankar et al. 2010; Villar-Pulido et al. 2011; Yu, Mun, and Hu 2012).

Discussion

Raw fish has become important in our diet and its consumption has tremendously increased worldwide due to its favorable nutritional values. However, fish is exposed to a number of contaminants that can be detrimental to the health of the consumer. These contaminants can be classified into biological and chemical hazards. Intensive production methods used to increase overall yield in order to meet the market demands amplify the risk of contamination. Depending on their characteristics most of these contaminants will live or accumulate in the edible fish tissue and subsequently transfer to people via the food chain. In the interest of public health, international institutions and experts have worked together to set maximum levels (MLs) and maximum residue limits (MRLs), that are used to control the safety and quality of fish and fishery products that will be merchandised for human consumption. Lehel et al. (2018) evaluated the presence of heavy metals in shellfish, oysters and squids. In shellfish, Cd was found at an average of 24.3 μg/kg, which is under the recommended tolerable intake of 25 μg/kg. However, oysters and squids were 26.1 μg/kg and 28.0 μg/kg, respectively. Their daily long-term consumption would cause a dangerous accumulation in the consumer's organism. The concentrations of Pb in shellfish, oysters and squids were within the recommended tolerable intake. Based on the results obtained, the products were considered safe for human consumption, but because of their cadmium levels a long-term consumption could pose a potential hazard to the health of the consumer.

Similarly, Cd concentration was detected up to 18.32 μg/g in squid (*Nototodarus sloanii*) over the regulated limit (1.0 mg/kg) at New Zealand (Lischka et al. 2019). Lead and cadmium was measured in mollusks (*Kunashiria coptzevi*, *Corbicula japonica*) over the official maximum level (Pb: 1,50 mg/kg, Cd: 1,0 mg/kg) such as 0.7–15 µg/g and 0.8–16 µg/g, respectively, at the coastal area of Japan Sea (Chernova and Lysenko 2019). The detected concentrations of Cd in different mollusk species and crustaceans at coastal lagoon of Mexico in the central-eastern Gulf of California were between 0.41 and 0.67 µg/g in clams (*Chione gnidia*, *Chione fluctifraga*, *Anadara tuberculosa*), 0.52–1.18 µg/g in oysters (*Crassostrea cortezienzes*, *Crassostrea gigas*), 0.62–1.18 µg/g in barnacles (*Fistulobalanus dentivarians*), 0.62–1.21 µg/g in snails (*Littoraria aberrans*, *Hexaplex erythrostoma*), 0.46–0.52 µg/g in shrimp (*Litopenaeus vannamei*) and 0.52–1.18 µg/g in crab (*Callinectes arcuatus*) showing seasonal variations. The majority of the samples were below the regulated limit. The levels of Pb in the same species were as follows, 0.99–3.58 µg/g, 2.14–2.62 µg/g, 1.12–2.29 µg/g, 0.73–1.81 µg/g, 0.56–0.72 µg/g and 0.51–1.13 µg/g (Jara-Marini et al. 2020).

High concentrations of methylmercury and total mercury were detected in the predatory fish such as eel (*Anguilla anguilla*) (178.8 µg/kg and 232.0 µg/kg) and cod (*Gadus morhua*) (53.8 µg/kg and 64.1 µg/kg), and low levels in herring (*Clupea harengus*) (14.8 µg/kg and 18.6 µg/kg) and sprat (*Sprattus sprattus*) (6.3 µg/kg and 10.0 µg/kg) originated from southern Baltic Sea (Polak-Juszczak 2018), however, they were below the maximum accepted level (0.5–1.0 mg/kg). Average concentration of mercury was 0.548–1.025 mg/kg in the muscle of anjumara (*Hoplias aimara*) in the rivers of French Guiana located in the northern part of South America (Maury-Brachet et al. 2020). The average values of total mercury and methylmercury in native species Benni (*Mesopotamichthys sharpeyi*) and common carp (*Cyprinus carpio*) were 19.8 and 10.49 µg/kg, and of non-native fish, redbelly tilapia (*Tilapia zillii*) was 28 and 14.62 µg/kg, respectively, at Shadegan International Wetland, Iran, showing lower concentration than the maximum accepted limit (Rahmanikhah, Esmaili-Sari, and Bahramifar 2020). The mean level of Hg was 0.61 µg/g (interval: 0.08–1.93 µg/g) in the muscle of dolphinfish (*Coryphaena hippurus*) sampled from Mexico (La Paz and Cabo San Lucas) in the southern area of the Gulf of California exceeding the regulated limit (Vega-Sánchez et al. 2020).

The muscle of tunas (skipjack [*Katsuwonus pelamis*], yellow fin tuna [*Thunnus albacares*)] from the Eastern Pacific area contained 1.4–4.98 µg/g arsenicals mainly as nontoxic arsenobetain and 0.43–3.38 µg/g mercury (Ruelas-Inzunza et al. 2018).

The concentrations of Cd and Pb in the flesh of common carp (*Cyprinus carpio*) (0.042 µg/g and 0.087 µg/g) and yellow catfish (*Pelteobagrus fluvidraco*) (0.028 µg/g and 0.052 µg/g) were much lower than the regulated limit (Cd: 0.05 mg/kg, Pb: 0.30 mg/kg) (Rajeshkumar and Li 2018). Concentration of Pb was below the regulated level (0.08–0.28 mg/kg) in red mullet (*Mullus surmuletus*) but the level of Cd (0.01–0.41 mg/kg) was exceeded the official accepted limit at Canary Islands (Tenerife and Gran Canaria) (Lozano-Bilbao et al. 2019). Levels of Cd were 0.025–0.377 µg/g and 0.018–0.096 µg/g in the flesh of yellowstripe grunt (*Haemulopsis axillaris*) and Peruvian mojarra (*Diapterus peruvianus*) exceeding the accepted limit at Eastern Pacific region of Mexico, however, the average concentration of Pb in both fish (0.264 µg/g, 0.088 µg/g) was below the legislation (Spanopoulos-Zarco et al. 2019). The average concentrations of Cd and Pb in all investigated fish species (e.g. European anchovy, Mediterranean horse mackerel, rainbow trout, common carp, European seabass, European barracuda, Atlantic salmon) were below the maximum permissible limits, but of inorganic As in red mullet exceeded it in Turkey. The estimated daily intakes of the investigated heavy metals in each fish species were very lower than their TDI values, suggesting that their consumption would not pose health risks for the consumers (Varol, Kaya, and Sünbül 2019). The measured levels of Cd in different fish species at coastal lagoon of Mexico in the central-eastern Gulf of California were between 0.62 and 1.07 µg/g in flathead mullet (*Mugil cephalus*), 0.87–1.14 µg/g in yellow fin mojarra (*Gerres cinereus*), 0.91–1.27 µg/g in white grunt (*Haemulopsis leuciscus*), and 0.92–1.40 µg/g in snapper (*Lutjanus argentivensis*) showing seasonal variations. The majority of the samples were below the regulated limit. The levels of Pb in the same species were as follows, 1.07–1.62 µg/g, 0.81–1.53 µg/g, 0.83–1.51 µg/g, and 0.92–1.38 µg/g exceeding the acceptable limits (Jara-Marini et al. 2020).

Furthermore, MLs and MRLs are used as a reflection of exposure to a particular contaminant from a specific type of food and not from the entire food supply, and do not evaluate the risk of two potential hazards being present in the same edible tissue. Additionally, they are not definite values; they are established based on worldwide research and literature so a value officially given today is subject to change as new information is discovered following more research (Chou and Williams-Johnson 1998). For this reason, they cannot be used as definite safety limits and as being relevant for assessing public health implications (Smart 2003). Humans are no longer sedentary, and as shown in Table 8, accepted residue limits may vary from country to country making permanent travelers susceptible to exceeding recommended weekly or monthly intakes, thus putting their health at risk. Liu et al. (2010) conducted a survey to evaluate the presence of pesticides such as DDT and chlordane in different fish and mollusk species. In agreement with Lehel et al. (2018), the values found were acceptable, which suggested that the products were safe for consumption. However, the authors emphasized that the health risk associated with the consumption of the products were not to be undermined. Sushi and sashimi are made up of other components than just fish, which themselves may contain the previously discussed biological and chemical hazards. So even though concentrations found in fish and fish products are within the recommended tolerable intake they will add up to the amounts found in the other ingredients. For instance, seaweed also accumulates potential toxic metals such as Pb, Cd, As and Hg, and concentrations of Pb, Cd, Hg Cr are also found in rice (Cao et al. 2010; Perryman et al. 2017; Yo et al. 2010). Spores of *B. cereus*, a bacterium found in raw fish can also be present in sushi rice due to poor acidification of the rice, cross-contamination or poor storage temperature (Brighton and Hove City Council 2008; Koo 2018; New South Wales Food Authority 2007). Other bacteria found in fish such as *Salmonella* spp., *E. coli*, *C. jejuni*, *L. monocytogenes*, *B. cereus* and *Staph. aureus* can also be found in the vegetables and eggs used to make sushi or sashimi (Microbiology Society 2018).

Conclusions

Raw fish is highly recommended today by scientists and researchers alike because of its nutritious components that are crucial to the health of vital organs such as the heart and which are able to reduce the risk of several diseases. However, its consumption is nonetheless without its hazards. Raw fish may contain contaminants of both biological and chemical origin, which can pose potential hazard to the health of consumers. Therefore, analytical and detection methods have been developed to assess the safety and quality of edible fish tissues and are continuously improved with time. Even though concentrations of the individual agents may be below the accepted maximum limit, the total amount of these agents deriving from different fish sources, just as the other components of sushi or sashimi dishes puts the consumer's health at risk in the long run. For this reason, health institutions and governments must continuously inform the public about the risks of raw fish consumption. It is undeniable that detection and analytical methods have greatly improved over the years and became faster, more selective, specific, accurate, and reliable. However, despite this improvement and the joined efforts of international experts and institutions to reduce food safety hazards associated with the consumption of raw fish, there is still room for improvement, especially, regarding the respective legislation regulating the food-borne hazards in association with the consumption of raw fish.

Disclosure statement

The authors declare that no actual or potential conflict of interest occurred including any financial, personal or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, our work.

Author agreement/declaration

All authors have seen and approved the final version of the manuscript being submitted. They warrant that the article is the authors' original work, hasn't received prior publication and isn't under consideration for publication elsewhere.

Funding

This work was supported by the European Union and co-financed by the European Social Fund under Grant No. EFOP-3.6.2- 16-2017-00012.

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