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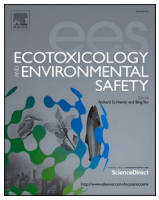

Comparative study between the top six heavy metals involved in the EU RASFF notifications over the last 23 years

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ABSTRACT

From the Rapid Alert System for Food and Feed (RASFF) database, a total of 4728 notifications regarding the six most frequently notified heavy metals (i.e., arsenic, cadmium, lead, mercury, chromium, and nickel) were tracked from January 1, 2000, to December 31, 2022, and analyzed based on year, notification classification, notifying countries, countries of origin, product types, product categories, risk decision, and action taken. Human risk assessment owing to consumption of mercury- and cadmium-contaminated seafood was estimated as well. Results revealed that the highest numbers of notifications were on mercury (36.6%), cadmium (25.1%), and lead (14.1%). Interestingly, the number of total notifications was at its peak between 2011 and 2014; from 2015 onward, it started to decrease considerably. Alert, border rejection, and information notifications represented 29.6%, 21.9%, and 48.5% of the total notifications, respectively. Chromium and nickel resulted in 33.8% and 23.3% of border rejection notifications, respectively. About 52.0% of the alert notifications were on mercury. Serious notifications represented 34.9% of the total notifications. Mercury and cadmium notifications accounted for 54.9% and 25.8% of serious notifications, respectively. Italy was the most notifying country, recording the highest number of notifications on cadmium (29.0%), mercury (52.6%), chromium (81.0%), and nickel (78.7%). China was the most notified origin country with regards to arsenic (18.7%), cadmium (12.8%), lead (27.6%), chromium (71.2%), and nickel (66.9%) notifications. Notifications on food, food contact materials (FCM), and feed represented 71.9%, 23.4%, and 4.7%, respectively, of the total notifications. About 91.5% of mercury notifications were on fish and fish products; 24.3% of arsenic notifications related to fruits and vegetables; and 20.1% of cadmium notifications corresponded to cephalopods and products thereof. Notified products were largely withdrawn from the markets according to arsenic (20.3%), lead (17.9%), and mercury (18.0%) notifications and re-dispatched because of cadmium (20.5%), chromium (42.1%), and nickel (49.5%) notifications. The target hazard quotient (THQ) values for mercury in swordfish, sharks, and tuna and cadmium in squid were all also below the threshold value of 1, implying that there is no significant risk for consumers. Overall, media coverage of RASFF alerts and actions may raise awareness of heavy metal contamination among the general public and industry professionals. The primary dietary advice of our study is to stay away from species with high mercury contents. Also, identifying the most dangerous heavy metals (HMs) and the most polluting products can help researchers prioritize their efforts in finding sustainable solutions for them.

1. Introduction

Heavy metals (HMs) are metallic elements that have a high atomic weight and density, typically greater than 5 g per cubic centimeter, and can be toxic even in small quantities. Examples of HMs include mercury (Hg), lead (Pb), cadmium (Cd), arsenic (As), chromium (Cr), and nickel (Ni). These metals are toxic to living organisms at certain levels and can cause serious health problems if they accumulate in the body (Raychaudhuri et al., 2021).

HMs are often released into the environment through human

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activities such as mining, manufacturing, and the use of certain products such as batteries, pesticides, and fertilizers. The exploitation of metal ores, the burning of fossil fuels, and the storage of trash are a few instances of their anthropogenic sources. On the other hand, natural geochemical processes can increase the amount of metal pollution in the environment. Examples include molten magma and rock erosion (Bradl, 2005). HMs can contaminate air, water, and soil and can be taken up by plants and animals, leading to bioaccumulation in the food chain (Sherameti and Varma, 2011). When compared to other organic contaminants, hazardous HMs are unbreakable since they cannot be degraded chemically or biologically. Even worse, since humans are at the top of the food chain, some HMs can concentrate and eventually assemble in the human body (Mengistu, 2021).

HM contamination can have serious consequences for both human and animal health (Jaishankar et al., 2014). HMs like lead, mercury, and cadmium can cause neurological and behavioral problems in both humans and animals. These include impaired learning and memory, reduced IQ, and behavioral disorders (El-Nahrawy et al., 2019; Trasande et al., 2005). HMs can also cause developmental problems in children and animals. For example, lead exposure during pregnancy can lead to low birth weight and developmental delays in children. HMs like cadmium can cause kidney damage in both humans and animals. This can lead to chronic kidney disease and even kidney failure (El-Nahrawy et al., 2019). Some HMs, like arsenic, can cause liver damage and increase the risk of liver cancer. HMs can also cause reproductive problems in both men and women. For example, lead exposure can cause infertility in men. Some HMs, like arsenic and cadmium, are known carcinogens, meaning they can cause cancer in both humans and animals (Mazumder, 2014). Overall, HM contamination can have a wide range of negative impacts on both human and animal health. It is important to monitor and limit exposure to HMs through measures such as reducing the use of products containing these metals, properly disposing of hazardous waste, and ensuring that water sources are free from contamination (El-Nahrawy et al., 2019).

The European Union (EU) has a comprehensive food safety system that is designed to protect the health and well-being of its citizens. The system is based on scientific risk assessment and includes regulations, standards, and monitoring programs that apply to all stages of the food production process, from farm to table. The European Food Safety Authority (EFSA) is the EU's main scientific agency responsible for providing independent scientific advice and communication on food safety. It evaluates the safety of food additives, pesticides, contaminants, and genetically modified organisms (GMOs), among other things (Tóth et al., 2016).

The European Commission has implemented regulations to control heavy metal contamination in food, feed, and FCM. Some of these regulations include: (1) Regulation (EC) No 1881/2006 (EC, 2006)– "This regulation sets maximum levels for certain contaminants in foodstuffs, including HMs such as lead, cadmium, and mercury", (2) Regulation (EC) No 629/2008 (EC, 2008)– "This regulation establishes maximum levels for certain contaminants in animal feed, including HMs", (3) Regulation (EC) No 450/2009 – "This regulation establishes maximum levels for certain contaminants in food supplements, including HMs", (4) Regulation (EC) No 1935/2004 (EC, 2004)– "This regulation establishes requirements for materials and articles intended to come into contact with food, including limits on heavy metal migration from such materials", and (5) Regulation (EU) No 10/2011 – "This regulation establishes a list of authorized substances for use in plastic FCM, including limits on HM migration from such materials" (Papapanagiotou, 2021; Pigłowski, 2018). In addition to these regulations, the European Commission also monitors and enforces compliance with the limits set for heavy metal contamination in food, feed, and DCM. This includes conducting inspections and tests on products to ensure that they meet the requirements set forth by these regulations. Accordingly, it was necessary to work on finding a way to know the degree of danger from HMs and try to avoid them.

The Rapid Alert System for Food and Feed (RASFF) is a notification system established by the European Union (EU) to facilitate the rapid exchange of information on food and feed safety issues between EU member states, the European Commission, and the European Free Trade Association Surveillance Authority (ESA), in addition to Switzerland, Iceland, Norway, and Liechtenstein. The system was created in 1979 and has since undergone several updates to improve its effectiveness in protecting public health; however, its legal basis is described by Regulation No. 178/2002. RASFF is designed to ensure that if a food or feed safety issue is detected in one EU country, it can be quickly shared with other countries to prevent or limit the spread of the problem. The RASFF system is based on a network of national contact points, which are responsible for receiving and transmitting information on food and feed safety issues within their respective countries (De Leo et al., 2021). When a food or feed safety issue is identified, the relevant national contact point sends an alert to the RASFF central database. Once the alert is received, the RASFF system disseminates the information to all RASFF members. If necessary, the system also alerts non-EU countries that may be affected by the issue. RASFF covers a wide range of food and feed safety issues and is consider as an important tool for protecting public health and ensuring the safety of the EU food supply (Kuchheuser and Birringer, 2022).

The purpose of this study was to analyze the most frequently notified HMS in the RASFF notifications (i.e., arsenic, cadmium, lead, mercury, chromium, and nickel) in food, FCM, and feed between 2000 and 2022, considering the following: year, notification classification, notifying countries, countries of origin, product types, product categories, risk decision, and action taken. Moreover, the Target Hazard Quotient (THQ) was calculated to estimate the human health risk assessment from consumption of mercury- and cadmium-contaminated seafood.

2. Materials and methods

2.1. Data collection

From the risk field, in the RASFF Window database, and under the hazard category entitled HMs, all notifications were tracked from January 1, 2000, to December 31, 2022. The following criteria were evaluated: notification reference, notification date, notification classification (i.e., alert when a product posing a serious risk is on the market, and prompt action is or may be needed in a country other than the notifying country, border rejection when a consignment of the product whose entry into the EU was denied due to a risk to human health, or information when a product for which a risk has been recognized that does not necessitate immediate action, either because the risk is not considered serious or because the product is not on the market at the same time of notification), notifying countries, countries of origin, product category, product, product type (food, feed or FCM), hazard (refers to the potential risk for that the product has already been recorded in the RASFF database), subject (reason for notifying), risk decision (not serious, serious, or undecided), and action taken. All data were exported as Excel files, and descriptive statistical analysis was applied. The data was sorted, filtered, and processed in pivot tables using Microsoft Excel spreadsheets and IBM SPSS Statistics 20 (SPSS, Chicago, Illinois, USA) software. Each criterion was analyzed on a case-by-case basis. A total of 4728 notifications corresponding to arsenic, cadmium, lead, mercury, chromium, and nickel were further analyzed. The concentrations of the investigated six HMs in 1651 serious notifications were calculated as average, minimum, and maximum values.

2.2. Human health risk assessment

The potential non-carcinogenic health risks associated with the consumption of contaminated seafood involved in serious notifications on Hg and Cd were assessed based on the target hazard quotient (THQ), which was estimated using the following equation (USEPA, 1989):

$$THQ = (EF \times ED \times SIR \times C) / (RfD \times BW \times AT)$$

where EF is the exposure frequency (365 days/year), ED is the exposure duration (70 years; equivalent to the average human lifetime), and SIR is the seafood ingestion rate (2.43, 0.0334, 4.67, and 3.5 g/person/day for swordfish, sharks, tuna, and squid, respectively, according to the (EFSA, 2011; Vélez et al., 2021), C is the concentration of Hg and Cd in seafood (mg/kg), RfD is the oral reference dose (USEPA, 2019), BW is the body weight (60 kg/person), and AT is the average time for non-carcinogens (365 days/year × ED). If the THQ value is ≥ 1, exposed individuals may experience health risks from consuming contaminated seafood. Therefore, corrective and preventive procedures should be taken (Eissa et al., 2021).

3. Results

3.1. Total RASFF notifications on six HMs between 2000 and 2022

The number of total RASFF notifications per year on six HMs (i.e., arsenic, cadmium, chromium, lead, mercury, and nickel) between 2000 and 2022 varied largely (Fig. 1). The period between 2000 and 2002 displayed the lowest number of notifications, ranging from 26 to 51, while the highest number of notifications occurred from 2003 to 2014, recording the highest number (317) in 2011. Later, the total number of notifications gradually decreased below 200, recording the lowest number (132) in 2020. Among the six selected HMs, mercury had the highest number of total notifications (1731) between 2000 and 2022, followed by cadmium (1185) and lead (665), while arsenic displayed the lowest number (235). The highest numbers of total notifications on mercury during the last two decades were reported between 2013 and 2017; however, the total notifications considerably declined after 2017, displaying the lowest number (49) in 2022.

Between 2005 and 2012, the number of total notifications on cadmium was the highest during the surveyed period (e.g., 80 notifications in 2006). Yet, between 2018 and 2021, the total notifications were below 50. Similarly, between 2010 and 2013, the highest numbers of total notifications on lead were noticed, while between 2014 and 2020, the total notifications did not exceed 30. Chromium revealed similar results to lead, where the total notifications were above 52 between 2010 and 2014. Nevertheless, between 2018 and 2022, the total number of notifications was below ten. Regarding arsenic and nickel, the critical period was between 2005 and 2014, recording the highest number of total notifications. Then a sharp decrease in the number of notifications was noticed, where the total notifications did not exceed 12, except for nickel in 2019.

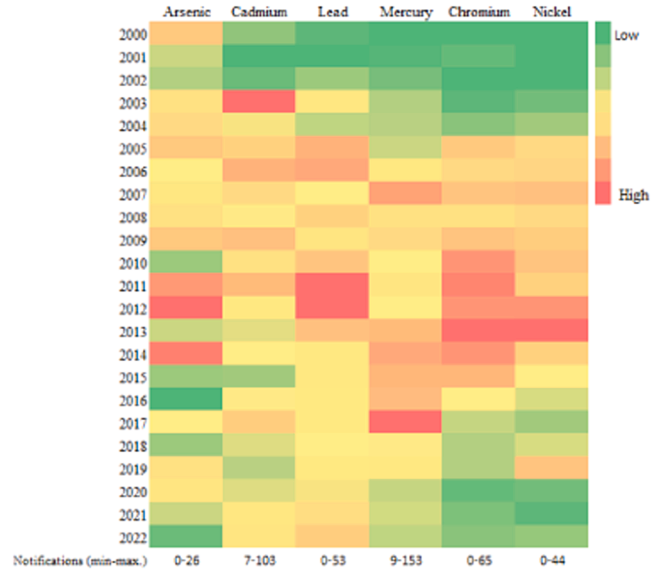

Fig. 1. Evolution of RASFF notifications number per year on the top 6 trace elements over the last 23 years.

3.2. Notification classification

The RASFF generates three types of notifications, i.e., alert, border rejection, and information, according to their risk to human and animal health. Out of 4728 total RASFF notifications on the six HMs between 2000 and 2022, alert notifications were 1401. Out of the alert notifications, 52.0% corresponded to mercury, followed by 21.8% for cadmium and 18.9% for lead. The sum of border rejection notifications was 1034, of which 33.8%, 23.3%, 19.1%, and 14.4% corresponded to chromium, nickel, mercury, and cadmium, respectively. Information notifications were the highest (2293 notifications), of which 36.0%, 31.8%, and 13.6% corresponded to mercury, cadmium, and lead, respectively (Fig. 2A). Alert notifications on each heavy metal largely varied within the surveyed period. Mercury resulted in the highest number of alert notifications, followed by cadmium and lead. From 2000–2004, the alert notifications on mercury were below 10 per year, except in 2003, when 12 alert notifications were reported. From 2014–2018, alert notifications were above 54 per year; nevertheless, alert notifications dropped considerably from 2018 onward, recording 17 notifications in 2022 (Fig. 2B). Alert notifications on cadmium were in harmony with those reported for mercury from 2000 to 2004. Alert notifications on cadmium were below three, and then considerably increased from 2005 onward. Interestingly, the last two years (2021 and 2022) displayed higher alert notifications, i.e., 21 and 23, respectively. Lead showed almost the same tendency of alert notifications as cadmium. In contrast, alert notifications on chromium, nickel, and arsenic have increased from 2019 onward.

The border rejection notifications on all six HMs were first reported in 2008 (Fig. 2C). Although it ranked fourth among the six HMs in the total notifications, chromium revealed the highest number of border rejection notifications. The total border rejection notifications were as follows: chromium (350) > nickel (241) > mercury (177) > cadmium (149) > lead (89) > arsenic (28). The period between 2008 and 2022, where border rejection notifications were reported, can be divided into two main periods: i) from 2008 to 2017, where higher numbers (ranged between 53 and 140) were notified, and ii) from 2018 to 2022 where lower numbers of border rejection notifications were reported (varied from 14 to 29), except for the year 2019 which recorded 40 notifications. The period between 2008 and 2016 was critical for chromium, recording the highest number of border rejection notifications (14−60) per year. However, this number markedly diminished after 2016, recording zero notifications in 2022 and 1–8 notifications between 2017 and 2021. Nickel also showed high numbers of border rejection notifications between 2008 and 2016, ranging from 11 to 42; yet, lower notifications (0−8) were reported between 2017 and 2022, except for the year 2019, which reported 21 notifications. Border rejection notifications on mercury ranged from 12 to 20 between 2008 and 2017 and from 5 to 9 between 2018 and 2022. Cadmium and lead revealed an almost similar tendency of border rejection notifications, while notifications on arsenic varied from 1 to 8 between 2008 and 2012, and no notifications were reported in the last five years.

The numbers of total information notifications were in the following order: cadmium > mercury > lead > chromium > nickel > arsenic. In the period between 2003 and 2010, the number of total information notifications was above 100 notifications, while this number dropped to 5 in 2011. No information notifications on any HMs were reported after 2011 (Fig. 2D).

3.3. Top 10 notifying countries

Out of the six surveyed HMs, Italy reported the highest total

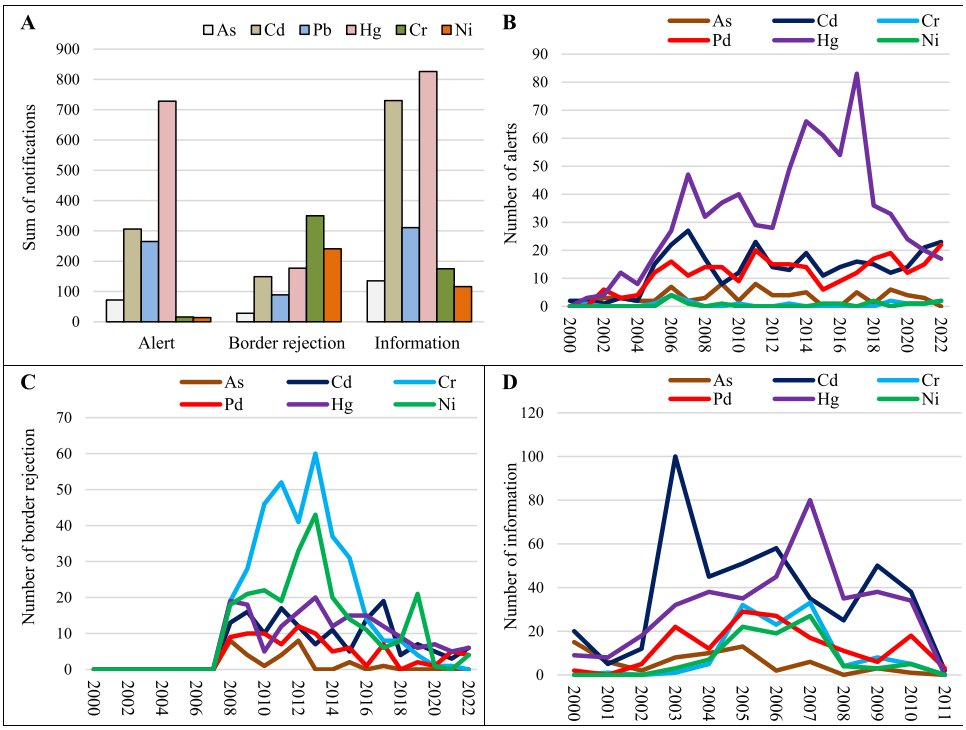

Fig. 2. RASFF notifications on the top 6 heavy metals between 2000 and 2022 according to notification classification. The category "information notifications (sum)" includes information notifications, information notifications for attention and information notifications for follow-up).

notifications on four HMs, i.e., cadmium (29.0%), mercury (52.6%), chromium (81.0%), and nickel (78.7%) (Table 1). Regarding arsenic, Spain shared about 24.5% of the total notifications, followed by Belgium (14.9%), the United Kingdom (12.8%), and Italy (11.1%). Germany shared the highest total notifications on lead (14.7%), followed by Poland (14.6%) and Italy (13.4%). The top 10 notifying countries represented 88.1%, 83.9%, 79.9%, 93.4%, 98.3%, and 100% of the total notifications on arsenic, cadmium, lead, mercury, chromium, and nickel, respectively.

3.4. Top 10 countries of origin

Most of the notified products originated from China (Table 2). China shared the highest notifications on arsenic (18.7%), cadmium (12.8%), lead (27.6%), chromium (71.7%), and nickel (66.9%). About 32.2% of the total notifications on mercury were made by Spain, followed by Vietnam (6.5%). Japan showed the second highest notifications on arsenic (6.8%), while India was the second highest country of origin that made notifications on cadmium (8.8%). The top 10 countries of origin represented 59.6%, 55.4%, 58.9%, 58.9%, 91.7%, and 96.2% of the total notifications on arsenic, cadmium, lead, mercury, chromium, and nickel, respectively.

3.5. RASFF notifications based on product types

Out of the total RASFF notifications (4728), 3401 notifications were on food, 1106 notifications were on FCM, and 221 notifications were on feed (Fig. 3A). About half (49.7%) of the notifications on food were because of mercury contamination. Notifications on cadmium-contaminated food represented 28.5%, whereas 11.0% were because of lead contamination. Arsenic, chromium, and nickel resulted in total notifications on the food of 4.8%, 3.4%, and 2.6%, respectively. Arsenic and lead contamination represented the highest percentage (29.0%) of notifications on feed within the surveyed period, followed by cadmium (23.1%), mercury (17.6%), and chromium (1.4%). Nickel did not result in any notifications on the feed. The percentages of total notifications on FCM were in the following order: chromium (38.2%) > nickel (25.7%) > lead (20.6%) > cadmium (14.8%) > arsenic (0.6%) > mercury (0.1%). Concerning food contamination with HMs, mercury, cadmium, arsenic, and lead were the most serious, while chromium and nickel were the most serious concerning food contact materials. Arsenic was the most serious heavy metal in the contamination of feed.

The lowest number of notifications on food was recorded between 2000 and 2003, while the highest number was noticed between 2005 and 2007. Between 2008 and 2017, the number of notifications on food

Table 1
Top 10 notifying countries involved in RASFF notifications on the top 6 heavy metals between 2000 and 2022.

As	%	Cd	%	Pb	%	Hg	%	Cr	%	Ni	%
Spain	24.7	Italy	29.0	Germany	14.7	Italy	52.6	Italy	81.0	Italy	78.7
Belgium	14.9	Spain	13.0	Poland	14.6	France	10.8	Finland	6.1	Slovenia	6.5
United Kingdom	12.8	Germany	8.6	Italy	13.4	Spain	10.1	Slovenia	5.2	Finland	6.5
Italy	11.1	France	6.2	Czech Republic	7.1	Germany	6.9	Lithuania	2.2	Germany	4.0
Germany	8.5	Poland	6.1	Finland	6.9	Netherlands	4.7	Belgium	0.7	Lithuania	1.4
Netherlands	5.1	Belgium	4.9	Belgium	5.7	Belgium	2.8	Croatia	0.7	Cyprus	1.1
Denmark	4.3	Netherlands	4.6	United Kingdom	5.6	Portugal	1.5	Germany	0.7	Belgium	1.1
France	2.6	Greece	4.6	Netherlands	4.7	Slovenia	1.4	Portugal	0.6	Slovakia	0.3
Austria	2.6	Czech Republic	4.1	Austria	4.1	Greece	1.4	Czech Republic	0.6	Switzerland	0.3
Sweden	1.7	United Kingdom	3.0	Slovenia	3.2	Switzerland	1.3	Greece	0.6	Spain	0.3
Sum	**88.1**		**83.9**		**79.9**		**93.4**		**98.3**		**100.0**

Table 2
Top 10 origin countries involved in RASFF notifications on the top 6 heavy metals between 2000 and 2022.

As	%	Cd	%	Pb	%	Hg	%	Cr	%	Ni	%
China	18.72	China	12.76	China	27.64	Spain	32.16	China	71.72	China	66.85
Japan	6.81	India	8.79	Italy	4.23	Vietnam	6.54	Hong Kong	5.91	Turkey	9.16
United States	6.81	Thailand	6.09	India	4.23	Indonesia	5.44	China, Hong Kong	5.55	Hong Kong	5.66
Thailand	4.68	France	5.75	Turkey	4.08	Portugal, Spain	2.78	United States	2.40	China, Hong Kong	4.85
India	4.68	Singapore	5.24	Germany	3.78	Sri Lanka	2.60	India	1.85	India	4.85
France	4.26	Vietnam	4.06	Poland	3.47	France	2.08	Turkey	1.29	United States	1.62
Turkey	3.83	Spain	3.55	France	3.02	Portugal	2.08	Brazil	1.11	Taiwan	1.35
Netherlands	3.83	Australia	3.13	United States	2.87	Tunisia	1.85	Japan	0.74	Thailand	0.81
South Korea	2.98	Indonesia	3.04	Netherlands	2.87	Chile	1.79	Pakistan	0.55	Germany	0.54
Germany	2.98	Poland	2.96	Ukraine	2.72	Denmark	1.56	Taiwan	0.55	Switzerland	0.54
Sum	**59.57**		**55.37**		**58.91**		**58.88**		**91.68**		**96.23**

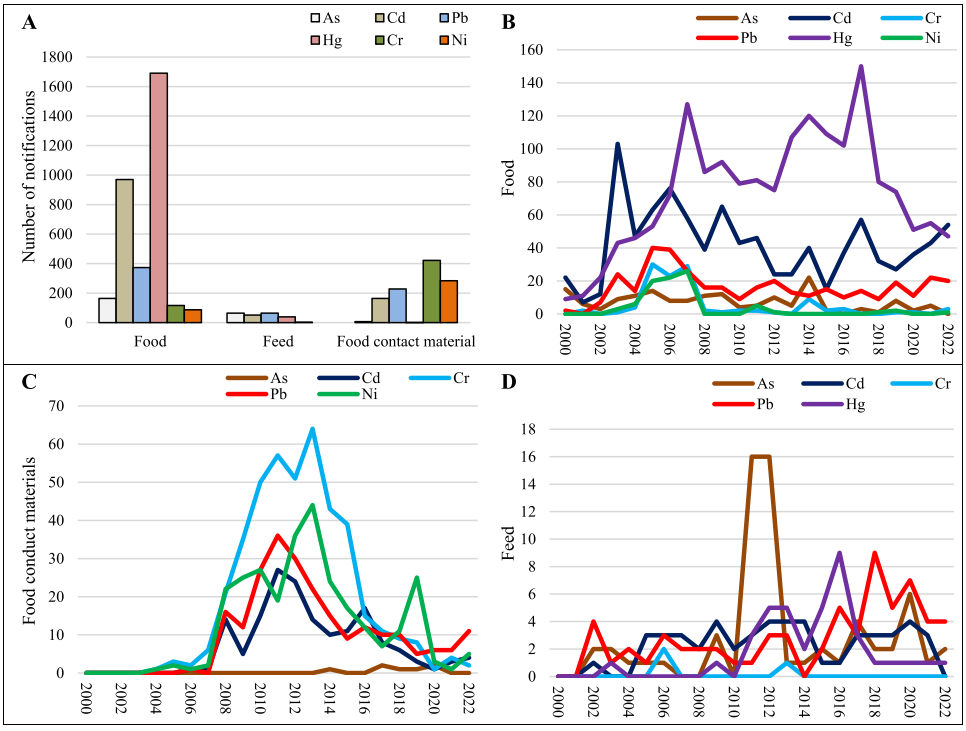

Fig. 3. : RASFF notifications on the top 6 heavy metals from 2000 to 2022 based on product type.

ranged between 131 and 224. The number of notifications on food markedly reduced between 2018 and 2022, where notifications varied from 101 to 131 (Fig. 3B).

Notifications on mercury regarding food varied markedly from 2000 to 2022. Mercury notifications on food between 2000 and 2004 were below 50, while between 2005 and 2012; they ranged between 50 and 100, except for the year 2007, which displayed 127 notifications (Fig. 3B). Between 2013 and 2017, the number of notifications on mercury increased considerably, ranging between 100 and 150. Noticeably, mercury notifications on food decreased below 100 between 2018 and 2022. Likewise, cadmium notifications on food fluctuated considerably within the surveyed period. The period between 2000 and 2002 showed the lowest number of notifications, followed by the most critical period, which displayed the highest number of notifications on cadmium (47–103). Between 2010 and 2021, the number of notifications on cadmium did not exceed 50, except for the year 2017. Notifications on lead, as the third highest reported number of notifications on food, were below 20 per year, except for 2005, 2006, 2007, and 2021. The period from 2000 to 2014 showed high numbers of notifications on food regarding arsenic, ranging from 3 to 22. Yet, the number of arsenic notifications on food between 2015 and 2022 did not exceed 8 per year. The number of chromium notifications on food did not exceed 4 per year within the surveyed period, except for the year 2014, which recorded nine notifications. The most critical period regarding chromium notifications on food was between 2005 and 2007, when notifications ranged between 23 and 30 per year. Likewise, the period between 2005 and 2007 revealed the highest numbers of nickel notifications on food, ranging between 20 and 26, while no more than six annual notifications were reported within the other years between 2000 and 2022. Most years exhibited zero notifications on nickel regarding food.

Notifications on the HMs regarding FCM within the last two decades could be divided into four distinguished periods as follows: i) from 2000 to 2003, where no notifications were reported; ii) from 2004 to 2007, where the total number of notifications did not exceed 9; iii) from 2008 to 2019, where there were high numbers of total notifications, ranging between 36 and 144; and iv) from 2020 to 2022, where the number of total notifications did not exceed 22. Between 2009 and 2015, chromium showed the highest notifications on FCM per year compared to the other examined HMs (Fig. 3C).

Regarding notifications of HMs on feed within the last two decades, arsenic showed the highest number of reported notifications (0–16), followed by mercury (0–9), lead (0–7), cadmium (0–4), and chromium (0–2), while nickel did not result in any notifications. The two years of 2016 and 2017 displayed the highest number of notifications (16) on

arsenic regarding feed (Fig. 3D).

3.6. Top 10 product categories

Heavy metal contamination occurred in a vast spectrum of products; however, the type of the notified products heavily depended on the nature of the HMs (Table 3). According to the collected data, fruits and vegetables showed higher sensitivity to arsenic contamination, representing 24.3% of the total notifications on arsenic. Dietetic foods, food supplements, and fortified foods represented 16.6% of the total notifications on arsenic, while feed materials formed 15.7%. Out of the total notifications on cadmium, 20.1% of the notified products were cephalopods and products thereof, followed by dietetic foods, food supplements, and fortified foods (13.5%). About 41.8% of the total notifications on lead corresponded to FCM, while dietetic foods, food supplements, and fortified foods formed 13.5%. Interestingly, the chief type of notified products due to mercury contamination was fish and fish products, representing 91.5% of the total notifications on mercury. Likewise, 93.7% and 97.3% of the total notifications on chromium and nickel, respectively, were reported on FCM. The top 10 product categories represented 87.7%, 91.5%, 87.5%, 99.1%, and 100% of the total notifications on arsenic, cadmium, lead, mercury, and chromium, respectively. About 100% of the total notifications on nickel corresponded to the top 5 product categories, as shown in Table 3.

3.7. Risk decision

The RASFF classifies the recorded notifications into three categories according to their risk to human and animal health, i.e., serious, not serious, or undecided. The total RASFF notifications (4728) on the six HMs were classified into 360 not-serious notifications, 1651 serious notifications, and 2717 undecided notifications (Fig. 4A). Concerning serious notifications, the highest percentages of notifications were on mercury (54.9%), followed by cadmium (25.8%) and lead (14.9%), while serious notifications on arsenic, nickel, and chromium were below 2.3%. Between 2000 and 2011, no record of not-serious and serious notifications was notified as the not-serious and serious notifications were included in the RASFF Portal database for the first time in 2011 onward (Fig. 4B, C, and D). The highest number of not-serious notifications (109) corresponded to the year 2013, followed by a gradual decrease from 72 (in 2014) to 5 (in 2022). Chromium displayed the highest number of total not-serious notifications (141), followed by nickel (88). Arsenic revealed the lowest number of not-serious notifications (Fig. 4B). The number of total serious notifications increased from 71 in 2012–241 in 2017, then linearly decreased to 102 in 2020; however, a higher number of serious notifications (134) was reported in 2022. On the other hand, the number of serious notifications on mercury was the highest (907), followed by cadmium (426) and lead (246). Concerning arsenic, nickel, and chromium, the serious notifications were below 38. More than 100 serious notifications on mercury were notified between 2013 and 2017; nevertheless, the number sharply decreased from 2018, recording 46 in 2022 (Fig. 4C). Regarding cadmium, the number of serious notifications was above 30 between 2013 and 2022; however, 45 and 53 serious notifications were reported in 2021 and 2022, respectively. Likewise, at least 20 serious notifications or more on lead were reported between 2013 and 2022. The highest numbers of serious notifications on arsenic, nickel, and chromium were 9, 6, and 3, respectively. The number of total undecided notifications on the six HMs increased from 48 in 2000–317 in 2011, then linearly decreased to 15 notifications in 2022 (Fig. 4D). Mercury and cadmium displayed the highest number of undecided notifications (787 and 722, respectively), while arsenic exhibited the lowest number (177).

Table 3
Top 10 product categories involved in RASFF notifications on the top 6 heavy metals between 2000 and 2022.

As	%	Cd	%	Pb	%	Hg	%	Cr	%	Ni	%
fruits and vegetables	24.3	cephalopods and products thereof	20.1	food contact materials	41.8	fish and fish products	91.5	food contact materials	93.7	food contact materials	97.3
dietetic foods, food supplements, fortified foods	16.6	fish and fish products	15.7	dietetic foods, food supplements, fortified foods	13.5	dietetic foods, food supplements, fortified foods	3.1	dietetic foods, food supplements, fortified foods	4.3	dietetic foods, food supplements, fortified foods	1.9
feed materials	15.7	food contact materials	15.3	fruits and vegetables	9.9	feed materials	1.1	pet food	0.4	cereals and bakery products	0.3
food additives and flavourings	10.2	crustaceans and products thereof	13.8	meat and meat products (other than poultry)	5.6	wild caught fish and products thereof (other than crustaceans and molluscs) - (obsolete)	1.0	herbs and spices	0.4	other food product / mixed	0.3
pet food	5.5	fruits and vegetables	8.7	feed additives	5.6	crustaceans and products thereof	0.9	natural mineral water	0.4	cocoa and cocoa preparations, coffee and tea	0.3
natural mineral water	3.4	molluscs and products thereof - (obsolete)	8.0	confectionery	3.0	pet food	0.6	meat and meat products (other than poultry)	0.2		
animal nutrition - (obsolete)	3.0	bivalve molluscs and products thereof	3.5	herbs and spices	3.0	compound feeds	0.3	fruits and vegetables	0.2		
water for human consumption (other)	3.0	meat and meat products (other than poultry)	3.3	cocoa and cocoa preparations, coffee and tea	2.3	poultry meat and poultry meat products	0.2	food additives and flavourings	0.2		
confectionery	3.0	feed materials	1.6	fish and fish products	1.5	fruits and vegetables	0.2	compound feeds	0.2		
cereals and bakery products	3.0	wild caught fish and products thereof (other than crustaceans and molluscs) - (obsolete)	1.5	cereals and bakery products	1.4	meat and meat products (other than poultry)	0.2	cocoa and cocoa preparations, coffee and tea	0.2		
Sum	**87.7**		**91.5**		**87.5**		**99.1**		**100.0**		**100.0**

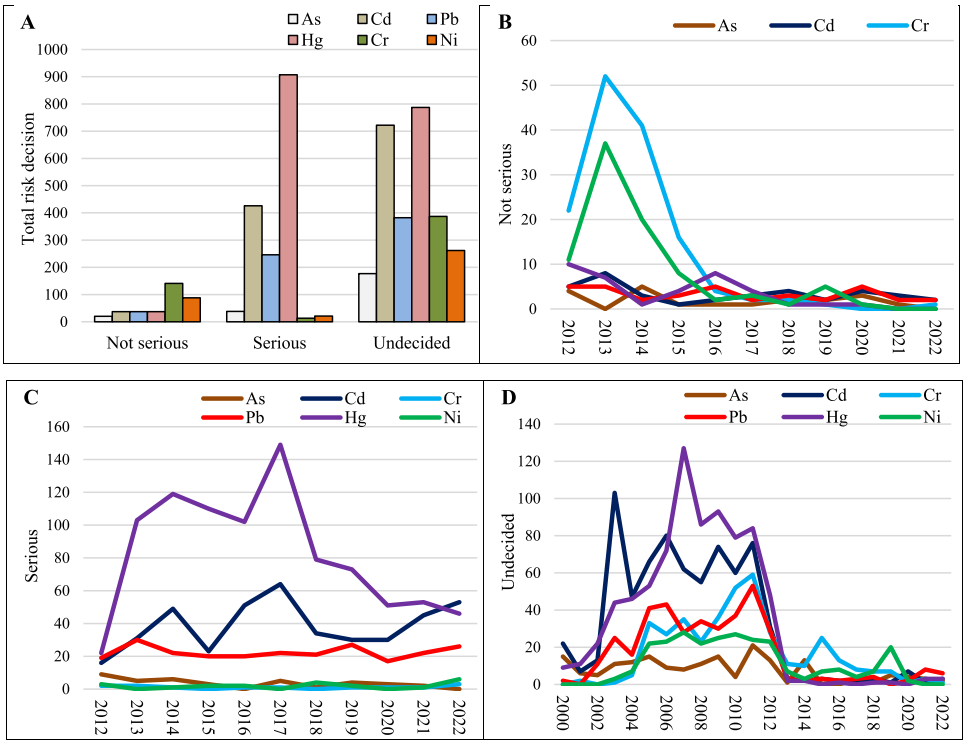

Fig. 4. RASFF notifications on the top 6 heavy metals from 2000 to 2022 based on risk decision.

3.7.1. Serious risk decision

RASFF serious notifications concerning the top six HMs from 2000 to 2022 based on risk decision reveal that food supplements represent 36.84% of the all serious notifications on arsenic, and its mean concentration in food supplements was 13.07 mg/kg. Squid as cephalopod molluscs represents 23.94% of the all serious notifications on cadmium, with a mean concentration of 2.96 mg/kg. Out of 102 serious notifications on cadmium pertaining to squid, 26 and 25 originated from India and Spain, respectively. FCM, food supplements, meat other than poultry, and fruits and vegetables represent 40.65%, 21.14%, 9.35%, and 7.72% of the all serious notifications on lead, respectively, and their mean concentrations of lead in FCM were 33.75, 30.98, 7.88, and 0.63 mg/kg, respectively. Out of 530, 117, and 51 serious notifications on mercury pertaining to swordfish, sharks, and tuna 264, 51, and 25 originated from Spain, respectively. Swordfish, sharks, and tuna represent 58.43%, 12.9%, and 6.17% of all serious notifications on mercury, and their mean concentrations were 1.61, 1.99, and 1.67 mg/kg, respectively. FCM represent 61.54% and 90.48% of the all serious notifications on chromium and nickel, respectively, and they mostly originated from China, where their released mean concentrations were 14.24 and 78.45 mg/kg, respectively.

3.8. Action taken

Actions taken regarding reported products are in harmony with the severity of the notification (Table 4). Due to the total notifications on arsenic in food, feed, and FCM, 20.3% of the notified products were withdrawn from the market, 17.2% were re-dispatched, 11.5% of their importation was not authorized, and 8.8% were destructed, while the other actions were $\leq$ 7%. However, the withdrawal of the notified

Table 4
RASFF notifications percentage of the top 6 heavy metals from 2000 to 2022 based on the top 10 actions taken.

As	%	Cd	%	Pb	%	Hg	%	Cr	%	Ni	%
withdrawal from the market	20.3	re-dispatch	20.5	withdrawal from the market	27.9	withdrawal from the market	18.0	re-dispatch	42.1	re-dispatch	49.5
re-dispatch	17.2	withdrawal from the market	19.8	re-dispatch	13.0	destruction	12.2	(obsolete)	9.2	official detention	9.6
import not authorized	11.5	(obsolete)	8.5	(obsolete)	8.4	Not specified	10.6	official detention	7.7	import not authorized	6.0
destruction	8.8	destruction	8.2	destruction	8.2	re-dispatch	10.4	import not authorized	7.5	placed under customs seals	6.0
(obsolete)	7.0	Not specified	7.8	official detention	7.7	official detention	9.8	withdrawal from the market	6.8	(obsolete)	5.8
Not specified	5.3	import not authorized	6.6	recall from consumers	7.2	seizure	6.6	placed under customs seals	6.2	withdrawal from the market	5.8
informing recipient(s)	4.8	recall from consumers	4.9	Not specified	4.7	(obsolete)	5.3	return to consignor	6.0	return to consignor	3.6
seizure	4.4	official detention	4.8	informing recipient(s)	3.0	informing authorities	4.6	destruction	5.3	destruction	3.6
recall from consumers	4.4	informing authorities	3.3	seizure	2.3	import not authorized	3.8	Not specified	3.4	Not specified	3.0
official detention	4.0	seizure	2.7	withdrawal from recipient(s)	2.3	informing recipient(s)	3.8	recall from consumers	1.7	informing recipient(s)	1.4

products because of arsenic did not exceed three notifications per year, except for the years 2011 (6), 2012 (7), and 2014 (15). Moreover, the notified products because of arsenic were re-dispatched only three times between 2013 and 2020. Despite the action of "import not authorized" representing a high percentage of the total notifications (11.5%), no case of "import not authorized" was reported from 2013 to 2019 based on notifications on arsenic; its high percentage is due to the year 2000, where 14 notifications were reported. Destruction of the notified products based on arsenic contamination was noticeably reported in two different periods (i.e., 2003–2005 and 2010–2014). However, between 2015 and 2022, only three notifications were reported, all in 2017.

According to notifications on cadmium, 20.5% of notified products were re-dispatched, 19.8% were withdrawn from the markets, 8.5% were obsoleted, and 8.2% were destructed, whereas other actions were below 8%. However, between 2003 and 2007, re-dispatch actions were the highest within the last two decades (ranging between 16 and 47 notifications per year); this might be the reason for the high percentage of re-dispatched products. The annual number of re-dispatched products based on cadmium notification was below ten between 2008 and 2020, except for the year 2017. The highest annual number of withdrawn products from the markets (41) due to cadmium notifications corresponded to the year 2011. Between 2008 and 2018, the number of withdrawn products was above 10, while in 2019 and 2020, 5 and 8 notifications were reported, respectively. Within the surveyed period, the years 2003, 2005, 2006, and 2009 exhibited the highest number of obsoleted products, recording 12, 22, 14, and 11 notifications, respectively. The highest number of destructed products due to cadmium notifications was 22 and recorded in 2003, while other years revealed destructed notified products below ten.

About 27.9% of the notified products on lead were withdrawn from the markets, whereas re-dispatched products represented 13.0%. The period between 2010 and 2013 showed the highest number of withdrawn products from the markets due to lead notifications, ranging between 14 and 35. Within the last three years (i.e., 2018–2020), the number of withdrawn products was < 10. The highest numbers of re-dispatched products corresponded to the period between 2003 and 2007; yet, from 2008 until 2020, the number of re-dispatched products did not exceed 7 cases per year, and the last four years (2016–2020) recorded only a total of three re-dispatched notifications.

About 18.0% of the notified products were withdrawn from the markets because of notifications on mercury, while 12.2% were destructed, 10.6% were not specified, and 10.4% were re-dispatched. The number of withdrawn products varied from 17 to 34 between 2008 and 2017; however, before 2008 and after 2017, lower numbers of withdrawn products were notified. The highest numbers of destructed products based on mercury notifications were recorded between 2009 and 2020, with some exceptions, whereas lower numbers were reported between 2000 and 2008.

Regarding chromium and nickel notifications, 42.1% of reported products were re-dispatched because of notifications on chromium, while nickel notifications resulted in the re-dispatch of 49.5% of notified products. The highest numbers of re-dispatched products due to chromium corresponded to the period between 2005 and 2015, while the period between 2005 and 2010 showed the highest numbers of re-dispatched products due to nickel notifications.

3.9. Human health risks from consuming contaminated seafood

The results of the THQ values for population consumption of contaminated seafood with mercury and cadmium are shown in Table 5. The THQ values for mercury in swordfish, sharks, and tuna were all below the threshold value of 1. The THQ values for cadmium in squid were all also below the threshold value of 1. This implies that the estimated daily intake is smaller than the RfD, suggesting that there is no significant risk associated with the consumption of the aforementioned seafood contaminated with the detected concentrations of mercury and cadmium. The highest values of THQ were observed for the maximum concentration of cadmium on squid (0.992), followed by the maximum concentration of mercury on both swordfish (0.494) and tuna (0.409). On the other hand, calculated THQ values for mercury in sharks at all concentrations, even the maximum concentrations (0.0075), were much lower than the threshold value of 1.

Table 5
Target hazard quotient (THQ) for the most frequently notified heavy metals in serious notification on seafood.

Trace element	Fish	Concentration (mg/kg)		RfD[a] (mg/kg/day)	THQ
Mercury	**Swordfish**	Mean	1.61	0.0005	0.1302
		Min	1.40	0.0005	0.1134
		Max	6.10	0.0005	0.4941
	Shark	Mean	1.99	0.0005	0.0022
		Min	0.55	0.0005	0.0006
		Max	6.70	0.0005	0.0075
	Tuna	Mean	1.67	0.0005	0.2594
		Min	1.16	0.0005	0.1806
		Max	2.63	0.0005	0.4094
Cadmium	**Squid**	Mean	2.96	0.001	0.1726
		Min	1.15	0.001	0.0671
		Max	17.0	0.001	0.9917

[a] Oral reference dose

4. Discussion

Food and feed safety are related concepts that focus on ensuring the safety and quality of food and animal feed products. Food safety refers to the measures taken to ensure that food is safe for human consumption and free from harmful contaminants, such as bacteria, viruses, and chemicals. The goal of food safety is to prevent foodborne illness and disease outbreaks caused by contaminated food. Consumers need to be aware of food safety issues and take steps to protect themselves by following safe food handling practices and buying food products from reputable sources (Ricke et al., 2018).

The RASFF was established by the European Union (EU) in 1979, making it the first country or region to launch such a system. The RASFF is a network that allows the EU and its member states to quickly exchange information and take action in response to serious risks to public health from food and feed products. Since its establishment, the RASFF has become a vital tool in ensuring the safety of the EU's food and feed supply and has served as a model for similar systems established in other regions of the world (Pigłowski, 2019).

Although several authors have discussed the RASFF notifications on many food and feed pollutants, such as mycotoxins (Pigłowski, 2019), pathogenic microorganisms (Pigłowski, 2020), and pesticides (Pigłowski, 2022), there is little that has dealt with heavy metal contamination. The present study focused on analyzing the RASFF notifications on the six riskiest HMs between 2000 and 2022. In addition to natural sources of HMs in the environment, anthropogenic activities significantly contribute to HM emissions in the environment. These human activities include industrial processes (i.e., mining, manufacturing, pesticides, and fertilizers), waste disposal (i.e., landfills and incineration), transportation, construction and demolition (i.e., paints and coatings), coal combustion, wastewater discharge, urbanization, deforestation, and land use changes. The cumulative impact of these anthropogenic activities can result in elevated HM concentrations in soil, water, and air, posing serious risks to ecosystems, wildlife, and human health (Vareda et al., 2019).

A total of 4728 notifications on six HMs were reported between 2000 and 2022. However, the cluster analysis proved that the period between 2011 and 2014 was the most critical, recording the highest number of notifications on the six HMs. Moreover, from 2015 onward, the recorded notifications markedly decreased; this may illustrate the increased public awareness of the risks of HMs contamination. Several authors

have documented the RASFF notifications on HMs in food and feed (Bouxin, 2014; Cheftel, 2011; Ismail and Nielsen, 2017; Tlustos et al., 2013).

Alert, border rejection, and information notifications represented 29.6%, 21.9%, and 48.5%, respectively, of the total HMs notifications. Indeed, the EC in 2008 started considering all the rejected products at the borders as "border rejection notifications" in the RASFF system (Pigłowski, 2017). A total of 4061 RASFF notifications on pesticide residues in food and feed were documented between 1994 and 2020, which consisted of 15.0% alert notifications, 48.4% border rejection notifications, and 36.6% information notifications (Pigłowski, 2022). The total RASFF notifications on FCM between 2007 and 2019 consisted of 12.0% alert notifications, 44.0% border rejection notifications, and 34.0% information notifications (De Leo et al., 2021).

Chromium displayed border rejection notifications of 33.8% as the highest value. The daily requirement for chromium in the human diet varies depending on age, sex, and other factors, such as pregnancy and lactation. The recommended dietary allowance (RDA) for chromium in adults is between 20 and 35 μg per day (Kapoor et al., 2022). Chromium is found in small amounts in many foods, including whole grains, meats, fruits, and vegetables. Some studies have suggested that higher intakes of chromium may have potential health benefits, such as improving glucose metabolism and insulin sensitivity and reducing the risk of type 2 diabetes (Wise et al., 2022).

In the present study, about 97.7% of mercury notifications, 81.9% of cadmium notifications, 69.8% of arsenic notifications, and 56.1% of lead notifications were on food, while 78.0% and 76.5% of chromium and nickel notifications were on FCM. The highest numbers of chromium and nickel notifications were recorded in 2013, which could be attributed in part to the implementation of Commission Regulation (EU) No 284/2011, which established specific conditions for Chinese kitchenware (De Leo et al., 2021). Due to their outstanding thermal conductivity and thermostability, nickel and chromium are among the most commonly used metals and alloys in the production of FCM for cooking (Jellesen et al., 2006). Arsenic, lead, and chromium could be found in the process of manufacture as contaminants or impurities (Koo et al., 2020).

About 91.5% of mercury notifications were on fish and fish products, 24.3% of arsenic notifications related to fruits and vegetables, and 20.1% of cadmium notifications corresponded to cephalopods and products thereof. Notifications of chromium (93.7%), nickel (97.3%), and lead (41.8%) were mainly related to FCM. Fish represented 52% of total RASFF notifications on HMs between 1979 and 2017 (Pigłowski, 2018). Fish or seafood was the most notified product category in the RASFF system due to HMs contamination, such as fish (Wiig and Kolstad, 2005), fish products (Xiong et al., 2016), swordfish and prawns (Rortais et al., 2010), and seafood (Naughton et al., 2015). Mercury, cadmium, and lead were the most commonly reported HMs in fish or seafood (Kleter et al., 2009; Nepusz et al., 2009).

Predatory marine fish species as carnivorous at the top of the food chain in marine ecosystems, such as swordfish, sharks, or yellowfin tuna, have the highest levels of Hg, due to the biomagnification process (Li and Tse, 2015). Moreover, Hg content is positively correlated with the size, age, or weight of those species (Sevillano-Morales et al., 2015; Teffer et al., 2014). Therefore, the primary dietary advice of our study is to stay away from species with high mercury contents.

The total RASFF notifications on seafood products made up 17% of all notifications between 1996 and 2020; however, HMs were among the most frequently reported dangers in seafood within this period (Amagliani et al., 2012). Mercury is a toxic heavy metal that can accumulate in the body and cause harm to human health. According to the U.S. Environmental Protection Agency (EPA), exposure to methylmercury at levels of 1–10 μg/kg body weight per day over a period of several years can result in adverse health effects (Gardner et al., 2010). Mercury toxicity can occur as a result of exposure to methylmercury, a form of mercury that is found in certain types of fish and seafood. Methylmercury can accumulate in the body over time, particularly in the brain and nervous system, and can cause a range of health problems, including neurological damage, developmental delays in children, and cardiovascular disease in adults (Guzzi and La Porta, 2008).

Contamination of fruits, vegetables, and herbs with HMs has been reported by several authors (Banach et al., 2016; Uyttendaele et al., 2014; Van Boxstael et al., 2013) as recorded in the RASFF. The most reported HMs in herbs and spices were lead, cadmium, arsenic, and mercury, according to the RASFF notifications (van Asselt et al., 2018). The US Centers for Disease Control and Prevention (CDC) has established a reference level of 50 μg/L of lead in blood as a level of concern for children. In fact, it is best to limit exposure to lead as much as possible, especially for pregnant women, infants, and young children (Wani et al., 2015). The primary sources of lead exposure in humans are contaminated food, water, and air, as well as lead-based paint and dust in older buildings. Therefore, it is important to take steps to reduce exposure to lead, where lead can have a wide range of harmful effects on human health, particularly on the nervous system, cardiovascular system, and reproductive system (Rehman et al., 2018). For humans, the lethal dose of arsenic has been estimated to be between 0.1 and 0.3 g of arsenic trioxide (As_2O_3) per kg of body weight, which is equivalent to 7–21 g of arsenic trioxide for an average adult. However, much lower levels of arsenic exposure can cause serious health effects over time, particularly with chronic exposure (Ravandi, 2004). Arsenic exposure can occur through contaminated food and water, as well as through inhalation of arsenic-containing dust or fumes. Chronic exposure to arsenic has been linked to a variety of health problems, including skin lesions, cancers of the lung, bladder, and skin, cardiovascular disease, diabetes, and neurological effects (Mandal, 2017).

Furthermore, mercury, cadmium, and lead were among the most reported HMs in dietary supplements, as RASFF notifications revealed (Christopher and Thompson, 2013; Justa Neves and Caldas, 2015). In 2011, the EFSA updated the tolerated weekly intake (TWI) for cadmium and set it as 2.5 μg/kg body weight (EFSA, 2011). The kidneys and bones are two of the primary organs affected by cadmium poisoning. Up to 30% of body Cd is deposited in the kidney tubule region, resulting in tubular damage and a reduction in vitamin D absorption, which causes general bone diseases called Itai-Itai illness (Ajjimaporn et al., 2012; Fujishiro et al., 2020).

FCM are also potential substances for heavy metal contaminants. RASFF notifications on FCM have been reported (Rortais et al., 2010). For instance, the migration of different HMs from kitchen utensils, including chromium and nickel (Kleter et al., 2009), lead, cadmium, and chromium (Elskens et al., 2012), and lead and nickel (Potter et al., 2012). According to regulation (EC) No. 1935/2004, FCM refer to any materials or articles that come into contact with food during production, storage, preparation, and serving. Examples of FCM include packaging materials, food containers, utensils, and processing equipment. These materials can be made from a variety of substances such as plastics, glass, ceramics, and metals (De Leo et al., 2021). For humans, nickel is generally considered to be a low-toxicity metal, and it is not classified as a carcinogen by the International Agency for Research on Cancer (IARC). However, exposure to high levels of nickel can cause acute toxicity, leading to symptoms such as nausea, vomiting, diarrhea, abdominal pain, and respiratory problems. Long-term exposure to lower levels of nickel can also cause chronic toxicity, leading to respiratory problems, dermatitis, and cancer (Song et al., 2017). HMs can have toxicological effects on a wide range of animals, not just humans. For instance, lead poisoning is a significant concern for birds, especially scavengers like eagles, vultures, and condors (McTee et al., 2023). Aquatic ecosystems are vulnerable to mercury contamination, which bioaccumulates in fish. Predatory fish, such as large species of sharks and swordfish, can accumulate high levels of methylmercury (Zheng et al., 2019). Marine and freshwater bivalves like mussels, clams, and oysters can accumulate cadmium from contaminated water, impairing their growth, reproduction, and overall health (Rodney et al., 2007).

Arsenic contamination, often associated with mining activities, can affect terrestrial wildlife. Animals like deer and rabbits can ingest arsenic-contaminated soil or plants, leading to poisoning and potential impacts on predators (Mathews and Porter, 1989). Nickel can enter marine environments through industrial discharges. Some species of marine algae can accumulate nickel, and when consumed by herbivorous marine animals like snails and sea urchins, it can disrupt their physiology and growth (Arulkumar et al., 2019). Hexavalent chromium (Cr^{6+}), a toxic form of chromium, can contaminate water bodies. It can harm aquatic organisms such as fish and amphibians by impairing reproduction, affecting the immune system, and causing developmental abnormalities (Velma et al., 2009).

RASFF serious notifications concerning the top six HMs from 2000 to 2022 based on risk decisions revealed that food supplements represented 36.84% of all serious notifications on arsenic, and its mean concentration in food supplements was 13.07 mg/kg. Squid, as cephalopod mollusks, represents 23.94% of all serious notifications on cadmium, with a mean concentration of 2.96 mg/kg. Out of 102 serious notifications on cadmium in squid, 26 and 25 originated from India and Spain, respectively. FCM, food supplements, meat other than poultry, and fruits and vegetables represent 40.65%, 21.14%, 9.35%, and 7.72% of all serious notifications on lead, respectively, and their mean concentrations of lead in FCM were 33.75, 30.98, 7.88, and 0.63 mg/kg, respectively. Out of 530, 117, and 51 serious notifications on mercury in swordfish, sharks, and tuna, 264, 51, and 25 originated from Spain, respectively. Swordfish, sharks, and tuna represent 58.43%, 12.9%, and 6.17% of all serious notifications of mercury, and their mean concentrations were 1.61, 1.99, and 1.67 mg/kg, respectively. FCM represent 61.54% and 90.48% of all serious notifications on chromium and nickel, respectively, and they mostly originated from China, where their released mean concentrations were 14.24 and 78.45 mg/kg, respectively. The highest numbers of chromium and nickel notifications were recorded in 2013, which could be attributed in part to the implementation of Commission Regulation (EU) No 284/2011, which established specific conditions for Chinese kitchenware (De Leo et al., 2021). Due to their outstanding thermal conductivity and thermostability, Ni and Cr are among the most commonly used metals and alloys in the production of FCM for cooking (Jellesen et al., 2006).

Italy, as a notifying country, recorded the highest number of notifications on cadmium (29.0%), mercury (52.6%), chromium (81.0%), and nickel (78.7%). At the same time, it ranked third for lead notifications (13.4%) and fourth for arsenic notifications (11.1%). Germany and Spain were the top notifying countries for lead (14.7%) and arsenic (24.7%), respectively. On the other hand, the top country of origin regarding notifications on arsenic (18.7%), cadmium (12.8%), lead (27.6%), chromium (71.2%), and nickel (66.9%) was China, whereas Spain was the top country of origin regarding mercury (32.2%). France, Ireland, the UK, and China were the most reported countries of origin of notified fish and fish products based on HMs contamination (Noël et al., 2011). Moreover, cadmium-contaminated fish products originating from developing countries were reported (Figueroa, 2008), causing huge economic losses to these countries.

In this paper, the most taken actions of notified products were withdrawal from the market due to arsenic (20.3%), lead (27.9%), and mercury (18.0%) and re-dispatch as a result of contamination of cadmium (20.5%), chromium (42.1%), and nickel (49.5%). Analysis of distribution status revealed that "no distribution" represented 29.0%, and "distribution restricted to notifying country" represented 25.6%.

The target hazard quotient (THQ) values for mercury in swordfish, sharks, and tuna were all below the threshold value of 1. The THQ values for cadmium in squid were all also below the threshold value of 1. This implies that the estimated daily intake is smaller than the oral reference dose (RfD). Similar findings were obtained by Jiao et al. (2018) who revealed that the THQ for contaminated squids with cadmium obtained from both Chinese offshore and oceanic fishing sites ranged from 0.01 to 0.03. On the contrary, Milatou et al. (2020) showed that THQ for intake of mercury through the consumption of reared Atlantic bluefin tuna from the Mediterranean Sea was greater than 1, suggesting the potential for non-carcinogenic health risks. Likewise, THQ for intake of mercury through the consumption of swordfish from the Mediterranean Sea significantly contributed to dietary exposure, revealing values of 5.841 and 2.607 evaluated on maximum and mean concentrations, respectively (Di Bella et al., 2020). Moreover, THQ results in shark muscles in the Pacific Ocean of Colombia were > 1 for adults, suggesting human health risks (Vélez et al., 2021). In general, further studies are still needed to see whether synergistic, additive, or antagonistic effects may be produced on consumer health from exposure to multiple contaminants.

Overall, media coverage of RASFF alerts and actions may help to raise public awareness about the risks associated with consuming contaminated food and feed products. While it is difficult to measure the specific impact of the RASFF on people's awareness of heavy metal contamination, the system may have played a role in raising awareness of the issue among both the general public and industry professionals. Also, identifying the most dangerous HMs and the most polluting products can help researchers prioritize their efforts in finding sustainable solutions for them. Also, this study would help researchers focus their interests on the most dangerous HMs and most polluting products and then work to find sustainable solutions for them.

5. Conclusion

While the RASFF aims to improve public health by detecting and preventing food and feed risks, it may also have played a role in raising awareness of heavy metal contamination. When a food or feed product is identified as a potential health risk due to heavy metal contamination, the RASFF issues an alert to member states, which can then take appropriate action to remove the product from the market or inform the public. This process can help to inform consumers about the risks associated with heavy metal contamination and encourage them to be more mindful of the food they consume. Notifications that are sent to the RASFF depend on national surveillance programs and on the efficiency of national laboratories for which the approaches are not fully harmonized between Member States (EFSA, 2011). Not all data are available on the public portal such as these items, products, hazards, hazard category, action taken, and notification basis in addition to the missing of some concentrations of detected contaminants, the size of the consignment, and the percent of violated consignments for each origin country.

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CRediT authorship contribution statement

Fawzy Eissa collected and analyzed the data; Nevien Elhawat and Tarek Alshaal did data curation and wrote the manuscript draft; Fawzy Eissa, Nevien Elhawat, and Tarek Alshaal discussed the results and finalized the manuscript writing.

Declaration of Competing Interest

The all authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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