



Irradiated and radioactively contaminated foods: Analysis of EU RASFF notifications from 1997 to 2022

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ABSTRACT

Food irradiation technique is an authorized tool used on a commercial scale in many countries to preserve different types of foodstuffs from deterioration caused by microorganisms, insects, and metabolic activity to prolong their shelf life without leaving any residual effect on processed foods, unlike preservatives and pesticides. This study was carried out to analyse the EU Rapid Alert System for Food and Feed (RASFF) notifications on food radiation from 1997 to 2022 in order to identify the most frequently reported products, their origin countries and associated reasons for notification, as well as the most notifying countries, product categories, notification classification, risk decisions, and actions taken. A total of 488 notifications were recorded during this time period. China was the most frequently notified origin country, accounting for 19.88% of all notifications, followed by the United States (11.68%), Russia (7.99%), Vietnam (7.17%), and Poland (5.53%). The top notified product categories were “dietetic foods, food supplements, and fortified foods” (37.09%), followed by fruits and vegetables (23.16%), herbs and spices (8.81%), and prepared dishes and snacks (5.53%). The top 5 notified products were food supplements (25.00%), mushrooms (20.70%), noodles (7.58%), tea (4.51%), and spices (3.69%). The four main reasons for food radiation notifications were unauthorized irradiation (57.58%), too high levels of radioactivity (22.34%), unlabeled irradiation (19.47%), and unauthorized facilities (14.96%). Too many notifications included more than one reason for the notification. Out of 109 notifications related to too-high levels of radioactivity (up to 10755 Bq/kg), 101 were due to the presence of ¹³⁷Cs, ¹³⁴Cs, ⁶⁰Co, and ⁴⁸Cd in mushrooms, mainly originating from Poland (25), Bulgaria (24), Ukraine (15), and Belarus (12). Such studies provide the necessary data to ensure food safety and encourage countries to implement comprehensive procedures to protect consumers health.

1. Introduction

Food irradiation technique employs a specific dose of ionizing radiation, including X-rays, electron beams, and gamma rays, to protect foodstuffs from deterioration caused by microorganisms, insects, and metabolic activity to prolong their shelf life without leaving any residual effect on processed foods, unlike preservatives and chemical pesticides (Pavlov et al., 2020; Bisht et al., 2021). Food irradiation pasteurizes and sterilizes food products without raising their temperature (cold pasteurization or sterilization), and thus does not cause any undesirable effects on the food components when the recommended doses are used. Therefore, it contributes to reducing the number of patients with food-borne diseases, which reduces treatment and health insurance expenses. Foods are processed by ionizing radiation after being packed into final

consumer packaging, then sterilized or pasteurized, which is a unique feature of food irradiation technology (Molins, 2001). Irradiation depends on its effect on improving food safety on the formation of free radicals. The effect of irradiation in various doses on the components of nutrients such as vitamins, proteins, fats, etc. has been studied intensively for more than half a century. In the 1950s, research initiatives on food irradiation were launched across Western Europe. In order to investigate and confirm the impacts of irradiation on the quality of food and its influence on nutritional content, the International Project in the field of Food Irradiation (IPFI) was established in 1970. A joint committee comprising the Food and Agriculture Organization (FAO), World Health Organization (WHO), and the International Atomic Energy Agency (IAEA) was formed to examine the results of this project. This committee approved specific doses of ionizing radiation that can be

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exposed to food without posing any toxic risks or causing nutritional or bacterial problems. After many studies in subsequent years, the committee concluded that the doses used vary according to the purpose to be achieved, as long as they do not lead to nutritional deficiency and can be taken safely, as doses, up to 10 kGy may be used with fresh food (high moisture content), and higher than that can be used with dry food, which can reach 70 kGy (Ravindran and Jaiswal, 2019; Satin, 2020; Raghul, 2022; Sahoo et al., 2023).

Accordingly, food irradiation has been adopted as a sanitary and phytosanitary treatment method for more than 60 foods and commodities in more than 70 countries. However, the committee stipulated that the Radura symbol (describing food as an agricultural product, or a plant (dot and two leaves) in a sealed container (the circle), which has been exposed to penetrating ionizing radiation from the top to maintain its quality (the breaks in the upper portion of the circle) or/and additional statements like “Treated with radiation”, “Treated by irradiation”, “Irradiated for Food Safety” or “Irradiated to Protect Agriculture from Harmful Insect Pests” in addition to the Radura logo, should be placed on the product that was exposed to irradiation or any of its components (Caputo, 2020), and that the absence of that logo on the food product exposed to irradiation is considered a violation. This is to guarantee the right of the consumer to choose between eating irradiated or non-irradiated food, as he is free to do so according to the consumer protection law (Junqueira-Gonçalves et al., 2011). The most well-known techniques for detecting irradiated food are Electron Spin Resonance (ESR) and Thermo-Luminescence (TL). ESR spectroscopy is suitable for detecting irradiated food that contains bone, seeds, shell, and skin, while the TL method is appropriate for silicate mineral-containing fruits, herbs and spices, vegetables, and grains (Chauhan et al., 2009; Ranby and Rabek, 2012).

On the other hand, radioactive accidents such as the Chernobyl accident on April 26, 1986 in Ukraine (due to design flaws in the reactor and Soviet scientists experimental operations errors, according to Kortov and Ustyantsev, 2013) and the collapse of the Fukushima nuclear fuel station in Japan in 2011, as well as nuclear weapons tests in the 1950s and 1960s, resulted in radioactive contamination through the release of radioactive elements into the soil, water, and air (Falandysz et al., 2015). The presence of several radionuclides like ^{137}Cs , ^{134}Cs , ^{60}Co , ^{48}Cd , and other radioelements was detected in several foodstuffs, whether of plant or animal origin, in the radio-contaminated regions. For example, a number of shipments of powdered milk containing dangerous levels of radiation were traced back to West Germany and Poland, from where they were to be exported to Africa and Bangladesh in the late 1980s (Yablokov et al., 2010). Most of these radionuclides turned into stable isotopes over time due to their short half-lives, for example, the half-life of ^{48}Cd is one year, and the half-life of ^{134}Cs is two years, etc. In contrast, ^{137}Cs is still present in radioactively contaminated areas in active and significant quantities due to its long half-life, which extends to 30 years (Baranwal et al., 2011; Falandysz et al., 2015). Plant species vary in their capacity to absorb and build up radioactive elements from soil, water, and air based on their different structures and morphological shapes, as plants with large, hairy, or rough leaves accumulate a higher level of these elements; however, the type and shape of roots, as well as their depth in the soil, are additionally contributing factors (Sawidis, 1988).

In order to facilitate the sharing of information linked to human health risks and support the control and safety of food and animal feed on the European market, the Rapid Alert System for Food and Feed (RASFF) was founded in 1979. The legal basis for the RASFF is provided by Article 50 of Regulation (EC) No. 178/2002, commonly known as the European General Food Law (Bouzembrak and Marvin, 2016). The RASFF system enables immediate action by EU countries in response to the risk, as well as quick information exchange and the eradication of products that are detrimental to consumer health.

To date, a comprehensive analysis has not been conducted on EU RASFF notifications of irradiated and radioactively contaminated foods.

Therefore, the purpose of this study was to analyse the EU RASFF notifications on radiation from 1997 to 2022 in order to identify the most frequently reported products, their origin countries and associated reasons for notification, as well as the most notifying countries, product categories, notification classification, risk decisions, and actions taken.

2. Materials and methods

2.1. Data collection and processing

For data collection, the notifications in the public database RASFF Window (RASFF, 2023) were filtered according to the criteria “type” (food), “hazard category” (“radiation”), and “date” (01/01/2020–31/12/2022) and exported as an Excel file. On the other hand, the whole data for the period between January 1, 1997, and December 31, 2019 was obtained by Nogales et al. (2023). Prior to 1997, there were only two reported notifications regarding radiation by RASFF. The first one was on April 30, 1986, pertaining to the too-high level of radioactivity in the Chernobyl accident from the Russian Federation. The second one belongs to the unauthorized irradiation of mussels from Denmark on February 11, 1987. The following variables were further processed in Microsoft Excel using pivot tables: the date on which the notification was made, notifying country, origin country, product category, product, subject (reason for notification), risk decision (not serious, serious, or undecided), action taken, and notification classification (alert, border rejection, and information). Alert when a product that poses a severe risk is sold in the EU and immediate action is or would be necessary in a nation other than the one that notified the EU. Border rejection occurs when a shipment of a product is denied admission into the EU due to a risk to human health. Information is provided when a product for which a risk has been identified but that risk is not believed to be serious or the product is not on the market at the time of notice.

3. Results and discussion

3.1. Notifications number over the last 26 years and their main reasons

Table 1 shows the number of RASFF notifications per year on radiation from 1997 to 2022 and their main reasons. There were a total of 488 notifications, accounting for 0.53% of the total number of RASFF notifications on all hazard categories (91625) during this time period. The number of notifications fluctuated from year to year. The lowest number of notifications was in 1997 and 2001, while the highest number of notifications was in 2012 (10.25%). The four main reasons for food radiation notifications were unauthorized irradiation (57.58%), too high levels of radioactivity (22.34%), unlabeled irradiation (19.47%), and unauthorized facilities (14.96%). Many notifications included more than one reason for the notification. 86.00% of unauthorized irradiation notifications were reported between 2003 and 2015, while half of the too-high level of radioactivity notifications were reported in 1998 and 1999. Moreover, 70.5% of unlabeled irradiation notifications were reported between 2004 and 2009, while 46.6% of unauthorized facility notifications were reported in 2005 and 2012. It is clear from the presented data that the first notifications related to food irradiation violations (unauthorized or unlabeled irradiation and unauthorized facilities) were in 2002, after the European Union allowed the import of irradiated foods from non-member countries, provided that those countries adhere to the same strict standards that apply within the European Union following directive 2002/840/EC. The number of notifications varied in the following years, experiencing both increases and decreases, but the increase was predominant until 2015 as a result of the increase in commercial activity related to the trading of irradiated foods, especially after the 2002/840/EC directive, as mentioned previously. The number of notifications decreased significantly in the following years after 2015 until 2022, which may be due to the tightening of control by the

Table 1

Total number of RASFF notifications per year on food radiation from 1997 to 2022 and their main reasons.

Year	Total No. of notifications	The four main reasons of notifications			
		Unauthorized irradiation	Too-high level of radioactivity	Unlabeled irradiation	Unauthorized facility
1997	2	0	2	0	0
1998	32	0	32	0	0
1999	22	0	22	0	0
2000	5	0	5	0	0
2001	2	0	2	0	0
2002	3	1	2	0	0
2003	22	16	6	1	0
2004	23	17	2	10	0
2005	32	14	4	22	13
2006	29	17	6	6	6
2007	30	19	2	7	5
2008	30	18	3	16	5
2009	16	10	1	6	5
2010	32	26	2	4	4
2011	34	28	4	4	2
2012	50	28	1	5	21
2013	20	14	2	2	3
2014	12	10	0	0	2
2015	26	25	0	0	1
2016	5	3	1	2	1
2017	11	6	1	2	0
2018	14	7	2	2	4
2019	13	7	3	2	1
2020	7	6	1	0	0
2021	11	4	3	2	0
2022	5	5	0	2	0
Total	488	281	109	95	73

European Union to reduce violations related to the irradiated food. On the other hand, as shown in Table 1, the first violation related to the presence of too-high levels of radioactivity in foodstuffs, especially those of wild origin such as mushrooms and deer meat, was reported in 1997 (2 notifications), and then 32 and 22 violations were reported in 1998 and 1999, respectively. This increase in the number of notifications in that period may be due to the proximity of the Chernobyl nuclear power plant accident in Ukraine on April 26, 1986, when most of the radionuclides with a relatively short half-life were still in active form. Cases of fetal malformations, malignant tumors, and fetal brain damage have increased at different stages of pregnancy, according to WHO reports, in addition to an unexpected rise in the number of thyroid cancer cases among residents of these or neighboring areas, especially among children (Yablokov et al., 2010). In the following years, too-high levels of radioactivity were reported due to the presence of radioactive cesium (^{137}Cs) until the year 2021 due to its long half-life (30 years), but the numbers of notifications were lower than in the first two years (1998 and 1999) due to the fact that most of the radionuclides with a short and medium half-life were transformed into stable forms.

As the European Parliament and Council constantly issue legislation related to food safety to protect the consumer and work to update these legislations and add new items constantly. In Europe, detecting irradiated food is governed by European Legislation L66/16–25 (1999), which cover Directive 1999/2/EC and Directive 1999/3/EC. A law regulates the terms and conditions that must be met when conducting the irradiation process, with a preliminary list of foods that can be treated with irradiation. The legislation also confirmed that the food irradiation process can only be carried out in authorized facilities approved by the EU authorities, and these facilities have been included in the approved list. Moreover, to allow irradiated foodstuffs to be placed on the European market, they must follow the directive, which specifies: the authorizing conditions for food irradiation that comprise technology needs and customer benefits; the permissible purposes (to reduce the microbial loads); the food should be in good condition, and irradiation may be used in combination with other chemical techniques but should not be used to substitute hygienic practices; the sources of ionizing radiation are gamma, X rays, and electron beam; the determination of the

absorbed dose and methods for measuring it; labels should be placed in visible places on the packaging indicating that the product has been treated with ionizing radiation, indicating the name and address of the facility. Additionally, the directive states that a food's maximum radiation dose may be administered in a series of smaller doses. As a result, marketing and use of products that violate these legislations were banned in 2001. The Directive 2002/840/EC allows the import of irradiated food from non-EU countries as long as these foods comply with EU rules and have been irradiated in authorized facilities. Since 2003, the EU food safety policy has focused on the concept of traceability for both inputs and outputs (e.g., animal feed/primary production, processing, storage, transport, and retail). Thus, food imported from outside the European Union is subject to strict examinations at every stage of production with the same standards that are followed within the European Union. In turn, the Regulation 2011/1169/EC relates to food products in general intended for sale to the final consumer, which stipulated that complete nutritional information be presented on the packages in a mandatory manner and that this information is not misleading, clear, correct, and easy to understand for the consumer (Paganizza, 2020). In Directive (2018)/775/EC, detailed rules were set to indicate the country of origin of the product or its main component, if it is different from that in the country of origin (Ballke and Kietz, 2020). Finally, after reviewing the European Union legislation on food safety, it is possible to notice the variation in the number of notifications regarding the reported violations. The following subsections present the results of the studies for particular criteria, as well as the relationships between them, resulting from the analysis of the pivot tables.

3.2. Notification classification

Concerning notification classification over the last 26 years, 67.01% were classified as "information", which corresponds to 327 notifications out of a total of 488 notifications. 20.70% ($n = 101$) were classified as "border rejection" and 12.30% ($n = 60$) were classified as "alert", as shown in Table 2. Most of the alert notifications were mainly for products from China (18.33%), South Korea (15.00%), the United Kingdom (11.67%), the United States (10.00%), and other countries. Products

Table 2

RASFF notifications percentage on food radiation from 1997 to 2022 according to notification classification.

Notification classification	Number	Percentage
Alert	60	12.30
Border rejection	101	20.70
Information (sum)	327	67.01
Total	488	100.00

from China, Russia, and the United States also had the highest number of “border rejection” notifications, accounting for 33.67%, 18.81%, and 11.88%, respectively.

3.3. Notifying and origin countries

Tables 3 and 4 show the number and percentage of the total notifications for the top 10 notifying and origin countries involved in RASFF notifications on radiation from 1997 to 2022, respectively. Germany was the notifying country with the highest number of notifications transmitted ($n = 107$), representing 21.92% of the total notifications (mostly from Poland (18.70%), Vietnam (10.30%), and other countries). Finland ranked second ($n = 70$), representing 14.34% of the total notifications (from China (30%), the United States (27.14%), and others). The number of notifications issued by Italy and Latvia was fairly close, constituting 10.86% and 10.04%, respectively, mostly from China (35.85%) and Vietnam (28.30%) for Italy, while Latvia mostly notified products from Russia (46.90%), and the United States (24.49%). The United Kingdom, Lithuania, Belgium, Romania, Denmark, and France issued fewer than 10.00% of notifications in the period under analysis, where the number of notifications was 43, 23, 22, 19, 18, and 14, respectively. It was noted that products from China received the most notifications overall.

The majority of RASFF notifications on radiation from 1997 to 2022 was related to unlabeled products, unauthorized facilities, and unauthorized irradiated products; there were 379 notifications. Moreover, there were 109 notifications related to a too-high level (up to 10755 Bq/kg) of radioactivity (specifically the presence of ^{137}Cs , ^{134}Cs , ^{60}Co , and ^{48}Cd , in mushroom products). As mentioned previously, the food irradiation technique is a safe technology that relies on ionizing radiation, which is electromagnetic waves that have no residual effect on processed foods, unlike preservatives and chemical pesticides (Akhila et al., 2021). Therefore, reporting some violations related to unlabeled irradiated products, unauthorized facilities, and undeclared irradiated products maybe not represent a threat to the health of the consumer, but are considered a violation of laws and legislation only. On the contrary, reporting the presence of high levels of radioactivity within food products or feed represents a great danger to the health of the consumer or animal. This may cause all kinds of cancerous diseases, especially thyroid cancer in children. Radiation exposure may also induce hypothyroidism and autoimmune reactions against the thyroid (Reiners et al.,

Table 3

Top 10 notifying countries involved in RASFF notifications on food radiation from 1997 to 2022.

Notifying Country	Number	Percentage
Germany	107	21.93
Finland	70	14.34
Italy	53	10.86
Latvia	49	10.04
United Kingdom	43	8.81
Lithuania	23	4.71
Belgium	22	4.51
Romania	19	3.89
Denmark	18	3.69
France	14	2.87
Total	418	85.66

Table 4

Top 10 origin countries involved in RASFF notifications on food radiation from 1997 to 2022.

Origin Country	Number	Percentage
China	97	19.88
United States	57	11.68
Russia	39	7.99
Vietnam	35	7.17
Poland	27	5.53
Bulgaria	24	4.92
United Kingdom	17	3.48
Ukraine	15	3.07
India	15	3.07
Belarus	12	2.46
Total	338	69.26

2020). The Chernobyl accident in 1986, and the collapse of the Fukushima nuclear fuel station in Japan in 2011, as well as nuclear weapons tests in the 1950s and 1960s, led to wide-scale radioactive contamination through the release of radionuclides into the soil, water, and air (Falandysz et al., 2015). A substantial number of radionuclides, among them the radiologically noteworthy short-lived cesium-134 (^{134}Cs) and long-lived caesium-137 (^{137}Cs), were released into the atmosphere, water, and soil as a result of the Chernobyl accident, which had a significant impact on Belarus, Ukraine, and the western part of Russia (Drozdovitch, 2021). After the collapse of the Japanese Fukushima nuclear fuel station in March 2011 as a result of exposure to the massive tsunami, too-high levels of radioactivity of ^{137}Cs were detected in different species of vegetables, mushrooms, and plants in general, especially in 2012, which was the first year after the accident (Falandysz et al., 2015). Therefore, the lack of sufficient information from the country of origin on its exported food product packaging is considered a violation, according to the legislation set by the European Union Directive 2018/775/EC (Ballke and Kietz, 2020).

The top ten origin countries involved in RASFF notifications on radiation from 1997 to 2022 were China (19.88%), followed by the USA (11.68%), Russia (7.99%), Vietnam (7.17%), Poland (5.53%), Bulgaria (4.92%), and the UK (3.48%), whereas both Ukraine and India were similarly notified (3.07%), as shown in Table 4. Most of the notifications were for products from China, with 97 notifications reported, mostly “dietetic foods, food supplements, and fortified foods”, followed by “herbs and spices”, “cocoa and cocoa preparations, coffee and tea”, and other product categories. On the other hand, the United States came in second with 57 notifications, mainly for “dietetic foods, food supplements, and fortified foods”, then “herbs and spices”, and other product categories. The number of notifications for Russian products accounted for 39 notifications, with “dietetic foods, food supplements, and fortified foods” being the most notified product category, followed by “fruits and vegetables”. Vietnamese food products, including “fish and fish products”, “meat and meat products”, “bivalve mollusks, cephalopods, and products thereof”, had 35 notifications. Polish and Bulgarian food products had 27 and 24 notifications, respectively, mostly for fruits and vegetables. Likewise, most of the notifications for Ukrainian and Belarusian food products were related to fruits and vegetables, which were 15 and 12, respectively. The number of notifications related to food products from the UK and India was 17 and 15, respectively, with the majority of them being “dietetic foods, food supplements, and fortified foods”.

In the countries of the Asia Pacific Region (such as, China, Japan, South Korea, India, etc.), food irradiation technology has increasingly become an agreed processing technique to meet rising sanitary and phytosanitary requirements in international trade (Ic and Cetinkaya, 2021). However, as a result of this expansion in this field, many violations related to commercial fraud operations that do not comply with the Consumer Protection Law and EU legislation were monitored, such as the export of unlabeled irradiated products. Many unauthorized

facilities and undeclared irradiated products have also been monitored, which is contrary to the agreed legislation. Additionally, numerous unauthorized facilities have been observed in the United States and China, explaining the increase in the number of notifications regarding food commodities from these countries, in particular (European Commission, 2011).

3.4. The top 10 notified product categories and products

Tables 5 and 6 reveal the top ten product categories and products involved in RASFF notifications on radiation from 1997 to 2022, respectively. It is clear from the data that the largest number of notifications ($n = 181$), was for “dietetic foods, food supplements, and fortified foods” accounting for 37.09% of the total notifications ($n = 488$). In second place, there were 113 notifications related to “fruits and vegetables”, equivalent to 23.16% of the total notifications, with most of them being related to mushrooms and their products. There were 43 notifications related to “herbs and spices”, accounting for 8.81% of the total notifications. 5.53% of the total notifications ($n = 27$) were about “prepared dishes and snacks” such as instant noodles, instant noodle soup, instant noodles seasoning, instant noodles with spice mixture bags. “Fish and fish products” category (such as dried anchovies, dried horse mackerel, canned crayfish in brine, etc.) and “meat and meat products” category (other than poultry) including frozen frog legs, dark red, fresh muscle meat of wild boar, account for 4.92% and 3.48%, of all notifications, respectively. “Cocoa and cocoa preparations, coffee and tea” had 16 notifications (3.28%). “Soups, broths, sauces, and condiments”, “cereals and bakery products” and “cephalopods and products thereof” product categories represented 2.66%, 2.25%, and 1.48% of all notifications, respectively.

Moreover, the top 10 notified products involved in RASFF notifications on radiation from 1997 to 2022 were food supplements (25.00%), followed by mushrooms (20.70%), noodles (7.58%), tea (4.51%), spices (3.69%) rice products (3.48%), ginseng (3.07%), frog legs (3.07%), meat (1.64%), and anchovies (1.43%).

The demand for dietary supplements is increasing globally due to their health benefits and economic considerations. The same applies to fruits and vegetables, which constitute a large part of the global food trade due to their high content of vitamins, minerals, etc. However, there are still issues with the safety of dietary supplements such as adulteration and contamination. Therefore, there is a need for continued efforts and improved techniques to evaluate the quality of dietary supplements, particularly concerning purity, bioavailability, and safety (Bailey, 2020; Cerino et al., 2021). Directive 2002/46/EC grants local authorities the right to suspend or restrict the sale of dietary supplements if they believe they would endanger human health. In such cases, the authorities inform the European Commission and all countries in the European Economic Area immediately.

Mushrooms are considered one of the complementary foodstuffs that are in constant demand, especially in Europe, because of their high

Table 5

Top 10 product categories involved in RASFF notifications on food radiation from 1997 to 2022.

Product category	Number	Percentage
Dietetic foods, food supplements, and fortified foods	181	37.09
Fruits and vegetables	113	23.16
Herbs and spices	43	8.81
Prepared dishes and snacks	27	5.53
Fish and fish products	24	4.92
Meat and meat products (other than poultry)	17	3.48
Cocoa and cocoa preparations, coffee and tea	16	3.28
Soups, broths, sauces and condiments	13	2.66
Cereals and bakery products	11	2.25
Cephalopods and products thereof	9	1.84
Total	454	93.03

Table 6

Top 10 products involved in RASFF notifications on food radiation from 1997 to 2022.

Product	Number	Percentage
Food supplements	122	25.00
Mushrooms	101	20.70
Noodles	37	7.58
Tea	22	4.51
Spices	18	3.69
Rice products	17	3.48
Ginseng	15	3.07
Frog legs	15	3.07
Meat	8	1.64
Anchovies	7	1.43
Total	362	74.18

nutritional value, and their use as an alternative to animal protein in diets. European consumers prefer edible wild mushrooms grown in forests as organic food, especially those produced in China. Mushrooms and some forest plants, like bilberries, serve as excellent biological indicators of radioactive contamination in the environment. They accumulate radionuclides in heavily contaminated areas affected by radioactive fallout, such as the countries affected by the Chernobyl accident, the collapse of the Fukushima nuclear fuel station, and nuclear weapons tests (Baranwal et al., 2011; Falandysz et al., 2015). Mushroom types differ in their ability to accumulate radionuclides inside them, as studies have shown that some species accumulate higher concentrations in their tissues, especially in the fruiting parts. For example, the *Boletus edulis* mushroom accumulates radionuclides in greater concentrations than the *Amanita caesarea* mushroom (Sawidis, 1988; Falandysz et al., 2015; Chiaravalle et al., 2018). Some types of wild mushrooms still carry high concentrations of ^{137}Cs , even long after these radioactive accidents, due to their long half-life, which reaches nearly 30 years (Guillén and Baeza, 2014; Chiaravalle et al., 2018). Therefore, eating contaminated mushrooms may pose a threat to consumer health, as accurate data on the places where wild mushrooms grow is not readily available. Therefore, further studies are necessary to assess the risks of consuming wild mushrooms and to provide data for their growing areas through soil analysis and mapping (Ernst et al., 2022). Thus, mushrooms and their products should be strictly controlled and examined, especially in the countries of origin, to protect consumer health, in accordance with legislation of Directive (2002)/46/EC and 2018/775/EC.

3.5. Risk decision and action taken

As previously mentioned, the total number of notifications issued by the RASFF in the period from 1997 to 2022 was 488. By analysing these data, it was found that the greatest proportion of the risk decisions was undecided, followed by not serious ones, as shown in Table 7. The number of undecided notifications was 350, accounting for 71.72% of the total notifications, while the number of not serious notifications was 126, representing 25.82% of the total notifications. Only 2.46% ($n = 12$) of the total notifications were classified as serious. On the other hand, the RASFF notification percentages on radiation from 1997 to 2022, based on action taken, varied between withdrawals from the market, re-dispatch, obsolete, etc., as shown in Table 8. The highest frequencies were “withdrawal from the market” (17.21%) and re-dispatch (13.32%),

Table 7

RASFF notifications percentage on food radiation from 1997 to 2022 based on risk decision.

Risk decision	Number	Percentage
Not serious	126	25.82
Serious	12	2.46
Undecided	350	71.72
Total	488	100.00

Table 8

RASFF notifications percentage on food radiation from 1997 to 2022 based on action taken.

Action taken	Number	Percentage
Withdrawal from the market	84	17.21
Re-dispatch	65	13.32
Obsolete	63	12.91
Not specified	53	10.86
Official detention	52	10.66
Destruction	46	9.43
Import not authorised	34	6.97
No action taken	17	3.48
Return to consignor	15	3.07
Recall from consumers	13	2.66
Informing authorities	12	2.46
No stock left	12	2.46
Informing recipient(s)	5	1.02
Seizure	5	1.02
Detained by operator	4	0.82
Informing consignor	3	0.61
Placed under customs seals	3	0.61
Withdrawal from recipient(s)	2	0.41
Total	488	100.00

followed by obsolete (12.91%). The EU food safety policy has focused on the concept of traceability for both inputs and outputs in all stages of production since 2003. So that food imported from outside the European Union is subject to strict examinations at every stage of production with the same standards that are followed within the European Union (Regattieri et al., 2007). The RASFF system enables immediate action by EU countries in response to risks, as well as quick information exchange and the eradication of products that are detrimental to consumer health.

4. Conclusions

Food safety is a worldwide issue that affects all countries and has significant effects on both human health and the economy. This study addresses an important issue of irradiated and radioactively contaminated foods through analysing EU RASFF notifications reported between 1997 and 2022, as no previous research has been carried out in this field so far. Among the 488 notifications, 379 were related to unlabeled irradiated products, unauthorized facilities, and unauthorized irradiated products. Additionally, 109 notifications were related to high levels of radioactivity, particularly concerning the presence of ^{137}Cs , ^{134}Cs , ^{60}Co , and ^{48}Cd , notably in mushroom products. The presence of ^{137}Cs in an active form in radioactively contaminated areas poses a great danger to consumer health due to its long half-life, which extends up to 30 years. Strict control over food from these contaminated areas is necessary. China was the most notified origin country (19.88%), followed by the United States (11.68%), while “dietetic foods, food supplements, and fortified foods” product category got the largest share of notifications (37.09%), followed by “fruits and vegetables” (23.16%). However, irradiation facilities must be certified by authorities with strict standards, and irradiation labels should be placed on products intended for export or domestic consumption. To protect human health, extensive monitoring studies on the prevalence of food radioactive contamination should be regularly conducted to identify its origin and implement corrective and preventive actions.

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Data availability

The data that has been used is confidential.

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