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ORIGINAL ARTICLE

Health risk resulting from pesticide residues in food of plant origin – a still valid challenge for health and ecological education

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Abstract
Introduction. Pesticides are synthetic or natural substances applied for control of harmful or undesirable organisms, used mainly for the protection of cultivated plants, food products, feeds, and other materials. Systematic and excessive use of plant protection products to combat pests and diseases of agricultural produce still creates risk for the health of consumers. Negative health effects of pesticides use are expressed by consuming their remains with food, changes in the chemical composition of plant raw materials, and consequently, changes in food. The toxicity and harmfulness of pesticides varies.
Objective. The aim of the study is the systematization of knowledge concerning the most important pesticides, the residues of which occur in food. The results of studies on the content of these compounds in food of plant origin, and their effect on consumers' health, are presented and discussed.
Materials and Method. Epidemiological studies were reviewed indicating undesirable health effects. Bibliometrics was used covering the period 2020–2024. The literature review was carried out by searching the PubMed, Scopus, and Google Scholar databases. Bibliographic data were analyzed using the open access criterion and selected subject classification entries.
Results. A diagnosis of residues of chemical compounds of natural and synthetic origin in selected food groups was presented.
Conclusions. Studies show the hazardous effect of pesticides on the majority of living organisms, including humans. Further actions are needed related with their identification in food of plant origin. It is justifiable to identify actions in the area of ecological and health education aimed at raising public awareness of risks resulting from pesticide residues in food of plant origin

Key words
control, safety, pesticides, food, risks, health

INTRODUCTION

Consumption of food is supposed to guarantee the proper functioning of the human body and its development, according to gender, age and physical status, as well as demographic and environmental conditions through the provision of its safety [1, 2, 3].

Every vegetable and fruit is part of living plants, and their cultivation, regardless of whether conventional or ecological, is exposed to similar risks on the part of diseases, pest, and weeds. Therefore, it is necessary to counteract these risks. As part of integrated protection, farmers prioritize the use non-chemical methods, which allows limiting the use of chemical plant protection products to the minimum necessary. Due to this, it is possible to reduce pressure on the natural environment and protect the biodiversity of the agricultural environment. When all the above used methods fail, farmers apply chemical preparations included in the register of plant protection products admitted to trading. The use of pesticides is strictly regulated and farmers must follow the rules described on the product label concerning principles and application dates [4, 5].

Despite the regulations and controls in place, pesticide residues in plant products still occur at levels that may pose a potential health risk to consumers, and their long-term consumption may contribute to negative health effects, indicating the need for further monitoring and improved control methods and the promotion of alternative cultivation methods.

Therefore, the aim of the presented review is to analyze the current state of knowledge. Despite the regulations and controls in place, pesticide residues in plant products still occur at levels that may pose a potential health risk to consumers, and their long-term consumption may contribute to negative health effects, indicating the need for further monitoring and improved methods of control, and the promotion of alternative cultivation methods.

Pesticides is a broad concept defining all substances used for the control of harmful organisms [6, 7]. In addition to plant

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protection products, pesticides include, for example, means to combat rodents and cockroaches, as well as mosquito and tick sprays. The use of pesticides is undoubtedly beneficial in agriculture and veterinary medicine. Their excessive application may contaminate the environment, and also exert a negative effect on the pollination of entomophilic horticultural and agricultural crops [8]. Active substances contained in pesticides undergo various transformations in the environment and translocate between its elements. They reach plants as a result of direct spraying of their surfaces, as well as through the root system, and as a result of environmental pollution [9]. Accumulation of harmful residues after these treatments depends on plant species, pesticide type, dose amount, method of application and soil type. It is dangerous to use expired plant protection products present on farms. In addition, pesticides applied in a liquid form are more harmful than those in a loose form due to the fact that they penetrate rapidly into the root systems of plants [10, 11].

The use of pesticides in the production of plant raw materials carries the risk of the occurrence of their residues throughout the food chain, which may pose a significant risk to the health of consumers [12, 13, 14, 15]. Human exposure to pesticide residues consumed with food is an inevitable consequence of the use of plant protection products in agriculture.

According to estimations, worldwide, nearly 2 million tons of pesticides are applied annually to plants and crops to increase productivity and reduce losses caused by pests and diseases [16]. As shown by the Food and Agriculture Organization of the United Nations (FAO), in 2020, the USA was the biggest user of pesticides, whereas the following 10 biggest users of pesticides worldwide were: Brazil, China, Argentina, the Russian Federation, Canada, France, Australia, India, and Italy [17].

Pesticide residues belong to commonly occurring chemical contaminants in food [12] and, in recent years, have constituted an issue of special interest for authorities responsible for food safety. This is evidenced by the constant expansion of the scope of coordinated monitoring of new products and examined compounds. This results from the need for the protection of consumers' health in connection with the use of pesticides which, by definition, show harmful effects (EFSA 2022) [18].

Member States of the European Union (EU) are obliged to conduct food inspections in order to document and guarantee its safety. In the case of pesticides, these tasks are performed through testing their residues in food present on the market as part of official control and monitoring. In the EU, official control and monitoring of pesticide residues in food is carried out for compliance with the maximum residue limits (MRL). Regulation (EC) No. 396/2005 obliges the member states to carry out inspections of food placed on the market for compliance with the applicable MRLs. This establishes both EU and national control programmes for this purpose [19].

Products containing contaminants harmful to consumers, in amounts exceeding the allowable values, are subject to appropriate procedures and, sometimes, due to safety issues, are withdrawn from the EU market. For this purpose, in the EU the Rapid Alert System for Food and Feed (RASFF) was created [20]. RASFF is used to exchange information between official control body members of this system in the EU. Into this system is entered information concerning food, feeds, and materials for contact with food, potentially hazardous to the health of humans, animals, or the environment, and follow-up actions as a result of identification of such products [21].

In Poland, in accordance with legal regulations on food safety and nutrition (UoBŻiŻ) [22], the Chief Sanitary Inspector (GIS) manages the RASFF system network. Official food and feed control bodies in Poland provide information about confirmed cases of harmful food, feeds, or materials for contact with food on the territory of Poland, in accordance with the scope of the RASFF system to the GIS. Based on the possessed information, they undertake appropriate actions and report to the European Commission (EC) on identified cases of unsafe food and feed. Table 1 presents the number of reports to the EC.

Table 1. Reports to RASFF by GIS in 2023 concerning pesticide residues in food during 2012–2023.

Number of reports	Year											
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
	43	41	6	8	8	7	10	0	17	41	42	63

Source: own compilation based on data included in reports by the Chief Sanitary Inspectorate (GIS) [23]

Control of poisonings with biocidal products in Poland is regulated at the level of the Biocidal Products Act (UoPB), and regulation No. 528/2012 [24]. These tasks are carried out within the structure of the Office for Registration of Medicinal Products, Medical Devices and Biocides. Table 2 demonstrates suspicions and poisonings with biocidal products.

Table 2. Number of suspicions and poisonings with biocidal products in Poland during 2012 – 2023.

Year	Number of registered cases of suspicion or confirmation of poisoning with biocidal products
2023	249
2022	232
2021	127
2020	152
2019	195
2018	227
2017*	275
2016	238 poisonings
2015	281 poisonings
2014	312 poisonings
2013	229 poisonings
2012	203 poisonings

Source: own compilation based on data included in reports by the Office for Registration of Medicinal Products, Medical Devices and Biocides [25].
*from 2017, reporting data were included concerning suspicions of poisoning with biocidal products, without differentiating data into suspicions and poisonings.

Control tests for residues of plant protection products (PPPs) of plant origin are performed by the State Plant Health and Seed Inspection (PIORiN) [26], including, among others: various species of fruits and vegetables (grown under cover and in the ground). Official control of the correct use of plant protection products (PPPs) includes the testing of samples of fruits and vegetable. Tables 3 and 4 present data concerning the number of samples, analyses performed, and determinations of plant protection product residues during 2012–2023.

Table 3. Compilation of tested samples, analyses, and determinations of plant protection product residues performed by the PIORiN during 2012–2023.

Year	Number of controlled crops	Type of testing	Number of samples	Number of analyses	Number of determinations	Number of samples containing residues ≥ DL*	Number of samples exceeding MRLs**	Number of samples containing active substances allowed in cultivation
2023	14	Official Planned Control	600	2 451	234 860	238 (39.7%)	12 (2.0%)	76 (12.7%)
2022	19		600	2 485	215 512	206 (34.3%)	11 (1.8%)	75 (12.5%)
2021	25		603	2 478	198 869	242 (40.2%)	10 (1.7%)	47 (7.8%)
2020	31		600	2 558	183 214	287 (47.8%)	9 (1.5%)	50 (8.3%)
2019	31		662	3 430	194 091	335 (50.6%)	11 (1.7%)	69 (10.4%)
2018	32		602	3 133	169 316	352 (58.5%)	11 (1.8%)	63 (10.5%)
2017	l.d.		604	l.d.	163 213	l.d.	l.d.	l.d.
2016	l.d.		599	3 189	147 668	311 (51.9%)	6 (1.0%)	44 (7.3%)
2015	l.d.		602	3 233	113 423	240 (39.9%)	7 (1.2%)	39 (6.5%)
2014	l.d.		702	3 780	124 718	269 (38.3%)	10 (1.4%)	66 (9.4%)
2013	l.d.		601	2 806	99 204	243 (40.4%)	3 (0.5%)	31 (5.2%
2012	l.d.		600	2 934	93 327	265 (44.2%)	3 (0.5%)	21 (3.5%)

Source: own compilation based on data included in activity reports by the State Plant Health and Seed Inspection (PIORiN) [26]; *DL – detection limit; **exceeding MRL – value of residue of a given compound exceeding the maximum allowable limit of residue of PPPs (after taking into account 50% uncertainty) [25], l.d. – lack of data

Table 4. Number of tested samples and types of determinations of residues of plant protection products performed by the PIORiN during 2012–2023

Year	Number of samples	Type of samples
2023	600	214 (35.7%) fruit samples 386 (64.3%) vegetable samples
2022	600	172 (28.7%) fruit samples 428 (71.3%) vegetable samples
2021	603	177 (29.4%) fruit samples 426 (70.6%) vegetable samples
2020	600	249 (41.5%) fruit samples 351 (58.5%) vegetable samples
2019	662	347 (52%) fruit samples 315 (48%) vegetable samples
2018	602	381 (63%) fruit samples 221 (37%) vegetable samples
2017	604	l.d.
2016	599	l.d.
2015	602	l.d.
2014	702	413 (58.8%) fruit samples 61 (8.7%) samples of vegetables grown under cover 228 (32.5%) samples of ground vegetables
2013	601	l.d.
2012	600	l.d.

Source: own compilation based on data included in activity reports by the State Plant Health and Seed Inspection (PIORiN) [25, 26], l.d. – lack of data

Reports on infectious diseases, infections and poisonings in Poland, including poisonings with pesticides, are provided by the Laboratory for Monitoring and Analysis of Epidemiological Situation/National Research Institute (NIZP-PIB) [27]. Table 5 demonstrates cases of poisonings with pesticides – acute and incidence during 2012–2023.

Global use of pesticides results in their increasing effect on both the environment and humans. An excessive and inappropriate use of pesticides may cause environmental pollution and, consequently, negative effects for human health in the long term. Therefore, it is necessary to intensify educational actions aimed at care of the natural environment which, without doubt, exerts an effect on human health [28, 29].

Health risks related with exposure to pesticides. Recognizing the effect of pesticides on consumer safety, the issue concerning food contamination with pesticides and their effect on human health, is important for public health. One of the basic problems related with ensuring food safety regarding pesticides and safety standards is the lack of globally harmonized regulations in this respect [30].

The progressing degradation of the natural environment is the process hindering the maintenance of food safety. Despite the damage caused by pesticides to the environment, they are indispensable for optimal growth and development, and high plant productivity. The effects of cumulative exposure to pesticide residues can be complex due to their possible interactions. Scientific data concerning possible synergistic effects of pesticide residues, as well as the effects of exposure to residues of many pesticides showing different modes of action [30, 31]. In addition, exposure to various chemical substances may result from different sources, which should also be taken into consideration. In consequence, the lack of knowledge in this area may lead to underestimation of the actual risk for health resulting from pesticide residues in food of plant origin.

Fruits and vegetables are the undisputed basis of the daily diet. According to the guidelines by the World Health Organization (WHO), their minimum daily consumption should be 400 gm, which should be consumed in at least 5 portions [32, 33]. These products provide many valuable ingredients indispensable for the normal functioning of the body. However, at the same time, they may also create health risk due to the occurring toxic substances, including pesticides. Pesticide residues are common chemical contaminants of fruits and vegetables; therefore, the consumption of products contaminated with pesticides may have unfavourable heath consequences [33].

Recent dietary recommendations to increase the consumption of fruit, vegetables, and full-grain products may increase the consumption of pesticides, which may lead to serious cumulative toxicity and increased the risk of the occurrence of chronic diseases, including cancer, respiratory, metabolic, reproductive and neurological disorders [6, 9, 13, 14, 33–36].

Table 5. Number of pesticide poisonings – acute and incidence per 100,000 population

	Year											
Number of cases and incidence per 100,000 opulation i zapadalność na 100 tys. ludności	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
	30	16	4	14	17	10	14	19	2	2	1	2
	0.08	0.04	0.01	0.04	0.04	0.03	0.04	0.05	0.01	0.01	0.00	0.01

Source: own compilation based on data included in reports of infectious diseases, infections and poisonings in Poland to the National Institute of Public Health / National Research Institute (NIZP-PIB) [27].

MATERIALS AND METHOD

The scope of scientific content was analyzed, taken from the PubMed database, English-language online database National Library of Medicine, National Institutes of Health, Bethesda, MD, USA (http://www.ncbi.nlm.nih.gov/PubMed), SCOPUS, Google Scholar, including articles in the field of medicine, with consideration of adverse effects on health of using EC/ENDS. Literature published during 2019–2024 in available scientific information databases was reviewed, assuming that the time period for analysis covers the latest scientific reports concerning the issue in question. During the process of searching for scientific articles, advanced search options were used, based on key words or their combination (Step 1, Tab. 6).

Table 6. Step 1 of the analysis of the literature trends based on key words

Key words	impact of pesticides on consumer health

The next step was to determine the number of publications on pesticides and their effects on consumer health in 2020–2024 (Step 2, Tab. 7), selected articles describing pesticide residues in foods of plant origin were then presented (Step 3, Tab. 8).

Table 7. Publications concerning pesticides and their effect on consumer health during 2020–2024

Year of publication	Number of publications based on searching by key words
	impact of pesticides on consumer health
2020	30
2021	37
2022	44
2023	50
2024	57
Results in total	**218**

Reviews, conference materials, letters to editors, chapters in books, as well as notes from conferences and trainings, were not considered in the review and were excluded from the analysis.

The search was limited to literature in English and literature published with a link to full free access to the text.

RESULTS

The analysis performed confirmed that in the PubMed scientific database (as from 8 December, 2024) there are 218 publications concerning health effects related with pesticide residues in food of plant origin during 2020–2024. Table 7 presents the quantitative list of publications regarding pesticides and their effect on consumer health during the analyzed period. Table 8 demonstrates the selected articles concerning pesticide residues in food of plant origin.

Table 8 presents pesticide residues in food of plant origin.

Studies revealed that pesticides were present in a significant proportion of samples, ranging from about 13% [42] to over 58% [40] of analyzed plant products. In some studies, about half or more of the samples contained pesticide residues. Many studies reported cases of pesticide residues exceeding the Maximum Residue Limits (MRLs); for example, Khazaal et al. [38] found that more than half of detected residues exceeded MRLs, especially chlorpyrifos in cucumbers. Galani et al. [39] detected MRL exceedances in 40% of samples, and the presence of many banned pesticides. Bhatnagar et al. [40] and Ssemugabo et al. [41] also reported MRL exceedances, with some pesticides posing potential health risks. The most commonly detected substances included azoxystrobin, chlorpyrifos, carbendazim, acetamiprid, and DDT, among others. Some studies reported banned pesticides or substances with high toxicity and bio-accumulation potential [39, 45].

Several studies assessed the risk associated with pesticide exposure, indicating potential health hazards, particularly with long-term exposure (e.g., chlorpyrifos in cucumbers — HQ > 1) [41]. This suggests possible chronic health effects that require attention and preventive measures. The studies originated from various regions worldwide, including Poland, China, Cameroon and India, showing the global nature of the issue. Analytical methods, such as QuEChERS, gas chromatography, and mass spectrometry, enabled the detection of numerous pesticides with different chemical properties. Multiple pesticide residues were often detected in single samples, complicating risk assessment due to possible synergistic and cumulative effects. In summary, Table 8 demonstrates that pesticide residues in plant-derived food are a common and global problem, frequently involving the exceeding of permissible limits and detection of highly toxic substances. The study results highlight the need for continuous monitoring, global harmonization of standards, and promotion of safe agricultural practices to reduce health risks to consumers.

CONCLUSIONS

The problem of pesticide residues in agricultural produce has proved to be difficult and remains so. Despite technological efforts aimed at their elimination, pesticide residues are still encountered in agricultural produce. Pesticide residues in plant-based food remain a significant concern for food safety and consumer health, despite advances in technology and regulatory measures. There is a critical need for further development and global harmonization of methods for monitoring and risk assessment related to pesticide residues to enhance public health protection.

Open access to current scientific research plays a vital role in shaping effective risk management strategies and public education about potential pesticide hazards. A comprehensive, holistic approach covering the entire food production chain-from agricultural practices to processing is essential for the effective control of pesticide contamination.

Encouraging and adopting alternative agricultural practices that reduce reliance on chemical pesticides can mitigate environmental and health risks, and on-going monitoring of human pesticide exposure and implementation of preventive measures against adverse health effects, including hormonal disruption and chronic illnesses, are imperative.

Table 8. Characteristics of studies and literature reports were presented in the field pesticide residues in food of plant origin.

Author of the study	Research result
Kowalska et al., 2020 [37]	The analysis of 160 samples revealed pesticide residues in 83 samples (approximately 52%), while 77 samples (around 48%) showed no traces of these substances. In all cases where the targeted compounds were detected, their concentrations remained within the Maximum Residue Levels (MRL). The most frequently identified pesticides were azoxystrobin, found in 36 samples (22.5%); linuron, detected in 33 samples (20.6%); chlorpyrifos and carbendazim, each present in 13 samples (8.1%); metalaxyl and metalaxyl M, identified in 11 samples (6.9%); and acetamiprid, detected in 7 samples (4.4%).
Khazaal et al., 2021 [38]	Out of 387 samples, pesticide residues were detected in 58 (32.2%). For 14 of these residues, more than half of the positive samples exceeded the European Union's Maximum Residue Limits. The hazard quotient (HQ) values for all age groups remained below 1, except for chlorpyrifos in cucumbers, which had an HQ of 1.7945.
Galani el al., 2021 [39]	Residues of 20 halogenated pesticides were identified in 11 agricultural products collected from the three largest cities in Cameroon using QuEChERS extraction and gas chromatography with an electron capture detector (GC-ECD). The health risks associated with dietary exposure were also evaluated. The most frequently detected pesticides were aldrin (85.0% of samples), p,p'-dichlorodiphenyl-trichloroethane (DDT) (81.9%), and β-hexachlorocyclohexane (β-HCH) (72.5%). The highest average residue concentrations, found in chili pepper, were 1.12 mg/kg for methoxychlor, 0.74 mg/kg for alachlor, and 0.39 mg/kg for β-HCH. The highest pesticide residue occurrences were observed in chili pepper (58.9%), cowpea (56.8%), black beans (56.5%), and kidney beans (54.0%). Exceedances of the European Union's maximum residue limits (MRLs) were detected for all 20 pesticides in 40.1% of the positive samples, with 14 banned pesticides present in the analyzed food samples. Chronic, acute, cumulative, and carcinogenic risk assessments indicated that long-term consumption of maize, black beans, kidney beans, groundnuts, and chili pepper contaminated with aldrin, dieldrin, endrin, HCB, heptachlor, o,p'-DDT, p,p'-DDD, p,p'-DDT, p,p'-DDE, and β-HCH could pose potential health risks.
Bhatnagar et al., 2022 [40]	The study results indicated that 58.3% of the collected samples contained pesticide residues below the maximum residue limit (MRL), while 12.5% exceeded the recommended MRL. Analysis of the collected fruit and vegetable samples detected the presence of chlorantraniliprole, carbendazim, beta-endosulfan, chlorpyrifos, malathion, carbaryl, thiomethoxam, DDT, and flubendiamide, with residue levels ranging from 0.00 to 1.41 mg/kg.
Ssemugabo et al., 2022 [41]	A total of 57 pesticides were detected in fruits and vegetables throughout the supply chain. Of these, 39 pesticides were found in all analyzed produce. In some samples, the concentrations of fonofos, fenitrothion, and fenhexamid exceeded the European Union's maximum residue limits (MRLs). Hazard quotient assessments based on dietary exposure scenarios revealed that 18 pesticides, including dichlorvos (444), alanycarb (314), fonofos (68), fenitrothion (62), dioxacarb (55), and benfuracarb (24), had values exceeding 1, suggesting a potential chronic health risk to consumers.
Zheng et al., 2022 [42]	The findings revealed that 726 samples (13% contained pesticide residues, with 94 samples (1.7%) exceeding the maximum residue limit (MRL) set by the national standard (GB 2763–2021, China). Meanwhile, 632 samples (11.2%) had residue levels below the MRL, and 4,881 samples (87.1%) were free of pesticide residues. Bananas and peppers exhibited the highest occurrence of multiple pesticide residues, with contamination from acetamiprid, imidacloprid, pyraclostrobin, and thiacloprid.
Wang et al., 2023 [43]	The findings showed a high occurrence of carbendazim in fruits (26.4%) and elevated concentrations in vegetables (approximately 110 mg/kg), suggesting extensive misuse of the fungicide. Acute consumption risks for certain vegetables and cereals surpassed the recommended limits by up to 12 and 5 times, respectively.
Elmastas et al., 2023 [44]	The study identified active substances such as chlorpyrifos, acetamiprid, azoxystrobin, difenoconazole, malathion, dieldrin, boscalid, triticonazole, tebuconazole, triadimenol, trifloxystrobin, pirimicarb, and dodine in the analyzed fruit and vegetable samples. No active substances were detected in 55 samples (61.0%). Among the 35 samples (39.0%) that contained residues, 31 samples (34.0%) had a single active substance, while 4 samples (5.0%) contained two. Additionally, 6 samples (7.0%) exceeded the maximum residue level (MRL) limits.
da Silva et al., 2024 [45]	Data analysis identified 263 authorized active ingredients, primarily insecticides (43.0%), fungicides (40.0%), and herbicides (14.0%), approved for use in 40 food types. Notably, 4.0% of detected residues are classified as extremely toxic, 5.0% as highly toxic, and 14.0% as moderately toxic. Forty-two compounds, particularly those allowed in animal-derived foods, exhibit a high potential for bioaccumulation. Some foods contain multiple pesticide residues, raising concerns, even though 99.0% of residues remain within the Acceptable Daily Intake. The insecticide methomyl presents potential ingestion risks during lunch, highlighting the need for caution.

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