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Original article

PATHOGENS ASSOCIATED WITH SEAFOOD EXPORTS FROM SOUTHEAST ASIA TO THE EUROPEAN UNION: ANALYSIS OF THE RAPID ALERT SYSTEM FOR FOOD AND FEED (1997–2020)

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Summary

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Over the years, the need for healthy food has increased the demand for seafood in the international market. However, despite the high global demand, seafood is highly perishable and may harbour pathogenic microorganisms that could be transferred to humans during handling, processing, and consumption. Therefore, establishing strict food safety standards and risk communication tools is critical to prevent the infiltration of unsafe seafood into global markets. In the global food supply chain, the European Union (EU) is the largest importer of seafood, while more than 80% of global seafood production is from Asia. Additionally, Southeast Asian countries account for 32% of global seafood production. Therefore, this study aimed to evaluate the microbiological safety of seafood imported from Southeast Asia to the EU by analysing alert notifications in the Rapid Alert System for Food and Feed (RASFF) database. The RASFF is a tool used for reporting and communicating food safety-related risks among the EU Member States and other members of the RASFF network. A total of 301 notifications of pathogens in seafood originating from four Southeast Asian countries (Malaysia, Thailand, Vietnam, and Indonesia) were reported by 19 EU countries, including the United King-

dom (1997–2020). More than 56% of the pathogen notifications involved crustaceans and related products. Fifty-two percent of the notifications involved seafood from Vietnam, while 30% of the notifications from EU member countries were from Italy. *Vibrio* spp. was the most predominant bacterial pathogen responsible for 50% of the notifications, followed by *Salmonella* spp. and *Clostridium* accounting for 38% and 2% of the notifications, respectively. Norovirus was implicated in 10% of the notifications, and this was only in clams from Vietnam. These pathogens pose a risk to consumers' health, indicating the need to enforce stringent food safety standards in producing countries to ensure the safety of seafood exported to other parts of the world. These actions will ultimately prevent economic loss associated with the rejection, destruction or import restrictions of contaminated seafood originating from Southeast Asia to the EU.

Key words: European Union, foodborne pathogens, RASFF, seafood export, seafood safety, Southeast Asia

INTRODUCTION

Global seafood production and consumption have increased over the years (FAO, 2020). In 2018, it was estimated to be over 175 million tonnes and valued at USD 401 billion. Also, in the last twenty years, Asia has produced over eighty percent of the global volume of seafood, while seafood production is the largest employer of labour within the sector (FAO, 2020). Southeast Asian countries account for 25% of global fish production. Indonesia, Thailand, Vietnam, and the Philippines are among the top ten seafood producers, while Indonesia is the largest seafood producer in Southeast Asia. Vietnam and Thailand are the third and sixth major seafood exporters, and the European Union (EU) – the largest seafood importer (FAO, 2020).

As a major food products importer, the EU established the Rapid Alert System for Food and Feed (RASFF) in 1979. The objective of RASFF is prompt, efficient and effective sharing of information among member states regarding the safety of food imported into the region, enabling prompt responses to avert potential foodborne disease outbreaks capable of impacting public health (D'Amico *et al.*, 2018). Various studies have analysed data from the RASFF database in the last decade; however, most of these studies focused on food fraud. For example, the pattern of food fraud in food exported into the EU was studied by Tähkäpää *et al.* (2015). Bouzembrak & Marvin (2016) used Bayesian network modelling to develop a predictive model for food fraud. Adulteration of cereal and bakery products exported to the EU was studied by Kowalska *et al.* (2018), adulteration of food supplements by Czepielewska *et al.* (2018), while an investigation on food fraud in the global beef supply chain was carried out by Robson *et al.* (2020). Soon (2020) also predicted food fraud in different food products from China. Although most studies focused on food fraud, studies on food recalls have also been conducted. For example, food recalls due to the presence of allergens (Pádua *et al.*, 2019) and food contact materials (De Leo *et al.*, 2021) have been studied. While studies on the chemical safety of food exported to the EU have been reported (Leuschner *et al.*, 2013; Guardone *et al.*, 2022), there is a dearth of published studies on the microbiological safety of exported food, especially seafood. A few studies on pathogenic microorganisms in

food exported to the EU based on RASFF data have been reported, however, these studies are not focused on seafood. For example, Lüth *et al.* (2019) reported the presence of *Listeria monocytogenes* in fish and fish products exported to the EU from Germany, while Somorin *et al.* (2021) – the presence of *Salmonella* in sesame seeds exported from Africa to the EU.

D.'Amico *et al.* (2018) and Pigłowski (2020) reported pathogens such as *Salmonella* in bivalve molluscs, fish and crustaceans exported from Thailand, India and Vietnam; however, details of the specific seafood were not provided. In these studies, pathogens were only reported at the genus level of identification. Hence, variation of pathogens at the species level was not provided. Additionally, D.'Amico *et al.* (2018) only reported RASFF alert notifications from 2011 to 2015. The reasons for limiting the study to only five years of data were not specified. Also, Pigłowski (2020) reported data on seafood, but their analysis had no specific focus on Asian countries as major exporters. For instance, Malaysia, one of the major seafood exporting countries from Southeast Asia to the EU, was not included in the study. What is more, WHO (2017) reported that more than 20 million people fall ill due to the consumption of contaminated food in the WHO European region causing at least 5,000 deaths annually. Norovirus, *Campylobacter* spp., and *Salmonella* spp. were reported as causes of most of these reported deaths. Therefore, the current study aims to understand the microbiological safety of seafood exported from Southeast Asia to the EU. To achieve this aim, five specific research questions were asked: 1) What are the predominant seafood-borne pathogens associated with seafood originating from Southeast Asian countries and exported to the EU? 2) What is the most contaminated seafood category and specific seafood implicated? 3) What is the trend of notifications over the years? 4) Which EU member state is most affected by contaminated seafood? and 5) Which countries in Southeast Asia are associated with the highest number of notifications?

MATERIALS AND METHODS

RASFF data collection and analysis

The dataset used for this study was obtained from the RASFF portal as described by Somorin *et al.* (2021) based on three search criteria, namely 1) product: country of origin (The database was searched for information relating to the eleven Southeast Asian countries - Indonesia, Laos, Myanmar, Philippines, Singapore, Brunei, Cambodia, East Timor, Malaysia, Thailand and Vietnam); 2) hazard category (pathogenic microorganisms) and 3) product category (bivalve molluscs and products thereof; cephalopods and products thereof; crustaceans and products thereof; and fish and products thereof). The notification date was not restricted to enable complete capturing of all the available notifications.

The notifications obtained for each country of origin were exported as an Excel file and then combined as a single file for analysis. A table was created using a Microsoft Excel spreadsheet. The table enabled sorting, filtering, and formatting of the data. “Not specified” was used to signify missing data. From the 306 notifications, five were eliminated from further analysis because they were related to histamine contamination (n=4) and an undefined hazard (n=1).

Statistical analysis

Descriptive statistics were used to determine the predominant pathogens associated with seafood originating from Southeast Asia countries, the most contaminated seafood category, the t period of the lowest and highest notifications, the number of notifying countries and the country of origin. Chi-square analysis was carried out to determine the significance (P<0.01) of the relationships between the variables using IBM® Statistical Package for the Social Sciences (SPSS®) software version 24. Chord diagrams were generated using R-studio, a free and open-source environment for the statistical language R (https://www.r-project.org).

RESULTS

Notifications of pathogenic microorganisms by notifying countries and countries of origin

A total of 306 notifications covering 1997 to 2020 were obtained from Malaysia, Thailand, Vietnam, and Indonesia (Fig. 1). No notifications were reported for Brunei, Cambodia, East Timor, Laos, Myanmar, Philippines and Singapore. Between 2000 and 2004, notifications were received from all four Southeast Asian countries (Fig. 1). However, from 2008 to 2020 there was a significant difference (P<0.01) in the seafood exported from Vietnam compared to other countries. The total notifications were from 19 EU member countries (Table 1). The highest notifications were from Italy (91/301; 30%), Norway (54/301; 18%), Spain (35/301; 12%), while Cyprus, Finland, Lithuania, Luxembourg, Romania and Slovakia only had one notification each. More than half (159/301; 52%) of the notifications were concerned with seafood originating from Vietnam, 20% were from Malaysia, while Thailand and Indonesia accounted for 15% and 13%, respectively. Four of the notifying countries (Italy, Norway, France, and Denmark) reported the presence of pathogens in seafood originating from the four Southeast Asian countries. In contrast, Spain, Germany and the United Kingdom reported pathogens in

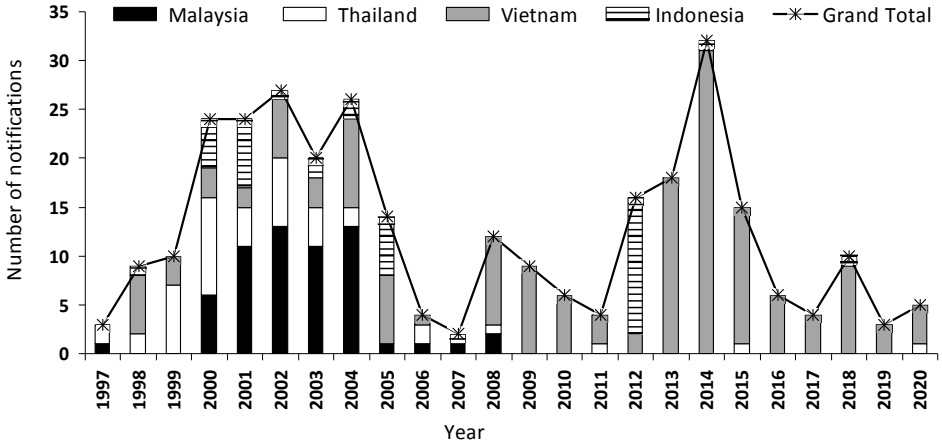

Fig. 1. RASFF notifications of pathogenic microorganisms in seafood originating from Southeast Asia (n=301) from 1997 to 2020 based on notifying year.

Table 1. RASFF notifications of pathogenic microorganisms in seafood originating from Southeast Asia (n=301) from 1997 to 2020 based on notifying country

Notifying country	Country of origin				
	Malaysia	Thailand	Vietnam	Indonesia	Total
Italy	44	6	21	20	91
Norway	1	15	30	8	54
Spain	7	1	27	0	35
Portugal	2	0	26	0	28
France	2	5	5	8	20
Sweden	0	4	8	0	12
Germany	3	1	10	0	14
Denmark	1	5	7	1	14
Netherlands	0	1	7	0	8
Belgium	0	3	4	0	7
United Kingdom	0	3	1	2	6
Greece	0	0	3	1	4
Bulgaria	0	0	2	0	2
Cyprus	0	0	0	1	1
Finland	0	0	1	0	1
Lithuania	0	0	1	0	1
Luxembourg	0	0	1	0	1
Romania	0	0	1	0	1
Slovakia	0	0	1	0	1

seafood originating from only three Southeast Asian countries. In addition, 21% (4/19) and 32% (6/19) of the notifying countries reported pathogens from Vietnam (n=5) and Indonesia (n=1).

Notifications of pathogenic microorganisms by seafood category

It was observed that the RASFF database has four categories of seafood, bivalve molluscs (clams) and products thereof, cephalopods (octopus) and products thereof, crustaceans (shrimps and prawns) and products thereof, fish and products thereof. A significant difference (P<0.01) was observed between the four countries regarding notifications of pathogens in the four categories of seafood (Table 2). Vietnam had the highest (52%) number of notifications across the seafood originating countries, while the least notifications were reported for seafood exported from Indonesia (n=41) (Table 2). Across the seafood category, 56% (168/301) of the notifications were from crustaceans and products thereof, 20% from bivalve molluscs and products thereof, and 18% from fish and products thereof, while cephalopods and products thereof had the least (0.06%) notifications. All notifications concerning bivalve molluscs and products thereof were for seafood originating from Vietnam. Indonesia had the significantly highest (P<0.01) notifications for cephalopods and products thereof. Vietnam and Malaysia had significantly higher (P<0.01) notifications for crustaceans and products thereof than Thailand and Indonesia. Malaysia had the significantly lo-

Table 2. RASFF notifications of pathogenic microorganisms in seafood originating from Southeast Asia (n=301) from 1997 to 2020 based on seafood category

Seafood category	Malaysia	Thailand	Vietnam	Indonesia	χ^2	P value
Bivalve molluscs and related products	0^a	0^a	59^b	0^a	110.62	<0.01
Cephalopods and related products	2^a	2^a	1^a	14^b	81.19	<0.01
Crustaceans and related products	57^b	27^a	64^b	20^a	79.97	<0.01
Fish and fish products	1^a	15^b	32^b	7^b	23.61	<0.01

χ^2 = chi-square. Different superscripts in a row imply a significant difference while similar superscripts imply no significant difference.

west notifications for fish and products thereof. There was no significant difference (P>0.01) in the occurrence of pathogens in cephalopods and products thereof exported from Malaysia, Thailand and Vietnam (Table 2). Overall, however, a significant difference (P<0.01) was observed in the notification of pathogens in seafood originating between the four countries.

Notification categories

As shown in Table 3, three levels of notification categories (Notification basis, Notification type and Action taken) were observed in this study. The highest basis of notification was border control (53%), with the consignment either detained (42%) or released (11%), while 5% of the notifications were from the importing company's own checks (Table 3). Only 1% of the notifications was due to food poisoning while <1% was due to consumer complaints. The notification type was mainly due to information (47%) and border rejection (26%). The most severe action taken was designating the seafood product as "re-dispatch" and "import not authorised" (28% each). Only 10% of the consignment was destroyed (Table 3).

Pathogens associated with notifications

Norovirus and pathogenic bacteria (n=339) belonging to eight genera were reported in the notifications. They include *Salmonella*, *Vibrio*, *Bacillus*, *Clostridium*, *Staphylococcus*, *Escherichia*, *Yersinia* and *Plesiomonas* (Table 4). *Vibrio* was the predominant genus (50%) comprising *V. parahaemolyticus* (28%), *V. cholerae* (19%), *V. vulnificus* (2.4%) and *V. alginolyticus* (0.6%). The share of *Salmonella* was 38% of the pathogens reported and comprised 18 serovars. However, *B. cereus*, *Staphylococcus* spp., *Y. enterocolitica* and *P. shigelloides* made up only 0.3% of the pathogens. It was observed that 53% of the pathogens were reported in seafood from Vietnam, while the least was reported in seafood from Indonesia. Norovirus constituted only 9% of the pathogens reported. Seafood from Vietnam had significantly (P<0.01) more pathogens than the other three countries.

Members of the genus *Salmonella* were the most predominant (33/60; 55%) pathogens across the fish and fish products exported from the four countries. Among the 60 pathogen occurrences reported in fish and fish products, 55% (n=33) were from Vietnam (Table 5). *Sal-*

Table 3. RASFF notifications of pathogenic microorganisms in seafood originating from Southeasta Asia (n=301) from 1997 to 2020 based on notification category.

Classification category	Notifications	
	Number	Percentage (%)
Notification basis		
Border control – consignment detained	125	41.5
Not specified	99	32.8
Border control – consignment released	34	11.3
Official control on the market	24	7.8
Company's own check	15	4.9
Food poisoning	3	1.0
Consumer complaint	1	0.3
Notification type		
Information	141	46.8
Border rejection	78	25.9
Alert	43	14.3
Information for attention	29	9.6
Information for follow-up	10	3.3
Action taken		
Re-dispatch	85	28.2
Import not authorised	84	27.9
Destruction	30	9.8
Not specified	16	5.3
Withdrawal from the market	15	5.0
Product recall or withdrawal	13	4.3
Informing authorities	11	3.7
Recall from consumers	6	2.0
Detained by operator	5	1.7
Official detention	5	1.7
Prohibition to trade – sales ban	5	1.7
Re-dispatch or destruction	5	1.7
Informing recipient(s)	4	1.3
Product destruction or return after official permission	4	1.3
Return to consignor	4	1.3
No action taken	2	0.7
Relabelling	2	0.7
Screening sample	2	0.7
No stock left	1	0.3
Physical treatment – heat treatment	1	0.3
Public warning – press release	1	0.3
Withdrawal from recipient(s)	1	0.3

monella Weltervreden was the predominant pathogen in fish from Vietnam. Fish exported from Malaysia had one notification of *Salmonella* contamination. *B. cereus* and *Staphylococcus* spp. were reported from tuna and fermented fish respectively, exported from Thailand. Similarly, *C. bifermentans* and *C. perfringens* were reported in pickled catfish and Gouramy fish originating from Thailand.

Among the 199 notified pathogens in crustaceans and products thereof, 146 (73%) were pathogens from the genus *Vibrio* from the four countries with the highest occurrence (n=51) from Malaysia (Table 6). *V. parahaemolyticus* was the most predominant (43%; n=86) notified pathogen in the shrimps and prawns exported from Malaysia. Twenty-four per cent of the pathogens (n=47) were members of the genus *Salmonella* and the most predominant in shrimp exported from Vietnam.

For cephalopods and products thereof, 19 pathogens were reported. *Salmonella* was the predominant pathogen reported in octopus, squid and cuttlefish exported from Indonesia (n=14) and cuttlefish in Malaysia (n=2), Thailand (n=1) and Vietnam (n=1) (Table 7). *Y. enterocolitica* was reported in squid from Thailand (n=1).

Vietnam was the only country with notifications involving bivalves and products thereof as there were no notifications of bivalves from other countries. Sixty-one pathogens were reported and most of the notifications involved clam (58/59 notifications). *Salmonella* (n=30; 49%) and norovirus (n=29; 48%) were the predominant pathogens reported in bivalves (Table 8).

DISCUSSION

Microbiological contamination poses a significant threat to the health of consumers and global trade. Since seafood production makes a significant contribution to Southeast Asian economies, this study analysed RASFF notifications on pathogenic microorganisms associated with seafood from Southeast Asia.

The study reviewed 301 notifications regarding seafood originating from Southeast Asia between 1997 and 2020, and all notifications were from only four countries, namely Malaysia, Thailand, Vietnam

Table 4. Pathogenic microorganisms in seafood originating from Southeast Asia (n=301) from 1997 to 2020.

Pathogens	Malaysia	Thailand	Vietnam	Indonesia	%
Vibrio spp.	51	35	60	24	50.1
Salmonella spp.	10	8	87	23	37.8
Norovirus	0	0	29	0	8.6
Clostridium spp.	0	5	1	0	1.8
Escherichia coli	0	0	2	0	0.6
Bacillus cereus	0	1	0	0	0.3
Plesiomonas shigelloides	0	0	0	1	0.3
Staphylococcus spp.	0	1	0	0	0.3
Yersinia enterocolitica	0	1	0	0	0.3

The total number of pathogens (n=339) exceeds the total number of notifications (n=301) because of the co-occurrence of pathogens in some notifications.

Table 5. Pathogenic species associated with fish and related products from Southeast Asia (1997–2020).

Country of origin (notifications)	Pathogens	Number of pathogens[a]	Fish and related products
Indonesia (n=7)	*Salmonella* spp., *Salmonella enterica*, *Salmonella* Weltevreden	4	Red mullet fish, snappers, oil-fish
	V. cholerae	2	Marlin fish & sushi
	V. parahaemolyticus	2	Marlin fish, oil-fish
Malaysia (n=1)	*Salmonella*	1	Fish
Thailand (n=15)	*Bacillus cereus*	1	Tuna
	Clostridium bifermentans and *C. perfringens*	3	Pickled catfish and Gouramy fish
	Salmonella spp., *Salmonella* Augustenborg, *Salmonella* paratyphi B, *Salmonella enterica*, *Salmonella* Schwarzengrund	5	Catfish, shrimp sushi, fish meat, fermented fish
	V. cholerae	4	Fish balls
	V. parahaemolyticus	4	Sole fish
	Staphylococcus	1	Fermented fish
Vietnam (n=32)	*Salmonella* spp, *Salmonella* Brunei, *Salmonella* enterica, *Salmonella* enteritidis, *Salmonella* Nottingham, *Salmonella* Tennessee, *Salmonella* Thompson, *Salmonella* Weltevreden	23	Pangasius, fish mousse, catfish, tuna, surinimi, cobbler fish, tail barb, leather fish paste, Climbing perch
	V. cholerae	9	Pangasius, basa fish,
	V. parahaemolyticus	1	Basa fish

[a] the number of pathogens (n=60) exceeded the notifications (n=55) due to the co-occurrence of pathogens in some seafood products.

Table 6. Pathogenic species associated with crustaceans and related products from Southeast Asia (1997–2020)

Country of origin (notifications)	Pathogens	Number of pathogens[a]	Crustaceans and related products
Indonesia (n=20)	*Salmonella* spp., *Salmonella enterica* subsp. Houtenae, *Salmonella* Lexington	5	Shrimp and prawn
	V. cholerae	5	Shrimp and prawn
	V. alginolyticus	2	Shrimp and shrimp sushi
	V. parahaemolyticus	11	Shrimp, prawn, and shrimp sushi
	V. vulnificus	2	Shrimp
	P. shigelloides	1	Prawn
Malaysia (n=57)	*Salmonella* spp., *Salmonella enterica*	7	Shrimp and prawn
	V. cholerae	6	Shrimp and prawn
	V. parahaemolyticus	44	Shrimp, shellfish, prawn, and cuttlefish kebab,
	V. vulnificus	1	shrimp
Thailand (n=27)	*Salmonella* spp., and *Salmonella enterica*	2	Shrimp
	V. cholerae	13	Shrimp and crab
	V. parahaemolyticus	13	Shrimp, prawn, and crab
	V. vulnificus	1	Shrimp
	Clostridium spp.	2	Shrimp paste
Vietnam (n=65)	*Salmonella* spp., *Salmonella enterica* ser. Weltevreden, *Salmonella* Kentucky, *Salmonella enterica*, *Salmonella enterica* ser. Hvittingfoss, *Salmonella* Oranienburg, *Salmonella* Newport, *Salmonella* Virchow	33	Shrimp, prawn, scampi, and crab
	V. cholerae	27	Shrimp, prawn, shark catfish
	V. parahaemolyticus	19	Shrimp, clam, prawn
	V. vulnificus	4	Shrimp
	Clostridium spp.	1	Shrimp paste
	Escherichia coli	1	Shrimp

[a] the number of pathogens (n=196) exceeded the notification (n=168) due to the co-occurrence of pathogens in some seafood products.

Table 7. Pathogenic species associated with cephalopods and related products from Southeast Asia (1997 - 2020).

Country of origin (notifications)	Pathogens	Number of pathogens	Cephalopods and related products
Indonesia (n=14)	*Salmonella enterica*, *Salmonella* Apeyeme, *Salmonella* paratyphi B, *Salmonella* spp.	14	Octopus, squid, Cuttlefish
Malaysia (n=2)	*Salmonella enterica*	2	Cuttlefish
Thailand (n=2)	*Yersinia enterocolitica* *Salmonella*	1 1	Squid Cuttle fish
Vietnam (n=1)	*Salmonella*	1	Cuttle fish

Table 8. Pathogenic species associated with bivalves and related products from Southeast Asia (1997–2020).

Country of origin (notifications)	Pathogens	Number of pathogens[a]	Bivalves and related products
Vietnam (n=59)	*Salmonella* spp., *Salmonella enterica*, *Salmonella* Colorado, *Salmonella* Weltevreden, *Salmonella* Neukoelln	30	Clam
	Norovirus	29	Clam
	Escherichia coli	1	Clam
	V. parahaemolyticus	1	Clam

[a] the number of pathogens (n=61) exceeded the notification (n=59) due to the co-occurrence of pathogens in some seafood products.

and Indonesia. More than half of the notifications were from Vietnam, followed by Malaysia, Thailand and Indonesia. Most of the notifications from 2013–2020 were from Vietnam. One of the possible reasons for the notifications being limited to these four countries may be because they are among the largest producers of fish, bivalve molluscs, cephalopods and crustaceans in the world (D.'Amico *et al.*, 2018). Data from the FAO showed that these four countries provided between 2 and 8% of the world's marine catch in 2018 (FAO, 2020) and they are also exporters of agri-food products to the EU (European Commission, 2022). According to Regulation (EU) 2017/625, EU Member States should provide official risk-based control of suitable frequency. Consignments arriving from third countries which require controls at their entry into the Union should be accompanied by a common health entry document, to be used for the prior notification of the arrival of consignments at the border control post, and to record the outcome of official controls performed and of decisions taken by the competent authorities in relation to

the consignment which they accompany (European Commission, 2017).

In the present study, the highest number of notifications were from Italy, Norway, Spain, Portugal and France. Similar to our results, Pigłowski (2017) reported that most of the notifications about hazards in fish and fish products between 2008–2015 were mainly from Italy and France. D.'Amico *et al.* (2018) reported that Italy ranks first for notifications related to hazards in seafood for the period 2011–2015 amounting to 35.7%, followed by Spain (19.3%), France (9.4%) and Germany (6.5%). These countries account for 70% of all notifications while the remaining 30% are distributed among 27 countries. According to D'Amico *et al.* (2018), the number of notifications for each country depends on the import volume. The member states with the greatest number of notifications are usually those with the highest volume of food exchange and food transit supplying the major ports of import. That was observed in our study as Italy imported 73.5% of the total consignment of seafood during the study period.

Crustaceans (shrimp and prawns) were the most contaminated seafood category constituting more than 55% of notifications related to seafood. This was followed by bivalve molluscs, fish and cephalopods. Historically, shrimp and prawns have been some of the most traded seafood products, the primary producers are countries in Asia and South America, while the major markets are the USA, EU and Japan (FAO, 2020). All reports (n=59) of pathogenic microorganisms in bivalves were from products originating from Vietnam, which also had the highest number of notifications (n=156) of the four countries. In addition, Vietnam and Malaysia had significantly more notifications about crustaceans compared to Thailand and Indonesia. The shrimp farming sector currently provides a significant share of the shrimp produced globally, but it has been affected by diseases and price variations related to the boom-and-bust cycle and the current COVID-19 pandemic (FAO, 2021). The large volume of aquaculture production in 2018 and 2019 pushed market prices too low levels, resulting in conservative planning by producers. Increasing imports from China to the EU have also contributed to the strict measures against shrimp smuggling through intermediary countries such as Vietnam (FAO, 2021). Contrary to our results, D.'Amico *et al.* (2018) reported that the highest number of notifications related to seafood products in the RASFF database between 2011 and 2015 were from the "fish and fish products" category. This emphasises the need for studies that focus on specific exporting regions to understand potential risks associated with specific food categories and take appropriate action.

Regulatory control over the movement of live animals and food of animal origin among EU member states is based on trust in the warranties provided by the supplying country and official inspections conducted at the point of origin (Giusti *et al.*, 2019). However, the import of live animals and food of animal origin from third countries (non-EU countries) are controlled by veterinary inspections at the border inspection points. Hence, border inspection points at seaports and airports contribute to the maintenance of food safety (Petróczi *et al.*, 2010) and foods not meeting these safety requirements are prevented from entering the EU. Border controls constituted the highest basis for the notifications reported (52.8%) with 25.9% of products affected rejected from

entering the EU. Border rejection was the second most frequently issued notification about seafood originating from Southeast Asia after information notification. Border rejections are implemented in other importing countries to prevent unsafe food from entering their food chain. For example, the United States rejected 1304 tonnes of seafood in 2019, of which 230 tonnes (18%) were rejected due to microbiological contamination (FAO, 2021). Furthermore, shrimp was the highest seafood rejected by Japan in 2019, but unlike the USA, 71% of the total seafood rejection was because of microbiological contamination. While border rejections prevent unsafe foods from entering the EU, information and alert notifications relate to foods already within the EU. The majority of the notifications in our study concerned Southeast Asian seafood already within the EU. Our results showed that the most frequent action taken for contaminated seafood from Southeast Asia were "re-dispatch" and "import not authorised". This observation is similar to Pigłowski (2017) who noted that the measure was taken after alert and information notifications was withdrawal from the market chain, while after border rejection re-dispatch and destruction were applied. D.'Amico *et al.* (2018) further showed that the actions after notifications about cephalopods and crustaceans were mainly re-dispatch or unauthorised to import.

Pathogenic microorganisms are the main hazards in seafood for which notifications are issued (Pigłowski, 2020). Since the EU is a major importer of seafood from Southeast Asia, our present study focused on the pathogenic microorganisms limiting this trade. The notifications reported pathogenic bacteria belonging to eight genera as well as norovirus as the major pathogens contaminating seafood from Southeast Asia. *Vibrio* (50%) and *Salmonella* (38%) were the dominant bacterial genera, while norovirus comprised 8% of pathogens reported in the notifications. It is no surprise that *V. parahaemolyticus* was the dominant pathogen associated with crustaceans representing 44% of pathogens reported from the four Southeast Asian countries including 76% in Malaysia alone. *V. parahaemolyticus* is also a major contaminant in crustaceans exported from Africa to the EU (Somorin *et al.*, 2021). The bacterium inhabits warm seawater along the shores of many continents and is most abundant during the warm months. Pathogenic strains cause gastroenteritis in humans after the consumption of contaminated raw or insufficiently cooked fish, crustaceans and molluscs. *V. parahaemolyticus* is one of the most common causative agents of food poisoning in Asia (Lopatek *et al.*, 2018; Song *et al.*, 2020).

Salmonella which should not be present in seafood constituted 24% of pathogens reported in crustaceans, 50.8% of bivalves, 55% of fish and 94.7% of cephalopods, and co-occurs with other pathogens, particularly *Vibrio* spp. Discharge of untreated sewage water into coastal waters is the most common cause of contamination of fish and other hydrobionts. Bivalve molluscs feed by filtering water and can accumulate *Salmonella* (Marceddu *et al.*, 2017). Contamination can also occur at first sale points, processing plants and stores during processing, storage and transport (Don *et al.*, 2020). In the current study, *Salmonella* was the dominant pathogen (69.7%) in fish and fish products exported from Vietnam and *S.* Weltervreden was the most frequently reported. It is a common causative agent of gastroenteritis in Southeast Asia and is

also responsible for food poisonings in Europe (Emberland *et al.*, 2007). Noor Uddin *et al.* (2015) isolated *S.* Weltervreden from shrimp reared in 11 out of 48 farms in the delta of the Mekong river in Vietnam. In a study to determine the incidence of *Salmonella* in seafood imported to the USA from around the world, Heinitz *et al.* (2000) reported that seafood from Vietnam had the highest incidence. *Salmonella* contamination was the basis of 77% of border rejections caused by pathogenic microorganisms in the USA in 2019 (FAO, 2021). In this study, it was observed that pathogenic microorganisms from bivalve molluscs originated from Vietnam only. Similarly, D.'Amico *et al.* (2018) had shown previously that bivalve molluscs from Vietnam are contaminated by pathogenic microorganisms with poor temperature control and poor hygiene being implicated. The presence of coliform organisms is an indication of unhygienic food production/processing condition and this was the basis for 55.8% border rejection of seafood attributed to a microbiological cause in Japan in 2019 (FAO, 2021), a country which is a major importer of seafood from Southeast Asia including Vietnam, Thailand and Thailand. Moreover, *E. coli* is used as an indicator of faecal contamination (European Commission, 2005) and for the classification of production and relaying areas for live bivalve molluscs (European Commission, 2019).

Norovirus is the third most important pathogen associated with seafood from Southeast Asia and it was only reported in bivalve molluscs, and clams, originating from Vietnam. The presence of norovirus in seafood is of great significance worldwide since it is the most common cause of viral gastroenteritis globally. Sewage waters are a significant source of contamination in areas for rearing shellfish in developing countries. Consumption of raw or insufficiently cooked bivalve molluscs is the most frequent cause of norovirus gastroenteritis since they accumulate the virus from contaminated water while filtering it. Poor hygiene, improper processing and transportation can also contaminate bivalve molluscs with norovirus (Das *et al.*, 2020). A European Union monitoring programme has shown that the prevalence of norovirus in raw oysters at production areas was 35%, while at dispatch centres it was 11% (EFSA, 2019). According to the EFSA's opinion, there is no threshold infectivity limit for norovirus. An experiment on human volunteers revealed that they became infected after exposure to 10^3–10^8 virus genome copies. Moreover, the virus concentrations detected in oysters linked to human cases varied from less than a hundred copies to more than ten thousand per gram of material analysed (EFSA, 2012). Norovirus outbreaks have increased in the EU and these have been linked to seafood including fish, crustaceans, shellfish and molluscs (EFSA & ECDC, 2021). Regardless of the significance of norovirus for human health, current EU legislation does not impose mandatory control on for its presence in food. Therefore, inspections are made based on previous RASFF alert notifications from the food product and originating country. For the period between 1979 and 2017, Papapanagiotou (2017) reported 219 RASFF notifications about norovirus, of which 65% were for bivalve molluscs.

Continuous surveillance of these pathogens in seafood imported from Southeast Asia to the EU is required to protect public health. Enforcement of stringent food safety standards in producing Southeast Asian countries would

ensure the safety of seafood exported to other parts of the world and ultimately prevent economic loss associated with the rejection, destruction and/or import restrictions of contaminated seafood originating from Southeast Asia to the EU.

CONCLUSIONS

Over the last two decades, Asia has become a significant producer of seafood as both capture and aquaculture producers. This has resulted in a significant amount of seafood exported from Southeast Asia to various parts of the world. Global trade facilitates the transmission of foodborne pathogens and analysis of RASFF notifications showed that seafood from Vietnam, Malaysia, Thailand and Indonesia harbour pathogenic microorganisms and viruses, which could pose a significant risk to the health of consumers. The major pathogens contaminating seafood were *Vibrio* spp., *Salmonella* spp. and norovirus with products from Vietnam having the highest cases of these three pathogens. Crustaceans, mainly shrimp and prawns, accounted for 55.8% of the notifications and were the most affected seafood category in all four countries. While *Vibrio* spp. was the most frequently reported pathogen in Malaysia, Thailand and Indonesia, *Salmonella* had the highest incidence in Vietnam. Since most of these pathogens are linked with unhygienic practices, implementing strict hygienic protocols and food safety standards across the seafood value chain in Southeast Asia would improve the safety and quality of seafood, protect incomes and promote global trade.

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