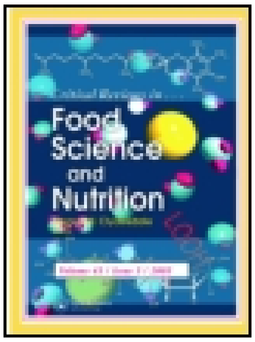

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REVIEW

Current status of food safety hazards and health risks connected with aquatic food products from Southeast Asian region

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ABSTRACT

Food safety issues associated with aquatic food products become more important with the increasing consumption and followed by its ongoing challenges. The objective of this paper is to review the food safety hazards and health risks related to aquatic food products for the Southeast Asian region. These hazards can be categorized as microplastics (MPs) hazard, biological hazards (pathogenic bacteria, biogenic amines, viruses, parasites), and chemical hazards (antimicrobial, formaldehyde, heavy metal). In different Southeast Asian countries, the potential health risks of aquatic food products brought by food hazards to consumers were at different intensity and classes. Among all these hazards, pathogenic bacteria, antimicrobials, and heavy metal were a particular concern in the Southeast Asian region. With environmental changes, evolving consumption patterns, and the globalization of trade, new food safety challenges are created, which put forward higher requirements on food technologies, food safety regulations, and international cooperation.

KEYWORDS
Food safety; risk assessment; Southeast Asia; aquatic food products; health risks

Introduction

Food safety is a crucial issue for public health and any compromise may cause an outbreak of foodborne diseases since food can be contaminated anytime and anywhere in the food chain system (Odeyemi 2016). Every year, one in ten people get sick due to food safety issues worldwide, and an estimated 420,000 die from foodborne diseases, the burden of which is comparable to that of malaria, tuberculosis, or human immunodeficiency virus and acquired immunodeficiency syndrome (HIV/AIDS) (World Health Organization (WHO) 2020a). In the Southeast Asian region, foodborne events are prone to occur due to climatic conditions and eating habits, which brings a negative impact on human health, social economy, and trade. For example, salmonellosis as one of the foodborne diseases caused approximately 22.8 million cases of diarrheal illness annually, with 37,600 deaths in Southeast Asia (Van et al. 2012). Thus, ensuring food safety and addressing foodborne diseases are particularly important, both globally and in the Southeast Asian region (Li et al. 2019). Among all kinds of food, aquatic food products occupied a significant place in any discussion of food safety issues due to the massive consumption of seafood in Southeast Asian countries.

Aquatic food products have been categorized as a low-fat high quality-protein food source (Noor Uddin et al. 2013), which contain n-3 polyunsaturated fatty acid, proteins with high nutritional value, minerals (calcium, selenium, iron, zinc), bioactive peptides, the free amino acid taurine as well as multiple vitamins (B3, B6, E, D) (Daschner 2016). Contrary to fats and oils of land animals, which cause or aggravate diabetes, obesity, and cardiovascular complications, fats, and oils of aquatic food products could boost up immunity against many diseases (Djoussé et al. 2012; Wu et al. 2012). Besides, aquatic food products have a lower carbon footprint than pork and beef, which are more environment-friendly (Nijdam, Rood, and Westhoek 2012). Despite the above merits, aquatic food products are not guaranteed to be risk-free.

Aquatic food products are highly perishable, which makes them vulnerable to different types of hazards including chemical, physical, and microbiological hazards (Hellberg, DeWitt, and Morrissey 2012). These hazards could seriously impact the quality and safety of aquatic food products and posing health risks to consumers (Lloret et al. 2016). For example, methylmercury (MeHg) as the main form of mercury (Hg) in fish can accumulate high concentrations in predatory fish due to biomagnification, thus posing a health risk to consumers (Drevnick, Lamborg, and Horgan 2015; Ferrantelli et al. 2012). The exposure of MeHg may impair neurological development and increase the rate of cardiovascular disease, particularly myocardial infarction (Stern and Korn 2011). In Southeast Asia, food safety associated with aquatic food products is paramount. The coastal waters of Southeast Asia are among the most productive and biologically diverse in the world. About 34% of the world's coral reefs, 30% of the mangrove, and 18% of the seagrass grow

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here (Tiquio, Marmier, and Francour 2017). And people in Southeast Asia are relying more heavily on fish as a primary source of dietary protein as well as household income than any other people in the world (Pomeroy et al. 2016). However, unsafe food poses a threat to human health and might lead to an increase in healthcare expenditure and consumption of national wealth. Hence, it is necessary to increase the awareness of aquatic food products safety issues and build scientific food handling criteria to ensure food safety.

Therefore, the main objective of this paper is to review the food safety hazards and health risks related to aquatic food products for the Southeast Asian region. These hazards can be categorized as the following: MPs hazard; chemical hazards which can be divided further into antimicrobial, formaldehyde and heavy metal; biological hazards which also can be divided into pathogenic bacteria, histamine and other biogenic amines, viruses, and parasites.

Food safety hazards and health risks related to fish and marine-based products

Microplastic

MPs are small pieces of plastic with less than five millimeters in size and without a lower limit (GESAMP 2016). The term "MPs" has only been commonly used for about fifteen years but they are of special concern due to their small size, the lack of technology available to quantify the existence of the MPs in the environment, and their potential physical hazard and/or harmful toxicological for marine biota and humans (Barboza et al. 2018; Thompson 2015).

Plastic has been found worldwide in the marine environment, with estimates of more than 5 trillion plastic debris (over 250,000 tons) afloat at sea (Eriksen et al. 2014). MPs, which originate from the fragmentation of larger plastics and the direct release of plastic particles, were also highly persistent in the environment and can increasingly accumulate at different marine ecosystems (Cózar et al. 2017; Suaria et al. 2016; Van Sebille et al. 2015; Waller et al. 2017; Woodall et al. 2014). The ecosystems most polluted by these particles were usually ocean gyres, estuaries, and other coastal areas which were heavily affected by human activities (Cózar et al. 2017; Eriksen et al. 2014; Frere et al. 2017; Galgani, Hanke, and Maes 2015; Peters and Bratton 2016). MPs have been detected in 11 of the 25 species that contribute the most to global marine fisheries (Barboza et al. 2018). In Indonesia, MPs were found in 28% of fish samples (Rochman et al. 2015). In Malaysia, MPs were found in different species of fish such as *Chelon subviridis, Clarias gariepinus, Colossoma macropomum, Ctenopharyngodon Idella, Eleutheronema tridactylum, Epinephelus coioides, Johnius belangerii, Megalaspis cordyla, Nemipterus bipunctatus, Rastrelliger kanagurta, Stolephorus waitei,* and *Thunnus tonggol* (Karami et al. 2017; Karbalaei et al. 2019). Summary of studies reporting the occurrence of MPs in aquatic food products in Southeast Asia as reported in Table 1. MPs is detected not only in the gastrointestinal tract, but also in muscle tissue of fish and crustacea (Abbasi et al. 2018; Akhbarizadeh, Moore, and Keshavarzi 2018; Karami et al. 2017; Karbalaei et al. 2019; Rochman et al. 2015).

Most of the studies assessed the MP contents in the gastrointestinal tract of fish while little has focused on MP loads in the edible tissues since it is believed that the MPs ingested by fish are mainly concentrated in the gastrointestinal tract. Unfortunately, the MPs that enter the gastrointestinal tract had been confirmed to be transferred into other organs and the presence of MPs is even detected in the edible tissues of fish (Avio, Gorbi, and Regoli 2015; Karami et al. 2017; Lu et al. 2016). Therefore, even if a person only consumes eviscerated fish, the risk of ingesting MPs still exists, so future studies should evaluate the content of MPs in various tissues of fish, especially the edible part.

To reduce human health risks, many measures to reduce plastic pollution have been initiated and implemented. However, even if humans could stop new plastics from entering the environment, the number of MPs will continue to increase due to the existing fragmentation of plastics (Thompson 2015). Hence, it is important to not only reduce plastic pollution but also to fully understand the pathway of MPs uptake into humans through the food chain, especially through aquatic food products, the behavior of MPs after entering the human body, and their risk to human health. There are solutions to eliminate the health risk of uptake MPs to humans, however, the knowledge about the impacts of MPs on human health is still in its infancy, and further investigations are needed (Barboza et al. 2018).

Biological hazards

Aquatic food products are highly perishable and susceptible to contamination by microorganisms such as bacteria and viruses causing various food-borne diseases (Samanta and Choudhary 2019). The presence of human pathogenic microorganisms in aquatic food products is affected by various factors, such as human activity and environmental conditions during harvesting, processing, and storage of products (Novoslavskij et al. 2016; Freitas et al. 2020). In addition to pathogenic microorganisms, some fish and marine products may contain parasites and biotoxins such as biogenic amines, which will also pose a potential health risk to consumers (Ryder, Iddya, and Ababouch 2014).

Pathogenic bacteria

Some pathogenic bacteria are naturally present in fish and marine animals and some of the bacteria are present during processing as a result of mishandling (Lehel et al. 2020). Among many species of pathogenic bacteria involved in aquatic food products, the most common bacteria belong to the genus of *Vibrio, Salmonella, Escherichia, Yersinia, Shigella, Listeria, Staphylo,* and *Clostridium* (Samanta and Choudhary 2019). Over the past decade, the prevalence of the bacteria reported from Southeast Asia is summarized in Table 2.

Table 1. Summary of studies reporting the occurrence of MPs in aquatic food products in South East Asia.

Species name	Levels of MPs	Size range	Parts	Types of debris	Location	References
Decapterus macrosoma	29%	0.5-5mm	Gastrointestinal tract	Fragments, styrofoam	Eastern Indonesia	Rochman et al. 2015
Rastrelliger kanagurta	56%			Fragments, film, monofilament		
Siganus canaliculatus	33%			Monofilament		
Spratelloides gracilis	40%			Fragments		
Chelon subviridis, Johnius belangerii, Rastrelliger kanagurta, Stolephorus waitei	MP particles were isolated from each individual fish.	0.001-1mm	Eviscerated flesh (whole fish excluding the viscera and gills) and excised organs (viscera and gills)	Fragments, filaments, films	Malaysia	Karami et al. 2017
Clarias gariepinus	60%	0.149-5mm	Viscera and gills	fragment, fiber, film	Malaysia	Karbalaei et al. 2019
Nemipterus bipunctatus	10%					
Colossoma macropomum	40%					
Megalaspis cordyla	20%					
Thunnus tonggol	20%					
Ctenopharyngodon idella	30%					
Rastrelliger kanagurta	50%					
Epinephelus coioides	30%					
Eleutheronema tridactylum	30%					

Vibrio spp

The *Vibrio* genus, which is now composed of 142 species, is ubiquitous and indigenous in aquatic environments and many of them are associated with marine organisms (Bonnin-Jusserand et al. 2019; Sawabe et al. 2013). Among 12 species of *Vibrio* known as pathogenic to humans, the three most common are *Vibrio cholerae*, *Vibrio parahaemolyticus,* and *Vibrio vulnificus* (Bonnin-Jusserand et al. 2019).

Fish are considered natural reservoirs and transmissions of *V. cholerae*, a deadly diarrheal pathogen (Hossain et al. 2018). Of the 1.4-4.0 million cases of cholera that occur globally every year, about 21,000 to 143,000 people could die (Ali et al. 2015). Despite considerable public health achievements, cholera is still an important public health problem worldwide (Ali et al. 2012; Zin et al. 2015). Jikal et al. (2019) investigated an outbreak of *V. cholera* which they took samples from food, water, and environment and they found that cholera was possibly spread by contaminated seafood.

V. parahaemolyticus is one of the most important foodborne pathogens in tropical and subtropical areas and has been recognized as an agent for gastroenteritis associated with consumption of seafood (Letchumanan, Chan, and Lee Letchumanan, Chan, and Lee 2014). Significantly, not all strains of *V. parahaemolyticus* are truly pathogenic (Jesser et al. 2019). The pathogenic strains contain two virulence factors: a thermostable direct hemolysin (TDH) and a TDH-related hemolysin (TRH) coded by the *tdh* gene and the *trh* gene, respectively (Nakaguchi 2013). The strains isolated from aquatic food products seldom possess *tdh* and/or *trh* genes (Lovell 2017). It is consistent with the conclusions of researches in Table 2, which showed that although there was a high prevalence of *V. parahaemolyticus* in aquatic food products but the incidences of *V. parahaemolyticus* with *tdh* and/or *trh* genes were very low.

Except for *V. cholerae* and *V. parahaemolyticus*, *V. vulnificus* is another most common pathogenic *Vibrio* to humans (Bonnin-Jusserand et al. 2019). Infection with *V. vulnificus* can occur by consuming contaminated seafood and lead to serious diseases, even developing into septicemia and fatality (Horseman and Surani 2011). Considering the harm of *V. vulnificus* to human health, Changchai and Saunjit (2014) determined the occurrence, population density, and virulence of *V. vulnificus* in 240 retailed raw oysters and detected the presence of *V. vulnificus* in 53 oyster samples amounting between 10 and 10^2 MPN/g. Similarly, a study by Yano et al. (2014) found that 12.5% of shrimp samples from inland ponds in Thailand detected *V. vulnificus* (densities: 16-1300 MPN/g). Meanwhile, *V. vulnificus* was also isolated from Shrimp (*Litopenaeus vannamei*) collected from Vietnam (Table 2) (Banerjee et al. 2012).

Salmonella *sp*

Salmonella sp. has also been identified from a variety of aquatic food products including clams, oysters, squid, mussels, lobsters, crabs, cuttlefish, and octopus (Ananchaipattana et al. 2012; Banerjee et al. 2012; Nguyen et al. 2016; Singh and Monda). *Salmonella* in aquatic food products can cause human salmonellosis. Approximately 22.8 million cases of diarrheal illness were caused by salmonellosis outbreaks annually, with 37,600 deaths in Southeast Asia (Van et al. 2012). In this regard, the prevalence of *Salmonella* in aquatic food products obtained from Southeast Asia was examined (Table 2). Nguyen et al. (2016) reported *Salmonella* were detected in shrimp samples (49.1%) and farmed freshwater fish samples (36.6%) purchased from Vietnam. While Ananchaipattana et al. (2012) reported that 35% of fish or seafood samples obtained from Thailand were detected with *Salmonella*. On the contrary, low occurrence rates of

Table 2. The occurrence and population density of pathogenic bacteria in aquatic food products at Southeast Asia.

Country	Name of samples	Counts of samples examined	Species of Isolated bacteria	Incidence (%)	Counts of bacteria (MPN/g)	References
Indonesia	Seafood (fish, shrimp, squid, crab, and shellfish)	130	*V. parahaemolyticus**	49.23	–	Nakaguchi 2013
			V. parahaemolyticus with *tdh* gene	2.31	–	
			V. parahaemolyticus with *trh* gene	6.92	–	
Malaysia	Short mackerels (*Rastrelliger brachysoma*)	130	*V. parahaemolyticus**	89.2	< 3 to $> 10^5$	Tan et al. 2017
			V. parahaemolyticus with *tdh* and/or *trh* gene	16.2	–	
	Fish	–	*V. cholera*	–	–	Jikal et al. 2019
	Fish (*Lutjanus sanguineus, Lates Calcarifer, Pangasius pangasius)*	58	*V. fluvialis, V. parahaemolyticus, Proteus mirabilis, Proteus vulgaris, Brucella* sp., and *Ochrabactrum anthropic*	–	–	Jalal et al. 2017
	Seafood (fish, shrimp, squid, crab, and shellfish)	52	*V. parahaemolyticus**	50	–	Nakaguchi 2013
			V. parahaemolyticus with *tdh* gene	3.8	–	
			V. parahaemolyticus with *trh* gene	5.8	–	
	Shrimp and cockles	–	*V. parahaemolyticus**	–	–	Al-Othrubi et al. 2011
	Shrimp (*Litopenaeus vannamei*)	180	*V. alginolyticus, V. cholera, V. mimicus, V. parahaemolyticus,* and *V. vulnificus*	48.3	–	Banerjee et al. 2012
			Salmonella	3.3	–	
	Shrimp (*Penaeus indicus* and *Solenocera subnuda*)	320	*V. parahaemolyticus**	57.8	–	Letchumanan et al. 2015
			V. parahaemolyticus with *tdh* gene	0	–	
			V. parahaemolyticus with *trh* gene	5.9	–	
	Shellfish (bloody clams and surf clams) and crustaceans (shrimps)	232	*V. parahaemolyticus**	98.7	30->110, 000	Malcolm et al. 2015
			V. parahaemolyticus with *tdh* gene	33.1	30->110,000	
			V. parahaemolyticus with *trh* gene	6.9	30-9300	
Singapore	Prawn	40	*V. parahaemolyticus**	2.5	–	Huang et al. 2012
	Shellfish	31	*Salmonella*	3.2	–	
	Fishball	32	*V. parahaemolyticus**	3.1	–	
Thailand	Seafood and fish	37	*E. coli*	59	–	Ananchaipattana et al. 2012
			Salmonella spp.	35	–	
			Yersinia spp.	5	–	
			Cronobacter sakazakii	3	–	
			Listeria spp.	3	–	
			Bacillus cereus	5	–	
			Staphylococcus spp.	22	–	
	Shrimp samples (white-leg shrimps and black-tiger shrimps)	16	*V. cholerae*	93.75	62-252,000	Yano et al. 2014
			*V. parahaemolyticus**	37.5	370-6,300,000	
			V. vulnificus	12.5	16-1300	
	Shellfish (bloody cockle, green mussel, oyster, and oriental hard clam)	300	*V. parahaemolyticus**	62.67	–	Nakaguchi 2013
			V. parahaemolyticus with *tdh* gene	13.33	–	
			V. parahaemolyticus with *trh* gene	2.3	–	
	Shellfish (Oyster)	240	*V. parahaemolyticus**	91	3-1,100	Changchai and Saunjit 2014
			V. parahaemolyticus with *tdh* gene	12	3-210	
			V. vulnificus	22	3-1,100	
Vietnam	Shrimp	53	*Salmonella*	49.1	–	Nguyen et al. 2016
	Fish	101	*Salmonella*	36.6	–	
	Seafood (shellfish and shrimp)	385	*V. parahaemolyticus**	86.2	–	Tran et al. 2018
			V. parahaemolyticus with *tdh* gene	5.7	–	
			V. parahaemolyticus with *trh* gene	1.3	–	
	Seafood (fish, shrimp, squid,	74	*V. parahaemolyticus**	70.3	–	Nakaguchi 2013

(*continued*)

Table 2. Continued.

Country	Name of samples	Counts of samples examined	Species of Isolated bacteria	Incidence (%)	Counts of bacteria (MPN/g)	References
	crab, and shellfish)					
			V. parahaemolyticus with tdh gene	6.8	–	
			V. parahaemolyticus with trh gene	2.7	–	

Note: *V. parahaemolyticus** include all strains of *V. parahaemolyticus*, not only pathogenic strains.

Salmonella in seafood products were examined in Malaysia and Singapore (Table 2) which might be contributed by strict enforcement of the food safety assurance system applied by the manufacturer.

Other human pathogenic bacteria such as *Bacillus cereus*, *Brucella* sp., *Cronobacter sakazakii*, *Escherichia. coli*, *Listeria* spp., *Ochrabactrum anthropic*, *Proteus mirabilis, Proteus vulgaris, Staphylococcus* spp., *Vibrio fluvialis,* and *Yersinia* spp. were also found in seafood collected from Southeast Asia (Table 2) (Ananchaipattana et al. 2012; Jalal et al. 2017).

Vibrio and *Salmonella* are two of the most common pathogenic bacteria in aquatic food products in Southeast Asia. *Vibrio* spp. are natural inhabitants of seawater in tropical and temperate regions, maybe it is one of the reasons why there are high occurrences of them in aquatic food products in Southeast Asia where the coastal water is always warm all year (Changchai and Saunjit 2014). Contrary to *Vibrio*, *Salmonella* is not indigenous in the aquatic environment and is usually found in the intestines of humans and animals (Banerjee et al. 2012). Thus, *Salmonella* can enter the environment through feces and contaminate seafood caught in contaminated seawater or processed by contaminated personnel. Therefore, to reduce the risk of seafood pathogens, it is necessary to adopt some control measures. For example, monitor the contaminated level of harvested water, formulate strict hygienic production practices, and prevent cross-contamination.

Open market and supermarket are the two main sites where consumers purchase aquatic food products. Figure 1 is showing the occurrence and population density of pathogenic bacteria in aquatic food products in the Southeast Asian region. Results from these studies (Figure 1) suggested the prevalence of pathogenic bacteria from open markets was found to be higher than supermarkets due to unsuitable handling processes and the impact of adverse environmental factors such as insects, rodents, and temperature in open markets (Ananchaipattana et al. 2012; Malcolm et al. 2015; Tan et al. 2017). Thus, it is suggested to standardize the handling processes and improve the hygienic conditions in open markets. To date, there is no proper practice for food safety assurance especially in a wet market that sells fresh fish and other marine products. Meanwhile, the proper handling measurements of aquatic food products should be correctly informed to consumers so that they can reduce risks through proper storage and cooking methods after they purchased these products.

Biogenic amines

Biogenic amines such as histamine, putrescine and cadaverine are widely regarded as indicators of fish spoilage. The possibility of biogenic amine formation can be increased during some manufacturing processes like fermentation, salting, marination and ripening, as well as during storage if holding temperatures are improper (Biji et al. 2016; Visciano et al. 2012). Large amounts of biogenic amines can be toxic for human (Ryder, Iddya, and Ababouch 2014). Therefore, researchers have investigated the level of biogenic amines in aquatic food products from Southeast Asia and the data of biogenic amine contents is summarized in Table 3.

With respect to toxicity of aquatic food products, histamine is the most important among all biogenic amines and one of the most common causes of foodborne illness caused by ingesting aquatic food products (Ryder, Iddya, and Ababouch 2014; Samanta and Choudhary 2019). Ingestion of histamine in the range of 8-40 mg, 40-100 mg or higher than 100 mg in one meal could lead to slight, intermediate and severe poisoning, respectively, and the typical symptoms include sweating, erythema, nausea, a peppery taste or burning sensation in the mouth, diarrhea, dizziness, headaches, and palpitations, which usually start within 10 minutes to 1 hour of food intake and last within 24 hours (Biji et al. 2016; Jantschitsch et al. 2011). For freshly caught fish, its level is generally very low (below 0.1 mg/100 g) (Visciano et al. 2012). However, the level of histamine can be increased, because the bacterial histidine decarboxylases resolve histidine as the temperature is elevated during processing and improper storage (Samanta and Choudhary 2019). Although histamine formation can be controlled by cold storage, a few psychrophilic bacteria such as *Photobacterium phosphoreum* and *Morganella psychrotolerans* can form histamine at temperatures as low as 0 °C-5 °C (Hungerford 2010). Meanwhile, histamine is heat stable in nature and can persist in heat-treated products even after the bacteria are inactivated (Jantschitsch et al. 2011). Due to its stability property and toxicological effects, currently, it is the only biogenic amine with the maximum limits regulated by law for the human consumption (Prester 2011). The regulatory limits in Thailand for histamine are 100 ppm, and in the Philippines, the hazard standard levels of histamine were below 100 ppm for fresh frozen products and 200 ppm for dried and fermented products (Tao et al. 2011). However, a study by Tao et al. (2011) showed that histamine was detected in 4 of 11 fish samples from Thailand, ranging from 56 ppm to 1964 ppm and about 60% of the dried bonito (*Sarda* spp.) samples purchased from Philippines contained histamine ranging from 19 ppm to 1530 ppm. While Amascual et al. (2020) reported that histamine was detected in 81.3% of 50 samples of dried-salted fish products obtained from different local supermarkets in the

Philippines. The study also reported that the species of fish with the highest concentration of histamine included *Bolinao (Stolephorus sp.)*, *Tamban (Sardinella sp.)*, *Lambiao (Selar boops)*, and *Hasa-hasa (Rastrelliger sp.)*. In Malaysia, the total biogenic amine contents in anchovy sauce samples and fermented fish samples were significantly lower than 1000 ppm (Ezzat et al. 2015; Zaman et al. 2010). While anchovy sauce samples contained higher biogenic amine contents than fermented fish samples. Nevertheless, they were still considered safe since anchovy sauce is usually used as a condiment and would not be consumed in large quantities by consumers (Zaman et al. 2010).

Biogenic amines in aquatic food products can be produced due to inadequate storage temperature and microbial contamination (Biji et al. 2016; Visciano et al. 2012). Among all biogenic amines, histamine is most widely investigated in aquatic food products because of its toxicological effects (Prester 2011). However, the determination of other biogenic amines such as putrescine and cadaverine has been recommended since they can potentiate histamine toxicity (Ezzat et al. 2015). To reduce the levels of biogenic amines, many methods have been proposed such as additives, packaging, irradiation, pasteurization, starter culture, smoking, and controlling temperature which can inhibit microbial growth and the formation of biogenic amines (Doeun, Davaatseren, and Chung 2017; FDA 2011; Křížek, Vácha, and Pelikánová 2011; Rabie et al. 2011; Yassoralipour et al. 2012; Zaman et al. 2011). To ensure the safety of commercial aquatic food products in Southeast Asia, the occurrences of biogenic amines need to be continuously monitored.

Viruses

Foodborne viruses are derived from the human gastrointestinal tract and present in water and food due to sewage pollution, poor hygiene, or contamination by food processors (Ryder, Iddya, and Ababouch 2014). Viral contamination of aquatic food products is an extensively documented food safety concern and most diseases involving aquatic food products are caused by viruses, especially Norovirus (NoV) which is the most common cause of viral gastroenteritis in humans around the world and can damage the lining of the small intestine, causing diarrhea and vomiting in the affected person (Daschner 2016; Feng 2012; Lehel et al. 2020). However, there is very limited date about viral contamination of aquatic food products in Southeast Asia (Table 4).

Suffredini et al. (2020) provided quantitative information on the occurrence of enteroviruses in bivalve shellfish collected from Vietnam and found that 83.5% of samples were contaminated by at least one virus and the prevalence of NoV (81.8% of samples) was higher than other viruses. Fortunately, the average amount of NoV in positive samples was 3.8×10^3 genome copies (g.c.)/g that is lower than the quantification limit (2.8×10^4 g.c./g). In a previous study, Nguyen et al. (2018) reported the NoV contamination level of oysters obtained from a lagoon receiving urban drainage and found that the maximum concentrations of genogroup (G) I and GII, which are two of genogroups (GI, GII, and GIV) that can infect humans, were 2.4×10^5 and 2.3×10^4 copies/g, respectively. The reason oysters samples contained a high concentration of NoV maybe because they were obtained from the lagoon where untreated domestic sewage produced by the urban population of 350,000 was discharged (Nguyen et al. 2018). Compared with Vietnam, the prevalence of NoV in bivalve shellfish collected from Thailand is significantly lower as suggested in Table 4.

The occurrence of a virus, especially NoV, in seafood is an important issue of concern. The mismanagement of hygiene in shellfish producing areas, improper handling, and transportation methods may cause shellfish to be contaminated by a virus (Das et al. 2020). There are very limited studies on the presence of viruses in seafood from the Southeast Asian region. Hence, it is very essential to conduct more research on the occurrence of viruses in seafood within this region. So that a better understanding can be established regarding their safety and health risks. Meanwhile, the improvement of wastewater treatment systems, maintaining good personal hygiene, and detecting products before being marketed are recommended as preventive measures for the safety of aquatic food products.

Parasites

Although the zoonotic parasites of aquatic food products make up only a small part of many parasite species that infect aquatic food products, they are a diverse and widespread group, primarily helminths including species of nematodes (roundworms), trematodes (flukes), cestodes (tapeworms) and recently myxosporidia (Daschner 2016; Ryder, Iddya, and Ababouch 2014). Humans are easily infected by consuming raw or improperly prepared aquatic food products such as oysters or shellfish (for *Giardia* and *Cryptosporidium*), tuna, salmon, herring, or mackerel (for *Anisakis* species) and cod or squid (for *Pseudoterranova decipiens*) (DePaola and Toyofuku 2014).

Liver and intestinal trematodes are major zoonotic parasites of humans transmitted by aquatic food products and affect the health of more than 18 million people worldwide, particularly in Asian countries (Wiriya et al. 2013). According to Hung et al. (2015), fish and fecal samples from human, dogs, cats, and pigs were collected from an endemic province of fish-borne zoonotic trematode transmission in Vietnam and the results of the study showed that all fish species were infected with trematode and 65.5% of the human fecal samples contain helminth eggs. Sanpool et al. (2018) reported the discovery of *Opisthorchis viverrini* in cyprinoid fishes purchased from Myanmar.

Some nematodes such as *Anisakid* nematodes, *Eurostrongylides,* and *Gnathostoma* worms are also zoonotic parasites affecting humans via aquatic food products and the most common species are *Anisakid* nematodes which include *Anisakis simplex, Contracaecum osculatum,* and *Pseudoterranova decipiens* (Lehel et al. 2020; Ljubojevic et al. 2015). Humans can be infected by *Anisakis* larvae after consuming uncooked marine fish or cephalopods, which leads to anisakiasis and acute gastrointestinal symptoms, such as diarrhea, abdominal pain, and nausea as well as vomiting (Nieuwenhuizen and Lopata 2013). According to

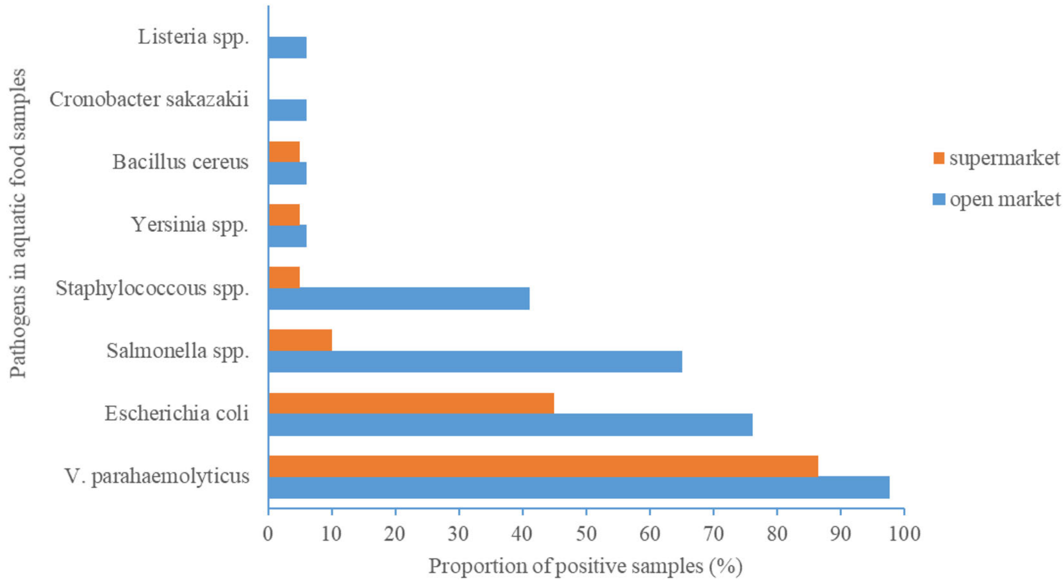

Figure 1. Comparison of the prevalence of pathogenic bacteria in aquatic food sold in open market and supermarket (Ananchaipattana et al. 2012; Malcolm et al. 2015; Tan et al. 2017).

Chaiphongpachara (2019), the prevalence of *Anisakis* larvae infection in Indian mackerel (*Rastrelliger kanagurta*) collected from a fish market in Thailand was 2.86%. Anisakiasis, which had never been seen in Malaysia, was first reported by Amir et al. (2016) which involved a 64-year-old man in Malaysia that had acute dysentery caused by anisakiasis.

The absence of published literature on the presence of parasites in aquatic food products does not exclude the possibility of the presence of parasites in aquatic food products in this region. Although, both the government and suppliers are responsible for ensuring the safety of aquatic food products provided to consumers, but consumers must take the necessary preventive measures to reduce the risk of infection. One of the most important measures is to avoid raw or poorly cooked seafood, especially for those with weak immune systems or liver disease, since most of the parasitic infections caused by consuming raw or undercooked seafood (DePaola and Toyofuku 2014; Ljubojevic et al. 2015; Shamsi 2019). It is perceived that harvesting smaller and younger fish can reduce the risk of infection by parasites since the number of worms in fish increases with the size and age of fish (Weissfeld 2014).

Chemical hazards

Chemical substances produced by human activities are released into the environment and passed on to humans through the food chain and pose potential human health hazards, such as carcinogenic and mutagenic effects (Duran, Tuzen, and Soylak 2014; FDA 2011). The common chemical pollutants in aquatic food products include antimicrobial, formaldehyde, and heavy metals.

Antimicrobial

The importance of antimicrobial agents in protecting animal health has been widely recognized, but, equally, the negative effects of using these agents in animals raised for food have attracted attention. Antibiotic residues in food as a global public health problem not only can cause a potential risk of direct toxicity to consumers but also can promote the development of resistant strains and then lead to failure of antibiotic therapy (Manyi-Loh et al. 2018; Vishnuraj et al. 2016). However, in many developing countries, the use of antimicrobials is often unregulated and data on their usage is scarce (Ryder, Iddya, and Ababouch 2014).

Southeast Asia is regarded as a hotspot for antimicrobial resistance (Nhung et al. 2016). In Vietnam, antibiotic residues were found in aquatic products, at a rate of 14.64% and enrofloxacin was commonly detected, at a rate of 10.8% (Uchida et al. 2016). Another study from Vietnam investigating antimicrobials (fluoroquinolone and tetracycline) residues in 104 fish/shrimp retail samples concluded that 27% of overall retail samples tested positive for either of the two (Pham et al. 2015). In Indonesia, antibiotic residues (e.g., chloramphenicol) in crab and shrimp were reported, and the export volume of products is affected for this reason (Wahidin and Purnhagen 2018).

The use of antimicrobials in aquaculture has resulted in the development of antibiotic-resistant bacteria which was detected from seafood in the Southeast Asian region as in Table 5. Meanwhile, the resistance of some bacteria to antibiotics is gradually increasing. For example, in the study by Al-Othrubi et al. (2014), the mean of a minimum inhibitory concentration of the *V. parahaemolyticus* isolated from cockles and shrimp marketed in Malaysia toward ampicillin was detected to be increased from 64 μg/ml in 2011 to 128 μg/ml in the year 2013. Surprisingly, although carbapenems were the antimicrobial drugs of last resort and recommended only for the severe community- and healthcare-associated multidrug-resistant bacterial infections, carbapenem-resistant *Enterobacteriaceae* was detected in shrimp and bivalve mollusks products exported from Vietnam (Janecko et al. 2016).

Antibiotic residues have been detected from aquatic food products in Southeast Asia, and many antibiotics used can

Table 3. Biogenic amine contents in aquatic food products in Southeast Asia.

Country	Name of samples	Number of positives/ number of samples	Biogenic amine content (ppm)			References
			Histamine	Putrescine	Cadaverine	
Cambodia	Fish (*Channa micropeltes* and *Channa striata*)	3/3	25-148	–	–	Tao et al. 2011
Malaysia	Anchovy sauces	5/5	62.5-393.3	5.6-242.8	187.1-704.7	Zaman et al. 2010
	Naturally fermented fish (Javanese carp and Black tilapia)	7/7	12.7-109.1	38.1-249.4	44.3-209.2	Ezzat et al. 2015
	Acid-assisted fermented fish (Javanese carp and Black tilapia)	8/8	7.1-113.4	52.9-184.4	25.7-211.2	
Philippines	Fish (*Auxis rochei*)	8/13	19-1530	–	–	Tao et al. 2011
	Dried-salted fish (*Assorted fish, Balanak, Baysa, Bokaw, Bolinao, Danggit, Dinorado, Galunggong, Hasahasa, Lahing, Lambiao, Lusod, Sapsap* and *Tamban*)	50/50	73.27- >1500	–	–	Amascual et al. 2020
Thailand	Fish (Unknown, *Auxis thazard, Rastrelliger Kannagurta, Lactarius lactarius, Liza vaigiensis,* and *Pangasius hypophthalmus*)	4/11	56-1964	–	–	Tao et al. 2011

Note: ND not detected (< 7 ppm).

Table 4. Prevalence of foodborne viruses in aquatic food products in Southeast Asia.

Country	Name of samples	No. of tested samples	No. of positive samples (%)								References
			NoV								
			GI	GII	GI + GII	GIV	HAV	HEV	AstV	AiV	
Thailand	Bivalve shellfish (oyster, mussel, and cockle)	300	23 (7.7)	8 (2.6)	6 (2.0)	–	–	–	–	–	Kittigul et al. 2016
Vietnam	Bivalve shellfish (*Crassostrea gigas* and *Meretrix lyrate*)	121	61 (50.4)	96 (79.3)	99 (81.8)	0 (0.0)	2 (1.7)	14 (11.6)	15 (12.4)	14 (11.6)	Suffredini et al. 2020
	Oyster	34	27 (79.4)	14 (41.2)	12 (35)	–	–	–	–	–	Nguyen et al. 2018

Note: HAV: Hepatitis A; HEV: Hepatitis E; AstV: Astrovirus; AiV: Aichi virus.

accumulate in the environment for a long time, thereby increasing the occurrence of antibiotic resistant bacteria (Al-Othrubi et al. 2014; Banerjee et al. 2012; Janecko et al. 2016; Letchumanan et al. 2015; Nguyen et al. 2016; Pham et al. 2015; Saifedden et al. 2016; Tan et al. 2017; Thuy, Nga, and Loan 2011; Uchida et al. 2016; Wahidin and Purnhagen 2018; Yano et al. 2014). One of the extremely important sources of antibiotics in the environment is aquaculture (Pruden et al. 2013). Worryingly, according to a survey in Vietnam, few farmers knew the regulations regarding the use of antibiotics in aquaculture and economic incentives prompted them to use antibiotics, even the banned antimicrobials such as fluoroquinolones by World Health Organization (WHO) (Pham et al. 2015). The severity of the increase in morbidity and mortality related to antibiotic resistance states the need for action, such as strictly regulating the use of antibiotics and looking for alternatives to antibiotics (Pruden et al. 2013).

Formaldehyde

Formaldehyde is a flammable, colorless, and readily polymerized gas at ambient temperature, and it's harmful to human health at a certain concentration. The aqueous solution of formaldehyde (37-40 wt%) is formalin, a colorless liquid used as a biological preservative (Alam 2014). Ingesting formalin regularly can damage the nervous system, liver, and kidneys, and may cause lung damage, asthma, and cancer (Abdu, Kinfu, and Agalu 2014; Mamun et al. 2014). Meanwhile, formaldehyde is listed as the first carcinogen in humans by the International Agency for Research on Cancer (IARC) (Noordiana, Fatimah, and Farhana 2011).

Formaldehyde can be found naturally in small amounts in a wide range of food items, including fish, crustaceans, fruits, vegetables, meat, and dried mushroom, as a common metabolic by-product (Nowshad, Islam, and Khan 2018). In fish flesh, formaldehyde may be formed during the ageing and deterioration, but high levels of formaldehyde do not accumulate in the fish tissues due to subsequent conversion of formaldehyde to other chemical compounds (Noordiana, Fatimah, and Farhana 2011). However, to extend the shelf life of aquatic food products, formaldehyde is sometimes added irresponsibly by fishermen and fishmongers as a food preservative, and due to aquatic food products are very perishable and can only be kept fresh in ice for 8 to 14 days depending on species (Noordiana, Fatimah, and Farhana 2011; Nowshad, Islam, and Khan 2018). It causes double

Table 5. The resistance of bacteria species isolated from different seafood in Southeast Asia to antibiotics.

Country	Name of samples	No. of tested samples	Species of isolated antibiotic resistant bacteria	No. of tested isolated bacteria	Occurrence of resistance (%)	Antimicrobial agent	References
Malaysia	Shrimp (*Litopenaeus vannamei*)	180	*Salmonella*	–	–	Individual and multiple antibiotics	Banerjee et al. 2012
			V. cholerae	–	18.3	Individual and multiple antibiotics	
			V. mimicus	–	16.7	Individual and multiple antibiotics	
			V. parahaemolyticus	–	10	Individual and multiple antibiotics	
			V. vulnificus	–	6.7	Individual and multiple antibiotics	
			V. alginolyticus	–	1.7	Individual and multiple antibiotics	
	Shrimp	–	*V. parahaemolyticus*	30	90	Ampicillin	Saifedden et al. 2016
					63.3	Amoxicillin-clavulanic acid	
					60	Cefotaxime	
					46.7	Ceftazidime	
					50	Cefepime	
					36.6	Tetracycline	
					26.7	Amikacin	
	Shrimp and cockles	>400	*V. parahaemolyticus*	–	–	Ampicillin	Al-Othrubi et al. 2014
	Short mackerels (*Rastrelliger brachysoma*)	130	*V. parahaemolyticus*	67	92.5	Penicillin G	Tan et al. 2017
					82.1	Ampicillin	
	Shrimp (*Penaeus indicus* and *Solenocera subnuda*)	320	*V. parahaemolyticus*	185	82	Ampicillin	Letchumanan et al. 2015
					51	Amikacin	
					37	Cefotaxime	
					15	Ceftazidime	
					4	Chloramphenicol	
					11	Gentamicin	
					2	Imipenem	
					28	Kanamycin	
					9	Levofloxacin	
					19	Nalidixic acid	
					19	Oxytetracycline	
					4	Sulfamethoxazole/trimethoprim	
					17	Tetracycline	
	Raw meat and seafood	409	*Salmonella*	336	53.3	Tetracycline	Nguyen et al. 2016
					43.8	Ampicillin	
					37.5	Chloramphenicol	
					31.3	Trimethoprim/sulfamethoxazole	
Thailand	Shrimp (White-leg shrimp and black-tiger shrimp)	16	*V. cholerae*	140	8	Ampicillin	Yano et al. 2014
					2	Oxytetracycline	
			V. parahaemolyticus	70	72	Ampicillin	
					3	Oxytetracycline	
			V. vulnificus	25	20	Nalidixic acid	
Vietnam	Seafood	–	*Enterobacter cloacae*	–	–	Carbapenem, ampicillin, cefoxitin, and amoxicillin/clavulanic acid	Janecko et al. 2016

damage to consumers: eating rotten food itself and ingesting the highly toxic formaldehyde (Yasin et al. 2019).

The addition of formalin to aquatic food products is one of the current concerns related to food safety (Yasin et al. 2019). However, research regarding the seafood contamination associated with formaldehyde in Southeast Asia is scarce (Hoque et al. 2018). Over the past decade, in Southeast Asia, there were only a few studies focused on the concentration of formaldehyde in aquatic food products. According to the first study by Aminah, Zailina, and Fatimah (2013), formaldehyde contents of different commercial fish collected from 3 wholesale markets in Malaysia were in the range 2.38 to 2.95 μg/g for fresh, 2.08 to 2.35 μg/g for boiled and 2.28 to 2.49 μg/g for fried, which were lower than the maximum limit value (5 μg/g) for formaldehyde in fish and fish products set by Malaysian Food Act

Table 6. Maximum allowable limits (MALs) with specifications for individual metals in aquatic food products by various regulatory bodies (mg/kg).

Metal	MAL	Regulatory body	Specifications
As	7.88	Food and Agriculture Organization (FAO) 1983	–
Cd	0.05	Food and Agriculture Organization (FAO) 2003	For the edible parts of the fishery products
	0.1		For edible parts of the following species: *Dicologoglossa cuneata* (Wedge sale), *Anguilla anguilla* (Eel), *Trachurus trachurus* (Horse Mackerel or Scad), *Mugil labrosus labrosus* (grey mullet), *Diplodus vulgaris* (Common two-banded seabream), *Sardina pilchardus* (European pilchard or sardine), *Engraulis encrasicholus* (European anchovy), *Luvarus imperialis* (Louvar or Luvar)
	0.5		For Crustaceans (excluding brown meat of crab)
	1		For Bivalve mollusks and Cephalopods (without viscera)
	0.5	Vietnam National Technical Regulation, Vietnam National Technical Regulation and Vietnam national technical regulation 2011	For crustaceans (excluding brown meat of crab, head and chest lobster, and large crustaceans)
	2.0		For mollusk (without organs)
	1	Malaysian Food Regulations 1985	–
	1	RHM No.382 (Indonesia)	–
	1	The National Standardization Agency of Indonesia (SNI) 2009 (Indonesia)	For bivalve mollusks and sea cucumbers
	2	CAC, 1995	For marine bivalve mollusks and cephalopods
	2	World Health Organization (WHO), 1982	–
Cu	30	Food and Agriculture Organization (FAO) 1983	–
	30	Malaysian Food Regulations 1985	–
Hg	0.5	RHM No.382 (Indonesia)	–
	1	The National Standardization Agency of Indonesia (SNI) 2009 (Indonesia)	For bivalve mollusks and sea cucumbers
	0.5	Food and Agriculture Organization (FAO) 2003	For the edible parts of the fishery products
	1		For the edible parts of the following species: *Lophius* (Anglerfish), *Anarhichas lupus* (Atlantic catfish), *Dicentrarchus labrax* (Bass), *Molva dipterygia* (Blue ling), *Sarda* spp. (Bonito), *Anquilla* spp. (Eel), *Hippoglossus hippoglossus* (Halibut), *Euthunnus* spp. (Little tuna), *Makaira* spp. (Marlin), *Esox lucius* (Pike), *Orcynopsis unicolor* (Plain bonito), *Centroscymnes coelolepis* (Portuguese dogfish), *Raja* spp. (Rays), *Sebastes marinus*, *S. mentella*, *S. viviparus* (Redfish), *Istiophorus platypterus* (Sail fish), *Lepidopus caudatus*, *Aphanopus carbo* (Scabbard fish), Shark (all species), *Lepidocybium flavobrunneum, Ruvettus pretiosus, Gempylus serpens* (Snake mackerel), *Acipenser* spp. (Sturgeon), *Xiphias gladius* (Swordfish), *Thunnus* spp. (Tuna)
	1.2	CAC, 1995	For fresh or frozen tuna (in general after removing the digestive tract)
	1.5		For fresh or frozen alfonsino (in general after removing the digestive tract)
	1.6		For fresh or frozen shark (in general after removing the digestive tract)
	1.7		For fresh or frozen marlin (in general after removing the digestive tract)

(*continued*)

Table 6. Continued.

Metal	MAL	Regulatory body	Specifications
iAs	1.0	MoH (Ministry of Health), 2007 (Vietnam)	–
Ni	80	USFDA/CFSAN 2007	–
Pb	0.3	CAC, 1995	For whole fish commodity (in general after removing the digestive tract)
	0.5	Vietnam National Technical Regulation, 2011	For crustaceans (excluding brown meat of crab, head and chest lobster, and large crustaceans)
	1.0		For mollusk (without organs)
	0.2	Food and Agriculture Organization (FAO) 2003	For the edible parts of the fishery products
	0.4		For edible parts of the following species: *Dicologoglossa cuneata* (Wedge sole), *Anguilla anguilla* (Eel), *Dicentrarchus punctatus* (Spotted seabass), *Trachurus trachurus* (Horse mackerel or Scad), *Mugil labrosus labrosus* (grey mullet), *Diplodus vulgaris* (Common two-banded seabream), *Pomadasys benneti* (Grunt), *Sardina pilchardus* (European pilchard or sardine)
	0.5		For Crustaceans (excluding brown meat of crab)
	1		For Bivalve mollusks and Cephalopods (without viscera)
	1.5	SNI, 2009 (Indonesia)	For bivalve mollusks and sea cucumbers
	2	Malaysian Food Regulations 1985	–
	2	RHM, 1989 (Indonesia)	–
	5	WHO,1982	–
Zn	30	Food and Agriculture Organization (FAO) 1983	–
	100	Malaysian Food Regulations 1985	–
	150	World Health Organization (WHO) 1989	–

Note: RHM: Regulation of Health Ministry of Indonesia; SNI: The National Standardization Agency of Indonesia; CAC: Codex Alimentarius Commission; MoH: Ministry of Health; USFDA: United States Food and Drug Administration; CFSAN: Center for Food Safety and Applied Nutrition.

1983 and Malaysian Food Regulations Malaysian Food Regulations 1985. Thus, they considered the fish from wholesale markets were safe for consumption. In contrast, high formaldehyde contamination was found in seafood samples collected from Thailand which is a matter of concern (Chaiphongpachara 2019; Suwanaruang 2018). These studies indicated that aquatic food products should be consumed carefully. To reduce the uptake of formaldehyde in these products, consumers could consider choosing products without unusual smell and avoid eating raw seafood since formaldehyde content decreases as it evaporates during the cooking process such as boiling and roasting (Immaculate and Jamila 2018).

Heavy metals

Heavy metals are naturally occurring metallic elements with a high atomic weight and a relatively high density compared to water (Tchounwou et al. 2012). Many elements, such as phosphorous (P), selenium (Se), iron (Fe), zinc (Zn), iodine (I), present in aquatic food products are essential for humans at low concentrations, but some of them may be toxic at elevated levels. At the same time, other elements, such as arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg), aluminum (Al), do not have known necessary biological functions and are toxic even at low concentrations when ingested for a long period (Ryder, Iddya, and Ababouch 2014). For example, As consumption brings cardiovascular disease, developmental anomalies, neurotoxicity, diabetes, hearing loss, hematologic disorders, and carcinoma; chronic low-level Cd exposure is associated with kidney dysfunction, osteoporosis, and reproductive deficiencies; Pb is termed as neurotoxins and the early symptoms of the effects of Pb exposure are headache, loss of memory, and dullness; the effects of Hg include neurotoxicity, gastrointestinal toxicity, and nephrotoxicity; high Al accumulation will cause ferric-independent microcytic anemia, lung fibrosis, osteomalacia, and dialysis dementia (Costa et al. 2016; Kelishadi 2012; Tchounwou et al. 2012).

Heavy metal contamination has a growing trend in Southeast Asia in recent years due to the development of chemical and mining industries, and it has affected the fishery industry (Ding 2019; Sowana et al. 2011). This is because marine organisms can acquire metals, which are non-biodegradable, from seawater, food, suspended matter. Certain metals could accumulate in some of them which resulted in a higher concentration of metals than the surrounding

Table 7. The concentrations of heavy metals in edible parts of aquatic food products in Southeast Asian countries.

Location	Species	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn	Remarks	References
Cambodia	Fish (*Hypsibarbus malcolmi*)	–	–	–	–	–	0.0119-0.158	–	–	–	–	mg/kg ww	Cheng et al. 2013
Indonesia	Gastropod (*Laevistrombus turturella*)	–	0.23	–	–	–	ND	–	–	0.61	–	mg/kg dw	Rasyid and Dody 2018
	Mussel (*Perna viridis* L.)	–	0.556	–	–	–	0.0054	–	–	1.258	–	mg/kg ww	Putri, Prasetyo, and Arifin 2012
	10 species of fish [1]	ND	0.02-0.31	–	–	–	0.01-0.28	–	≤0.04	0.16-0.71	–	mg/kg ww	Mugi Rahay, Heri Susen, and Ibrahim 2014
Malaysia	Fish (*Arius thalassinus*)	14.2 ± 2.34	0.088 ± 0.01	–	–	53.84 ± 5.1	–	–	–	0.12 ± 0.01	50.99 ± 5.34	mg/kg dw	Bashir, Shuhaimi-Othman, and Mazlan 2012
	Fish (*Pennahia anea*)	3.76 ± 0.2	0.048 ± 0.01	–	–	21.62 ± 4.7	–	–	–	0.13 ± 0.004	26.32 ± 1.6	mg/kg dw	
	Fish (*Arius thalassinus*)	–	0.027-0.058	–	1.21-1.56	–	–	0.62-0.92	–	–	20.54-30.21	mg/kg dw	Bashir et al. 2013
	Fish (*Johnius belangeri*)	–	0.04-0.055	–	0.66-0.95	–	–	0.54-0.97	–	–	13.12-18.27	mg/kg dw	
	Fish (*Arius maculatus*)	–	0.04-0.09	–	0.83-3.68	–	–	–	–	0.15-0.36	22.99-48.57	mg/kg dw	Bashir and Alhemmali 2015
	Fish (*Pennahia anea*)	–	0.03-0.21	–	0.94-4.38	–	–	–	–	0.14-0.41	17.7-32.95	mg/kg dw	
	Fish (Mackerel)	–	–	–	–	–	0.251-1.470	–	–	–	–	mg/kg ww	Hajeb, Jinap, and Ahmad 2010
	Fish (Tuna)	–	–	–	–	–	0.180-1.460	–	–	–	–	mg/kg ww	
	Fish (*Oreochromis niloticus*)	–	0.03-0.04	–	1.01-1.46	–	–	–	3.59-3.86	0.26-0.53	20.58-24.22	mg/kg dw	Taweel, Shuhaimi-Othman, and Ahmad 2013
	Fish (*Rastrelliger kanagurta*)	0.325-0.7485	–	0.0108-0.0516	0.0712-0.1977	3.546-4.857	ND-0.025	0.4372-1.841	–	ND-0.02	5.607-15.35	mg/kg dw	Khandaker et al. 2015
	5 species of fish [2]	0.004-0.025	–	–	–	–	0.012-0.019	–	–	0.036-0.263	2.327-5.870	mg/kg dw	Kamaruzzam et al. 2011
	13 species of fish [3]	–	0.013-0.076	–	–	–	–	–	0.024-0.262	0.022-0.169	–	mg/kg dw	Hashim et al. 2014
	15 species of fish [4]	–	0.28 ± 0.020	–	0.46 ± 0.023	–	–	–	–	0.45 ± 0.024	4.46 ± 0.051	mg/kg ww	Ahmad and Shuhaimi-Othman 2010
	19 species of marine fish [5]	–	–	–	–	–	0.14-0.90	–	–	–	–	mg/kg dw	Jeevanaraj et al. 2019
	46 species of marine fish [6]	–	–	–	–	–	0.055-2.537	–	–	–	–	mg/kg dw	Ahmad et al. 2015
		–	≤0.0786	≤0.411	≤1.614	–	–	≤1.542	–	≤0.057	≤15.9612	mg/kg ww	Azmi, Ahmad, and Mahiyuddin 2019
	29 species of fish [7]	–	–	–	–	–	0.106 ± 0.128	–	–	–	–	mg/kg ww	Anual et al. Anual et al. 2018
	Penaeidae	–	–	–	–	–	0.033 ± 0.033	–	–	–	–	mg/kg ww	
	Loliginidae	–	–	–	–	–	0.040 ± 0.025	–	–	–	–	mg/kg ww	
	Gastropod (*Strombus canarium*)	0.110-0.125	0.010-0.020	–	1.025-1.360	–	–	–	–	–	–	mg/kg ww	Said et al. 2013
	Mussel (*Nerita lineata*)	–	1.10-6.83	–	4.56-19.12	27.29-1353.54	–	–	3.37-28.67	5.69-67.29	10.26-133.76	mg/kg dw	Yap and Cheng 2013
	Mussel (*Perna viridis*)	–	0.35-3.15	–	2.82-103	105-1778	–	–	1.94-114	1.57-61.0	50.9-138	mg/kg dw	Yap et al. 2016
	Mussel (*Perna viridis*)	–	0.3 ± 0.06	–	19.05 ± 4.12	576.45 ± 87.78	–	–	–	0.47 ± 0.14	45.54 ± 8.75	mg/kg dw	Al-Barwani and Goddard 2011
	Mussel (*Perna viridis*)	–	0.041-0.39	–	–	–	–	–	–	4.30-8.43	45.2-76.52	mg/kg ww	Hadibarata et al. 2012
	Cockles (*Anadara granosa*)	–	1.09-1.98	0.61-2.86	12.52-24.93	530.03-1343.70	–	–	–	0.80-1.90	84.16-105.63	mg/kg dw	Yunus et al. 2014
	Cockles (*Anadara granosa*)	–	0.02 ± 0.01	0.13 ± 0.04	0.23 ± 0.07	25.22 ± 8.01	–	1.36 ± 0.75	0.13 ± 0.03	0.04 ± 0.02	3.12 ± 0.53	mg/kg ww	Ishak et al. 2016
	Cockles (*Anadara granosa*)	–	–	–	6.72-12.35	–	–	–	–	0.04-1.73	62.16-110.75	mg/kg dw	Zahir et al. 2011
	Clam (*Metretrix* spp.)	1.66 ± 1.07	0.08 ± 0.05	1.03 ± 0.61	–	–	–	–	1.70 ± 0.78	0.28 ± 0.10	–	mg/kg dw	Sharif, Chong, and Meng 2016
	Conch (*Strombus canarium*)	2.50 ± 0.55	0.05 ± 0.01	1.56 ± 0.38	–	–	–	–	0.45 ± 0.09	0.54 ± 0.10	–	mg/kg dw	
	Scallop (*Amusium pleuronectes*)	18.93 ± 5.30	4.38 ± 1.37	2.61 ± 0.67	–	–	–	–	1.48 ± 0.68	0.69 ± 0.16	–	mg/kg dw	
Thailand	Mussel (*Anadara granosa*)	–	0.07-0.74	0.03-0.40	0.31-1.74	–	0.0036-0.0120	2.12-21.84	0.06-0.48	0.0012-0.0573	2.50-17.64	mg/kg ww	Sudsandee et al. 2017
Vietnam	Fish (*Pangasius hypophthalmus*)	–	–	–	–	–	0.31-0.59	–	–	–	–	mg/kg ww	Ferrantelli et al. 2012
	Catfish	1.66 ± 0.08	1.06 ± 0.09	2.25 ± 0.15	–	–	–	–	–	0.10 ± 0.02	–	mg/kg ww	Ngoc et al. 2020
	Snake-head fish	1.18 ± 0.003	2.30 ± 0.26	2.12 ± 0.13	–	–	–	–	–	0.08 ± 0.01	–	mg/kg ww	
	Tiger shrimp	0.80 ± 0.01	1.62 ± 0.24	1.46 ± 0.28	–	–	–	–	–	1.24 ± 0.46	–	mg/kg ww	
	Stuffed snails	1.20 ± 0.01	3.26 ± 0.27	1.69 ± 0.40	–	–	–	–	–	2.13 ± 0.34	–	mg/kg ww	
	Mussel (*Saccostrea glomerate*)	10.10-19.33	3.53-12.74	0.81-4.47	238.1-1,597.8	–	–	–	–	0.79-6.20	823.6-3,201.6	mg/kg dw	Le, Bach, and Arai 2015

Note:
ND: not detected.
Most original metal data were reported in mg/kg dry weight, which could be converted into mg/kg wet weight by using a conversion factor (0.17) for marine mussels (Yap et al. 2016).
10 species of fish [1]: *Hemirhampus* spp, *Trichiurus savala*, *Saurida tumbil*, *Stolephorus* sp., *Carangoides* spp, *Leiognathus lineolatus*, *Formio niger*, *Rastrelliger kanagurta*, *Selaroides leptolepis*, *Sardinella* sp.
5 species of fish [2]: Chirocentrus dorab, Lutjanus sebae, Nemipterus japonicas, Pampus argenteus, and Otolithes ruber.
13 species of fish [3]: *Barbonymus gonionatus*, *Barbonymus schwanenfeldii*, *Chitala chitala*, *Clarias gariepinus*, *Cyclocheilichthys apogon*, *Hampala macrolepidota*, *Hemibagrus nemurus*, *Hemibragus wyckii*, *Notopterus notopterus*, *Osteochilus hasseltii*, *Pangasius micronemus*, *Puntioplites bulu*, *Tachysurus maculatus*.
15 species of fish [4]: *Puntius schwanenfeldii*, *Ompok bimaculatus*, *Cylocheinichtys apogon*, *Osteochilus hasseltii*, *Notopterus notopterus*, *Chana micropeltes*, *Puntius bulu*, *Labiobarbus festiva*, *Osteochilus melanopleura*, *Hampala macrolepidota*, *Chela oxygastroides*, *Mystus nigriceps*, *Thynnichthys thynnoides*, *barbichthys laevis*, *Helostoma temmincki*.
29 species of fish [5] were classified into seven families (Carangidae, Dasyatidae, Latidae, Lutjanidae, Nemipteridae, Scrombidae, and Sciaenidae).
46 species of marine fish [6] were classified into seven families (Carangidae, Dasyatidae, Latidae, Lutjanidae, Nemipteridae, Sciaenidae, and Scrombidae).
19 species of marine fish [7]: *Decapterus macrosoma*, *Mugil cephalus*, *Parastromateus niger*, *Pampus argenteus*, *Sillago sihama*, *Rastrelliger kanagurta*, *Selaroides leptolepis*, *Megalaspis cordyla*, *Chirocentrus dorab*, *Eleutheronema tetradactylum*, *Scomberomorus guttatus*, *Euthynnus affinis*, *Dasyatis zugei*, *Johnius dussumieri*, *Lutjanus johnii*, *Epinephelus areolatus*, *Nemipterus japonicus*, *Lutjanus argentimaculatus*, *Lates calcarifer*.

environment, such as Pb and Zn in *Tympanotonos fuscatus* (Jakimska et al. 2011). In the process of biomagnification, the concentration of a chemical substance in the organism increases with succeeding trophic levels (through the food chain), thereby magnifying the effects of metals in the body (Jakimska et al. 2011). Individual metals have different degrees of toxicity and therefore maximum allowable limits (MALs) for each metal in food are established to protect consumers (Bosch et al. 2016). MALs can also be species-specific because metal accumulation is influenced by different development and metabolic rates of different organisms. Considering the fish consumption patterns of specific populations, individual countries or regulatory agencies can have specific MALs that are different from general regulations. Regulatory limits of heavy metals present in commonly consumed marine organisms are summarized in Table 6.

The level of heavy metals may be different due to many factors such as location, species, and season. In general, compared with juvenile fish, mature fish have higher metal element content because fish growing at a constant rate in polluted habitats stably accumulate heavy metals (Ahmad and Shuhaimi-Othman 2010). Predatory fish with higher trophic levels accumulate more heavy metals than non-predatory fish (Hashim et al. 2014). The heavy metal contents of demersal fish, which contact with sediments, are higher than that of upper fish (Ahmad et al. 2015; Anual et al. 2018). Meanwhile, the ability of different organs to accumulate metals has also been reported. In general, fish show the lowest concentration of heavy metals in the muscle (Hajeb, Jinap, and Ahmad 2010; Kamaruzzam et al. 2011). Different types of muscles in fish, especially in large predatory fish, have different functions and might contain different levels and types of heavy metals, thus need further researches to confirm (Bosch et al. 2016).

Referring to Table 7, the levels of some heavy metals, including chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), concentrations have not exceeded the permitted level of international standards or national standards. And for Cr, Fe, and Mn, although there are hardly any MALs of them, the estimated daily intakes of Cr, Fe, and Mn in aquatic food products for consumers were lower than the reference dose guidelines (Sudsandee et al. 2017; Yap et al. 2016; Yunus et al. 2014).

However, some results reported that the concentrations of As, Cd, Hg, Pb, and Zn in some aquatic food products that were collected from Southeast Asia could pose health risks to consumers. For example, the results of four Malaysian studies showed that Pb concentrations in mussels and fish exceeded MAL (2.00 mg/kg ww) suggested by Malaysian Food Regulations (1985) (Hadibarata et al. 2012; Yap and Cheng 2013; Yap et al. 2016). And the highest level (11.44 mg/kg ww) of Pb was observed by Yap and Cheng (2013) in mussel collected from Selangor, Malaysia. Also, two studies in Vietnam showed that the maximum levels of As, Cd, Cu, Zn, and Pb which were detected in oysters and tiger collected from Vietnam could potentially pose health risks to consumers (Le, Bach, and Arai 2015; Ngoc et al. 2020). And Ferrantelli et al. (2012) reported that Hg levels in 12.8% of fillets samples of pangasius (*Pangasius hypophthalmus*) ranged from 0.54 mg/kg ww to 0.63 mg/kg ww, exceeding MAL (0.5 mg/kg ww) established by Food and Agriculture Organization (FAO), while Hg levels in 41.0% of samples ranged of 0.40-0.49 mg/kg ww which were near to MAL. As far as the results of Malaysian studies, the concentrations of Hg in fish purchased from Malaysia pose no non-cancer risk to consumers (Ahmad et al. 2015; Anual et al. 2018; Jeevanaraj et al. 2019; Kamaruzzam et al. 2011; Khandaker et al. 2015).

The issue of heavy metal pollution in aquatic food products is worthy of attention since it can affect the safety of these products and further threaten the health of consumers (Wang et al. 2013). Although the levels of heavy metals in most aquatic food products collected from Southeast Asia are below the MALs, the daily intake of heavy metals from consumption of them is still worth monitoring regularly to reduce the human health risk by consuming aquatic food products.

Future trends and challenges

The future megatrends including environmental changes, changes in consumption patterns, and the globalization of trade will introduce new food safety challenges associated with aquatic food products and put forward new requirements for producers, marketers, and regulators to ensure food safety. Meanwhile, the emergence of many novel technologies could serve as a positive role to overcome food safety challenges.

Environmental change

Pathogens, biological toxins, and chemical pollutants as the key threat to aquatic food safety are expected to increase due to the environmental change, thus posing higher health risks to humans (Lloret et al. 2016). Ocean warming together with climate change is beneficial for the occurrences of harmful algal blooms (HABs), which may produce potent and persistent biological toxins. HAB toxins, which are bio-concentrated, can be transferred up through aquatic food products to humans and further jeopardize human health (Berdalet et al. 2016). Additionally, ocean warming together with climate change could affect the distribution of pathogens and change the environmental conditions that pathogens or their competitors must adapt to survive, thereby affecting the microbial safety of aquatic food supply (Baker-Austin et al. 2016; Doyle et al. 2015; Lloret et al. 2016). To eliminate or significantly reduce pathogens, farmers tend to use more antimicrobial in the aquaculture and consequently cause the increase of antibiotic-resistant in aquatic food and the development of antibiotic-resistant pathogens (Al-Othrubi et al. 2014; Pham et al. 2015).

Changes in consumption patterns

Currently, consumers prefer low-salt and preservative-free foods, which puts forward higher requirements in food handling and preservation, especially for perishable foods such as aquatic food products (King et al. 2017). It is noteworthy that with the rapidly aging population in the Southeast Asian region, the harmful impacts of food hazards in aquatic food products may become more and more serious (Smith 2017; Teerawichitchainan, Prachuabmoh, and Knodel 2019). Therefore, it is urgent to enrich varieties of food to keep up with the evolving consumer preferences while ensuring food safety, especially for the high-risk groups.

The globalization of trade

With the globalization of trade, regional food safety incidents can quickly evolve into international emergencies. In the past decade, serious foodborne disease outbreaks that occurred in different regions were amplified by globalized trade (World Health Organization (WHO) 2020b). The current trade situation requires enforcement of food safety standards and effective surveillance not only at country and regional levels but also at global levels (World Health Organization (WHO) 2015). Meanwhile, the globalization of the food supply chain requires improvements and innovations in traceability measures to ensure the safety of the food chain (King et al. 2017).

Advances in technology

To better predict and evaluate food hazards, detect food ingredients and contaminants, as well as, trace food sources, various emerging technologies have been continuously upgraded and applied, which help meet food safety challenges. For instance, whole-genome sequencing (WGS), which is a process of determining the complete DNA sequence of an organism's genome, will help quickly and accurately identify, mitigate and prevent food safety issues (Allard et al. 2018; Brown et al. 2019). Also, the latest developments in radiofrequency identification (RFID) technology and the integration of data logger functions and integrated sensors provide the possibility to enhance the food traceability system (Alfian et al. 2017; Tian 2016). Big data, another important emerging technology, represents information assets with high velocity, volume, and variety, and specific technologies and analysis methods are needed to convert them into value (De Mauro, Greco, and Grimaldi 2015). To date, the use of big data analytics in food safety and quality merely focuses on providing root causes and retrospective analysis, but the development of predictive analytics in food safety is likely to grow rapidly in the near future (King et al. 2017). Creating a database, which contains complete information on food safety, helps speed up the process of harmonizing and developing unified food safety standards and regulations across countries, thus addressing the food safety challenges brought by regulatory heterogeneity (Devadason and Govindaraju 2016).

Conclusion

Food safety of aquatic food products is an issue of concern in the Southeast Asian region. In this review, the food safety hazards which is related to aquatic food products in the Southeast Asian region are classified into MPs, biological and chemical hazards. All these hazards were detected in aquatic food products, but the levels and intensities of potential health risks caused by them were different in different Southeast Asian countries. Among them, pathogenic bacteria, antimicrobials, and heavy metals are of particular concern. About pathogenic bacteria, the prevalence of them from open markets was found to be higher than supermarkets, and *Vibrio* and *Salmonella* are two of the most common pathogenic bacteria in aquatic food products in Southeast Asia. Antibiotic residues in food can cause a potential risk of direct toxicity to consumers and the use of antimicrobials in aquaculture has resulted in the development of antibiotic-resistant bacteria which was detected from aquatic food in this region. Heavy metal contamination has a growing trend in Southeast Asia in recent years and some results reported that the concentrations of As, Cd, Hg, Pb, and Zn in some aquatic food products collected from this region could pose health risks to consumers. Meanwhile, the absence of published literature on the presence of viruses, parasites, and formaldehyde in aquatic food products does not exclude the possibility of the prevalence of them in aquatic food products in this region. Lack of information poses health risk to consumers and hinders the enactment of effective and unified legislations.

To protect consumers from various food safety hazards, it is of necessity to conduct a continual research on food safety issues for aquatic food products at Southeast Asian countries and track their risks to human body, which is driven by the increasing awareness of food safety hazards for the public. Meanwhile, international cooperation is encouraged to reduce the food safety hazards concerning aquatic food products, which includes improving surveillance system, carefully assessment of these risks regularly and establishment of an informed progress for the public, so that consumers, specifically, sensitive groups, can obtain health benefits from fish consumption while ensuring safety.

Disclosure statement

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