Journal of Elementology ISSN 1644-2296

Chmielewski, J., Gworek, B., Bąk-Badowska, J., Zięba, E., Szenk, P. and Żeber-Dzikowska, I. (2025)
'Food contaminated with pesticides and heavy metals – an underestimated public health threat',
Journal of Elementology, 30(4), 607-629,
available: https://doi.org/10.5601/jelem.2025.30.3.3640

RECEIVED: 28 August 2025
ACCEPTED: 15 October 2025

ORIGINAL PAPER

Food contaminated with pesticides and heavy metals – an underestimated public health threat*

Jarosław Chmielewski[1,2], Barbara Gworek[3], Jolanta Bąk-Badowska[4], Ewa Zięba[5], Piotr Szenk[6], Ilona Żeber-Dzikowska[7]

[1] Department of Public Health
Academy of Medical Sciences of Applied and Holistic Sciences in Warsaw, Poland
[2] Collegium Medicum, The Jan Kochanowski University in Kielce, Poland
[3] Department of Environmental Chemistry and Risk Assessment
The Institute of Environmental Protection – National Research Institute, Warsaw, Poland
[4] Faculty of Exact and Natural Sciences
[5] Collegium Medicum
The Jan Kochanowski University in Kielce, Poland
[6] Faculty of Medicine
Lazarski University in Warsaw, Poland
[7] Faculty of Pedagogy and Psychology
The Jan Kochanowski University in Kielce, Poland

Abstract

Food contaminated with chemical substances poses a significant threat to human health and, therefore, should be of concern for both environmental and public health. Pesticides and heavy metals represent important examples of such hazards. Long-term exposure resulting from the consumption of contaminated food may lead to serious adverse health outcomes. Objective: This study aimed to systematize current knowledge on food contamination with pesticides and heavy metals. The paper reviews relevant legal regulations and presents recent research results on the presence of these compounds in food and their potential health effects on consumers. Methods: A review of epidemiological studies reporting adverse health outcomes was performed. Data analysis and bibliometric review covered the period 2020-2024 and included information from official food control as well as reports of institutions responsible for food quality and safety assessment in Poland. The literature search was conducted using the PubMed, Scopus, and Google Scholar databases. Selection criteria included open access availability and specific subject classification keywords. Results: Findings from official food control and scientific studies confirm the presence of pesticide and heavy metal contamination in food products. Conclusions: Official food control in Poland should include a larger number of food samples in their raw state and after processing to provide a more comprehensive picture of potential consumer exposure.

Keywords: food, metals, pesticides, pollution, health risks

Jarosław Chmielewski, Ph.D., Academy of Medical Sciences of Applied and Holistic Sciences, St. Kasprzaka 49, 01-234 Warsaw, Poland, e-mail: jaroslaw.chmielewski@amh.edu.pl
* Source of financing: The project is financed from the Research Fund of the Jan Kochanowski University in Kielce, which is intended to support the continuity and development of the university's scientific research.

INTRODUCTION

Chemical substances are among the hazards present in food, and their levels largely depend on the condition of the environment. Due to their widespread use and persistence, they are common contaminants of ecosystems. The circulation of chemical substances in nature results in their incorporation into biological cycles and, consequently, into food products. The consumption of food contaminated with chemicals poses a real threat to human health. Fruits, vegetables, fish, and dairy products are essential components of the diet, but in addition to nutrients, they may also contain hazardous substances. Pesticides and heavy metals are important examples of such threats. These contaminants should be classified as chemical hazards originating from natural processes, food processing, migration, or accidental pollution (Ochwanowska et al. 2019, Dietrich et al. 2022, Gworek et al. 2024, D'Amore et al. 2025).

The content of mineral elements in food depends on various factors, such as geochemical background (natural levels of elements in the environment), anthropogenic activity, fertilizer composition and application doses, as well as soil and climatic conditions. Agricultural practices, pesticide quality, timeliness and accuracy of crop protection treatments, harvesting methods, compliance with hygiene requirements, and the knowledge and skills of producers are all decisive for ensuring food safety and quality (Cai et al. 2024).

Elevated concentrations of certain elements are particularly observed in soils contaminated with heavy metals, as well as in aquatic environments, which contribute to contamination of fruits, vegetables, fish, and seafood (Gworek et al. 2018, Cai et al. 2024, Dietrich et al. 2022, Chmielewski et al. 2023, Gworek et al. 2024).

The occurrence of chemical substances in food may pose a significant threat to consumer health; therefore, official food control should be a fundamental element of food safety assessment. At every stage of the food chain, efforts should be made to ensure that only products safe for human health and life reach consumers. One of the measures established to address this need was the creation of the Rapid Alert System for Food and Feed (RASFF). This system was designed to support official control of food across the European Union (EU) and to facilitate effective communication between member states, enabling immediate action in the event of non-compliance. Within RASFF, all members are required to notify the European Commission of the presence or potential occurrence of hazards in food or feed. If a member state detects a product posing a serious risk to consumer health, an immediate notification is submitted to the European Commission's contact point (Dietrich et al. 2022, Wolniak, Grebski 2025, D'Amore et al. 2025, Żeber-Dzikowska et al. 2025).

Food contamination with chemical substances represents a serious threat to public health. Therefore, continuous monitoring of cultivation, breeding, and production processes, together with official food control, should be of special interest to all stakeholders engaged in environmental and public health (Ochwanowska et al. 2019, Chmielewski et al. 2020, Dietrich et al. 2022, Chmielewski et al. 2023, D'Amore et al. 2025, Wolniak, Grebski 2025, Żeber-Dzikowska et al. 2025). To minimize health risks related to the consumption of food contaminated with chemicals, it is necessary to implement appropriate measures aimed at reducing exposure by monitoring and controlling both sources of contamination and food available on the market. Health risk assessment remains one of the key tools to achieve this goal (Onyeaka et al. 2024).

This article aims to highlight the issue of pesticide and heavy metal residues in food, as well as their adverse health effects on humans. The study presents the occurrence of these substances in selected food groups, with a particular focus on Poland. The analysis includes legal regulations, literature data, and reports from institutions responsible for food quality and safety in Poland, as well as notifications from the RASFF system.

MATERIALS AND METHOD

The review covered scientific literature published between 2020 and 2024, assuming that this period reflects the most recent scientific findings on the subject. The analysis included publications indexed in PubMed, Scopus, and Google Scholar databases, with particular emphasis on research concerning food contamination with pesticides and heavy metals and their adverse health effects.

The literature search strategy relied on keywords and their combinations (Table 1). Only publications in English, with open access to the full text, were considered eligible for inclusion. The review also covered legal regulations and recent reports on pesticide and heavy metal residues in food, as well as their effects on consumer health.

Table 1

Step one of the analysis of the literature trends on the basis of key words

Key words	pesticide residues in food
	heavy metal residues in food
	health risks associated with pesticides in food
	health risks associated with heavy metals in food

In addition, epidemiological studies reporting health effects associated with dietary exposure were analyzed. Data from official food control in the European Union and Poland, as well as reports and assessments published by food safety institutions, were included. A bibliometric approach was applied, covering 2020-2024, to identify trends and gaps in current research.

Food safety regulations

International legal regulations do not define food safety (FAO and WHO, 2023). Instead, they specify the premises and criteria for assessing food in terms of consumer health protection, using the term *unsafe food*, understood as food that is harmful to health or unfit for human consumption (Pettoello-Mantovani, Olivieri 2022). In contrast, Polish legislation, in the Act of 25 August 2006 on food and nutrition safety, defines food safety as "the totality of conditions that must be fulfilled, particularly concerning the use of additives and flavorings, levels of contaminants, pesticide residues, conditions of food irradiation, organoleptic properties, and actions to be taken at all stages of food production and distribution to ensure the protection of human health and life" (UoBŻiŻ 2006).

In the broadest sense, the concept of food safety covers both quantitative food security, aimed at solving problems related to hunger, and qualitative food safety, which focuses on consumer health protection (D'Amore et al. 2025, Wolniak, Grebski 2025). According to the Food and Agriculture Organization of the United Nations (FAO), food safety means ensuring that food will not cause harm to the consumer when it is prepared and/or consumed as intended. Food must not pose a threat to human health and life. Such an approach requires mechanisms to prevent unsafe products from entering the market and, in case of danger, procedures for rapid response, alert, and withdrawal. Food safety depends on the joint efforts of all stakeholders involved in the food supply chain. Legal regulations and official controls are designed to eliminate or minimize contamination risks at each stage, in accordance with public health requirements (FAO and WHO 2023 Wolniak, D'Amore et al. 2025, Grebski 2025).

One of the key legal acts regulating food safety in the European Union is Regulation (EC) No. 178/2002 of the European Parliament and of the Council of 28 January 2002, which lays down the general principles and requirements of food law, establishes the European Food Safety Authority (EFSA), and sets procedures in matters of food safety (OJ L 31, 1.2.2002). According to this regulation, food law means statutory, regulatory, and administrative provisions governing food matters in general and food safety in particular, both at the EU and national levels. The regulation created a basis for ensuring a high level of human health protection and consumer interests related to food. It established common principles and obligations, institutional arrangements, and procedures supporting decision-making in food and feed safety matters. It applies to all stages of production, processing, and distribution of food and feed, except primary production for private domestic use and domestic food preparation, handling, or storage for private consumption. The key subject of these regulations is to ensure food safety in the EU at every stage of the food chain, including the production, processing, and distribution of food and feed intended for farm animals (OJ L 31, 1.2.2002, D'Amore et al. 2025).

Official food control

Existing legislation does not fully prevent the occurrence of food contaminated with chemical substances. National inspections annually identify numerous irregularities, some of which pose significant risks to human health and life (D'Amore et al. 2025, Wolniak, Grebski 2025).

According to FAO and WHO, food safety control systems can be classified into three main models depending on their level of organization and institutional integration: multi-institutional, single-institutional, and integrated (FAO/WHO).

In 2020, the European Commission introduced its Farm to Fork Strategy as a key element of the European Green Deal (EGD). One of its priorities is food safety, aiming to ensure food security, promote sustainable food production (including reduced use of pesticides, fertilizers, and antipathogens, as well as increased organic farming), and counteract food fraud in the supply chain (Weber et al. 2025).

In the EU, food quality and safety are the responsibility of the producer or the entity placing the product on the market. However, at each stage of production, processing, and distribution, official controls cover food quality, safety, and the protection of consumer interests, including health (OJ L 95, 7.4.2017; D'Amore et al., 2025). Official controls at the EU level are regulated by Regulation (EU) 2017/625 of the European Parliament and of the Council of 15 March 2017 (OJ L 95, 7.4.2017). Its purpose is to establish a uniform EU framework for organizing official controls throughout the agri-food chain, taking into account provisions of Regulation (EC) 882/2004 of 29 April 2004 (OJ L 165, 30.4.2004) and sectoral legislation.

The food safety control system in Poland is multi-institutional and consists of five inspectorates: the State Sanitary Inspectorate (PIS), the Veterinary Inspectorate (IW), the Agricultural and Food Quality Inspection (IJHARS), the Main Inspectorate of Plant Health and Seed Inspection (PIORiN), and the Trade Inspection (IH). In addition, the system is supported by two national research institutions: the National Institute of Public Health – National Institute of Hygiene (NIZP PZH-PIB) and the National Veterinary Research Institute (PIW-PIB), which conduct research in the field of food safety (Żeber-Dzikowska et al. 2025).

In Poland, the analysis of chemical residues in food collected from the market is carried out by laboratories of the State Sanitary Inspectorate as part of the annually developed monitoring and official control plans. The RASFF network in Poland is managed by the Chief Sanitary Inspector (GIS), who establishes and operates the National Contact Point (NCP). Based on available information, GIS takes appropriate actions and reports to the European Commission on identified cases of food contamination with pesticides and heavy metals (Żeber-Dzikowska et al. 2025).

Food healt risk assessment

Ensuring food safety requires the identification, assessment, and control of hazards that may affect public health. Therefore, food safety should be based, among other elements, on risk analysis, which includes hazard identification, the assessment of risks associated with these hazards, estimation of their impact on public health (i.e., risk assessment), and the classification of risks according to their level of impact on public health. Decision-making in food safety should be grounded in risk assessment (FAO 2020, Liao et al. 2025).

The foundations for developing the risk analysis framework were established by the Codex Alimentarius Commission (CAC) of FAO/WHO. According to Codex Alimentarius (CA), risk analysis is a process consisting of three components: risk assessment, risk management, and risk communication. These stages are internationally recognized and widely applied by CAC as the basis for establishing scientific standards and criteria related to food safety hazards. In this context, the food safety management system aims to assess risks to human health resulting from food consumption and to identify, select, and implement risk mitigation strategies to control and reduce these risks, thereby improving the overall level of public health (LeJeune, Wearne 2024).

Risk assessment involves the scientific analysis of known or potential adverse health effects resulting from human exposure to foodborne hazards, in line with CA guidelines (Ng et al. 2022). Health risk associated with contaminants is usually assessed by distinguishing between non-carcinogenic and carcinogenic risk (Polak-Juszczak, Podolska 2021). Health risks can be estimated by calculating the Estimated Weekly Intake (EWI) and comparing the results with the Provisional Tolerable Weekly Intake (PTWI) values established by the Joint FAO/WHO Expert Committee on Food Additives (Ferreira et al. 2023).

The literature extensively describes the methods of assessing health risks related to food contaminated with pesticides and heavy metals (Liang et al. 2022, Huda et al. 2024). Traditional risk assessments often rely on comparing metal concentrations with permissible regulatory limits. However, such strategies may not fully address the uncertainty related to actual exposure (Shaibur et al. 2024).

RESULTS AND DISCUSSION

The bibliometric analysis demonstrated that, as of 12 May 2025, the PubMed scientific database contained a total of 6,324 (100%) publications related to pesticide and heavy metal residues in food and their effects on consumer health. Among these, 4,011 (63.42%) publications concerned the occurrence of pesticide and heavy metal residues in food, including 2,887 (45.65%) on pesticides and 1,124 (17.77%) on heavy metals. Furthermore, 2,313 (36.57%) publications referred to the health effects of contaminated food, including 631 (9.97%) related to pesticides and 1,682 (26.59%) to heavy metals, during the period 2020-2024 (Table 2).

Table 2

Publications on Pesticide and Heavy Metal Residues in Food and Their Impact on Consumer Health in 2020-2024

Year of publication	Number of publications based on searching by keywords			
	pesticide residues in food	health risks associated with pesticides in food	heavy metal residues in food	health risks associated with heavy metals in food
2020	523	88	166	275
2021	572	126	203	306
2022	561	123	235	368
2023	591	120	229	361
2024	640	174	291	372
Results in total	2 887	631	1 124	1 682
Total number of publications	**6 324**			

The traditional approach to food safety, based on hazard analysis and largely reliant on official inspections and sampling systems, is insufficient to ensure adequate consumer protection. It is now recognized that a modern food safety management system should link hazards to public health outcomes and be based on prevention rather than solely on end-product testing and control (Rhouma et al. 2024).

According to the 2024 Annual Report of the European Commission (EC) on food health and safety, which includes a review and analysis of information exchanged through the Alert and Cooperation Network (ACN), fruits and vegetables accounted for 16% of notifications (1,479) in ACN, making them the most frequently reported product category in the EU. The majority of cases (approximately 66%) concerned potential health hazards, including pesticide and heavy metal residues. Pesticide residues remained the main issue reported in ACN, particularly in citrus fruits, dried fruits, and peppers, with the most frequently detected substances being chlorpyrifos, acetamiprid, and dimethoate (European Commission 2025).

Cereal products and bakery goods accounted for 6% of notifications (562), with rice being the most frequently reported commodity (45%), particularly basmati rice. The main issues were pesticide residues exceeding EU maximum limits. Fishery products accounted for 4% of notifications (388), with the majority (40%) concerning tuna products. Key problems included contamination with heavy metals, notably elevated mercury levels in swordfish. Herbs and spices accounted for 4% of notifications (392), with safety concerns primarily related to oregano and cumin. Multiple pesticide residues in cumin were frequent problems, with one sample containing as many as 18 different pesticides (European Commission 2025).

A summary of RASFF food safety notifications in EU countries in 2020 and 2022 (European Commission RASFF), along with the percentage of violations of maximum residue levels (MRLs) – EFSA, is presented in Table 3.

Table 3

Number of RASFF notifications and MRL violations in EU countries in 2020 and 2022

Country	2020		2022	
	RASFF notifications	pesticide MRL exceedances (%)	RASFF notifications	pesticide MRL exceedances (%)
Austria	267	0.8	45	0.8
Belgium	215	1.2	60	1.2
Bulgaria	21	1.5	212	1.5
Croatia	16	0.7	30	0.7
Cyprus	70	0.9	25	0.9
Czech Republic	105	1.0	40	1.0
Denmark	27	0.6	50	0.6
Estonia	81	0.5	20	0.5
Finland	220	0.4	35	0.4
France	531	1.1	100	1.1
Germany	51	1.0	100	1.0
Greece	28	1.3	80	1.3
Hungary	58	1.0	45	1.0
Ireland	297	0.5	25	0.5
Italy	32	1.2	90	1.2
Latvia	103	0.7	18	0.7
Lithuania	31	0.6	15	0.6
Luxembourg	4	0.4	10	0.4
Malta	498	0.8	12	0.8
Netherlands	185	0.9	70	0.9
Poland	30	1.2	60	1.2
Portugal	33	1.1	55	1.1
Romania	35	1.3	50	1.3
Slovakia	40	0.9	35	0.9
Slovenia	193	0.6	20	0.6
Spain	115	1.4	90	1.4
Sweden	267	0.5	40	0.5

Source: Own elaboration based on data from the European Commission RASFF and the European Food Safety Authority (EFSA).

According to the 2024 report on public health activities of the State Sanitary Inspectorate (PIS), EU Member States submitted a total of 5,270 notifications to the RASFF network. The Polish Contact Point submitted 297 notifications to the RASFF system. The number of notifications in 2024 was lower than in 2023. Of the notifications submitted by Poland, 258 concerned food. One of the most frequent reasons for notification was the presence of pesticide residues (52 notifications), mainly in fruits and vegetables (GIS – Report on the Sanitary Condition of the Country).

The number of RASFF notifications submitted by Poland to the European Commission is presented in Tables 4 and 5.

Table 4

RASFF notifications by type of hazard in 2020-2024

Number of notifications	Year									
	(mainly in fruits and vegetables)					metals (mainly in vegetables)				
	2020	2021	2022	2023	2024	2020	2021	2022	2023	2024
	17	41	42	63	52	3	6	9	11	8

Source: Own elaboration based on data from the GIS activity reports for 2020-2024, https://www.gov.pl/web/gis/raport---stan-sanitarny-kraju

Table 5

RASFF notifications concerning products from Poland by type of hazard in 2020-2024 (own elaboration based on GIS reports)

Number of notifications	Year									
	pesticides (mainly in fruits and vegetables)					metals (mainly in vegetables)				
	2020	2021	2022	2023	2024	2020	2021	2022	2023	2024
	12	18	18	16	14	2	3	5	13	11

Source: Own elaboration based on data from GIS activity reports for 2020-2024, https://www.gov.pl/web/gis/raport---stan-sanitarny-kraju

Food contamination with pesticides and heavy metals

As part of official control and monitoring conducted by the State Sanitary Inspectorate (PIS) in Poland in 2022, a total of 4,925 food samples were tested for pesticide residues. Analyses were carried out for the presence of 486 pesticide residues in total. Out of 4,890 (100%) food samples examined, no pesticide residues were detected in 2,198 samples (44.9%). In 2,375 samples (48.6%), residues of at least one pesticide were found, but at levels not exceeding the corresponding maximum residue limits (MRLs). In 317 samples (6.5%), 374 results exceeded the MRLs for at least one pesticide. After including the default expanded uncertainty of 50.0%, 144 samples (2.9%) with 160 results were considered non-compliant with the applicable MRLs.

The most common causes of non-compliance were the presence of chlorpyrifos and chlorpyrifos-methyl (29 cases in total) and ethephon (15 cases), most frequently detected in Chinese cabbage, grapefruits, and peppers, respectively.

The number of positive results, i.e., at levels equal to or above the corresponding limits of quantification (≥LOQ), amounted to 7,741. The most frequently detected pesticides in 2022 included fungicides such as azoxystrobin, boscalid, fludioxonil, fluopyram, tebuconazole, captan, and dithiocarbamates, the insecticide acetamiprid, as well as the bromide ion. The products with the highest number of residues per sample were grapefruits, lemons, grapes, bananas, rocket, and gooseberries. The highest numbers of different pesticide residues were detected in strawberries (53), grapes (53), tomatoes (46), tea (44), apples (36), and cucumbers (36) (Struciński et al. 2022).

Studies of pesticide residues carried out under official control in Poland by the Main Inspectorate of Plant Health and Seed Inspection (PIORiN) in 2024 covered 24 crops: 21 vegetable crops (both greenhouse and field-grown) and 3 fruit crops. Among the samples analyzed, 421 (64.8%) contained no pesticide residues. Residues were detected in 229 samples (35.2%), of which 208 samples (32.0%) contained residues at or below the MRL, or residues above the MRL but not classified as exceedances after accounting for 50.0% uncertainty. However, 21 samples (3.2%) contained residues exceeding the MRLs. As part of the RASFF system, 6 notifications were issued since the exceedances of maximum residue levels were found in post-harvest samples (PIORiN).

In 114 samples (17.5%), active substances not approved for use in the tested crop were detected. In 12 samples (1.8%), the simultaneous presence of non-approved substances in amounts exceeding MRLs was recorded. Detailed data on the number and type of samples, analyses performed, and pesticide residue determinations in 2020–2024 are presented in Table 6 (PIORiN).

The Institute of Agricultural and Food Biotechnology – State Research Institute in Warsaw (IBPRS-PIB), commissioned by the Ministry of Agriculture and Rural Development, conducts research on the quality analysis of agricultural raw materials, with particular attention to the occurrence of contaminating substances. As part of the annual work carried out at IBPRS-PIB, analyses of basic cereal raw materials from domestic harvests are performed, including the occurrence of contaminants such as pesticide residues and heavy metals.

In 2024, a total of 552 (100%) grain samples were examined, including 77 (14.0%) barley, 89 (16.0%) maize, 65 (12.0%) oats, 158 (29.0%) wheat, 78 (14.0%) triticale, and 85 (15.0%) rye. The analyses identified the presence of pesticide residues and heavy metals in these samples.

The detected levels of pesticide residues in grain from the 2024 harvest are presented in Tables 7 and 8, while the concentrations of heavy metals in grain are shown in Tables 9 and 10 (IBPRS-PIB).

Table 6

Summary of studies, sample types, analyses, and pesticide residue determinations carried out by PIORiN in 2020-2024

Year	Number of crops inspec-ted	Type of analysis	Number of samples	Type of samples	Number of analyses	Number of samples with residues ≥ LOQ*	Number of samples with MRL exceedances**	Number of samples with active substances not authorized for the crop
2024	24	planned official control	650	67 (10.3%) fruits 583 (89.7%) vegetables	2 754	208 (32.0%)	21 (3.2%)	114 (17.5%)
2023	14		600	214 (35.7%) fruits 386 (64.3%) vegetables	2 451	238 (39.7%)	12 (2.0%)	76 (12.7%)
2022	19		600	172 (28.7%) fruits 428 (71.3%) vegetables	2 485	206 (34.3%)	11 (1.8%)	75 (12.5%)
2021	25		603	177 (29.4%) fruits 426 (70.6%) vegetables	2 478	242 (40.2%)	10 (1.7%)	47 (7.8%)
2020	31		600	249 (41.5%) fruits 351 (58.5%) vegetables	2 558	287 (47.8%)	9 (1.5%)	50 (8.3%)

Source: Own elaboration based on data from the activity reports of the Main Inspectorate of Plant Health and Seed Inspection (PIORiN) for 2020-2024. * LOQ – limit of quantification; ** MRL exceedance – residue level of a given substance exceeding the maximum residue limit (after including 50.0% uncertainty); https://www.gov.pl/web/piorin/sprawozdania-z-dzialalnosci-piorin

Table 7

Active substances detected in the analyzed grain samples in 2024

No	Active substance	*n*	Content (mg kg^{-1})		MRL (mg kg^{-1})	Maximum % of MRL
			min	max		
Barley						
1.	Bixafen	1	0.09	0.09	1.5	6
2.	Spiroxamine	1	0.01	0.01	0.05	20
3.	Fluxapyroxad	1	0.06	0.06	3	2
4.	Azoxystrobin	3	0.02	0.08	1.5	5
5.	Pirimiphos-methyl	4	0.01	0.04	5	1
6.	Tebuconazole	6	0.03	0.12	2	6
Maize						
1.	Flupyradifuron	2	0.01	0.02	0.05	40
Oats						
1.	Deltamethrin	1	0.01	0.01	2	1
2.	Fluxapyroxad	1	0.01	0.01	0.4	3
3.	Tebuconazole	3	0.01	0.15	2	8
4.	Pirimiphos-methyl	5	0.01	0.28	5	6
Wheat						
1.	Tebukonazole	9	0.01	0.01	0.3	3.3
2.	Azoxystrobin	8	0.01	0.04	0.5	8
3.	Boscalid	8	0.01	0.05	0.8	6.25
4.	Diphenylamine	3	0.01	0.02	0.05	40
5.	Fludioxonil	1	0.02	0.02	0.01	200
6.	Pirimiphos methyl	6	0.01	0.07	5	1.4
Triticale						
1.	Tebuconazole	1	0.01	0.01	0.3	3.3
2.	Pirimiphos-methyl	1	0.01	0.01	5	0.2
3.	Azoxystrobin	1	0.01	0.01	0.5	2.0
Rye						
1.	Tebuconazole	1	0.02	0.02	0.3	6.7
2.	Azoxystrobin	2	0.01	0.01	0.5	2.0
3.	Pirimiphos-methyl	2	0.01	0.03	0.5	6.0
4.	Malathion	4	0.01	0.02	8	0.3

Source: Own elaboration based on research reports conducted by IBPRS-PIB in 2024 on grain samples of barley, maize, oats, wheat, triticale, and rye (IBPRS-PIB).

Table 8

Pesticide residues in the analyzed grain samples in 2024

Substance	Number of samples	Number of active substances (a.s.)	Samples with residues n	Samples with residues (%)	Number of samples containing 1 a.s.	Number of samples containing 2 a.s.	Number of samples containing 3+ a.s.	Number of samples with MRL exceedances*	Number of samples ≥ 0,5 MRL exceedances*
	barley								
Pesticides excluding glyphosate	77	6	12	16	9	2	1	0	0
	maize								
	89	1	2	2	2	0	0	0	0
	oats								
	65	4	9	14	8	1	0	0	0
	wheat								
	158	6	25	16	17	6	2	1	1
	triticale								
	78	3	3	4	3	0	0	0	0
	rye								
	85	4	6	7	3	3	0	0	0

Source: Own elaboration based on IBPRS-PIB research reports (2024) covering the analysis of grain samples: barley, maize, oats, wheat, triticale, and rye.

Table 9

Range of heavy metal contents in the analyzed grain samples in 2024

Element	n	≥LOQ		Content (mg kg^{-1})			
		n	(%)	min	max	median	mean
Barley							
Lead	77	75	97.4	0.000	0.156	0.044	0.0483
Cadmium	77	71	92.2	0.000	0.051	0.007	0.0110
Arsenic	77	6	7.8	0.00	0.01	0.00	0.0008
Mercury	77	1	1.3	0.000	0.001	0.000	0.000013
Maize							
Lead	89	89	100.0	0.002	0.153	0.013	0.0216
Cadmium	89	58	65.2	0.000	0.035	0.003	0.0045
Arsenic	89	2	2.2	0.000	0.01	0.00	0.0002
Mercury	89	0	0.0	0.000	0.000	0.000	0.000
Oats							
Lead	65	65	100.0	0.003	0.085	0.031	0.0336
Cadmium	65	65	100.0	0.002	0.083	0.030	0.0315
Arsenic	65	17	26.2	0.000	0.04	0.00	0.0042
Mercury	65	1	1.5	0.000	0.001	0.000	0.000015
Wheat							
Lead	158	139	88.0	0.0005	0.489	0.019	0.0366
Cadmium	158	149	94.3	0.0005	0.086	0.024	0.0273
Arsenic	158	6	3.8	0.005	0.03	0.005	0.0053
Mercury	158	1	0.6	0.0005	0.001	0.0005	0.0005
Triticale							
Lead	78	71	91.0	0.0005	0.198	0.021	0.0310
Cadmium	78	62	79.5	0.0005	0.073	0.008	0.0134
Arsenic	78	2	2.6	0.005	0.02	0.005	0.0053
Mercury	78	0	-	0.0005	0.0005	0.0005	0.0005
Rye							
Lead	85	70	82.4	0.000	0.159	0.027	0.0339
Cadmium	85	78	91.8	0.000	0.067	0.013	0.0151
Arsenic	85	2	2.4	0.00	0.02	0.00	0.0004
Mercury	85	0	-	0.000	0.0000	0.000	0.0000

Results are presented as the middle limit of quantification (<LOQ = 0.5 × LOQ).
Source: Own elaboration based on IBPRS-PIB research reports (2024) covering the analysis of grain samples: barley, maize, oats, wheat, triticale, and rye (IBPRS-PIB).

Table 10

Heavy metal contents in the analyzed grain samples in 2024

Element	MRL ($mg\ kg^{-1}$)	Samples with concentration						Maximum % of MRL
		≥MRL		≥0,5 MRL		≥0,25 MRL		
		n	(%)	*n*	(%)	*n*	(%)	
Barley								
Lead	0.2	0	-	5	6.5	34	44.2	78
Cadmium	0.05	1	1.3	6	7.8	24	31.2	102
Maize								
Lead	0.2	0	-	4	4.5	8	9.0	77
Cadmium	0.05	0	-	2	2.2	8	9.0	70
Oats								
Lead	0.2	0	-	0	-	14	21.5	43
Cadmium	0.1	0	-	0	13.8	41	63.1	83
Wheat								
Lead	0.2	1	0.6	13	8.2	37	23.4	245
Cadmium	0.1	0	-	23	14.6	78	49.4	86
Triticale								
Lead	0.2	0	-	2	2.6	15	19.2	99
Cadmium	0.1	0	-	1	1.3	16	20.5	73
Rye								
Lead	0.2	0	-	2	2.4	24	28.2	80
Cadmium	0.05	1	1.2	18	21.2	43	50.6	134

Source: Own elaboration based on IBPRS-PIB research reports (2024) covering the analysis of grain samples: barley, maize, oats, wheat, triticale, and rye (IBPRS-PIB).

Scientific studies have demonstrated the contamination of fruits and vegetables with pesticides and heavy metals. Selected research findings are presented in Table 11.

Health effects of food contamination with pesticides and heavy metals

Environmental pollution, food safety, and consequently human health are closely interconnected. Food contamination with chemical substances has been identified in a wide range of products, including fruits, vegetables, fish, and seafood, and their potential impact on human health has been documented. Nutritional recommendations to increase the consumption of fruits, vegetables, and whole grain products may result in the introduction of pesticides and heavy metals into the human body through prior contamination, which can lead to severe cumulative toxicity.

Table 11

Pesticide and heavy metal residues in plant-based food products in selected studies

Author of the study	Research result
Gaouar et al. 2021	The aim of the study was to assess the levels of residues of pesticides commonly used in tomato cultivation in western Algeria. A total of 30 tomato samples were analyzed using a multi-residue method based on liquid chromatography coupled with tandem mass spectrometry (LC-MS/MS) following QuEChERS extraction. Five pesticides (difenoconazole, triadimenol, metalaxyl, chlorpyrifos, and methomyl) were detected in 14 samples (47%). Among these, residues of two different pesticides were found in five samples. The concentration levels ranged from 2.29 to 64.3 μg kg^{-1}. Methomyl residue in one sample exceeded the maximum residue limit (MRL) established by the European Union.
Liang et al. 2022	A study conducted in China included 37,462 (100%) samples of 133 types of fruits and vegetables analyzed using HPLC-Q-TOF/MS. Pesticide residues were detected in 24,957 samples (66.6%), while no residues were found in 12,505 samples (33.3%). Among the 318 pesticides detected, 18 were identified as banned by the Chinese Ministry of Agriculture. In total, these banned pesticides at measurable concentrations were detected 1,896 times in 1,798 samples (4.8% of all collected samples and 7.2% of positive samples).
El-Sheikh et al. 2022	Samples of vegetables and fruits collected from farmers' markets in the Sharqia province of Egypt were analyzed for pesticide residues using LC-MS/MS and GC-MS/MS. A total of 40 pesticides were detected in the analyzed vegetable and fruit samples. Insecticides represented the most frequently detected group, occurring in 85% of vegetable samples and 69% of fruit samples. The highest numbers of pesticide residues were found in cucumber and apple samples. Mean residue levels ranged from 7 to 951 μg kg in vegetables and from 8 to 775 μg kg^{-1} in fruits. Among the residues detected, 35 (40.7%) out of 86 in vegetables and 35 (38.9%) out of 90 in fruits exceeded the permissible limits. The results for lambda-cyhalothrin, fipronil, dimethoate, and omethoate in spinach, zucchini, persimmons, and strawberries, respectively, indicated potential acute or chronic health risks when consumed in amounts of 0.1-0.2 kg per day.
Ouakhssase et al. 2024	A total of 30 green bean samples from various popular markets in the Souss--Massa region (Morocco) were analyzed for pesticide residues. The QuEChERS extraction method was applied, followed by liquid chromatography coupled with tandem mass spectrometry (LC-MS/MS) and gas chromatography coupled with mass spectrometry (GC-MS/MS). The results showed that 8 out of 30 green bean samples tested positive, with residue levels ranging from 0.015 to 0.112 mg kg^{-1}. Azoxystrobin was the most frequently detected pesticide, present in 5 samples. For authorized pesticides, none of the samples exceeded the European maximum residue limit (MRL) for green beans; however, fipronil, a banned substance, was detected in one sample at a concentration of 0.027 mg kg^{-1}.
Almutiriy et al. 2024	The presence of pesticide residues in leafy vegetables was assessed in 100 samples collected from the Central Market in Jeddah, Kingdom of Saudi Arabia. The QuEChERS extraction method combined with liquid chromatography – tandem mass spectrometry (LC-MS/MS) was applied to comprehensively analyze a database of 237 different pesticides. The results showed that 60.0% of the analyzed samples were free of pesticide residues, while 40.0% were contaminated with 17 different pesticide residues. The most frequently detected pesticide was triallate. Approximately 45.0% of the samples contained pesticide residues at or below the maximum residue limits (MRLs) established by the European Union, whereas the remaining 55.0% exceeded these levels.
Andrade et al. 2024	In 1,063 fruit and vegetable samples collected from 12 markets in São Paulo, the levels of 237 pesticides were assessed. The QuEChERS extraction method was applied, followed by GC-MS/MS and LC-MS/MS analysis. The results showed that 30.0% of the samples contained residues below the maximum residue limits (MRLs), while 6.0% exceeded them. In addition, 23.0% of the samples exhibited excessive residues relative to their crops, and no residues were detected in 40.0% of the samples.

Bayissa, Gebeyehu 2021	The study aimed to determine the concentrations of selected heavy metals in vegetables (cabbage and tomato) from the Koka area in central Ethiopia using inductively coupled plasma optical emission spectrometry (ICP-OES). The concentrations of As, Pb, Cd, Cr, and Hg detected in tomato and cabbage samples exceeded the recommended values, with mean levels ranging from 0.93-6.76, 1.80-7.26, 0.33-1.03, 0.86-5.16, and 3.23-4.36 mg kg^{-1} dry weight, respectively. The results indicate that leafy vegetables accumulate more heavy metals than non-leafy vegetables.
Tahir et al. 2022	The study determined the concentrations of chromium (Cr), arsenic (As), cadmium (Cd), and lead (Pb) in the soil–plant system of agricultural fields in the Siran Valley, Mansehra, Pakistan. Although heavy metal concentrations in soils were within permissible limits for agricultural soils, the concentrations in many vegetables exceeded recommended safe values. Among the six leafy vegetables analyzed, all had As levels above the safe limit, four also exceeded Cr, and two exceeded Cd. For the five fruiting and flowering vegetables, all contained As above the safe limit, two exceeded Cr, and one exceeded Pb at hazardous levels. Among the five tuber, bulb, and root vegetables, all exceeded safe limits for As, and one for Cd.
Lazović et al. 2023	Concentrations of Cd, Pb, Hg, and As were determined in 455 samples of 27 vegetable species and 28 different vegetable products. Vegetables (*n*=387) and vegetable products (*n*=68) originated from 31 countries, including Serbia. Samples were analyzed using inductively coupled plasma optical emission spectrometry (ICP-OES). The maximum permissible levels of Cd and Pb for vegetables and vegetable products were exceeded in 118 samples (25.9% of the total; *n*=455), including 95 vegetable samples (Cd in 67 and Pb in 28 samples) and 23 vegetable product samples (Cd in 20 and Pb in 3 samples).
Chowdhury et al. 2024	The study aimed to assess the concentrations of heavy metals in fifteen vegetable species. The study was conducted in the Noakhali district of Bangladesh. Fifteen different vegetable species were collected from three local markets in the district, with three replicate samples taken for each species at each market. In total, 135 samples were collected. Heavy metal concentrations were determined using atomic absorption spectrometry (AAS). The mean concentrations of Pb, Cd, Cr, Ni, and Fe in vegetables were 4.78, 0.713, 9.266, 0.083, and 5.06 mg kg^{-1} fresh weight (fw), respectively, all exceeding the FAO/WHO reference values.
Rahim et al. 2024	The study examined the levels of heavy metals, including Cd, Cr, Ni, Pb, Zn, and Cu, in locally cultivated and commercially available leafy vegetables, comparing them with the safety limits established by WHO/FAO. The results showed that Cd, Cr, Ni, and Pb levels in vegetables exceeded the WHO/FAO limits, while Zn and Cu remained within acceptable ranges. Commercially sold vegetables exhibited higher concentrations of heavy metals compared to those from nearby farms.

The level of risk associated with food contamination varies depending on the amount of food consumed and the concentration of chemical contaminants in food. There is no universally safe level of exposure to chemicals; however, for many of them, acceptable exposure levels have been established, below which no toxic effects are expected. The type of contamination, the dose received, and individual biological factors all contribute to determining the toxic effects of exposure. Long-term or repeated exposure to pesticides and heavy metals leads to chronic toxicity. The consumption of fruits and vegetables contaminated with pesticides and heavy metals may result in their accumulation in the human body, thereby affecting health status. These contaminants have been linked to the development of various chronic diseases, including cancers, respiratory, metabolic, reproductive, and neurological disorders (Ochwanowska et al. 2019, Chmielewski et al. 2020, Alengebawy et al. 2021, Dietrich et al. 2022, Chmielewski et al. 2023, Onyeaka et al. 2024, Żeber-Dzikowska et al. 2025).

Scientific studies demonstrate health risks arising from contamination of fruits and vegetables with pesticides and heavy metals. Selected findings are presented in Table 12.

Table 12

Health risks associated with pesticide and heavy metal residues in plant-based food in selected studies

Author of the study	Research result
Liang et al. 2022	In a study of 37,462 samples of 133 types of fruits and vegetables analyzed using HPLC-Q-TOF/MS, pesticide residues were detected in 24,957 of the 37,462 samples. The dietary exposure risk to banned pesticides was assessed. The results showed that 66.62% of the samples contained at least one pesticide. Among the pesticide-positive samples, a total of 18 banned pesticides were detected 1,896 times in 1,798 samples. Risk assessment indicated that 11.71% of positive detections exceeded safety thresholds and posed unacceptable risk.
El-Sheikh et al. 2022	To assess pesticide residues in vegetables, 66 samples representing 13 vegetable types were analyzed. Pesticide residues were detected in 44 samples (67.0%). For fruits, residues were found in 33 of 54 analyzed samples (61.0%). Residue levels in vegetables and fruits were determined using LC-MS/MS and GC-MS/MS. A total of 40 pesticides were identified across all samples. Insecticides were the most frequently detected group, present in 85.0% of vegetable samples and 69.0% of fruit samples. Among the detected residues, 35 (40.7%) out of 86 in vegetables and 35 (38.9%) out of 90 in fruits exceeded permissible limits. The findings indicate a potential for acute or chronic risk at consumption levels of 0.1-0.2 kg per day.
Rahim et al. 2024	The study assessed the levels of heavy metals, including Cd, Cr, Ni, Pb, Zn, and Cu, in locally cultivated and commercially available leafy vegetables, comparing them with WHO/FAO safety limits. The health risk index (HRI) values for Zn, Cd, Cu, Ni, and Pb suggested potential health hazards associated with the consumption of green leafy vegetables. The results indicate that consuming leafy greens may expose consumers to health risks related to Cd, Cu, Ni, Pb, and Zn intake.
Chowdhury et al. 2024	The aim of the study was to assess the concentrations of heavy metals in fifteen vegetable species, as well as the associated health risks. Atomic absorption spectrometry (AAS) was used for the determination of heavy metals. The mean concentrations of Pb, Cd, Cr, Ni, and Fe in vegetables were 4.78, 0.713, 9.266, 0.083, and 5.06 mg kg^{-1} fresh weight (fw), respectively, all exceeding the FAO/WHO reference values, indicating consumption-related hazards. The total target hazard quotient (THQ) values for Pb, Cd, Fe, and Ni were >1 through vegetable consumption. Considering the total cancer risk (TCR) values, the cumulative TCR for Pb, Cd, and Cr was higher than 1.0E-04, suggesting potential health risks associated with vegetable consumption.

Liao et al. 2025	The study aimed to assess potential health risks associated with heavy metal intake from vegetables and fruits. A total of 203 vegetable samples and 79 fruit samples were analyzed. The highest mean concentrations were observed in stone fruits. The hazard quotient (HQ) for arsenic from stone fruits exceeded 1 among high consumers. The cancer risk (CR) of arsenic in stone fruits exceeded the acceptable threshold in individuals aged 19-65 years (2.64E-04) and over 65 years (2.99E-04), while consumption of leafy vegetables also exceeded this threshold in the >65 age group (1.48E-04).

CONCLUSIONS

The determination of pesticide and heavy metal residues in food is an essential activity for monitoring contamination and ensuring food safety in the context of public health. Access to food that is safe and compliant with chemical contamination standards is crucial for the health and well-being of consumers. Food products tend to accumulate pesticides and heavy metals, which, due to their widespread use, may significantly affect human health through dietary intake. The quality of food is closely related to its origin and to environmental contamination. Numerous studies confirm the presence of pesticide and heavy metal residues in food products. Even at low concentrations, these contaminants may cause adverse health effects, especially under long-term exposure.

Pesticides and heavy metals represent chemical hazards in food, with levels largely dependent on environmental conditions. Halting cultivation on soils with elevated heavy metal content, in industrial areas, as well as reducing excessive amounts of pesticides (not in accordance with good agricultural practices) used in agriculture, appear to be the most effective strategies to limit consumer exposure to these hazardous substances.

The primary method of reducing the risk of unacceptable levels of chemical contaminants in food is to minimize their presence in agricultural raw materials, including through the application of good agricultural practices. Nevertheless, many contaminants present in agricultural raw materials cannot be eliminated through agronomic methods due to their environmental or non-anthropogenic origin. Therefore, food components and agricultural raw materials must be subject to continuous monitoring.

Control institutions should systematically monitor food quality with respect to contamination by pesticides and heavy metals, while health risk assessment of food should remain a permanent component of the activities of public health authorities.

Author contributions

J.C., B.G. – designed research, J.C., B.G. – analyzed data and wrote the manuscript, I.Ż.D., J.B.B., E.Z., R.S, P.S. – analyzed data. All authors read and approved the manuscript.

Conflicts of interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The present research did not receive any specific donation from any funding agency in the public, commercial, or non-profit sector. Artificial intelligence (AI) was not used in the creation of the paper.

REFERENCES

Alengebawy, A., Abdelkhalek, S.T., Qureshi, S.R., Wang, M.Q. (2021) 'Heavy metals and pesticide toxicity in agricultural soil and plants: Ecological risks and human health implications', *Toxics*, 9(3), 42, available: https://doi.org/10.3390/toxics9030042

Almutiriy, R.S., Alnajeebi, A.M., Elhalwagy, M.E., Thabet, O.A., Alenzi, F.K., Aljadani, M.M. (2024) 'Investigation of pesticide residue levels on commonly consumed leafy vegetables picked from the central market in Jeddah, Saudi Arabia', *Environmental Science and Pollution Research*, 31(4), 6232-6242, available: https://doi.org/10.1007/s11356-023-31694-z

Andrade, G.C.R.M., Barbosa, C.M., Zanquetta, M.S., Viana, M.M., Santiago, M.R., Monteiro, S.H. (2024) 'Pesticides in vegetables and fruits from Brazil and risk assessment', *Food Additives and Contaminants*, Part B, 17(3), 275-285, available: https://doi.org/10.1080/19393210.202.2373347

Baba, F.V., Esfandiari, Z. (2023) 'Theoretical and practical aspects of risk communication in food safety: A review study', *Heliyon*, 9(7), e18141, available: https://doi.org/10.1016/j.heliyon.2023.e18141

Bayissa, L.D., Gebeyehu, H.R. (2021) 'Vegetables contamination by heavy metals and associated health risk to the population in the Koka area of central Ethiopia', *PloS One*, 16(7), e0254236, available: https://doi.org/10.1371/journal.pone.0254236

Cai, Z., Ren, B., Xie, Q., Deng, X., Yin, W., Chen, L. (2024) 'Assessment of health risks posed by toxicological elements of the food chain in a typical high geologic background', *Ecological Indicators*, 161, 111981. available: https://doi.org/10.1016/j.ecolind.2024.111981

Chowdhury, A.I., Shill, L.C., Raihan, M.M., Rashid, R., Bhuiyan, M.N.H., Reza, S., Alam, M.R. (2024) 'Human health risk assessment of heavy metals in vegetables of Bangladesh', *Scientific Reports*, 14(1), 15616, available: https://doi.org/10.1038/s41598-024-65734-6

Chmielewski, J., Gworek, B., Florek-Łuszczki, M., Nowak-Starz, G., Wójtowicz, B., Wójcik, T., Żeber-Dzikowska, I., Szpringer, M. (2020) 'Heavy metals in the environment and their impact on human health', *Przemysł Chemiczny*, 99(1), 50-57, (in Polish) available: http://doi.org/10.15199/62.2020.1.3

Chmielewski, J., Dietrich, G.J., Walosik, A., Zięba, E., Żeber-Dzikowska, I., Motyl, M., Kosoń, A., Gworek, B. (2023) 'Fish as bioindicators of mercury contamination in aquatic environments – an underestimated threat to consumer health', *Journal of Elementology*, 28(3), 633-648, available: http://doi.org/10.5601/jelem.2023.28.2.2421

Dietrich, G.J., Florek-Łuszczki, M., Wojciechowska, M., Wójcik, T., Bąk-Badowska, J., Wójtowicz, B., Zięba, E., Gworek, B., Chmielewski, J. (2022) 'Fish as bio-indicators of environmental pollutants and associated health risks to the consumer', *Journal of Elementology*, 27(4), 879-896. available: http://doi.org/10.5601/jelem.2022.27.3.2322

El-Sheikh, E.S.A., Ramadan, M.M., El-Sobki, A.E., Shalaby, A.A., McCoy, M.R., Hamed, I.A., Ashour, M.B., Hammock, B.D. (2022) 'Pesticide residues in vegetables and fruits from farmer markets and associated dietary risks', *Molecules*, 27(22), 8072, available: https://doi.org/10.3390/molecules27228072

EFSA. European Food Safety Authority Carrasco Cabrera, L., Di Piazza, G., Dujardin, B., Medina Pastor, P. (2023) 'The 2021 European Union report on pesticide residues in food', *EFSA J*, 21(4):e07939, available: https://doi.org/10.2903/j.efsa.2023.7939

European Commission. (2025) 'Health and food safety 2024 annual report: Alert & cooperation network', *Publications Office of the European Union*, available: http://doi.org/10.2875/0397221

RASFF. European Commission. Rapid Alert System for Food and Feed (RASFF) Portal, available online: https://food.ec.europa.eu/safety/rasff_en (accessed on 09.06.2025)

FAO/WHO. Assuring food safety and quality: Guidelines for Strengthening National Food Control Systems, Roma 2023, available: http:// www.fao.org/3/y8705e/y8705e00.htm (accessed on 09.06.2025)

FAO and WHO. 2023. General Principles of Food Hygiene. Codex Alimentarius Code of Practice, No.CXC 1-1969. Codex Alimentarius Commission. Rome, available: https://doi.org/10.4060/cc6125en (accessed on 09.06.2025)

Ferreira, S.L., Cerda, V., Cunha, F.A., Lemos, V.A., Teixeira, L.S., dos Santos, W.N., de Jesus, R.F. (2023) 'Application of human health risk indices in assessing contamination from chemical elements in food samples' *TrAC Trends in Analytical Chemistry*, 167, 117281, available: https://doi.org/10.1016/j.trac.2023.117281

Fernandes, V.C., Pestana, D. (2022) 'Environmental chemicals: integrative approach to human biomonitoring and health effects', *Toxics*, 10(6), 314. available: https://doi.org/10.3390/toxics10060314

FAO. Food and Agriculture Organization of the United Nations (2020). FAO guide to ranking food safety risks at the national level. Food Safety and Quality Series 10. Rome, available: https://doi.org/10.4060/cb0887en

Gaouar, Z.L., Chefirat, B., Saadi, R., Djelad, S., Rezk-Kallah, H. (2021) 'Pesticide residues in tomato crops in Western Algeria' *Food Additives and Contaminants*, Part B, 14(4), 281-286, available: https://doi.org/10.1080/19393210.2021.1953156

GIS. Raport – Stan sanitarny kraju, (in Polish), available: https://www.gov.pl/web/gis/raport---stan-sanitarny-kraju (accessed on 24.06.2025)

Gworek, B., Baczewska-Dąbrowska, A.H., Kalinowski, R., Górska, E.B., Rekosz-Burlaga, H., Gozdowski, D., Olejniczak, I., Graniewska, M., Dmuchowski, W. (2018) 'Ecological risk assessment for land contaminated by petrochemical industry', *PloS One*, 13(10), e0204852, available: https://doi.org/10.1371/journal.pone.0204852

Gworek, B., Baczewska-Dąbrowska, A.H., Kalinowski, R., Górska, E.B., RekoszBurlaga, H., Olejniczak, I., Chmielewski, J., Dmuchowski, W. (2024) 'Ecological risk assessment based on the TRIAD approach in an area contaminated by the metallurgical and mining industries', *Journal of Elementology*, 29(1), 99-121, available: http://doi.org/10.5601/jelem.2023.28.4.2439

Huda, M.N., Harun-Ur-Rashid, M., Hosen, A., Akter, M., Islam, M.M., Emon, S.Z., Ismail, M. (2024) 'A potential toxicological risk assessment of heavy metals and pesticides in irrigated rice cultivars near industrial areas of Dhaka, Bangladesh' *Environmental Monitoring and Assessment*, 196(9), 794, available: https://doi.org/10.1007/s10661-024-12927-1

Integrated Risk Information System (IRIS). U.S. Environmental Protection Agency. Chemical Assessment Summary. National Center for Environmental Assessment, available: https://iris.epa.gov/AtoZ/?list_type=alpha (accessed on 09.12 2024)

IBPRS-PIB. Institute of Agricultural and Food Biotechnology – State Research Institute. Research tasks in 2024. (in Polish), available: https://www.ibprs.pl/zadania-badawcze-w-2024-roku/

Lazović, M., Tomović, V., Vasiljević, I., Kecojević, I., Tomović, M., Martinović, A., Đorđević, V. (2023) 'Cadmium, lead, mercury, and arsenic in fresh vegetables and vegetable products intended for human consumption in the Republic of Serbia, 2015–2017', *Food Additives and Contaminants*, Part B, 16(2), 102-119, available: https://doi.org/10.1080/19393210.202.2169359

LeJeune, J.T., Wearne, S. (2024) 'A recipe for safer food: The theory of change underpinning risk analysis in the context of the Codex Alimentarius', *Microbial Risk Analysis*, 27, 100313, available: https://doi.org/10.1016/j.mran.2024.100313

Liao, K.W., Luo, M.P., Chen, M.L., Chen, Y.H., Say, Y.H., Chin, W.S. (2025)' Health risk assessment of heavy metals with nephrotoxic effects from vegetables and fruits: Taiwan food-related environmental surveillance of hazards (T-FRESH)', *Food and Chemical Toxicology*, 115623, available: https://doi.org/10.1016/j.fct.2025.115623

Liang, S.X., Li, H., Chang, Q., Bai, R., Zhao, Z., Pang, G.F. (2022) 'Residual levels and dietary exposure risk assessment of banned pesticides in fruits and vegetables from the Chinese market based on long-term nontargeted screening by HPLC-Q-TOF/MS', *Ecotoxicology and Environmental Safety*, 248, 114280, available: https://doi.org/10.1016/j.ecoenv.2022.114280

Lučić, M., Miletić, A., Savić, A., Lević, S., Ignjatović, I.S., Onjia, A. (2022) 'Dietary intake and health risk assessment of essential and toxic elements in pepper (*Capsicum annuum*)', *Journal of Food Composition and Analysis*, 111, 104598, available: https://doi.org/10.1016/j.jfca.2022.104598

Ochwanowska, E., Czarny-Działak, M., Żeber-Dzikowska, I., Wójtowicz, B., Gworek, B., Król, H., Dziechciaż, M., Szpringer, M., Chmielewski, J. (2019) 'Chemicals in food as a health threat', *Przemysł Chemiczny*, 98(10), 1614-1618, (in Polish), available: http://doi.org/10.15199/62.2019.10.17

Onyeaka, H., Ghosh, S., Obileke, K., Miri, T., Odeyemi, O.A., Nwaiwu, O., Tamasiga, P. (2024) 'Preventing chemical contaminants in food: Challenges and prospects for safe and sustainable food production', *Food Control*, 155, 110040, available: https://doi.org/10.1016/j.foodcont.2023.110040

Ouakhssase, A., El Aouad, N., Zinedine, A., & Ait Addi, E. (2024) 'Residual levels of pesticides in filet green beans from Souss-Massa, Morocco', *Environmental Science and Pollution Research,* 31(47), 57595-57604, available: https://doi.org/10.1007/s11356-024-34970-8

OJ L 31, 1.2.2002, pp. 1-24. Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety, available: https://eur-lex.europa.eu/eli/reg/2002/178/oj (accessed on 14.06.2025)

OJ L 165, 30.4.2004. Regulation (EC) No 882/2004 of the European Parliament and of the Council of 29 April 2004 on official controls performed to ensure the verification of compliance with feed and food law, animal health and animal welfare rules, available: https://eur-lex.europa.eu/eli/reg/2004/882/oj (accessed on 14.06.2025)

OJ L 95, 7.4.2017. Regulation (EU) 2017/625 of the European Parliament and of the Council of 15 March 2017 on official controls and other official activities performed to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection products, amending Regulations (EC) No 999/2001, (EC) No 396/2005, (EC) No 1069/2009, (EC) No 1107/2009, (EU) No 1151/2012, (EU) No 652/2014, (EU) 2016/429 and (EU) 2016/2031 of the European Parliament and of the Council, Council Regulations (EC) No 1/2005 and (EC) No 1099/2009 and Council Directives 98/58/EC, 1999/74/EC, 2007/43/EC, 2008/119/EC and 2008/120/EC, and repealing Regulations (EC) No 854/2004 and (EC) No 882/2004 of the European Parliament and of the Council, Council Directives 89/608/EEC, 89/662/EEC, 90/425/EEC, 91/496/EEC, 96/23/EC, 96/93/EC and 97/78/EC and Council Decision 92/438/EEC (Official Controls Regulation – text with EEA relevance), https://eur-lex.europa.eu/eli/reg/2017/625/oj (accessed on 14.06. 2025)

PIORiN. Państwowa Inspekcja Ochrony Roślin i Nasiennictwa. Sprawozdania z działalności PIORiN. (in Polish), available: https://www.gov.pl/web/piorin/sprawozdania-z-dzialalnosci-piorin (accessed on 12.05. 2025)

Polak-Juszczak, L., Podolska, M. (2021) 'Mineral and toxic metal composition in three commercial species of Gadidae', *Journal of Food Composition and Analysis*, 95, 103658, available: https://doi.org/10.1016/j.jfca.2020.103658

Rahim, N., Noor, A., Kanwal, A., Tahir, M.M., Yaqub, A. (2024) 'Assessment of heavy metal contamination in leafy vegetables: implications for public health and regulatory measures' *Environmental Monitoring and Assessment*, 196(8), 684, available: https://doi.org/10.1007/s10661-024-12855-0

Rhouma, M., Gaucher, M.L., Badredine, S., Bekal, S., Sanders, P. (2024) 'Food risk assessment in the farm-to-table continuum: report from the conference on good hygiene practices to ensure food safety', *Agriculture & Food Security*, 13(1), 21, available: https://doi.org/10.1186/s40066-024-00476-2

Sadee, B. A., Ali, R. J. (2023) 'Determination of heavy metals in edible vegetables and a human health risk assessment', *Environmental Nanotechnology, Monitoring and Management*, 19, 100761, available: https://doi.org/10.1016/j.enmm.2022.100761

Shaibur, M.R., Howlader, M., Ahmmed, I., Sarwar, S., Hussam, A. (2024) 'Water quality index and health risk assessment for heavy metals in groundwater of Kashiani and Kotalipara upazila, Gopalganj, Bangladesh', *Applied Water Science*, 14(5), 106, available: https://doi.org/10.1007/s13201-024-02169-4

Sharafi, K., Mansouri, B., Omer, A. K., Bashardoust, P., Ebrahimzadeh, G., Sharifi, S., Soleimani, H. (2022) 'Investigation of health risk assessment and the effect of various irrigation water on the accumulation of toxic metals in the most widely consumed vegetables in Iran', *Scientific Reports*, 12(1), 20806, available: https://doi.org/10.1038/s41598-022-25101-9

Struciński P., Lewiński R., Czaja K., Liszewska M., Korcz W. 'Raport: Report: Analysis of potential health risks to consumers resulting from the presence of pesticide residues in food available on the Polish market in 2022. Prepared within the framework of the National Health Program for 2021–2025', National Institute of Public Health NIH – National Research Institute, Warsaw, December 2024. (in Polish), available: https://www.pzh.gov.pl/raport-analiza-potencjalnego-zagrozenia-zdrowia-konsumentow-wynikajacego-z-obecnosci-pozostalosci-pestycydow-w-zywnosci-dostepnej-na-polskim-rynku-w-roku-2022/

Tahir, M.A., Shaheen, H., Rathinasabapathi, B. (2022) 'Health risk associated with heavy metal contamination of vegetables grown in agricultural soil of Siran valley, Mansehra, Pakistan – a case study', *Environmental Monitoring and Assessment*, 194(8), 551, available: https://doi.org/10.1007/s10661-022-10210-9

UoBŻiŻ. Ustawa z dnia 25 sierpnia 2006 r. o bezpieczeństwie żywności i żywienia (Dz.U. 2006 nr 171 poz. 1225), (in Polish), available: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=wdu20061711225 (accessed on 09.12. 2024)

Wolniak, R., Grebski, W.W. (2025) 'Food safety in the European Union: A comparative assessment based on RASFF notifications, pesticide residues, and food waste indicators', *Foods*, 14(14), 2501. available:https://doi.org/10.3390/foods14142501

Weber, M., Liscio, M.C., Bregoli, D., Sospiro, P. (2025) 'From agriculture to agroindustry: the European Union farm to fork policy', *Journal of Industrial and Business Economics*, 1-23. available: https://doi.org/10.1007/s40812-025-00355-2

Żeber-Dzikowska, I., Gworek, B., Goździewska M. (2025) 'Health risk resulting from pesticide residues in food of plant origin – a still valid challenge for health and ecological education', *Annals of Agricultural and Environmental Medicine*, 23(2), 274-279, available: https://doi.org/10.26444/aaem/20573818.06.2025