Microbiological hazards associated with food products imported from the Asia-Pacific region based on analysis of the rapid alert system for food and feed (RASFF) notifications

Food Control

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Abstract:	The Rapid Alert System for Food and Feeds (RASFF) is a monitoring and notification tool developed by the European Commission to serve as a central database for collating food safety-related information for member states of the European Union (EU). This study evaluated the microbiological safety of foods originating from the Asia-Pacific region in the past two decades (2000-2020) by analysing incidences and trends of notifications and alerts on the RASFF database. The highest number of notifications were for foods exported from India and Thailand as foods exported from these two countries constituted more than half (54%) of the notifications recorded on the RASFF database for the entire Asia-Pacific region from 2000-2020, compared to ANZ (Australia and New Zealand), which had very low notifications (1.2% = 23/1873). Among the 2121 notifications of pathogenic microorganisms, consisting of 14 genera, Salmonella was the most predominant as approximately 7 out of every 10 pathogens isolated from exported foods from the Asia-Pacific Region in the past two decades (74%, 1560/2121) were Salmonella species. More than 95% of pathogen species notifications for fruits and vegetables exported from India and Bangladesh were associated with betel leaves. Among the nuts, nut products and seeds, sesame seeds were the main food item contaminated by Salmonella , and these accounted for 87% of total Salmonella notifications. Across the food categories, there was a statistically significant reduction in the number of notifications associated with seafoods over the years (r = -0.73, p=0.0001). Although a statistically significant increase in notifications for fruits and vegetables (r = 0.66, p=0.008) was recorded between 2000-2014, more recent years (2015-2020) have been associated with reducing trends in the number of notifications associated with this food type (r = -0.85, p=0.03). Results indicate that imported foods may be potential vehicles for the transmission of clinically relevant microorganisms.

Office of Research Services,
University of Tasmania,
Australia
19th April 2021

Editor,
Food Control
Dear Editor,

RE: Response to Review Comments [Ref. No.: FOODCONT-D-21-00745]

Thank you for the review of our manuscript " Microbiological hazards associated with food products exported from the Asia-Pacific region based on analysis of the Rapid Alert System for Food and Feed (RASFF) notifications [Ref. No.: FOODCONT-D-21-00745]".

All the editor's and reviewer's comments have now been addressed. Kindly find tablutaed below point-by-point responses to each comment. Locations in the journals where changes have been effected are also stated, with changes in the manuscript fet as tracked change, as per journal specification.

We thank you in advance for your time in considering this work for publication and look forward to hearing your response.

Yours sincerely,

Dr Olumide Odeyemi

Highlights

- RASFF pathogen notifications analysed for Asia Pacific food imports (2000 – 2020).
- 1873 notifications reported over 2 decades across 29 notifying countries.
- Imported foods can potentially transmit clinically relevant microorganisms.
- *Salmonella* was the predominant pathogen (7 out of every 10 pathogens).
- Inconsistent actions in responses to notifications by different EU member states

Response to Reviewers' comments:

Reviewer #1		
No	**Comment**	**Response**
1	In this study, the authors evaluated the microbiological safety of foods being imported from the Asia-Pacific region from 2000 to 2020 by analyzing incidences and trends of notifications and alerts in the Rapid Alert System for Food and Feeds database. Overall, this is well-organized research article with some interesting findings.	Thank you
2	The scientific names of pathogens in latin should be in italic, no matter they are in the manuscript or the supplementary materials.	In agreement with the reviewer, issues with the pathogen names in the manuscript relate to the supplementary tables. We have now gone through each of the supplementary tables and have corrected the anomalies in the description of pathogen names. The names are now consistent with acceptable norms in literature (e.g. Jiang et al 2021,Food Control, https://doi.org/10.1016/j.foodcont.2020.107535 and Bangtrakulnonth et al 2004, Emerging infectious diseases https://doi.org/10.3201/eid1001.02-0781), e.g. *Salmonella enterica* ser. Derby, *Salmonella* Typhimurium etc
3	It is confusing both "export" and "import" were used. It is more proper to use "import" since this study was conducted from the perspective of who imported foods from the Asia-Pacific region.	In agreement with the reviewer, issues with import/export clarifications have now been made. Given these changes, the manuscript now reflects that it was conducted from the perspective of who imported foods from the Asia-Pacific region. These changes are reflected in Lines 1,34-42,189,201,226,240, 308,369, 381,383,395,404, 412-414, 447-456, 482-484, 496-502,553,566, 583, 641, 667 and 714
Reviewer #2		
5	The MS entitled "Microbiological hazards associated with food products exported from the Asia-Pacific region based on analysis of the Rapid Alert System for Food and Feed (RASFF) notifications" describes microbial hazards associated with exported food items. The subject of the MS is relevant and this type of scientific investigation helps countries to implement policies to improve export quality. Authors have collected data for last 20 years which is significant amount of data analysis.	Thank you

6	Authors may want to break this data into 5 years slots such as 2000-2004, 2005-2009, and so on to see if there is any improvement in number of notifications reported. Alternatively, authors may want to consider analyzing this data over time to see any if number of notifications have gone up or down over 20 years.	Actually, this has already been done in the manuscript and results presented in Table 3. The data was split into distant years (2000-2014) versus most recent years (2015-2020) and assessed for trends in the different data timeframes (i.e. does the pathogen notification increase with years considering the entire period (2000-2020), most recent years (2015-2020) or distant years (2000-2014). However, we agree with the reviewer that this statement does not come out clearly in the methodology section so we have now added this into the methodology section.
Reviewer #3		
7	Table 2, it would be better to provide information on the total number of foods imported or sample for detection from each country or region.	It is difficult to get data on total number of foods imported or sample for detection from each country or region. One limitation of the RASSF database is that it does not record the number of detection per given number of food items tested. We have now included this as a limitation in the study and suggestion for RASSF database operators to consider including in the future (Line 713-716)
8	In the results part, brief analysis of observed results should be provided. More specific analysis should be conducted in the Discussion. For example, the author mentioned that "The highest number of notifications was made by the UK (28%)", why?.	Analysis and discussion of the results is already presented in the discussion section and would be repetitive if these analysis are presented again in the results section. However, as the reviewer as advised, we have now included more specific analysis….in the discussion section e.g. Line 519-527, 499-503, 594-597)
9	The significance of the research should be provided in both abstract and discussion section	This has now been added into the abstract (line 52-53…) and discussion (line 488-490).
Editor		
11	The highlights do not conform to the journal's requirements: maximum 85 characters, including spaces, per bullet point. Please revise.	The highlights have now been edited to conform with the journal’s standard.

Microbiological hazards associated with food products imported~~exported~~ from the Asia-Pacific region based on analysis of the Rapid Alert System for Food and Feed (RASFF) notifications

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Abstract

The Rapid Alert System for Food and Feeds (RASFF) is a monitoring and notification tool and food safety-related database developed by the European Commission ~~to serve as a central database for collating food safety-related information for member states of the European Union (EU)~~. This study evaluated the microbiological safety of foods originating from the Asia-Pacific region in the past two decades (2000-2020) by analysing incidences and trends of notifications and alerts on the RASFF database. The highest number of notifications were for foods imported~~exported~~ from India and Thailand as foods imported~~exported~~ from these two countries constituted more than half (54%) of the notifications recorded on the RASFF database for the entire Asia-Pacific region from 2000-2020, compared to ANZ (Australia and New Zealand), which had very low notifications (1.2% = 23/1873). Among the 2121 notifications of pathogenic microorganisms, consisting of 14 genera, *Salmonella* was the most predominant as approximately 7 out of every 10 pathogens isolated from ~~exported~~ foods imported from the Asia-Pacific Region in the past two decades (74%, 1560/2121) were *Salmonella* species. More than 95% of pathogen species notifications for fruits and vegetables imported~~exported~~ from India and Bangladesh were associated with betel leaves**.** Among the nuts, nut products and seeds, sesame seeds were the main food item contaminated by *Salmonella*, and these accounted for 87% of total *Salmonella* notifications**.** Across the food categories, there was a statistically significant reduction in the number of notifications associated with seafoods over the years ($r = -0.73$, $p=0.0001$). Although a statistically significant increase in notifications for fruits and vegetables ($r = 0.66$, $p=0.008$) was recorded between 2000-2014, more recent years (2015-2020) have been associated with reducing trends in the number of notifications associated with this food type ($r = -0.85$, $p=0.03$). Results indicate that imported foods may be potential vehicles for the transmission of clinically relevant microorganisms. Studies of this nature can potentially encourage countries to implement policies that improve export quality.

Keywords: Microbiological safety, supply chain, foodborne pathogens, food products

1. Introduction

Food safety is everyone's business, and it is pivotal to public health protection. Many factors make food unsafe for human and animal consumption, ranging from chemical contaminants such as pesticides, and mercury in seafood, to biological hazards, including parasites and microorganisms (2010). It is imperative to maintain consumers' health by ensuring optimum standards for food from production/harvest through the food supply chain up to the point of consumption. However, the impact of globalization, leading to a long food supply chain coupled with the rapid distribution of foods across the world, has made it difficult to track the origin and history of most foods and/or food additives resulting in food spoilage, lose and waste, as well as foodborne disease outbreaks from the consumption of unsafe food (Rezaei & Liu, 2017). The major causes of foodborne illnesses include; bacteria (*Salmonella, Campylobacter, Listeria, Vibrio cholerae,* enterohaemorrhagic *Escherichia coli*), viruses (*Norovirus*, Hepatitis A), parasites (*Echinococcus spp*, *Taenia solium*, *Ascaris, Cryptosporidium, Entamoeba histolytica*, *Giardia*), prions, fungi, and chemical agents (naturally occurring toxins such as mycotoxins and phycotoxins, persistent organic pollutants such as dioxins and polychlorinated biphenyls, heavy metals such as lead, mercury and cadmium) (World Health Organization, 2020a, 2020b). Over the past few years, there has been a significant increase in the number of documented cases of foodborne diseases reported by various countries across the globe. Worldwide, the number is estimated to be 600 million cases of foodborne illnesses annually, resulting in 420,000 deaths, with about 30% of the deaths recorded in children (Food and Agriculture Organization, 2019). In the Asia-Pacific region, which comprises countries within South, East, Southeast Asia and Oceania, the number of foodborne illnesses continues to rise, with current estimates pegged at 275 million cases annually (Food and Agriculture Organization, 2019). The Asia-Pacific region has a population of about 4.6 billion people, accounting for about 60% of the global population (Worldometer, 2021). This large, growing population places a lot of demand on water, energy and food resources. Furthermore, although the region is rapidly becoming one of the largest economies globally, over 40% of the population live at or below the poverty line (ESCAP, 2020). The high poverty rate coupled with the growing population and other factors, including poor hygiene, lack of adequate food processing and preservation routines and poor food policy enforcement, can be considered the main drivers of foodborne disease outbreaks within the region (Food and Agriculture Organization, 2019).

A large proportion of foodborne disease outbreaks are not noticed immediately, traced to the consumption of a particular food item, or even recognised as a foodborne disease outbreak. Others go unreported and are not investigated. Furthermore, there are limitations in the capacity of many countries to undertake food surveillance due to inefficient food regulatory agencies and unavailability of reference laboratories and analytical tools/expertise to identify sources of foodborne disease outbreaks and conduct investigations (Wang, et al., 2016). The Rapid Alert System for Food and Feeds (RASFF), created in 1979, is a monitoring and notification tool developed by the European Commission to serve as a central database for collating food safety-related information for member states of the European Union (EU). It allows the food regulatory bodies of member countries to report and submit information and notifications about unsafe foods and unauthorised/illegal foods/food additives in circulation within the market, ensuring the rapid transmission and sharing of information regarding food safety risks as they occur in real time. This allows actions, including product recalls/withdrawals, to prevent adverse health and economic consequences to consumers within the European Union and beyond (European Commission, 2020a). RASFF features a consumer portal that is interactive and has been available to consumers since 2014. Its interactive online database can be used for customised searches of food safety-related information using criteria including Notification, Type, Hazard, Date, Product and Keywords. In addition to monitoring food safety, RASFF is also used to track food fraud, substitutions, and other economically motivated adulterations (EMAs), which may not be considered direct food hazards, but are still of public health and economic significance (Tähkäpää, Maijala, Korkeala, & Nevas, 2015). The system operates on a 24-hour basis, allowing for a seamless flow of information and ensuring regulatory compliance. Thus, the RASFF serves the very important function of mitigating risks associated with foods and continuously ensuring public health safety (Kowalska & Manning, 2020).

The RASFF has recently been used in tracing the origin of food contaminations and in foodborne outbreak investigations such as the *Salmonella* Poona infections reported in France in 2019 and the multi-country outbreak of *Listeria monocytogenes* in cold-smoked fish products in five member EU states of Denmark, Estonia, Finland, France and Sweden (European Commission, 2020b). Similarly, there have been RASFF notifications from countries within the Asia-Pacific region, including Australia, Hong Kong, Japan and Nepal, amongst others (European Commission, 2020a). It is imperative that food exporters, especially those exporting from developing countries to the more developed countries in Europe, meet the food standards of the destination country. The presence of microbiological and chemical hazards in foods destined for Europe, when flagged by RASFF, can lead to import rejection with attendant economic loses (Somorin, Odeyemi, & Ateba, 2021). The European Food Safety Authority (EFSA) and the European Center for Disease Prevention and Control (ECDC) have identified *Salmonella enteritidis, Campylobacter* spp., shiga-toxin producing *Escherichia coli, Yersinia* spp. and *Listeria monocytogenes* as the major bacteria species implicated in human cases of foodborne illnesses (European Food Safety Authority, 2021) and are actively monitored for by the RASFF. These species have previously been identified in foods of Asian-Pacific origin (Food and Agricultural Organisation, 2018; Kaakoush, Castaño-Rodríguez, Mitchell, & Man, 2015; Rivas, Strydom, Paine, Wang, & Wright, 2021; Sodagari, Wang, Robertson, Habib, & Sahibzada, 2020; Sugiri, et al., 2014), highlighting the need for deliberate measures to eliminate these pathogens from foods, especially those destined for export to Europe.

Although systems such as the RASFF are in operation worldwide in both the public and private sector to assure food safety, there continue to be incidences of consumer foodborne illnesses that are directly related to lapses in food regulations, inadequate monitoring and enforcement or the deliberate attempts by Food Business Operators (FBOs) to increase profits through opportunistic malpractices (Tähkäpää, et al., 2015). Furthermore, the Covid-19 pandemic, with its disruption of the food supply chain both domestically and internationally, has worsened the food security risks, especially in the Asia-Pacific region. The pandemic undermined food accessibility and availability, while the global lockdown of 2020 disrupted food production, distribution operations, logistics and trading (Kim, Kim, & Park, 2020). Also, the disruption in the food supply chain and food production and trade led to an increase in food spoilage rates due to longer wait times, thus increasing the risks of foodborne illnesses and economically motivated fraud (Kim, et al., 2020). Therefore, it is evident that continued vigilance is required to assure food safety, which continues to be a challenge globally, especially regarding the presence of microorganisms in foods. This article evaluates the microbiological safety of foods originating from the Asia-Pacific region by analysing incidences and trends of notifications and alerts on the RASFF database.

2. Materials and Methods

2.1. RASFF database

Six sections (Notification, Type, Hazard, Date, Product and Keywords), presented as fill-in forms, constitute the RASFF portal search page. In the “Notification” section, users can use four sub-sections to enter details related to a food item for which notification information is being sought. These sub-sections include 1) ‘Reference’ – a unique reference number associated with each notification; 2) ‘Subject’ – a field wherein specific subjects can be searched using the “AND”,”OR” Boolean operators; 3) ‘Notified by’ – a drop-down list of notifying countries (EU member states); and 4) ‘Open alert’ – a field where users can select for information that includes or excludes open alerts. The “Type” section consists of three subsections; 1) ‘Type’- allows users to select their preference for information related to food, feed or food contact material; 2) ‘Classification’- where users can select the notification classification; and 3) ‘Basis’- where users can select the notification basis for which information is being sought. The ‘Date’ section allows users to select dates or periods of the year for which notification data is required. The ‘Product’ section consists of four subsections; ‘Category’ (a drop-down list of types of food included in the RASFF database); ‘Country’ (a drop-down list of all notifying and originating countries); ‘action taken’ (a drop-down list of action taken following notification); and ‘flagged as’ (with two sublevels – distribution and origin). The ‘Keyword’ section allows users to search by keywords.

2.2 Data collection

The dataset used for this study was obtained from the RASFF database as described by Yinka M. Somorin, Olumide A. Odeyemi, and Collins N. Ateba (2021) with slight modifications based on the three search criteria that focused on the product country of origin, product type and hazard category. In terms of the product’s country of origin, the database was searched for information relating to all Asia-Pacific countries. Notification data was only available for imports from 20 ~~exporting~~ countries in the Asia-Pacific region: Afghanistan, Australia, Bangladesh, Cambodia, China, Hong Kong, India, Indonesia, Laos, Malaysia, Nepal, New Zealand, Pakistan, Philippines, Singapore, South Korea, Sri Lanka, Taiwan, Thailand and Vietnam. In terms of product type, the search was restricted to food only, excluding feed and food contact materials. In terms of hazard category, the focus was placed on “pathogenic microorganisms” included in the RASFF database. The initial notification date was not restricted to enable complete capturing of all the available notifications; however, considering the paucity of data preceding the year 2000, notification data preceding 2000 were subsequently excluded from the dataset. The dataset used therefore spans two decades.

2.2. Data analysis

The notifications obtained for the imports from 20 ~~exporting~~ countries in the Asia-Pacific region were exported as an Excel file. Data sorting, filtering, and formatting were completed using Microsoft Excel spreadsheets. Missing data instances were replaced with the term “not specified”. Descriptive statistics were collated to determine the predominant pathogens associated with seafood originating from countries in the Asia-Pacific region (the most contaminated food category); period of lowest and highest notifications; number of notifying countries; and the country of origin. To determine trends in the yearly notifications, Pearson correlations of year versus number of notifications per sub-region and per food category were conducted using IBM® Statistical Package for the Social Sciences (SPSS®) software version 24. The data was split into distant years (2000-2014) versus most recent years (2015-2020) and assessed for trends in the different data timeframes (i.e., does the pathogen notification increase with years considering the entire period (2000-2020), most recent years (2015-2020) or distant years (2000-2014). A statistically significant increasing trend of notifications was reported when the Pearson correlation statistics (r) were >0.5 with an associated p-value <0.05. A statistically significant decreasing trend of notifications was reported when the Pearson correlation statistics (r) were < -0.5 with an associated p-value <0.05. A map of originating Asia-Pacific countries was processed in Tableau, and Chord diagrams were generated using Rstudio, a free and open-source environment for the statistical language R (https://www.r-project.org). A Sankey Diagram was developed using Python to display notification flows and their quantities in proportion to one another, with the originating country designated as the source node, while the product type and action taken were designated as target nodes.

3. Results

3.1. Notifications - originating and notifying countries.

A total of 1873 notifications from 2000 to 2020 were obtained, based on our search criteria, for food items imported from 20 countries in the ~~exporting countries~~ in the Asia-Pacific region: Afghanistan, Australia, Bangladesh, Cambodia, China, Hong Kong, India, Indonesia, Laos, Malaysia, Nepal, New Zealand, Pakistan, Philippines, Singapore, South Korea, Sri Lanka, Taiwan, Thailand and Vietnam (**Fig.1**).

3.2 Notification categories

Presented in Table 1 are three levels of notification categories associated with the RASFF database (i.e., Notification basis, Notification type and Action taken). was observed in this study. In more than half of the notifications (51%), the basis of notification was border control, with the consignment detained (**Table 1**). Only 1% of notifications were due to food poisoning and < 1% due to consumer complaints. The notification type was mainly border rejection (43%) while the most prevalent action taken was re-dispatching (17.6%) and destruction of the consignments (17.5%, **Table 1**). The highest number of notifications were for foods imported~~exported~~ from India (31% = 588/1873), followed by Thailand (23% = 428/1873, **Table 2**). The categories of foods categories originating from Asia-Pacific Region (n=1873) by country of origin from 2020 – 2020 are shown in **Fig. 2**. Together, foods imported ~~exported~~ from these two countries constituted more than half (54%) of the notifications recorded on the RASFF database for the entire Asia-Pacific region from 2000-2020 (**Fig 3**), compared to ANZ (Australia and New Zealand), which had very low notifications (1.2% = 23/1873). Also, the prevalent actions taken associated with notifications from India and Thailand were re-dispatching and destruction of the consignments (**Fig. 4.**).

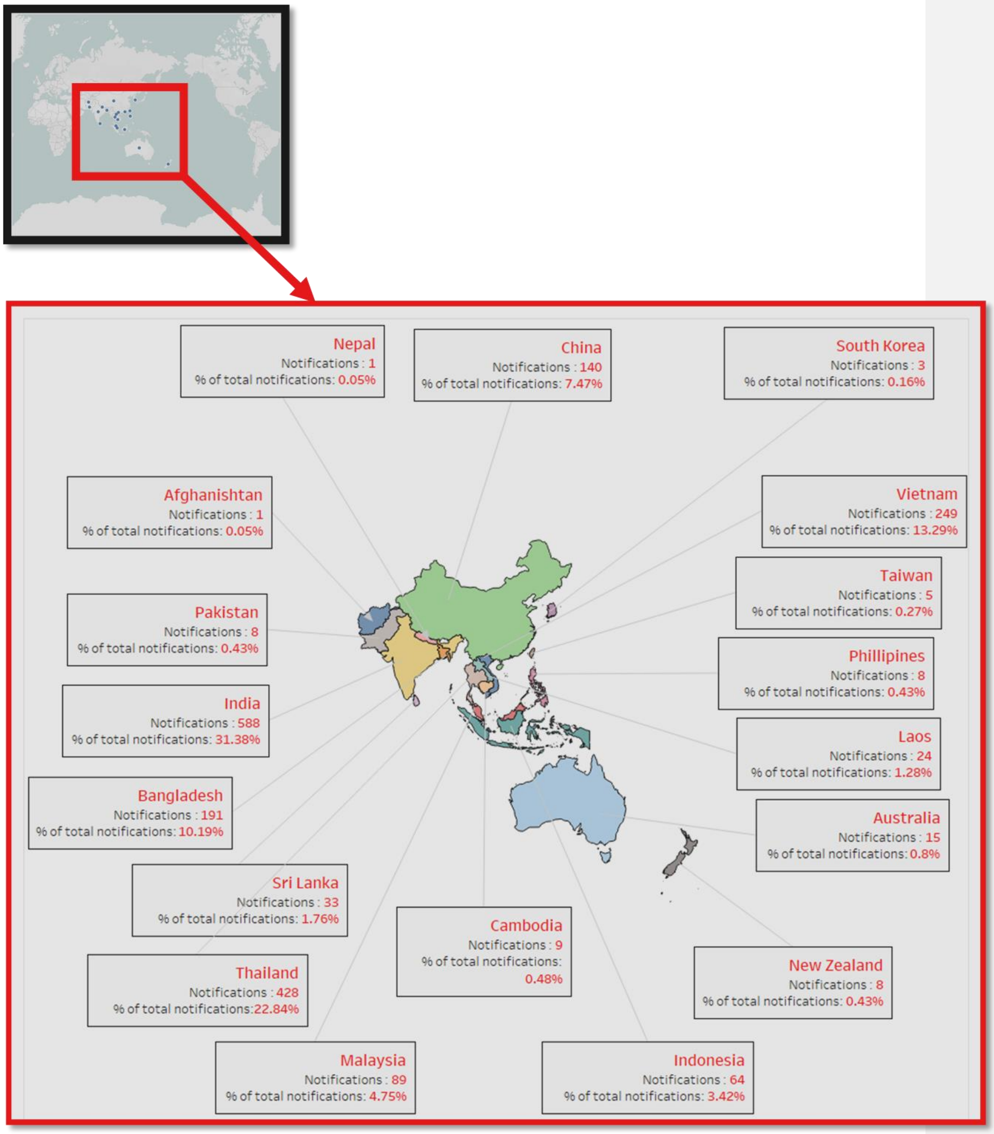


Fig. 1: Map of originating country and number of notifications listed in the *RASFF* database

[N.B. Additional countries not on the map: Hong Kong (Notifications: 6, % of total notifications: 0.32%) and Singapore (Notifications: 3, % of total notifications: 0.16%)]

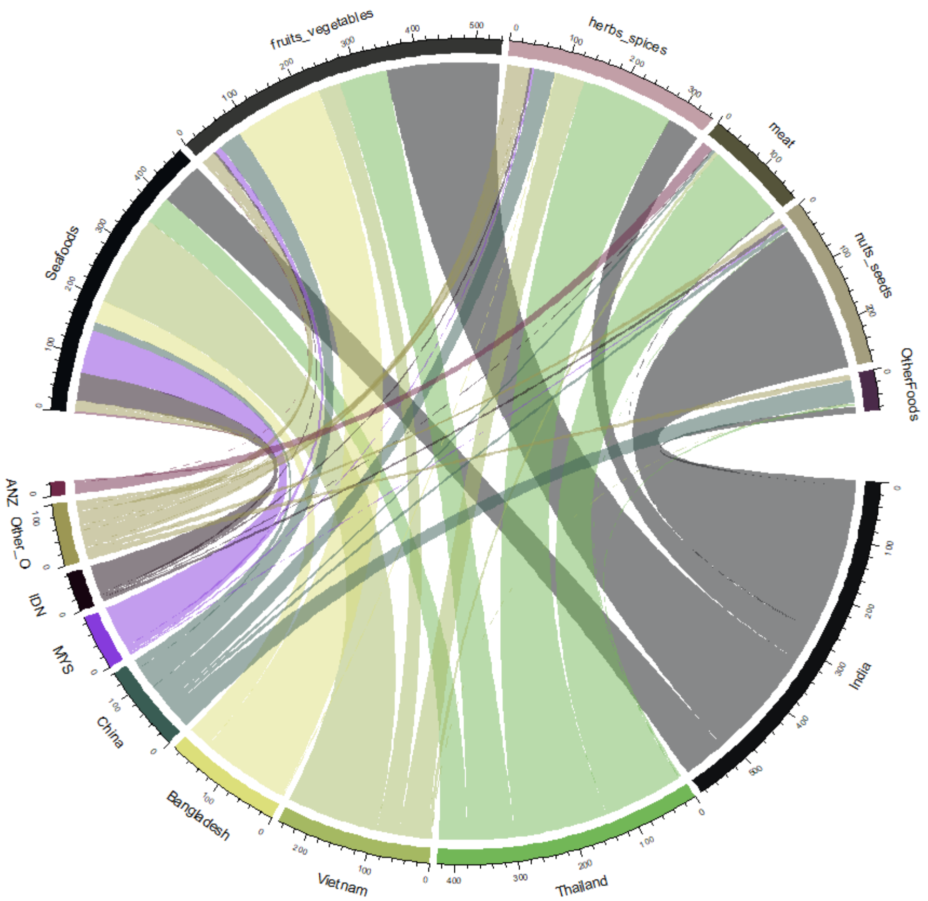


Fig. 2 Food categories of RASFF notifications (n=1873) originating from Asia-Pacific Region (n=1873) by country of origin from 2020 - 2020. Meat includes meat and meat products (other than poultry), poultry meat and poultry meat products. Seafoods include bivalve molluscs and products thereof, cephalopods and products thereof, crustaceans and products thereof, fish and fish products. Other foods include prepared dishes and snacks, soups, broths, sauces and condiments, cereals and bakery products, cocoa and cocoa preparations, coffee and tea, confectionery, eggs and egg products, food additives and flavourings, milk and milk products and other food product / mixed dietetic foods, food supplements, fortified foods. ANZ= Australia and New Zealand, IDN = Indonesia, MYS=Malaysia. Other_O = Other originating countries, i.e., Pakistan, Philippines, Hong Kong, Taiwan, Sri Lanka, Singapore, South Korea, Afghanistan, Chile, Nepal and Cambodia. The length of the arc on the circumference of the circle represents the number of notifications in each food category.

Fig. 3. Types of RASFF notifications (n=1873) originating from Asia-Pacific Region by country of origin from 2020 - 2020. Inform_ATTN= Information for attention, Inform_FLP = Information for follow-up. ANZ= Australia and New Zealand, IDN = Indonesia, MYS=Malaysia. Other_O = Other originating countries, i.e., Pakistan, Philippines, Hong Kong, Taiwan, Sri Lanka, Singapore, South Korea, Afghanistan, Chile, Nepal and Cambodia. The length of the arc on the circumference of the circle represents the number of notifications in each food category.

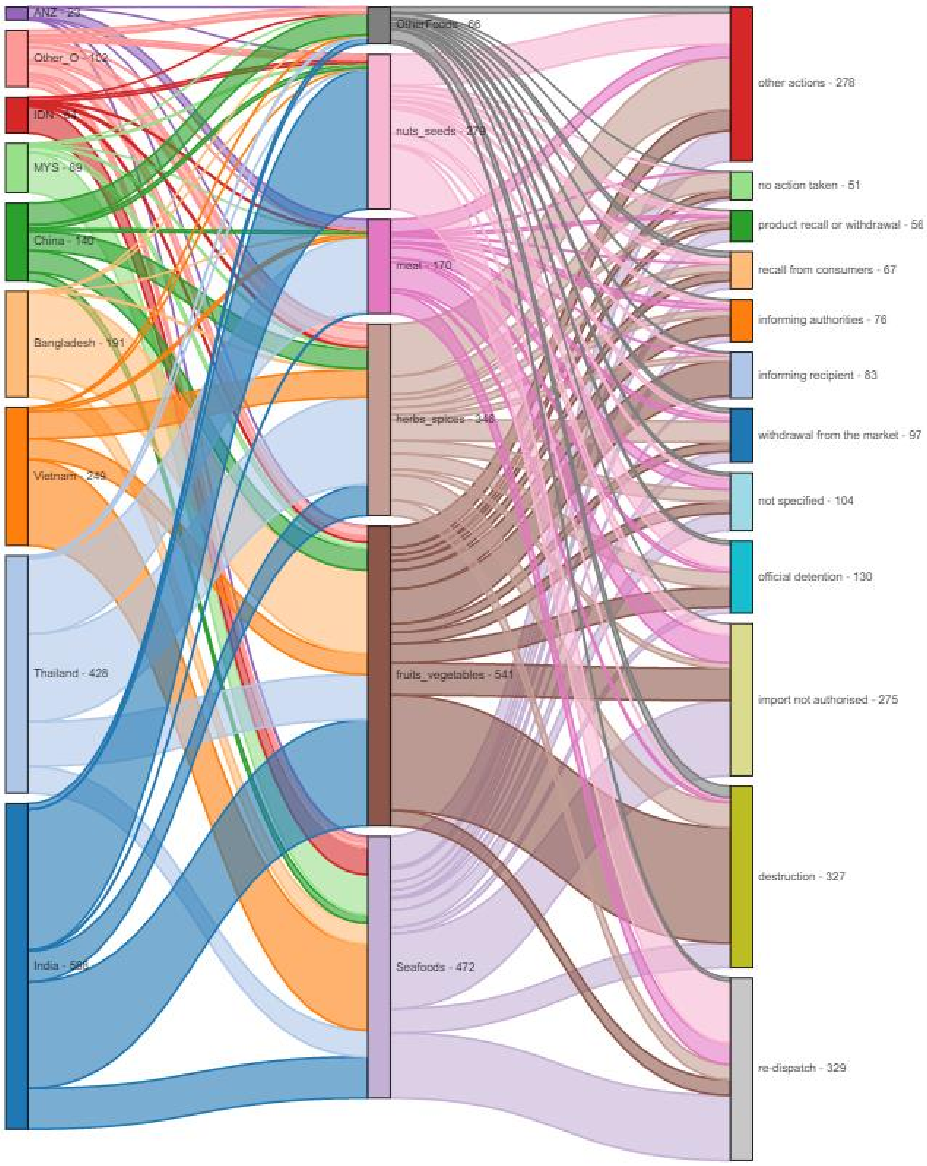


Fig. 4. Sankey diagram of originating country versus food type and action taken.

N.B. The width of the arrows or lines show their magnitudes, so the bigger the arrow, the larger the flow (i.e., the number of pathogen notifications associated with that source-target node). Colours have been used to divide the diagram into different categories in a way that shows different source-target node connections.

Table 1

RASFF notifications of pathogenic microorganisms in seafood originating from the Asia-Pacific Region (n=1873) from 2020 – 2020 based on notification category.

Classification category	Notifications	
	Number	**Percentage (%)**
Notification basis		
border control - consignment detained	949	50.67%
official control on the market	349	18.63%
border control - consignment released	239	12.76%
not specified	216	11.53%
company's own check	70	3.74%
food poisoning	24	1.28%
border control - consignment under customs	17	0.91%
consumer complaint	8	0.43%
Notification type		
border rejection	810	43.25%
information	509	27.18%
information for attention	283	15.11%
alert	246	13.13%
information for follow-up	25	1.33%
Action taken		
re-dispatch	329	17.57%
destruction	327	17.46%
import not authorised	275	14.68%
official detention	130	6.94%
not specified	104	5.55%
withdrawal from the market	97	5.18%
informing recipient(s)	83	4.43%
informing authorities	76	4.06%
recall from consumers	67	3.58%
product recall or withdrawal	56	2.99%
no action taken	51	2.72%
no stock left	43	2.30%
prohibition to trade - sales ban	37	1.98%
re-dispatch or destruction	29	1.55%
return to consignor	27	1.44%
placed under customs seals	21	1.12%
physical/chemical treatment	21	1.12%
detained by operator	19	1.01%
reinforced checking	16	0.85%
withdrawal from recipient(s)	13	0.69%
public warning - press release	11	0.59%
Other actions	41	2.19%

Other actions: Screening sample, Product destruction or return after official permission, physical treatment - heat treatment, relabelling, Product recalled / Product to be destroyed, destination of the product identified, informing consignor and seizure.

Table 2

RASFF notifications of pathogenic microorganisms in foods originating from the Asia-Pacific Region (n=1873) from 2000 - 2020 based on notifying country.

	Country of origin										
Notifying country	**India**	**Thailand**	**Vietnam**	**Bangladesh**	**China**	**Malaysia**	**Indonesia**	**Laos**	**ANZ**	**Other_O**	**Grand Total**
United Kingdom	216	80	5	150	28	11	3	16	2	19	**528**
Italy	51	17	29	1	22	58	27	0	3	16	**221**
Netherlands	29	92	35	2	10	1	1	6	1	3	**179**
Norway	27	54	36	19	6	1	9	1	8	15	**168**
Germany	46	30	39	1	9	3	2	1	3	14	**145**
Finland	13	72	7	4	10	1	0	0	1	8	**115**
Spain	15	2	30	0	18	8	1	0	0	0	**74**
Greece	64	0	2	1	2	0	3	0	0	1	**73**
Sweden	6	26	9	1	10	0	1	0	1	7	**60**
Poland	48	0	6	0	2	0	0	0	0	0	**56**
France	16	5	5	8	5	2	7	0	3	6	**54**
Denmark	3	27	10	1	8	1	1	0	0	2	**53**
Portugal	1	0	26	0	0	2	1	0	0	1	**31**
Belgium	4	8	4	2	3	1	0	0	0	2	**24**
Other_N	49	15	6	1	7	0	8	0	1	6	**92**
Grand Total	**588**	**428**	**249**	**191**	**140**	**89**	**64**	**24**	**23**	**100**	**1873**

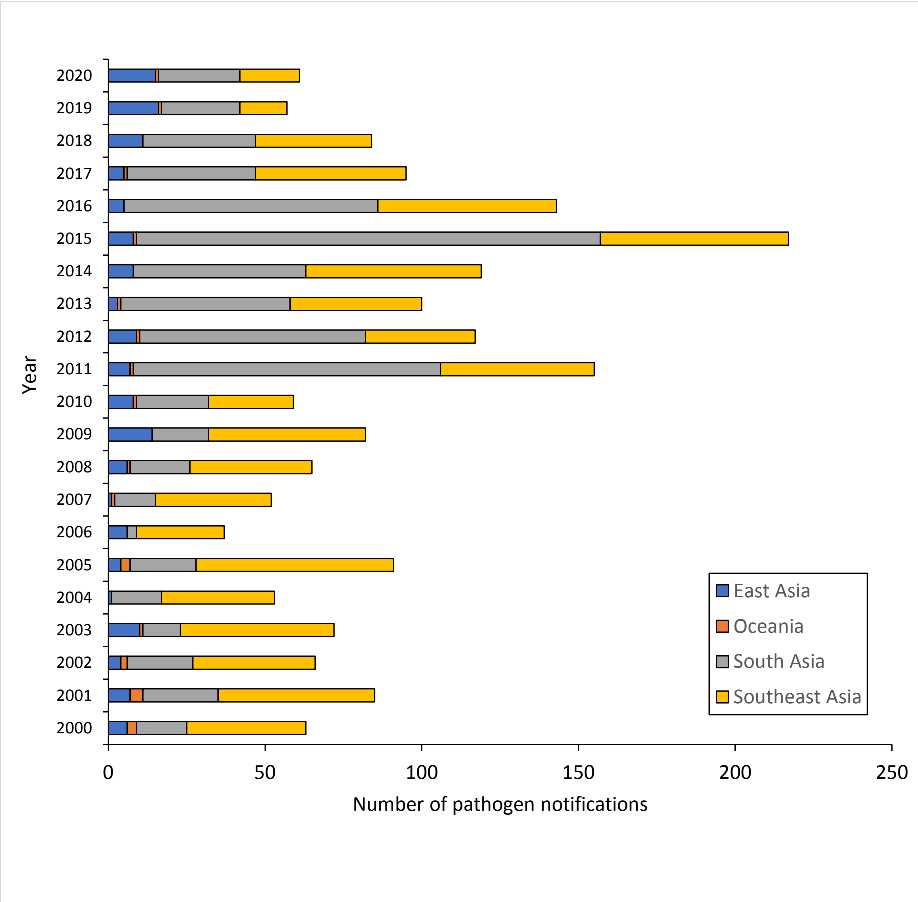
Other_N: Other notifying countries: Cyprus, Austria, Slovenia, Ireland, Lithuania, Iceland, Romania, Switzerland, Bulgaria, Croatia, Estonia, Hungary, Latvia, Luxembourg, Slovakia, Sri Lanka

ANZ= Australia and New Zealand. **Other_O: Other originating countries:** Cambodia, Pakistan, Phillippines, Hong Kong, Taiwan, Singapore, South Korea, Afghanistan, Nepal.

During the two decades studied, very few notifications were recorded for foods imported~~exported~~ from Cambodia, Pakistan, Philippines, Hong Kong, Taiwan, Singapore, South Korea, Afghanistan, and Nepal (**Table 2**). Notifications were recorded by a total of 29 notifying countries. Among these, the highest number of notifications were from the United Kingdom (28% = 528/1873), Italy (12% = 221/1873) and the Netherlands (~10% = 179/1873), while the least number of notifications were reported from Cyprus, Austria, Slovenia, Ireland, Lithuania, Iceland, Romania, Switzerland, Bulgaria, Croatia, Estonia, Hungary, Latvia, Luxembourg, Slovakia and Sri Lanka (a total of only 92 notifications were reported in these 16 countries over the two decades studied, **Table 2**).

3.3. Trends in RASFF notifications of pathogenic microorganisms across sub-regions and food categories

Fig. 5 presents RASFF notifications of pathogenic microorganisms in food originating from the Asia-Pacific Region (n=1873) from 2000–2020, based on the notifying year. In the two decades considered, notifications were greatest in 2015 and 2011. Consistently over the years, food originating from South Asia was associated with the highest number of notifications while the least notifications were reported for Oceania (**Fig. 5**). Over the entire two decades of notifications data recorded in the RASFF database, there was no observable trend across sub-regions, with the notable exception of Oceania. Pearson correlation of year versus RASFF notifications of pathogenic microorganisms in food sub-regions indicates that notifications from Oceania have significantly reduced over the years (r=-0.68, p=0.006). In more recent years, however, (2015-2020), notifications from the sub-regions have reduced significantly, with the notable exception of East Asia **(Table 3a).** Across the food categories, there has been a statistically significant reduction in the number of notifications associated with seafoods over the years (r = -0.73, p=0.0001, **Table 3b**). In contrast, there has been a statistically significant increase in the number of notifications associated with nuts, nut products and seeds over the years (r = 0.57, p=0.007, **Table 3b**). Although a statistically significant increase in notifications for fruits and vegetables (r = 0.66, p=0.008, **Table 3b**) was recorded between 2000-2014, more recent years (2015-2020) have been associated with reducing trends in the number of notifications associated with this food type (r = -0.85, p=0.03, **Table 3b**).



345

346 **Fig. 5.** RASFF notifications of pathogenic microorganisms in food originating from Asia-Pacific Region
347 (n=1873) from 2020 - 2020 based on notifying year.

Table 3

Pearson correlation of year versus RASFF notifications of pathogenic microorganisms in various (a) Asia-Pacific sub-regions and (b) food categories.

a) Yearly notification versus sub-region

Period	Statistics	East Asia	Oceania	South Asia	Southeast Asia	Grand Total
2000-2020	Pearson Correlation	.486*	-.676**	.452*	-0.188	0.353
	Sig. (2-tailed)	0.025	0.006	0.040	0.415	0.116
	N	21	15	21	21	21
2000-2014	Pearson Correlation	0.205	-.731*	.653**	0.025	.562*
	Sig. (2-tailed)	0.464	0.011	0.008	0.929	0.029
	N	15	11	15	15	15
2015-2020	Pearson Correlation	.821*	.b	-.873*	-.957**	-.918**
	Sig. (2-tailed)	0.045		0.023	0.003	0.010
	N	6	4	6	6	6

b) Yearly notification versus food category

Period	Statistics	nuts, nut products and seeds	seafoods	fruits and vegetables	herbs and spices	meat	others	Grand Total
2000-2020	Pearson Correlation	.567**	-.725**	0.387	0.004	0.354	0.419	0.294
	Sig. (2-tailed)	0.007	0.000	0.083	0.988	0.115	0.059	0.197
	N	21	21	21	19	21	21	21
2000-2014	Pearson Correlation	.655**	-.727**	.658**	0.187	-0.258	0.496	0.483
	Sig. (2-tailed)	0.008	0.002	0.008	0.541	0.353	0.060	0.068
	N	15	15	15	13	15	15	15
2015-2020	Pearson Correlation	-0.681	-0.709	-.849*	-0.332	-.878*	-0.427	-.915*
	Sig. (2-tailed)	0.136	0.115	0.032	0.520	0.021	0.399	0.011
	N	6	6	6	6	6	6	6

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed). b- too few samples, blue cells indicate a downward trend, and red cells indicate an upward trend

3.4. Pathogens associated with notifications

Although the total number of notifications was 1873, a higher total number of pathogens (n=2121) was recorded because of co-occurrence of pathogens in some food products (**Table 4**). Among the 29 notifying countries, more than a quarter (28%) of pathogen notifications for foods originating from the Asia-Pacific Region were reported by the United Kingdom (28%, i.e., 587/2121, see **Supplementary Table 1**). Cumulatively, the United Kingdom, Italy, Norway, the Netherlands, Germany and Finland accounted for more than 70% (i.e., 1556/2121) of pathogen notifications in the two-decade study period (**Supplementary Table 1**). The least number of pathogen notifications was observed for France, Poland, Portugal, Belgium, Cyprus, Austria, Slovenia, Ireland, Lithuania, Iceland, Romania, Switzerland, Bulgaria, Croatia, Estonia, Luxembourg, Hungary, Latvia and Slovakia, as these 19 countries accounted for less than 15% (i.e., 277//2121) of pathogen notifications in the two-decade study period (Supplementary Table 1).

Among the 2121 notifications of pathogenic microorganisms from 2000-2020, the following 14 genera consisting of *Salmonella, Vibrio, Bacillus, Escherichia, Norovirus, Clostridium, Campylobacter, Staphylococcus, Enterococcus, Hepatitis, Pseudomonas, Cronobacter, and Plesiomonas*, *were* observed in this study (**Table 4**). Among these, the least commonly isolated pathogen genera were observed to be *Cronobacter*, Fungi (moulds - no specific genus was identified), *Plesiomonas, Shigella, Yersinia* and *Streptococci* (**Table 4**). Conversely, *Salmonella* was the most predominant as approximately 7 out of every 10 pathogens isolated from foods imported from ~~exported foods from~~ the Asia-Pacific Region in the past two decades (74%, 1560/2121) were *Salmonella* species (**Table 4**). Foods exported from India had the highest pathogen notifications (642/2121, **Table 4**).

Table 4

RASFF notifications of pathogenic microorganisms in food originating from the Asia-Pacific Region (n=1873) from 2000 - 2020 based on originating country.

	Country of origin										
Pathogen genus	India	Thailand	Vietnam	Bangladesh	China	Malaysia	Indonesia	Laos	ANZ	Others	Grand Total (%)
Salmonella	551	411	182	165	69	30	38	30	23	61	1560(73.55%)
Vibrio	61	40	59	35	12	62	31	0	1	8	309(14.57%
Bacillus	16	5	14	2	42	0	3	0	0	10	92(4.34%)
Escherichia	3	16	5	0	2	4	0	15	0	2	47(2.22%)
Norovirus	0	0	30	0	11	0	0	0	0	1	42(1.98%)
Not specified	6	2	5	0	4	0	0	0	0	11	28(1.32%)
Clostridium	3	5	2	0	12	0	0	0	0	0	22(1.04%)
Campylobacter	0	5	1	0	0	0	0	0	0	0	6(0.28%)
Staphylococcus	0	1	2	0	0	0	0	0	0	0	3(0.14%)
Enterococcus	1	0	0	0	0	0	1	0	0	0	2(0.09%)
Hepatitis	0	0	0	0	1	0	0	0	1	0	2(0.09%)
Pseudomonas	1	0	0	0	0	0	0	0	0	1	2(0.09%)
Cronobacter	0	0	0	0	1	0	0	0	0	0	1(0.05%)
Fungi	0	0	0	0	1	0	0	0	0	0	1(0.05%)
Plesiomonas	0	0	0	0	0	0	1	0	0	0	1(0.05%)
Shigella	0	1	0	0	0	0	0	0	0	0	1(0.05%)
Yersinia	0	1	0	0	0	0	0	0	0	0	1(0.05%)
Streptococci	0	0	0	0	1	0	0	0	0	0	1(0.05%)

Other_N: Other notifying countries: Cyprus, Austria, Slovenia, Ireland, Lithuania, Iceland, Romania, Switzerland, Bulgaria, Croatia, Estonia, Hungary, Latvia, Luxembourg, Slovakia, Sri Lanka. **Other_O: Other originating countries:** Australia, Cambodia, New Zealand, Pakistan, Philippines, Hong Kong, Taiwan, Singapore, South Korea, Afghanistan, Nepal.
The total number of pathogens (n=2119) exceeds the total number of notifications (n=1873) because of the co-occurrence of pathogens.

Among the pathogens identified in imported~~exported~~ foods originating from the Asia-Pacific Region, India also had the highest *Salmonella* notifications (551/1560). On the whole, more than 80% (i.e.1309/1560) of *Salmonella* notifications were from foods imported~~exported~~ from India, Thailand, Vietnam and Bangladesh. Forty percent (i.e., 625/1560) of the time, pathogen identification did not exceed the genus level for RASFF notifications of Salmonella in food originating from the Asia-Pacific Region during the two-decade study period (**Table 5**). Hence in these instances, the species or serovar implicated in the *Salmonella* notification was not identified. In the remaining 935 instances of *Salmonella* notifications in food originating from the Asia-Pacific Region, a total of 178 serovars of *Salmonella enterica* were identified (**Table 5**). The top 10 most frequently isolated serovars in the RASFF *Salmonella* notifications are serovars Weltevreden, Enteritidis, Hvittingfoss, Agona, Stanley, Senftenberg, Augustenborg, Brunei, Typhimurium, Lexington, Newport and Mbandaka (**Table 5**).

Apart from *Salmonella*, *Vibrio* was the next most common, albeit at a reported frequency far lower than that of *Salmonella* (14.6% = 309/1562). The most commonly isolated *Vibrio* in food products imported~~exported~~ from the Asia-Pacific Region from 2000 – 2020 were *V. cholerae* (46.6%, i.e., 144/309) and *V. parahaemolyticus* (46%, i.e., 142/309) while the least isolated *Vibrio* were *V. fluvialis* and *V. mimicus* (0.32% each, i.e., 1/309) (**Fig. 6**).

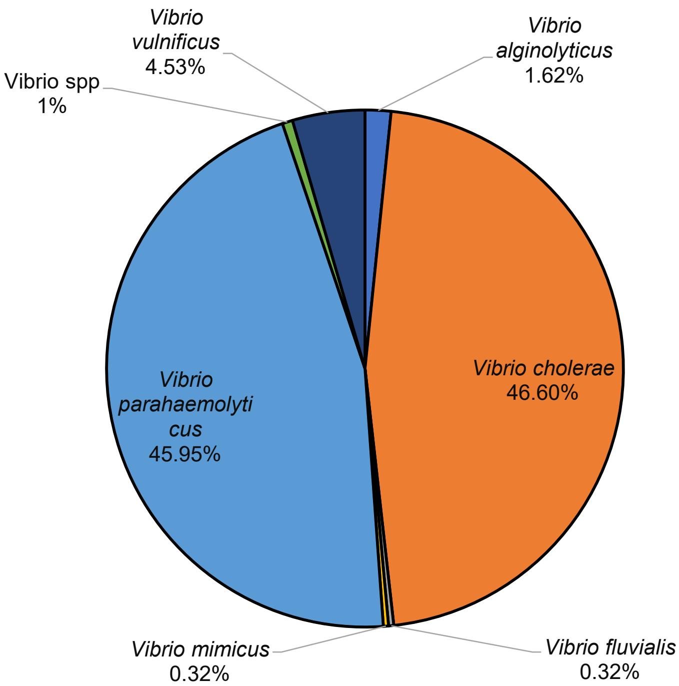


Fig. 6. Species identified in 309 RASFF notifications of Vibrio in food originating from Asia-Pacific Region from 2000 - 2020.

Apart from hepatitis A and norovirus, viruses were generally not detected in the foods imported~~exported~~ form the Asia-Pacific region (**Table 4).** When Hepatitis A was reported in food items, both instances were in 2012 when frozen green mussels (*Perna canaliculus*) from

New Zealand and frozen strawberry cubes from China tested positive for the virus. The action taken in each instance was different. In the case of contaminated frozen green mussels from New Zealand, the notifying country (Italy) withdrew the product from the market. In contaminated frozen strawberry cubes from China, the notifying country (Belgium) only informed recipients. Norovirus detection in foods imported from the Asia-Pacific region was reported 42 times in the two-decade study period (**Table 4).** Eleven of these notifications were from raspberries, seaweed salad and strawberries imported~~exported~~ by China and thirty other instances were from other fruits imported~~exported~~ by Vietnam between 2011 and 2019. In 6 out of the 11 norovirus notifications for fruits and vegetables from China, notifications were informed by the occurrence of ongoing food poisoning or consumer complaints.

There was no consistency in response to ~~N~~norovirus notifications as the action taken varied between countries. For instance, actions taken included rejection at the border (Denmark and Lithuania). Other actions included recall from consumers (Denmark), withdrawal from the market (Netherlands, Germany), product recall or withdrawal (Sweden), withdrawal from recipients or destruction (Germany), public warning - press release (Norway), and informing recipients (Spain). The two instances when h~~H~~epatitis A was reported in food items were in 2012 when frozen green mussels (Perna canaliculus) from New Zealand and frozen strawberry cubes from China tested positive to the virus. The action taken in each instance was different. In the case of contaminated frozen green mussels from New Zealand, the notifying country (Italy) withdrew the product from the market while in the case of contaminated frozen strawberry cubes from China, the notifying country (Belgium) only informed recipient.

Campylobacter notifications in foods originating from the Asia Pacific region were made only in six instances (between 2009 and 2012) for asparagus, corn, ground peppers and spring onions from Thailand and Vietnam. Nearly half (46%, i.e., 42/92) of *Bacillus* notifications in food items from the Asia Pacific were from China.

3.4. Pathogens associated with specific product categories

Fig. 7 presents RASFF notifications of pathogenic microorganisms in food originating from Asia-Pacific Region (n=1873) from 2020 - 2020 based on product category. The most important product categories with *Salmonella* contamination were fruits and vegetables, herbs and spices, nuts, nut products and seeds, while the most important product category with *Vibrio* contamination was crustaceans and related products (**Fig. 7**).

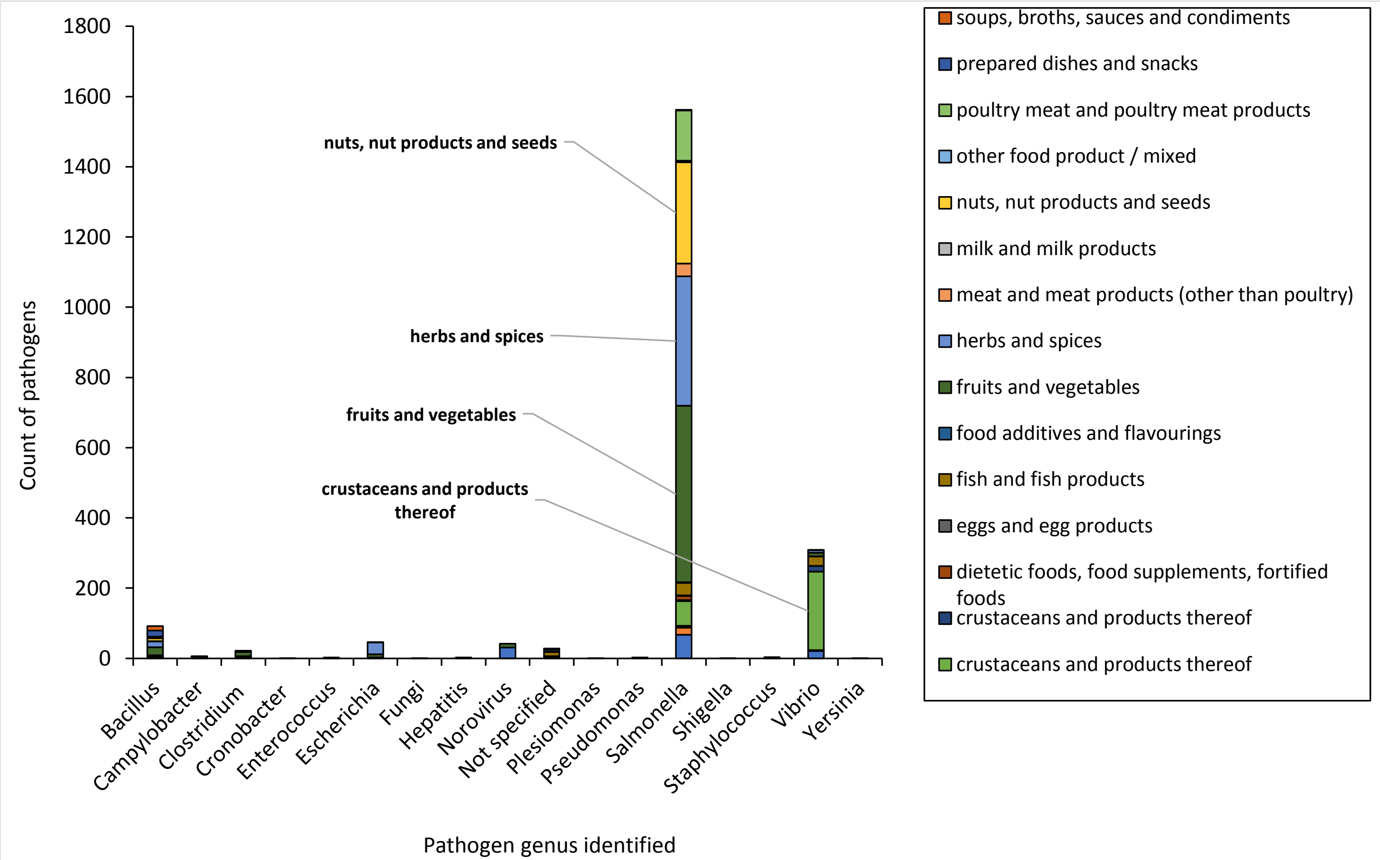


Fig. 7 RASFF notifications of pathogenic microorganisms in food originating from the Asia-Pacific Region (n=1873) from 2020 - 2020 based on food type.

A further analysis of pathogen diversity associated with notifications (2000 - 2020) revealed that crustaceans and related products from India, Malaysia and Vietnam showed the highest number of pathogen species (n >60) **(Supplementary Table 2).** Most of the pathogen species in crustaceans and related products in these countries were associated with shrimps (Table 6). Sri Lanka and Pakistan presented with the least (n=7) pathogen species in crustaceans and related products imported~~exported~~ from the Asia-Pacific Region **(Supplementary Table 2).** Among the Asia-Pacific countries, the highest counts of pathogen species in fruits and vegetables were observed among imports~~exports~~ from India and Bangladesh **(Supplementary Table 3)**. More than 95% (i.e., India=184/193, Bangladesh = 149/152) of pathogen species notifications for fruits and vegetables imported~~exported~~ from India and Bangladesh were associated with betel leaves **(Supplementary Table 3).** All the 346 pathogen notifications in fruits and vegetables imported~~exported~~ from India and Bangladesh were *Salmonella* serovars **(Supplementary Table 3)**. Pathogen notifications for mushrooms imported~~exported~~ from the Asia-Pacific countries were all due to *Salmonella*, with the notable exception of mushrooms imported~~exported~~ from China, which had additional pathogen notifications due to *Bacillus cereus*, *Clostridium perfringens*, *Clostridium* spp, aerobic mesophiles and moulds. Among the Asia-Pacific countries, spinach imported from Thailand had the highest number of reported *Salmonella* serovars (S*almonella* Ndolo, *Salmonella* Aberdeen, *Salmonella* Bovismorbificans, *Salmonella enterica*, *Salmonella group B*, *Salmonella group D*, *Salmonella* Hvittingfoss, *Salmonella* Mbandaka, *Salmonella* Newport - see **Supplementary Table 3**).

Among the nuts, nut products and seeds, sesame seeds were the main food item contaminated by *Salmonella* (261 notifications), and these accounted for 87% of total *Salmonella* notifications (261/299, **Supplementary Table 4).** *Salmonella*-contaminated sesame seeds originated from India (n=260; 99.6%) and Thailand (n=1; 0.4%) (**Supplementary Table 5**). Fifty serovars of *Salmonella enterica* were isolated from sesame seeds **(Supplementary Table 4).** Among the herbs and spices, basil, mint and coriander from Thailand had the highest number of pathogen notifications. For instance, basil was associated with at least 8 *Salmonella enterica* serovars and 65 notifications, coriander with at least 12 *Salmonella enterica* serovars and 24 notifications, and mint with at least 2 *Salmonella enterica* serovars and 25 notifications **(Supplementary Table 6**).

4. Discussion

The presence of pathogenic microorganisms in food products, particularly in minimally processed and ready-to-eat foods, constitutes a significant public health risk to consumers. In this study, we analysed notifications associated with microbiological hazards (MH) in foods imported~~exported~~ from the Asia Pacific region into the EU between 2000 and 2020. Studies of this nature can potentially encourage countries to implement policies that improve quality of exported food products.

Unlike a previous report (Somorin, et al., 2021) which noted a growing trend in notifications from food products imported~~exported~~ from Africa, there was no overall trend in the number of notifications from the Asia Pacific region during the same study period. This difference could be attributed to the significant decrease in MH notifications from the South and Southeast Asia subregions between 2015 and 2020. Interestingly, the countries responsible for the highest number of notifications during the study period are located in the South and Southeast Asia subregions.

Of the 1873 notifications, most (n=1456/1873) of them concerned food originating from India, Thailand, Vietnam and Bangladesh. A contributory factor could be the volume of trade between these countries and the EU. In 2018/19, India, Thailand and Vietnam ranked 10th, 14th and 17th, respectively, in terms of ~~for the export~~ value of food products traded with the EU (European Commission, 2020a). However, this appears not to be the sole reason. Compared to other countries in the Asia-Pacific region, EU food imports from China and Indonesia are the largest, with a combined value of about 10 billion euros (European Commission, 2020a), but only contributed 11% of notifications observed during the study period. New Zealand is the 19th highest exporter of food to the EU but contributed the least number of notifications from the region.

A more likely explanation for our observations is the nature of the microbial hazard and implicated foods. The highest number of MH notifications from the Asia-Pacific region was recorded in 2015. Aflatoxin contamination of nuts, nut products and seeds imported from China and *Salmonella* contamination in fruits and vegetables and nuts, nut products and seeds imported from India produced the three highest MH notifications from all regions for 2015 (European Commission 2016). In addition, *Salmonella* contamination of herbs and spices, fruits and vegetables, nuts, nut products, and seeds were responsible for the highest number of notifications overall. These~~ products~~ were predominantly products imported~~s~~ from India, Thailand, Vietnam and Bangladesh. Food safety remains a significant challenge in the Asia-Pacific region and a hurdle to expanding agricultural and food product exports (Pham & Dinh, 2020). Food safety challenges include inadequate sanitation infrastructure, poor food safety knowledge and practices, and insufficient implementation of national food safety management systems (Food and Agricultural Organisation, 2018; Jaffee, Henson, Unnevehr, Grace, & Cassou, 2018; Mangla, et al., 2021; Ortega, 2017).

The highest number of notifications was made by the UK (28%). This is understandable because the standard for food quality, in terms of compliance requirement, is generally high in the UK. With about half of UK's food produced locally (DEFRA, 2020), a recent survey showed that a majority (97.5%) of food manufacturers within the UK had an integrated food safety management system in place (Mensah & Julien, 2011). Only about 5% of UK's food are imported from Asia and Australasia (DEFRA, 2020), yet exporters wishing to supply the UK are expected to have monitoring systems that ensure compliance with retail (product quality) and legislative (due diligence) requirements in the UK (Dolan & Humphrey, 2000). Notifications made by the UK (28%) mainly concerned foods originating from India and Bangladesh. Food safety has been a major challenge in South Asia and Southeast Asia, with huge impacts on public health, economics, and international trade (World Health Organization, 2020a). Southeast Asia has the second highest annual burden of foodborne diseases among the six

World Health Organization (WHO) regions, with 150 million foodborne illnesses and 175,000 deaths in 2010 (World Health Organization, 2015). In contrast to South Asia and Southeast Asia, there were significantly fewer notifications of pathogenic microorganisms in foods imported from Australia and New Zealand (n=23/1873; 1.2%), and this could be due to the strong food control systems in Australia and New Zealand (Ghosh, 2014).

Data received through the RASFF are a vital source of information on emerging health risks associated with specific food products. Import border rejections were the most common notification type in this study, while the most common actions taken were product redispatch, destruction and non-authorisation of imports. Besides constituting a significant revenue loss for exporting countries, and causing reduced consumer confidence, these actions may lead to more stringent responses from the EU to safeguard the health of consumers (Chaoniruthisai, Punnakitikashem, & Rajchamaha, 2018; Somorin, et al., 2021). For example, peppers (*Capsicum* spp. except sweet) from India and Pakistan were subjected to increased official controls in 2018 due to concerns about the levels of pesticide residues (European Commission, 2020b). Data from these official controls and RASFF notifications provided evidence of continuous non-compliance, and these food products were assessed as constituting a serious risk to human health. In 2020, the EU legislated that these products should now include an official certificate confirming that maximum pesticide levels have not been exceeded (European Commission, 2020b).

Increased official controls are the first stage of a continuum that can end in the suspension of imports of a specific product. A good example is the suspension of imports into the EU of foodstuff containing betel leaves from Bangladesh due to the presence of *Salmonella*. This suspension has been in place since 2014 as no action plan for managing this hazard has been provided (European Commission, 2014, 2020b). A national monitoring programme for betel leaves imported into the United Kingdom between 2011 and 2017 showed that *Salmonella* contamination remains a significant hazard in this product (McLauchlin, et al., 2019). Betel is an important cash crop in Bangladesh and the principal source of livelihood in many rural communities (Nath & Inoue, 2009; Ullah, Tani, Tsuchiya, Rahman, & Rahman, 2020). Import~~Export~~ bans can have devastating consequences on income generation and food security. The poor food safety record in South Asia and Southeast Asia is due to several factors including climatic factors, poor sanitary conditions, and food habits. For example, extreme weather conditions and natural disasters, such as flooding, have been frequently occurring in countries Southeast Asia (A. Chen, Giese, & Chen, 2020), and since flood waters are often contaminated with sewage, this leads to increased contamination risk in the food supply chain and exposure to faecal pathogens (Yu, et al., 2018). Consumption of street-foods is common in many Asian countries and it is the only affordable form of nutrition for most people in low-income groups. However, inadequate observation of food hygiene practices significantly increases the exposure of consumers to foodborne pathogens (Reddy, Ricart, & Cadman, 2020).

There was a significant ($p<0.006$) downward trend in the numbers of pathogenic microorganism notifications from foods imported~~exported~~ from Oceania to the EU from 2000-2020, unlike South Asia and East Asia. In more recent years (2015-2020), East Asia was the only sub-region with a significantly increasing trend in RASFF notifications due to contamination by pathogenic microorganisms. When considered by food categories, RASFF notifications regarding “nut, nut products and seeds” significantly increased over the years from 2000 - 2020. However, notifications of pathogenic microorganisms in “fruits and vegetables” significantly reduced in recent years (2015 – 2020). To address the food safety concerns in the affected regions, it is important that appropriate and effective methods to minimise contamination of foods by pathogenic microorganisms are implemented across the value chains in the originating countries. For instance, a framework has been recently established in the WHO Southeast Asia region (including India, Thailand and Bangladesh) to strengthen food control systems across the value chain and protect consumer health, building on previous regional multi-actor interventions (World Health Organization, 2020b). These actions could have contributed to the downward trend in notifications of pathogenic microorganisms from South Asia and Southeast Asia in recent years (2015-2020) (Table 3). It is however important to take these RASFF database trend results cautiously As argued in published literature (Kowalska & Manning, 2020) iterative changes in food law potentially impacts on the frequency of regulatory sampling associated with border and inland regulatory checks in a way that could affect the generalisability of the trends noted.

Border rejection was the most frequent type of notification received (42.3%) in this study. When food imports~~exports~~ do not meet the standards set by the EU, a variety of actions can be taken, which have huge economic implications for the originating countries. About half of the notifications from the Asia-Pacific region resulted in importation not being authorized, leading to destruction or re-dispatch of the contaminated food product. Frequent non-compliance of some food products with EU food safety requirements has led to increased official control at border control posts and the imposition of suspension of entry into the EU (European Commission, 2020b). Increased identity and physical checks at EU border control points is in place for betel leaves and sesame seeds from India, and sweet peppers from China due to *Salmonella* contamination (European Commission, 2020b). Similar official controls exist for black pepper from Brazil as well as sesame seeds from Ethiopia, Nigeria, Sudan and Uganda due to *Salmonella* contamination (European Commission, 2020a, 2020b; Somorin, et al., 2021). Continuous non-compliance has led to the suspension of importation of betel leaves from Bangladesh to the EU since 2014 due to *Salmonella* contamination (European Commission, 2015). A similar ban is in place for dried beans from Nigeria due to pesticide residues (European Commission, 2020a, 2020b).

The most frequently reported genera of pathogenic microorganisms in foods from the Asia-Pacific region were *Salmonella* (73.6%), *Vibrio* (14.6%), *Bacillus* (4.3%) and *Escherichia* (2.2%). *Salmonella* spp. are the most reported pathogens associated with foods imported into the EU from the Asia-Pacific region. This corroborates the report by Somorin et al., (2021) on products imported into the EU from Africa. The predominance of *Salmonella*, an enteric bacterium, could be attributed to unhygienic practices during food production processes and this is corroborated by a previous study that reported a significant association between the presence of *Salmonella* spp. and *E. coli* in imported edible leaves retailed in the England (McLauchlin, et al., 2018). Foods reported in *Salmonella* notifications were mainly “fruits and vegetables”; “herbs and spices” and “nuts, nut products and seeds”. India accounted for over 35% of the *Salmonella* notifications in this study and were mostly from “nuts, nut products and seeds”, “fruits and vegetables” and seafoods. In our study, about 178 serovars of *Salmonella enterica* were reported in foods from Asia-Pacific from 2000-2020 with serovars Weltevrede, Enteritidis and Hvittingfoss beng the most frequently reported. These serovars are significant causes of diarrhoea, and sometimes, invasive infections in tropical low-income Asian countries (Bangtrakulnonth, et al., 2004; Kantama & Jayanetra, 1996; Makendi, et al., 2016) as well as in Europe (ECDC/EFSA, 2021; Emberland, et al., 2007).

Over 95% of notifications regarding “fruit/vegetables” were from India and Bangladesh. Several *Salmonella* serovars have been shown to contaminate ready-to-eat betel leaves in Asia and those imported into the UK. Fakruddin *et al*. (2017) reported that 77% of betel leaves collected in local markets in Bangladesh were contaminated with *Salmonella* spp., with some of them imported from India. *Salmonella* from betel leaves also harbour multidrug resistance genes (Singh, et al., 2006), which could be disseminated to other countries through international trade**.** The majority of the notifications regarding *Salmonella* in betel leaves were from the UK, affecting products originating from India and Bangladesh. With South Asians being the largest ethnic minority group in the UK, and accounting for about 5% of the UK population (Office of National Statistics, 2011), there is a ready demand for betel leaves and other indigenous foods. Analysis of betel leaf consignments at Border Inspection Posts in England between 2011 and 2017 showed that 57% had *Salmonella* contamination

(McLauchlin, et al., 2019). In a separate study by McLauchlin *et al.* (2018), 14% of betel leaves collected from retailers in England had unsatisfactory levels of *Salmonella* including *Salmonella* Bareilly, *Salmonella* Hvittingfoss, *Salmonella* Lichfield, and *Salmonella* Newport. The frequency and high contamination rates of *Salmonella* in betel leaves pose a public health concern for importing countries. While the UK is no longer part of the EU, it is expected to remain an important market for produce from South Asia and Southeast Asia and retain stringent food safety regulations.

Salmonella is a principal aetiological agent of foodborne disease and is the third leading cause of death due to diarrhoeal disease globally (Ferrari, et al., 2019; World Health Organization, 2019, 2020c). *Salmonella* is the most common cause of foodborne outbreaks in the EU and in 2018, was implicated in almost 30% of outbreaks in the region (EFSA/ECDC, 2019). Fresh produce, including fruits, vegetables, herbs, and spices imported ~~exported~~ from the Asia-Pacific region, were the food products most associated with *Salmonella*. Fruit and vegetables are increasingly recognised as vehicles for transmitting pathogenic organisms and have been implicated in global foodborne outbreaks (Bisht, et al., 2021; Carstens, Salazar, & Darkoh, 2019; Wadamori, Gooneratne, & Hussain, 2017).

Contamination of fresh produce can occur at different stages of the supply chain. *Salmonella* is widespread in the environment and is commonly found in materials susceptible to faecal contamination (Machado-Moreira, Richards, Brennan, Abram, & Burgess, 2019). Contaminated soil and irrigation water are important sources of preharvest contamination. Unhygienic practices during harvest, processing and transport are the main contributors to post-harvest contamination (Dos Santos, et al., 2020; Park, et al., 2012). Fresh produce is usually consumed with minimal processing, making it challenging to eradicate pathogenic microorganisms via conventional methods like cooking. Several studies have noted unacceptable levels of *Salmonella* contamination in fresh produce available for retail sale in the Asia-Pacific region (Abatcha, Effarizah, & Rusul, 2018; Nguyen, et al., 2021; Vital, Dimasuay, Widmer, & Rivera, 2014). These reports are of concern and highlight the need for improved food safety management practices along the fresh produce supply chain. To our knowledge, no outbreaks linked to *Salmonella* in fresh produce from the Asia-Pacific region have been reported in the EU. However, it is not always possible to identify the potential source and vehicle of infection during an outbreak (EFSA/ECDPC, 2018).

The most frequently reported *Vibrio* spp. in the notifications were *V. cholerae* (46.6%) *and V. parahaemolyticus* (46%) while *V. vulnificus, V. alginolyticus, V. fluvialis* and *V. mimicus* were less frequently isolated. The main food category contaminated by *Vibrio* was “crustaceans and related products” particularly shrimps and prawns. Precious studies have reported that most of the foods with *Vibrio* contamination originated from India, Malaysia and Vietnam. For instance. *V. parahaemolyticus* was reported in 76% of shrimps imported~~exported~~ from Thailand (Wong, Chen, Liu, & Liu, 1999) and 43.4% of shrimps in China (Xu, Cheng, Wu, Zhang, & Xie, 2016). A *V. parahaemolyticus* pandemic serotype O3:K6 originating from India have been detected in many Asian countries (Bag, et al., 1999) as well as in Europe (Martinez-Urtaza, et al., 2005). predominantly linked to crustaceans such as shrimps and prawns and related products. *Vibrio* spp. are important causes of diarrhoea and cholera associated with the consumption of raw or undercooked seafood and are frequently detected in seafood products from countries in the Asia-Pacific region (X. Chen, et al., 2018; Fu, et al., 2020; Kumar & Lalitha, 2013; Lee, et al., 2019; Nakaguchi, 2013). Seafood imported from Asia was associated with an outbreak in France in 1997 (Lemoine, Germanetto, & Giraud, 1999). Similarly, Briet et al. (2018) reported the presence of a carbapenemase-producing strain of *V. parahaemolyticus* isolated from shrimps imported into France from Vietnam. This study provides evidence that imported foods may be potential vehicles for the transmission of clinically relevant microorganisms.

The predominant *Bacillus* spp. reported in the notifications was *Bacillus cereus* and it was reported in cheese, soy cheese, tofu, garlic powder, ground pepper, pumpkin seeds, mushroom, sesame seeds, desiccated coconut, cinnamon powder, curry powder, ginger powder and ground cumin across East-, South- and Southeast Asia. Production and processing of these food products involves drying and/or grinding, where they could come in contact with soil harbouring *Bacillus* spores (Vilain, Luo, Hildreth, & Brözel, 2006). *B. cereus* has been previously reported in soybean products/tofu (Ananchaipattana, et al., 2012; Keisam, Tuikhar, Ahmed, & Jeyaram, 2019), spice and herbs (Banerjee & Sarkar, 2003) and cheese (Kumari & Sarkar, 2014).

Furthermore, foodborne viruses, such as Hepatitis A and Norovirus, were reported in green mussels and berries (strawberry and raspberry) mainly originating from Vietnam and China. Norovirus has been reported in whole fruits and vegetable leaves in France (EFSA/ECDC, 2021) and the UK (Cook, Williams, & D'Agostino, 2019) and the majority of foodborne viral outbreaks are associated with frozen fruits (Nasheri, Vester, & Petronella, 2019). A large outbreak in Germany in 2012 was associated with strawberries imported from China (Bernard, et al., 2014). Norovirus was associated with 22.5% of all outbreak-related illnesses in the EU in 2019, with contaminated shellfish and fish products playing a significant role (EFSA/ECDC, 2021). Although there were few notifications regarding *Campylobacter* and *Yersinia*, and no report of *Listeria monocytogenes* in foods from the Asia-Pacific region, foodborne diseases caused by these pathogens are among the most common in Europe (EFSA/ECDC, 2021), hence requiring continuous surveillance of imported foods from other parts of the world. The lack of consistency in the actions taken by different EU member states in response to notifications arising from the presence of norovirus and Hepatitis A is of interest. This suggests a lack in uniformity across Member States with respect to pathogens detected in food items. To safeguard public health, it may be necessary for stakeholders to collate a guidance action document with respect to specific actions that should be taken if a particular pathogen is detected in imported food products. This will ensure consistency across notifying countries. One limitation with the current study is the lack of comparison between the numbers of pathogen notifications and the total number of foods or food product category from each country that is tested for pathogens. This is partly because this data is not recorded in the RASSF database. It is hoped that these considerations will be included in future improvements in the RASSF database.

5. Conclusion

The analysis of RASFF notifications for foods from the Asia-Pacific region from 2000 – 2020 showed that foods from India, Thailand, Vietnam and Bangladesh had the most notifications due to pathogenic microorganisms. *Salmonella* was the most predominant foodborne pathogen reported in foods imported~~exported~~ from Asia-Pacific to the EU, with India accounting for over 35% of *Salmonella* notifications (fresh produce) and *Vibrio* spp. contamination of seafood products such as shrimps and prawns from India, Malaysia, and Vietnam. There were very few notifications regarding *Campylobacter* spp. and *Yersinia* spp., and no notification of *L. monocytogenes* was reported. Increasingly, food producers are connected to consumers via food supply chains that cross international borders. These value chains offer a stable supply of food that meet consumers varied needs and preferences and provide a source of income to producers (OECD, 2020). An improved understanding of the food safety challenges along these international supply chains, and capacity building to support implementation of good manufacturing practices and food management systems, is required to safeguard consumer health and sustain the economic development of food-producing nations. Similarly, improved hygienic practices should be implemented across the value chains of imported food products from the region to ensure continuous access to international markets and sustained income.

CRediT authorship contribution statement

Ayokunle C. Dada: Conceptualization, Methodology, Formal analysis, Writing - original draft, Review and Editing, Writing - review & editing. **Yinka M. Somorin**: Writing - original draft, Review and Editing, Writing - review & editing. **Collins N. Ateba**: Writing - original draft, Review and Editing, Writing - review & editing. **Helen Onyeaka**: Review and Editing, Writing - review & editing **Amarachukwu Anyogu**: Review and Editing, Writing - review & editing**.** **Nor Azman Kasan:** Writing - original draft, Review and Editing, Writing - review & editing. **Olumide A. Odeyemi:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Review and Editing, Writing - review & editing.

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Supplementary Table 1

RASFF notifications of pathogenic microorganisms in food originating from the Asia-Pacific Region (n=1873) from 2020 - 2020 based on notifying country.

	Notifying country											
Pathogen genus	**United Kingdom**	**Italy**	**Norway**	**Netherlands**	**Germany**	**Finland**	**Greece**	**Spain**	**Denmark**	**Sweden**	**Others**	**Total (%)**
Salmonella	515	95	102	172	137	122	80	47	30	44	216	1560(73.55%)
Vibrio	4	87	124	4	10	7	2	8	24	12	27	309(14.57%
Bacillus	36	19	1	3	13	9	0	0	0	0	11	92(4.34%)
Escherichia	27	2	8	1	1	1	0	0	2	1	4	47(2.22%)
Norovirus	0	4	1	1	3	1	0	20	3	1	8	42(1.98%)
Not specified	2	11	0	1	1	0	0	0	1	5	7	28(1.32%)
Clostridium	2	18	0	0	1	0	0	0	0	0	1	22(1.04%)
Campylobacter	0	0	0	0	0	0	0	0	4	1	1	6(0.28%)
Staphylococcus	0	0	2	0	0	0	0	0	1	0	0	3(0.14%)
Enterococcus	0	1	0	0	0	0	0	0	1	0	0	2(0.09%)
Hepatitis	0	1	0	0	0	0	0	0	0	0	1	2(0.09%)
Pseudomonas	0	0	0	0	2	0	0	0	0	0	0	2(0.09%)
Cronobacter	0	0	0	1	0	0	0	0	0	0	0	1(0.05%)
Fungi	0	0	0	0	0	0	0	0	0	0	1	1(0.05%)
Plesiomonas	1	0	0	0	0	0	0	0	0	0	0	1(0.05%)
Shigella	0	0	0	0	0	0	0	0	1	0	0	1(0.05%)
Yersinia	0	1	0	0	0	0	0	0	0	0	0	1(0.05%)
Streptococci	0	0	0	0	0	1	0	0	0	0	0	1(0.05%)
Total	**587**	**239**	**238**	**183**	**168**	**141**	**82**	**75**	**67**	**64**	**277**	**2121**

Other_N: Other notifying countries: Cyprus, Austria, Slovenia, Ireland, Lithuania, Iceland, Romania, Switzerland, Bulgaria, Croatia, Estonia, Hungary, Latvia, Luxembourg, Slovakia, Sri Lanka. **Other_O: Other originating countries:** Australia, Cambodia, New Zealand, Pakistan, Philippines, Hong Kong, Taiwan, Singapore, South Korea, Afghanistan, Nepal. The total number of pathogens (n=2121) exceeds the total number of notifications (n=1873) because of the co-occurrence of pathogens.

Supplementary Table 2

Pathogens associated with notifications and their diversities in Crustaceans and related products from Asia and Pacific (2000 - 2020).

Country of origin	Notifications (n)	Pathogens	No of pathogens	Crustaceans and related products
Bangladesh	38	Salmonella Bareilly, Salmonella Brunei, Salmonella enterica, Salmonella spp, Vibrio cholerae, Vibrio parahaemolyticus	43	Shrimps
		Salmonella spp, Vibrio cholerae, Vibrio parahaemolyticus	5	Prawns
China	12	Salmonella enterica ser. Newport, Vibrio mimicus, Vibrio parahaemolyticus, Vibrio cholerae	9	Crayfish
		Salmonella spp	2	Crab
		Vibrio parahaemolyticus	1	Shrimps
India	49	aerobic mesophiles, Enterococcus spp, Pseudomonas spp, Salmonella enterica, Salmonella spp, Salmonella Weltevreden, Vibrio alginolyticus, Vibrio cholerae, Vibrio fluvialis, Vibrio parahaemolyticus, Vibrio vulnificus	60	Shrimps
		Salmonella enterica, Salmonella spp, Vibrio cholerae, Vibrio parahaemolyticus	7	Prawns
		Vibrio cholerae	1	Crab
Indonesia	26	Salmonella enterica subsp. houtenae (VI), Salmonella Lexington, Salmonella spp, Salmonella Wandsworth, Vibrio alginolyticus, Vibrio cholerae, Vibrio parahaemolyticus, Vibrio spp, Vibrio vulnificus,	21	Shrimps
		Plesiomonas shigelloides, Salmonella spp, Vibrio parahaemolyticus, Vibrio cholerae	12	Prawns
Malaysia	65	Salmonella enterica, Salmonella Give, Salmonella spp, Vibrio cholerae, Vibrio parahaemolyticus, Vibrio vulnificus,	48	Shrimps
		Salmonella enterica, Salmonella spp, Vibrio cholerae, Vibrio parahaemolyticus	17	Prawns
		Vibrio parahaemolyticus	1	shellfish
Sri Lanka, Pakistan	4	Salmonella Weltevreden, Vibrio cholerae	4	Crab
		Vibrio cholerae, aerobic mesophiles, Salmonella spp	3	Shrimps
Thailand	23	Salmonella enterica, Vibrio cholerae, Vibrio parahaemolyticus, Vibrio vulnificus	21	Shrimps
		Clostridium perfringens, Clostridium sulphite reducer	3	Shrimp paste
		Vibrio cholerae	1	Crab
		Vibrio parahaemolyticus	1	Prawns

Country of origin	Notifications (n)	Pathogens	No of pathogens	Crustaceans and related products
Vietnam	48	*Escherichia coli, Salmonella enterica, Salmonella enterica ser.* Weltevreden, *Salmonella* Kentucky , *Salmonella* Newport, *Salmonella* Oranienburg, *Salmonella* spp, *Salmonella* Virchow , *Salmonella* Welshimeri, *Salmonella* Weltevreden, *Vibrio cholerae, Vibrio parahaemolyticus, Vibrio* spp, *Vibrio vulnificus*	55	Shrimps
		Salmonella enterica, Salmonella spp, *Vibrio cholerae, Vibrio parahaemolyticus*	6	Prawns
		Clostridium sulphite reducer	1	Shrimp paste
		Salmonella enterica ser. Hvittingfoss	1	Crab
		Vibrio parahaemolyticus	1	Clams
		Salmonella enterica	1	Crustaceans

Supplementary Table 3

Pathogens associated with notifications and their diversities in Fruits and Vegetables from Asia and Pacific (2000 - 2020).

Country of origin	**No of notifications**	**Pathogen**	**Count of Pathogen species**	**Food**
Afghanistan	1	*Salmonella enterica* ~~ser.~~ ser. Agona	1	mulberry
Australia	1	*Salmonella enterica* ~~ser.~~ ser. Chester	1	mushroom
Bangladesh	151	*Salmonella enterica, Salmonella* Jerusalem, *Salmonella spp, Salmonella* T~~t~~yphimurium, *Salmonella* Virchow	149	betel leaves
		Salmonella enterica	3	paan leaves
Cambodia	6	*Salmonella spp*	2	Basil
		Salmonella enterica, Salmonella enterica ~~ser.~~ ser. Stanley	2	betel leaves
		Salmonella Hvittingfoss, *Salmonella* Brunei, *Salmonella enteritidis, Salmonella* T~~t~~yphimurium, *Salmonella* Weltevreden	5	vine leaves
Chile	1	*Salmonella spp*	1	mushroom
China	39	*Salmonella* ~~e~~Enteritidis	1	beans sprouts
		Escherichia coli, Salmonella spp	2	Cep powde
		Salmonella Thompson	1	Chanterelle powder
		Bacillus cereus	1	Cheese
		Salmonella Rissen	1	chlorella
		Salmonella spp	1	goji berries
		Bacillus cereus, Clostridium perfringens, Clostridium sporulated sulphite reducer, Clostridium spp, Salmonella spp, aerobic mesophiles, moulds, Salmonella enterica	18	mushroom
		Norovirus, ~~*Norovirus*~~ Norovirus GII	5	raspberries
		~~*Norovirus*~~ Norovirus ~~*GI*~~ GI & GII	2	seaweed salad
		Bacillus cereus	1	soy cheese
		Salmonella Tennessee	1	soy protein
		Hepatitis A, Norovirus, Norovirus ~~*GI*~~ GI & *GII*	5	strawberrie
		Bacillus cereus	2	tofu
Hong Kong	2	*Salmonella Senftenberg*	1	mushrooms
		Bacillus cereus	1	tofu
India	192	*Salmonella enterica, Salmonella spp*	184	betel leaves
		Salmonella enterica	2	curry leaves
		Salmonella spp	1	fennel seed
		Salmonella spp	1	moringa leaves
		Salmonella agona, Salmonella Westminster	2	onions
		Salmonella infantis	1	sorrel leaves

Country of origin	No of notifications	Pathogen	Count of Pathogen species	Food
Laos	1	*Escherichia coli, Salmonella Brunei, Salmonella Weltevreden*	3	vine leaves
Malaysia	15	*Salmonella enterica* ser. *Aberdeen*	1	beans
		Escherichia coli, Salmonella Colindale, Salmonella group D , Salmonella spp, Salmonella Weltevreden, Vibrio cholerae	14	betel leaves
Pakistan	1	*Salmonella Weltevreden, Vibrio cholerae*	2	Alfalfa
Sri Lanka	7	*Escherichia coli, Salmonella enterica, Salmonella enterica* ser. *Weltevreden, Salmonella spp*	5	betel leaves
		Salmonella Weltevreden, Vibrio cholerae	2	centella
		Salmonella poona, Salmonella Weltevreden, Vibrio cholerae	3	Spinach
Taiwan	1	*Bacillus cereus*	1	tofu
Thailand	81	*Salmonella anatum, Escherichia coli, Salmonella Stanley*	3	magosa
		Salmonella spp, Salmonella Virchow	2	Acacia
		Campylobacter spp, Salmonella Bareilly	2	Asparagus
		Salmonella spp, Salmonella Weltevreden, Vibrio cholerae	3	Banana leaves
		Escherichia coli, Salmonella enterica, Salmonella Jerusalem Salmonella spp	16	betel leaves
		Bacillus cereus, Salmonella Weltevreden, Vibrio cholerae	3	black fungus
		Salmonella Thompson, Salmonella spp	1	broccoli
		Salmonella spp	3	Cabbage, Cha leaves
		Campylobacter spp, Salmonella enterica, Salmonella spp, Salmonella typhimurium, Salmonella Weltevreden, Salmonella Zanzibar, Shigella sonnei, Vibrio cholerae	8	Corn
		Salmonella spp	2	fresh lime and banana, Ipomea aquatica
		Salmonella Stanley	1	kaffir lime leaves
		Salmonella Hvittingfoss, *Salmonella* Infantis, *Salmonella* Zanzibar	3	lemon grass
		Salmonella Hadar, *Salmonella* Lexington	2	lime leaves
		Salmonella enterica, Salmonella enterica ser. Hvittingfoss , *Salmonella enterica* ser. Newport , *Salmonella spp, Salmonella* Stanley	6	morning glory
		Salmonella Hvittingfoss, *Salmonella spp*	2	mushroom
		Salmonella enterica ser. Hvittingfoss	1	neem leaves

Country of origin	No of notifications	Pathogen	Count of Pathogen species	Food
		Salmonella Weltevreden, *Vibrio cholerae*	2	okra
		Salmonella spp	1	ong choi
		Salmonella ~~b~~Braenderup	1	Other vegetables
		Salmonella enterica	1	paan leaves
		Salmonella ~~a~~Altona, *Salmonella* Stanley	2	pak peaw
		Salmonella Brunei	1	pak wan
		Salmonella enterica ~~ser.~~ ser. Chester, *Salmonella enterica* ~~ser.~~ ser. Rubislaw, *Salmonella enterica subsp.* Salamae	3	pandang leaf
		Salmonella Ndolo, *Salmonella* Aberdeen, *Salmonella* ~~b~~Bovismorbificans, *Salmonella enterica, Salmonella group B, Salmonella group D, Salmonella* Hvittingfoss, *Salmonella* Mbandaka, *Salmonella* Newport	12	Spinach
		Campylobacter spp, Salmonella enterica, Salmonella Hvittingfoss, *Salmonella spp*	5	spring onions
		Salmonella ~~a~~Anatum	1	tamarind leaves
		Salmonella ~~a~~Augustenborg	1	watercress
		Salmonella Saint Paul, *Salmonella* Stanley	2	wildbetal leafbush
Vietnam	38	*Bacillus cereus, Salmonella* ~~a~~Augustenborg, *Salmonella enterica* ~~ser.~~ ser. Stanley, *Salmonella spp, Salmonella* Weltevreden, *Vibrio cholerae*	8	black fungus
		Salmonella Brunei	1	celery
		Salmonella ~~e~~*Enterica*	1	coriander
		Salmonella group B	1	morels
		Salmonella spp	1	morning glory
		Bacillus cereus, Salmonella Thompson, *Clostridium perfringens, Salmonella enterica, Salmonella enterica* ~~ser.~~ ser. Derby, *Salmonella enterica* ~~ser.~~ ser. Panama, *Salmonella enterica* ~~ser.~~ ser. Stanley, *Salmonella enterica* ~~ser.~~ ser. Virchow, *Salmonella group B, Salmonella* Java, *Salmonella* Meleagridis, *Salmonella* Rissen, *Salmonella* spp, *Salmonella* Weltevreden, *Vibrio cholerae*	29	mushroom
		Salmonella Stanley	1	okra
		Campylobacter spp	1	peppers
		Salmonella spp	1	pineapple
		Salmonella spp	1	Spinach

Country of origin	No of notifications	Pathogen	Count of Pathogen species	Food
		Salmonella Lexington, *Salmonella* Weltevreden	2	coriander, houttuynia and celery

Supplementary Table 4

Pathogens associated with notifications and their diversities in nuts and related products from Asia and Pacific (2000 - 2020).

Country of origin	Notifications (n)	Pathogens	No of pathogens	Nuts and related products
China	7	*Salmonella* Newport, *Salmonella* Stanley	2	peanuts
		Salmonella spp	1	pine nuts
		Bacillus cereus	1	pumpkin seeds
		Bacillus cereus	1	soy cheese
		Salmonella Senftenberg, *Salmonella spp,* *Salmonella* Tennessee	3	sunflower seeds
India	253	*Salmonella spp*	1	amaranth
		Salmonella enterica ser. Matadi	1	cashew
		Salmonella ~~e~~Elomrane, *Salmonella enterica ser.* Bareilly	2	nigella seed
		Escherichia coli, Salmonella spp	2	Coconut
		Bacillus cereus, Escherichia coli, Salmonella ~~m~~Mbandaka, *Salmonella* Montevideo, *Salmonella spp, Salmonella* ~~a~~Agona, *Salmonella* Amsterdam, *Salmonella* ~~a~~Anatum, *Salmonella* Bareilly, *Salmonella* ~~b~~Binza, *Salmonella* B~~b~~raenderup, *Salmonella* Chittagong, *Salmonella* ~~d~~Dallgow, *Salmonella* ~~d~~Drypool, *Salmonella enterica, Salmonella enterica ser.* Agona, , *Salmonella enterica ser.* Amsterdam, *Salmonella enterica ser.* Bareilly, *Salmonella enterica ser.* Braenderup, *Salmonella enterica ser.* Derby, *Salmonella enterica ser.* Hvittingfoss, *Salmonella enterica ser.* Isangi, *Salmonella enterica ser.* Kentucky, *Salmonella enterica ser.* Kisil, *Salmonella enterica ser.* Livingstone, *Salmonella enterica ser.* Londo, *Salmonella enterica ser.* Montevideo, *Salmonella enterica ser.* Orion, *Salmonella enterica ser.* Ouakam, *Salmonella enterica ser.* Pensacola, *Salmonella enterica ser.* Schwarzengrund, , *Salmonella enterica ser.* Senftenberg, , *Salmonella enterica ser.* Typhimurium, *Salmonella enterica ser.* Umbadah, *Salmonella* E~~e~~nteritidis, *Salmonella* ~~g~~Gaminara, *Salmonella group C1* , *Salmonella* Hvittingfoss,	262	Sesame seeds

Country of origin	Notifications (n)	Pathogens	No of pathogens	Nuts and related products
		Salmonella Java, *Salmonella* Kastrup, *Salmonella* Kentucky, *Salmonella* Kristianstad, *Salmonella* Livingstone, *Salmonella* London, *Salmonella* Matopeni, *Salmonella* Molade *Salmonella* Newport, *Salmonella* Ngili, *Salmonella* Orion, *Salmonella* Richmond, *Salmonella* Ruiru, *Salmonella* Senftenberg, *Salmonella spp*, *Salmonella* Tennessee, *Salmonella* Tilburg, *Salmonella* Urbana		
Indonesia	6	*Bacillus cereus, Enterococcus spp, Salmonella* Brunei, *Salmonella enterica, Salmonella enterica ser.* Senftenberg, *Salmonella* spp, *Salmonella* Westhampton, *Salmonella* Bareilly	12	Coconut, desiccated coconut
Malaysia	2	*Salmonella* spp	3	Coconut, desiccated coconut
Pakistan	3	*Salmonella enterica, Salmonella* Hadar	2	pine nuts
		Bacillus cereus	2	Sesame seeds
Philippines	2	*Salmonella* Mbandaka , *Salmonella* Albany, *Salmonella* T~~t~~yphimurium, *Salmonella* Westhampton, *Salmonella* spp	5	Coconut
Singapore	1	*Salmonella enterica ser.* Weltevreden	2	Coconut
Sri Lanka	4	*Salmonella enterica*	2	coconut flour
		Salmonella ~~e~~Enteritidis	1	desiccated coconut
		Salmonella spp	1	poppy seeds
Thailand	1	*Salmonella* Lexington	1	Sesame seeds
Vietnam	1	*Salmonella enterica*	1	Coconut

Supplementary Table 5

Yearly RASFF notifications of pathogenic microorganisms in nuts, nut products and seeds originating from Asia-Pacific Region (n=1873).

	Nuts, nut products and seeds					**Sesame seeds**		
Year	**India**	**Indonesia**	**Thailand**	**Others**	**Total**	**India**	**Thailand**	**Total**
2000	0	0	0	1	1	0	0	0
2001	3	0	1	2	6	3	1	4
2002	0	0	0	2	2	0	0	0
2003	1	0	0	2	3	1	0	1
2004	6	1	0	0	7	6	0	6
2005	10	1	0	1	12	10	0	10
2006	1	1	0	0	2	1	0	1
2007	4	0	0	1	5	4	0	4
2008	11	0	0	2	13	11	0	11
2009	13	0	0	2	15	13	0	13
2010	8	0	0	1	9	8	0	8
2011	6	0	0	0	6	6	0	6
2012	8	2	0	2	12	8	0	8
2013	5	0	0	2	7	5	0	5
2014	24	2	0	1	27	24	0	24
2015	68	1	0	1	70	67	0	67
2016	19	0	0	0	19	19	0	19
2017	20	1	0	0	21	18	0	18
2018	24	0	0	3	27	23	0	23
2019	17	0	0	0	17	17	0	17
2020	18	0	0	0	18	16	0	16
Total	266	9	1	23	299	260	1	261

Others: Malaysia, Pakistan, Phillipines, Singapore, Sri Lanka, China, Vietnam

Supplementary Table 6

Pathogens associated with notifications and their diversities in herbs and spices from Asia and Pacific (2000 - 2020).

Country of origin	**Notifications (n)**	**Pathogens**	**No of pathogens**	**Herbs and spices**
Bangladesh	2	*Bacillus cereus*	2	other spice
Cambodia	3	*Salmonella* spp.	1	basil
		Salmonella enterica, Salmonella Stanley	2	mint
China	35	*Bacillus cereus*	2	garlic powder
		Salmonella Aberdeen, *Salmonella* spp.	3	Ginger powder
		Bacillus cereus, Salmonella Aequatoria, *Salmonella enterica, Salmonella enterica ser.* Enteritidis, *Salmonella* spp., *Salmonella* Thompson	12	ground pepper
		Salmonella group B, *Salmonella* spp.	2	other spice
		Salmonella spp.	16	paprika
		Escherichia coli, Salmonella spp., sulphite reducing anaerobes	3	parsley
		Salmonella spp.	1	red ground pepper
		Salmonella spp.	1	turmeric powder
India	56	*Salmonella enterica*	1	seasoning mix
		Salmonella ~~p~~Poona, *Salmonella* spp.	4	coriander
		Salmonella ~~d~~Derby	1	cumin powder
		Salmonella spp.	1	cumin seed
		Salmonella ~~e~~Enteritidis, *Salmonella* spp.	2	curry leaves
		Bacillus cereus, Salmonella ~~a~~Agona, *Salmonella* ~~b~~Braenderup, *Salmonella enterica, Salmonella* spp.	6	Curry powd
		Escherichia coli, Salmonella spp.	2	fenugreek leaves

Country of origin	Notifications (n)	Pathogens	No of pathogens	Herbs and spices
		Bacillus cereus, Clostridium perfringens, Salmonella Ohio	4	ginger powder
		Salmonella Weltevreden, *Vibrio cholerae*	2	ginseng powder
		Bacillus cereus, Salmonella group C, *Salmonella* spp	3	ground cum
		Salmonella Agona, *Salmonella* Bareilly, *Salmonella* Cubana	3	ground cum and ground coriander
		Salmonella spp	1	ground nutmeg
		Bacillus cereus, Bacillus pumilus, Bacillus subtilis, Clostridium perfringens, Salmonella Bareilly, *Salmonella enterica Salmonella* Give, *Salmonella* Newport, *Salmonella* Richmond, *Salmonella spp*	16	ground pepper
		Salmonella Richmond	1	Indian ginseng powder
		Salmonella spp	1	moringa leaves
		Salmonella enterica	3	onion powd
		Salmonella spp		
		Salmonella ~~b~~Butantan	1	other herbs
		Bacillus cereus, Clostridium perfringens, Salmonella Amsterdam, *Salmonella* spp	4	other spice
		Salmonella enterica	1	sesame seeds
		Salmonella Senftenberg, *Salmonella* Amsterdam	2	turmeric powder
		Salmonella enterica	1	ground peppers
		Salmonella enterica, Salmonella enterica ser. Agona, *Salmonella* Senftenberg, *Salmonella* Livingstone, *Salmonella* spp, *Salmonella* Virchow	7	turmeric powder

Country of origin	Notifications (n)	Pathogens	No of pathogens	Herbs and spices
Indonesia	4	*Bacillus cereus*	1	cinnamon powder
		Salmonella Aberdeen, *Salmonella* Albany, *Salmonella* Mbandaka	3	ground pepper
Laos	23	*Escherichia coli, Salmonella* Lexington, *Salmonella* spp	4	basil
		Salmonella spp	1	chives
		Salmonella spp	1	coriander
		Escherichia coli, Salmonella Brunei, *Salmonella* spp, *Salmonella* Weltevreden	8	mint
		Salmonella spp	1	parsley
		Escherichia coli, Salmonella Brunei, *Salmonella* Heidelberg, *Salmonella spp, Salmonella* Thompson, Salmonella *typhimurium*	12	perilla
		Escherichia coli, Salmonella A~~a~~gona, *Salmonella* Bareilly, Salmonella Hvittingfoss, *Salmonella* Javiana	8	piper lolot
		Escherichia coli, Salmonella Hvittingfoss, *Salmonella* Meleagridis, *Salmonella* Rissen, *Salmonella* spp	6	praew leav
		Salmonella enterica	1	ground min
Malaysia	3	*Salmonella* Bareilly, *Salmonella* Weltevreden, *Vibrio cholerae*	3	Curry powd
		Salmonella spp	1	parsley and betel leaves
Nepal	1	*Salmonella enterica ser.* Java	1	betel leave
Pakistan	3	*Salmonella* ~~e~~Edinburgh	1	ground pepper
		Bacillus cereus, Salmonella Hvittingfoss	2	other spice
Singapore	1	*Salmonella enterica*	1	ground pepper
Sri Lanka	8	*Bacillus cereus*	1	cinnamon powder
		Salmonella ~~w~~Waycross , *Salmonella* Weltevreden, *Vibrio cholerae*	3	curry leave
		Moulds, Salmonella A~~a~~gona, *Salmonella* Java, *Salmonella* P~~p~~aratyphi B	4	ground pepper
		Escherichia coli, Salmonella spp	2	moringa leaves
		Salmonella spp	1	other herbs

Country of origin	Notifications (n)	Pathogens	No of pathogens	Herbs and spices
Thailand	158	*Salmonella* spp	1	betel leave
		Salmonella spp *Salmonella* Stanley	2	pennywort
		Salmonella spp	1	phak-phae
		Salmonella Hvittingfoss, *Escherichia coli, Salmonella enterica, Salmonella* Hadar, *Salmonella* spp, *Salmonella* Stanley, *Salmonella* Virchow, *Salmonella* Weltevreden, *Vibrio cholerae*	10	acacia
		Salmonella spp	1	amaranth greens
		Salmonella spp	1	Asiatic pennywort
		Salmonella Thompson, *Escherichia coli, Salmonella* spp, *Salmonella* A~~a~~gona, *Salmonella Amsterdam, Salmonella arizonae, Salmonella augustenborg, Salmonella* Bareilly, *Salmonella* Brunei, *Salmonella Dublin, Salmonella enterica, Salmonella* Goverdhan, *Salmonella* Java, *Salmonella enterica subsp.* Salamae, *Salmonella* group D, *Salmonella* Hvittingfoss, *Salmonella* Javiana, *Salmonella* Lexington, *Salmonella* Rubislaw, *Salmonella* Saint Paul, *Salmonella* spp, *Salmonella* Stanley, *Salmonella* Thompson, *Salmonella* Weltevreden	65	basil
		Salmonella Weltevreden, *Vibrio cholerae*	2	betel leave
		Salmonella spp	1	Cha leaves
		Salmonella ~~a~~Augustenborg	1	chives
		Salmonella A~~a~~natum, *Salmonella* A~~a~~ugustenborg, *Salmonella* Brunei, *Salmonella* Corvallis, *Salmonella enterica, Salmonella ~~enterica ser.~~* Hvittingfoss, *Salmonella ~~enterica ser.~~* Lexington, *Salmonella* Hvittingfoss, *Salmonella* Jerusalem, *Salmonella* Newport, *Salmonella* Rissen, *Salmonella* Rubislaw, *Salmonella* Singapore, *Salmonella* spp, *Salmonella* Virchow, *Salmonella* Weltevreden, *Vibrio cholerae*	24	coriander
		Salmonella A~~a~~ugustenborg	1	doksadao
		Salmonella Mbandaka	1	edible flowe
		Salmonella Weltevreden	1	galingale

Country of origin	Notifications (n)	Pathogens	No of pathogens	Herbs and spices
		Salmonella Hvittingfoss, *Salmonella* spp.	2	ground pepper
		Salmonella spp.	1	guichai leaves
		Salmonella spp.	2	horopa leaves
		Escherichia coli, Salmonella ~~b~~Braenderup	2	horseradish
		Salmonella spp.	1	kayang leaves
		Salmonella spp.	1	lalo leaves
		Salmonella group C, *Salmonella* spp., *Salmonella* Wandsworth	3	lemon gras
		Salmonella Lexington	1	lime leaves
		Salmonella spp.	1	magaso sadao
		Salmonella spp.	1	malabar nightshade
		Salmonella enterica	1	mimosa
		Escherichia coli, Salmonella Javiana, *Salmonella spp, Salmonella* Stanley, *Salmonella* Zanzibar, *Salmonella* Weltevreden, *Salmonella* ~~c~~Chester, *Salmonella enterica, Salmonella* Heidelberg, *Salmonella* Hvittingfoss, *Salmonella* Javiana, *Salmonella* P~~p~~oona, *Salmonella spp, Salmonella* Stanley, *Salmonella* Thompson, *Salmonella* Zanzibar	25	mint
		Salmonella Give, *Salmonella* K~~k~~edougou, *Salmonella* T~~t~~yphimurium	3	mint and basil
		Salmonella enterica *Salmonella* Rissen *Salmonella* Virchow	3	mint leaves
		Salmonella Bleadon, *Salmonella* Hvittingfoss, *Salmonella* Kentucky, *Salmonella* Mount Pleasant, *Salmonella* R~~r~~amat-gan, *Salmonella* Rissen, *Salmonella* spp.	8	morning glo
		Salmonella Hvittingfoss, *Salmonella* Javiana, *Salmonella* Stanley, *Salmonella* Weltevreden, *Salmonella* Zanzibar	5	other herbs
		Salmonella spp.	1	pakdum
		Salmonella enterica *Salmonella* spp.	2	pandang leaves
		Salmonella augustenborg, *Salmonella* Newport , *Salmonella* spp.	3	parsley
		Salmonella Virchow	1	perilla
		Salmonella spp.	3	praew leav

Country of origin	Notifications (n)	Pathogens	No of pathogens	Herbs and spices
		Salmonella enterica	1	rice paddy herb
		Salmonella Saint Paul, *Salmonella* spp, *Salmonella* Stanley	3	Spinach
		Salmonella Hvittingfoss	1	wildbetal le
		Salmonella ~~a~~Augustenborg, *Salmonella* P~~p~~aratyphi B (variant Java monophasic variant 4,5,12)	2	Basil and ri paddy herb
		Salmonella ~~a~~Augustenborg *Salmonella* Lexington	2	basiland lim leaves
Vietnam	49	*Salmonella* spp	2	pennywort
		Escherichia coli, Salmonella Javiana, *Salmonella* spp, *Salmonella* Virchow	8	basil
		Salmonella enterica	1	celery
		Salmonella enterica ser. Virchow	1	chilli
		Salmonella spp	1	coriander
		Salmonella spp	1	eryngo
		Salmonella spp	2	green herbs
		Salmonella enterica, Salmonella Lexington, *Salmonella* Orion, *Salmonella* spp, *Salmonella* Weltevreden, *Vibrio cholerae*	13	ground pepper
		Salmonella Stanley	1	hing choi
		Salmonella spp	1	houttunyia leaves
		Salmonella spp	1	houttuynia leaves
		Salmonella spp	2	kinh gioi leaves
		Salmonella spp	4	la lot leaves
		Salmonella enterica, Salmonella spp	3	mint
		Salmonella spp	1	mong toi leaves
		Salmonella spp	1	morning glo
		Salmonella Abony, *Salmonella* Dublin, *Salmonella* Orientalis, *Salmonella* Virchow, *Salmonella* Weltevreden, *Salmonella* spp	7	other herbs
		Salmonella spp	3	parsley
		Salmonella spp	1	perilla
		Salmonella spp	1	Piper sarmentosum

Country of origin	Notifications (n)	Pathogens	No of pathogens	Herbs and spices
		Salmonella spp.	1	rau ram leaves
		Salmonella Javiana	1	rice paddy herb

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Declaration of competing interest

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