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Social Perception of Healthy Food in the Light of Interdisciplinary Scientific Certainty

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SOCIAL PERCEPTION OF HEALTHY FOOD IN THE LIGHT OF INTERDISCIPLINARY SCIENTIFIC CERTAINTY

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INTRODUCTION[1]

Food is an indispensable element of tradition and culture and may also determine an individual's self-identification and belonging to a specific group. At the same time, it is the basic condition for the survival of humanity. For much of the history of humanity, the key problem was providing enough safe food. However, over the years, the way of obtaining food has changed significantly. As a result of the Neolithic revolution and the agricultural revolution, traditional farming was transformed into much more effective modern agriculture, and (especially in highly developed countries) the supply of food that we would now call safe food increased significantly.[2] At the same time, the human diet also changed. As a result of the above processes, food-related issues concerning its quality, nutritional value, and long-term impact on health and the environment have become increasingly important in recent years.

In prehistoric times, humans were hunter-gatherers, and their diet depended on what they found or hunted. Over time, humans learned to grow crops and raise animals, which allowed them to meet their nutritional needs in a more stable and predictable way. As technology has evolved, people have increasingly better understood and improved the ways food is produced, processed, and distributed. Technological and social developments resulted in further changes in food and nutrition, and advances in food production and processing allowed for a greater satisfaction of humanity's basic needs. Extremely dynamic changes have occurred in recent decades. In particular, it should be emphasized that the possibility of long-term food storage and the taste of highly processed food have led to a sit-

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1 This monograph contains the results of research conducted as part of the project, Social Perception of Healthy Food in the Light of Interdisciplinary Scientific Certainty financed by the Ministry of Education and Science under the „Science for Society" program. Registration number: NdS/551580/2022/2022.

2 See M. Roser, H. Ritchie, P. Rosado, Food Supply, Our World in Data 2013, accessed: January 4, 2023, https://ourworldindata.org/food-supply.

uation in which, in the 21st century, it is often more available and cheaper than fresh and unprocessed food.[3]

As indicated by the World Health Organization (WHO), the gradual control of most of the dangerous infectious diseases that have plagued humanity since the dawn of time, as well as the complete elimination of some of them, allowed in the second half of the twentieth century to draw attention to the prevalence and etiology of non-communicable diseases (NCDs).[4] These diseases do not spread from one person to another and usually have a long-term course, which is why they are also called chronic diseases.[5] Deaths from NCDs now exceed all deaths from infectious diseases combined. According to WHO, NCDs kill 41 million people every year, which constitutes 71% of all deaths in the world. More than 15 million people aged 30 to 69 die from NCDs each year, and more than 85% of these deaths occur in low – and middle-income countries. Cardiovascular disease causes the majority of NCD deaths (17.9 million people per year), followed by cancer (9.0 million), respiratory disease (3.9 million), and diabetes (1.6 million). According to estimates by the Organization for Economic Co-operation and Development (OECD), approximately 550,000 working-age people die prematurely from NCDs each year in the European Union (EU). They are the leading cause of death in the EU and account for the majority of healthcare spending, costing the EU economy €115 billion a year, or around 0.8% of the GDP of all European Union member states.[6] The most important NCD risk factors include excessive salt consumption and the risk of nutrition-related metabolic disorders, i.e., increased blood pressure, overweight and obesity, hyperglycemia, and hyperlipidemia.[7] Moreover, numerous studies also indicate a relationship between diet and the incidence of cancer.[8] All of the above risk factors are closely related to improper nutrition.[9] Excessive amounts of certain nutrients, such as simple sugars and saturated fats,

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3 G. Adamczyk, Popularność „żywności wygodnej”, „Journal of Agribusiness and Rural Development” 2010, no. 18(4); P. Serafim, C.A. Borges, W. Cabral–Miranda, P.C. Jaime, Ultra-Processed Food Availability and Sociodemographic Associated Factors in a Brazilian Municipality, „Frontiers in Nutrition” 2022, no. 9, https://doi.org/10.3389 /fnut.2022.858089; S. O’Hara, E.C. Toussaint, Food Access in Crisis: Food Security and COVID-19, „Ecological Economics” 2021, no. 180, https://doi.org/10.1016/j.ecolecon.2020.106859.

4 R. Beaglehole, R. Bonita, T.K. Kjellstrom, Podstawy epidemiologii, World Health Organization, 1993.

5 WHO, Non-Communicable Diseases, accessed: August 8, 2022, https://www.who.int/news-room/fact-sheets/detail/noncommunicable-diseases.

6 European Commission, Public Health–Non-Communicable Diseases, accessed: August 8, 2022, https://health.ec.europa.eu/non-communicable-diseases/overview_en.

7 WHO, Non-Communicable Diseases.

8 WHO, Cancer: Carcinogenicity of the Consumption of Red Meat and Processed Meat, accessed: August 8, 2022, https://www.who.int/news-room/questions-and-answers/item/cancer-carcinogenicity-of – the-consumption-of-red-meat-and-processed-meat.

9 WHO, Non-Communicable Diseases.

found in highly processed foods can lead to obesity and diseases such as type 2 diabetes and heart disease. Therefore, the initial enthusiasm related to the possibility of mass production of highly processed food has partially faded due to scientific reports on the health effects of its consumption.

Over the last few decades, public institutions have begun to place increasing emphasis on educating people about a healthy lifestyle, including healthy eating. One of the main reasons behind this is the increasing number of scientific studies indicating the relationship between proper nutrition and health. Currently, in the era of strong saturation of the market with highly processed food, consumers are looking for foodstuffs that will not only be safe but will also allow them to maintain health in the long term: To maintain proper body weight, reduce the risk of diseases and improve general well-being, being rich in vitamins, minerals, and nutrients.

The increased demand has been met with a response from food producers trying to meet new consumer demands, i.e., the „need for healthy food." Despite the plethora of food regulations, the concept of healthy food is not included in any legal framework. Moreover, society's understanding of this concept is inconsistent. It should also be noted that consumers' search for wholesome food is increasingly accompanied by ecological awareness and care for the environment. The number of people deciding to choose food that is healthy but also produced sustainably and ecologically is also growing.[10]

It was not only the market that responded to the increased demand for healthy food. At their very beginnings, the European Communities introduced extensive and detailed food regulations. However, they were primarily aimed at promoting the free movement of goods. Nonetheless, relatively recently, problems related to the increase in the number of NCDs and those resulting from climate change and environmental pollution have made a certain shift in the approach to food visible at the EU level. In recent years, increasing emphasis within the EU has been placed on promoting wholesome food and improving the quality of products placed on the market, as well as taking into account climate and environmental goals in food production.[11] This turn is well illustrated by the assumptions of the „farm to fork" strategy, according to which the EU is to pursue goals such as:

10 W. Kuźniar, T. Surmacz, B. Wierzbiński, The Impact of Ecological Knowledge on Young Consumers' Attitudes and Behaviors towards the Food Market, „Sustainability" 2021, no. 13(4), https://doi.org/10.3390 /su13041984.

11 See White Paper–Strategy for Europe on health issues related to nutrition, overweight and obesity, SEC(2007) 706, Brussels 2007.

– improving the food environment to make it easier to choose healthy and sustainable diets, which will benefit the health and quality of life of consumers and reduce health-related costs for society;
– reducing dependence on pesticides and antimicrobials; or
– strengthening organic agriculture.[12]

It is worth mentioning that the internationalization of issues related to healthy eating takes place not only on a regional (EU) scale but also globally. In its General Assembly resolution of September 25, 2015 (A/RES/70/1), the United Nations adopted the „Transforming our world: 2030 Agenda for Sustainable Development."[13] The sustainable development goals set out in the agenda can be described as specific „development guidelines" that are intended to ensure sustainable economic, social, and environmental development around the world by meeting the needs of current generations without limiting the opportunities of future generations. Each of the 17 general objectives has its own specific goals, of which there are 169 in total, which are more specific guidelines for achieving the general objective. Healthy food plays a vital role in achieving the Sustainable Development Goals, in particular concerning General Goal 2 – „End hunger, achieve food security and improved nutrition and promote sustainable agriculture" and General Goal 3 – „Ensure healthy lives and promote well-being all at all ages."[14]

Currently, many voices are heard from many sides talking about healthy food. Still, it is uncertain whether everyone understands healthy food in the same way and how, if at all, legal regulations influence the social perception of food and the classification of specific products as healthy. The answer to these doubts is this monograph, which presents research conducted as part of the project with a name identical to the title of this monograph. The three main research questions that were asked as part of the research were the following:

– What does the concept of healthy food mean, and, in particular, how do consumers understand it?

12 Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A Farm to Fork Strategy for a fair, healthy and environmentally friendly food system, COM(2020) 381, Brussels 2020.

13 UN General Assembly Resolution, Transforming our world: The 2030 Agenda for Sustainable Development, adopted at the General Assembly Sustainable Development Summit in New York on 25 September 2015 (A/RES/70/1).

14 In the scope related to healthy nutrition, in particular, Goal 2, Goal 2.1 should be indicated – by 2030, eliminate hunger and ensure that all people, especially the poor and vulnerable, including infants, have access to safe, nutritious food in sufficient quantities throughout the year, and under Goal 3, Goal 3.4 – by 2030, reduce premature mortality from non-communicable diseases by 1/3 through prevention and treatment, and promoting mental health and well-being.

- How, if at all, do legal regulations influence the criteria through which consumers perceive food or its particular categories as healthy?
- Do foods perceived by society as healthy have specific features in terms of health quality?

The authors hypothesize that consumers' perception of food, including the classification of specific foodstuffs as healthy or unhealthy, is strongly influenced by irrelevant factors from the perspective of health sciences. Moreover, it appears that the way certain aspects of food trade are regulated contributes to shaping the way people attribute „health" to certain foodstuffs, contrary to the *ratio legis* of these regulations. It also raises serious doubts about whether these foodstuffs actually have specific characteristics that would allow them to be clearly and confidently stated as having significant health-promoting properties.

The answers to the above questions and the verification of the presented hypotheses will, on the one hand, be valuable as new insights into healthy food. On the other hand, the same can be a helpful, practical guideline in designing public health policies and related legislation.

The subject of research outlined above required an interdisciplinary approach. It is worth emphasizing that an interdisciplinary approach to the study of healthy food is important not only because of the research questions posed by the authors. Healthy food and eating, as well as its determinants, are complex issues analyzed from the perspective of various fields of science. In order to understand the complexity of factors contributing to the perception of wholesome food and its impact on human health, it is necessary to integrate knowledge from various areas, such as law, medicine, chemistry, biology, psychology and sociology. The complexity of the issue and its perception requires cooperation in various fields of science.

It is worth emphasizing that the above complexity of the research area is currently one of the greatest challenges for legislators whose goal is to create laws ensuring a high level of protection of people's health and lives. The introduction of legal regulations in areas that require specialized knowledge should be based on scientific certainty. This is a concept that has developed in EU case law, appearing, among others, in the judgments of the Court of Justice of the EU of April 17, 2018, Commission/Poland, C441/17, ECLI:EU:C:2018:255, points 117–120; of April 11, 2013, Sweetman and others, C 258/11, EU:C:2013:220, paragraph 40; of November 8, 2016, Lesoochranárske zoskupenie VLK, C 243/15, EU:C:2016:838, point 42; of October 26, 2006, Commission v Portugal, C 239/04, EU:C:2006:665, point 24; of April 26, 2017, Commission v Germany, C 142/16, EU:C:2017:301, paragraph 42; of July 21, 2016, Orleans and others, C 387/15 and C 388/15, EU:C:2016:583, point 53. The scientific certainty required for the implementation of a specific project is understood as the circumstance in which a given project does not raise, from a scientific point of view, any reasonable doubt as to the lack of adverse effects.[15] In other words, we can speak of scientific certainty when no rational participant in scientific discourse indicates possibly credible and worthy of consideration data that could suggest any negative effects related to the implementation of a given undertaking. Scientific certainty in the interdisciplinary sense is a circumstance in which conclusions regarding a given undertaking are the result of an integrated analysis conducted at the interface of various fields of science. This means that data and research approaches derived from different scientific disciplines are combined in a way that allows for a more comprehensive understanding of the issue. An approach based on scientific certainty is particularly important in the context of food. Scientific certainty in this case means that regulations regarding the production, control and distribution of food are based on a broad, interdisciplinary analysis of data from various scientific disciplines. This monograph is an attempt to establish such interdisciplinary scientific certainty in relation to the issue of healthy food, and the conclusions presented within it are conclusions drawn as a result of interdisciplinary considerations.

With this in mind – apart from surveys and legal analysis – it is necessary to chemically verify specific examples of food that are considered „healthy" in social perception so that any recommendations do not raise doubts as to the lack of their adverse effects.

The structure of this monograph was determined by the project of which it is the result (its content and schedule) and the adopted research assumptions. It consists of 4 chapters with a standard introduction, summary, and bibliography. In the first chapter, the authors attempt to determine healthy food from three research perspectives. First, the public health literature was analyzed. Then, the focus was on the concept of healthy food in the social science literature and the importance of this concept to legal regulations. The last section summarizes the findings on the „healthy food" concept, focusing primarily on the differences and relationships between different approaches to it. The second chapter presents the survey results, which included questions that determined how consumers viewed healthy food, forming the basis for further research. The next chapter analyzes se-

15 Judgment of the Court of Justice of the European Union of 17 April 2018, Commission v Poland, C441/17, ECLI:EU:C:2018:255, point 120.

lected legal regulations covering those aspects of food law, which, according to the survey results, influence the social perception of food in such a way that they encourage the classification of foodstuffs as healthy. The fourth chapter contains a description of the empirical research and the conclusions drawn from it. The monograph ends with a synthesis of the key research conclusions and a bibliography.

Research questions determined the choice of methodology. The first chapter is based primarily on a review of the literature on the subject, available in open access mode and in the databases Eurlex, Lex, Legalis, Public Portal of Information on Law, and Pubmed. The second chapter contains an analysis and conclusions drawn from the conducted survey. The third chapter, devoted to the legal aspects of food circulation, uses a method typical of legal sciences, i.e., dogmatic-legal analysis. The penultimate chapter is an analytical study that determines the presence of chemical (pesticides and toxic elements) and biological (mycotoxins) food contaminations and nutritional compounds (minerals, amino acids, and vitamins) and antioxidants (phenolic acids). The conclusions are based on an interdisciplinary scientific discussion of the researchers involved in the project.

The authors hope that the readers – both non-professionals and professionals interested in the examined issues – will significantly expand their knowledge, understand more of the analyzed relationships, and find inspiration to join the social debate on health, food, and healthy food by reading this monograph.

Chapter 1

UNDERSTANDING THE CONCEPT OF HEALTHY FOOD

1. Healthy Food in the Medical and Health Sciences Literature

Diet-related diseases, such as cardiovascular diseases, type 2 diabetes, obesity, osteoporosis, and some types of cancer, are among the most critical health problems in highly developed countries. Moreover, it is currently believed that lifestyle, in particular lack of physical activity, smoking, consuming ethyl alcohol, or improper nutrition, are important factors increasing the risk of developing neurodegenerative diseases.[1] Growing consumer awareness and the desire to care for their own health result in increased interest in healthy eating.

Proper, well-balanced nutrition is the basis for maintaining health. Providing the body with all the necessary nutrients (there are currently about 60) in amounts consistent with the established demand,[2] adjusted to age, sex, and physical activity, is crucial because both their deficiency and excess may lead to various diseases. Some of them, including B vitamins, flavonoids, unsaturated fatty acids, and probiotic and prebiotic products, have a positive effect on the nervous system and cognitive functions. A poor diet may negatively affect the central nervous system and increase the risk of developing neurodegenerative diseases. In order to ensure health safety, the food consumed should be of high quality, contain the optimal amount of

1 J. Garre–Olmo, Epidemiology of Alzheimer's Disease and Other Dementias, „Rev. Neurol." 2018, vol. 66, pp. 377–386.

2 M. Jarosz, E. Rychlik, K. Stoś, J. Charzewska, Normy żywienia dla populacji Polski i ich zastosowanie, Warsaw 2020.

desirable components, and have the lowest possible content of undesirable components, including contaminants.

In science and legal language, the concept of healthy food generally is not applied due to its imprecision. However, in a broader sense, it is usually associated with food with specific health-promoting properties, including functional food, organic food – free from environmental pollutants, food with a high content of bioactive components – superfood – and fresh food, as little processed as possible, containing small amounts of salt and sugar.

Functional food comes from traditional Eastern medicine, with no clear boundary between medicine and food. Functional food should, by definition, have specific health-promoting properties, benefit body functions beyond just the nutritional effect, resemble conventional food in form, and have a beneficial effect in amounts normally consumed in the diet.[3] Functional food very often contains bioactive components that have health-promoting properties, confirmed by scientific research. For many of them, it is permissible to use health claims indicating the role of a specific components in supporting specific body functions, for example, aiding the proper functioning of the immune system, preventing osteoporosis, or maintaining healthy skin, hair, and nails.[4]

Nutrients, Minerals, and Antioxidants

The bioactive components of functional foods include dietary fiber, polyunsaturated fatty acids, oligosaccharides, polyphenols, phospholipids, amino acids, peptides, vitamins, minerals, phytochemicals, and probiotics that induce the desired course of metabolic changes in the body. There is also scientific literature on the effects of functional foods, including in neurodegenerative diseases,[5] cardiovascular diseases,[6] diabetes,

3 F. Świderski, Żywność wygodna i żywność funkcjonalna, Warsaw 2018.

4 Commission Regulation (EU) No 432/2012 of 16 May 2012 establishing a list of permitted health claims made on foods, other than those referring to the reduction of disease risk and to children's development and health (OJ L 136, 25/05/2012, p. 1 as amended).

5 R.J. Tangvik, F.K. Bruvik, J. Drageset, K. Kyte, I. Hunskar, Effects of oral nutritional supplements in persons with dementia: A systematic review, „Geriatric Nursing" 2021, no. 42(1), pp. 117–123; M. Essat, R. Archer, I. Williams, N. Zarotti, E. Coates, M. Clowes, the HighCALS group, Interventions to promote oral nutritional behaviors in people living with neurodegenerative disorders of the motor system: A systematic review, „Clin. Nutr." 2020, no. 39(8), pp. 2547–2556.

6 M.C. Coelho, R.N. Pereira, A.S. Rodrigues, J.A. Teixeira, ME Pintado, The use of emerging technologies to extract added value compounds from grape by-products, „Trends Food Sci. Technol." 2020, no. 106, pp. 182–197; S. Baumgartner, E. Bruckert, A. Gallo, J. Plat, The position of functional foods and supplements with a serum LDL-C lowering effect in the spectrum ranging from universal to care-related CVD risk management, „Atherosclerosis" 2020, no. 311, pp. 116–123.

and obesity,[7] as well as in cancer.[8] Research has shown that many dietary components are involved in the proper functioning of the immune system. The most important components that play a vital role in the body's defense mechanisms include antioxidants, such as vitamins C and E, coenzyme Q10, beta-carotene, and other carotenoids (e.g., lycopene), phytonutrients (e.g., polyphenols), zinc, selenium, n-3 and n-6 polyunsaturated fatty acids, as well as vitamin D, magnesium, and calcium. Components necessary for the proper functioning of the intestinal microflora, including individual fractions of dietary fiber and components with pro – and prebiotic properties, also play a key role in maintaining the body's defense mechanisms and thus preventing the above-mentioned diseases. Many studies assessing the diet of various populations have shown that the intake of most of the above components is deficient in relation to demand.[9] Vitamin C is necessary for the synthesis of collagen, maintaining the elasticity of capillaries, as well as the proper functioning of the immune system by stimulating phagocytic activity and the formation of antibodies.[10] Its antioxidant function consists in neutralizing free oxygen radicals, counteracting the aging process, preventing the formation of lipid peroxidation products in the body, and forming atherosclerotic plaque and carcinogenic nitrosamines.[11] Studies have shown that oral vitamin C may effectively prevent the development of certain types of malignant tumors, e.g., lung, colon, or endometrial cancer.[12] The human body cannot synthesize it; as a water-soluble vitamin, it is not accumulated in the body, so it is necessary to supply it

7 C. Dhuique–Mayer, L. Gence, K. Portet, D. Tousch, P. Poucheret, Preventive action of retinoids in metabolic syndrome/type 2 diabetic rats fed with citrus functional food enriched in P-cryptoxanthin, „Food Funct." 2020, no. 11(10), pp. 9263–9271; T. Vezza, F. Canet, A.M. de Maranón, C. Banuls, M. Rocha, V.M. Victor, Phytosterols: Nutritional health players in the management of obesity and its related disorders, „Antioxidants" 2020, no. 9(12), pp. 1–20.

8 P. Cerda–Opazo, M. Gotteland, F.A. Oyarzun–Ampuero, L. Garcia, Design, development and evaluation of nanoemulsion containing avocado peel extract with anticancer potential: A novel biological active ingredient to enrich food, „Food Hydrocolloids" 2021, no. 111, 106370; E. Zhuang, E. Uchio, M. Lilly, X. Zi, J.P. Fruehauf, A phase II study of docetaxel plus lycopene in metastatic castrate resistant prostate cancer, „Biomed. Pharmacother" 2021, no. 143, 112226.

9 D.B. Kumssa et al., Dietary calcium and zinc deficiency risks are decreasing but remain prevalent, „Sci. Rep." 2015, no. 5, 10974; L. Gramlich et al., Essential fatty acid deficiency in 2015: The impact of novel intravenous lipid emulsions, „J. Parenter Enteral Nutr." 2015, no. 39(1 Suppl), pp. 61S–6S; M.F. Holick, The vitamin D deficiency pandemic: Approaches for diagnosis, treatment and prevention, „Rev. Endocr. Metab. Disord." 2017, no. 18(2), pp. 153–165; A.A.A. Ismail, Y. Ismail, A.A. Ismail, Chronic magnesium deficiency and human disease; time for reappraisal?, „QJM" 2018, no. 111(11), pp. 759–763.

10 H. Hemilä, E. Chalker, Vitamin C for preventing and treating the common cold, „Cochrane Database Syst. Rev." 2013, CD000980.

11 M. Doseděl et al., Vitamin C–sources, physiological role, kinetics, deficiency, use, toxicity, and determination, „Nutrients" 2021, vol. 13, no. 2, p. 615.

12 J. Luo, L. Shen, D. Zheng, Association between vitamin C intake and lung cancer: A dose-response meta-analysis, „Sci Rep." 2014, no. 4, p. 6161; X.; E.V. Bandera et al., Antioxidant vitamins and the risk of endometrial cancer: A dose-response meta-analysis, „Cancer Causes Control" 2009, vol. 20, pp. 699–711.

with food. The sources of this vitamin are products of plant origin, such as peppers, parsley, cruciferous vegetables, black currants, strawberries, berries, and citrus fruits.[13] Additionally, the presence of compounds in natural products such as bioflavonoids, hesperidin, and rutin facilitates absorption, weakens its decomposition in the body, and thus prolongs its action. Vitamin A includes retinol (which comes from animal products) and its derivatives, as well as carotenoids, called provitamin A, the most active of which is beta-carotene. The highest amounts of beta-carotene are yellow and orange vegetables and fruits such as carrots, pumpkins, apricots, peaches, and green vegetables: spinach, chard, and parsley.[14] Vitamin A has antioxidant properties and is necessary, among others, for the proper functioning of the immune system. Vitamin A and its metabolites are direct regulators of gene expression in immune cells and play a key role in the maturation, differentiation, and response of immune cells. It is also crucial for maintaining proper vision, healthy skin, and preventing aging and cancer.[15] Zinc is a component or cofactor of approximately 300 enzymes (including oxidoreductase, transferase, lyase, isomerase, and ligase) involved in various body transformations. One of the most important is superoxide dismutase (Cu/Zn-SOD), which is also dependent on copper and responsible for antioxidant properties. This micronutrient has anti-inflammatory and antiviral properties. It is necessary for the proper functioning of the reproductive, nervous, and immune systems, as well as for the sense of taste and maintaining the healthy appearance of skin, hair, and nails. Zinc increases the efficiency of the immune system by participating, among others, in the formation and acceleration of the maturation of T cells, one of the most important immunity cells.[16] Its deficiency limits the efficiency of the immune system, including impaired functions of macrophages, neutrophils, and natural killer (NK) cells. Reduced zinc concentration is associated with a higher incidence of pneumonia and upper respiratory tract infections in children and the elderly.[17] Food sources of zinc include oysters, meat, pumpkin and sunflower seeds, groats, nuts, and whole-grain cereal products.[18] Se-

13 H. Kuchanowicz, B. Przygoda, I. Nadolna, K. Iwanow, Tabele składu i wartości odżywczej żywności, Warsaw, 2020.

14 *Ibid.*

15 P.C. Calder, Nutrition, immunity and COVID-19, „BMJ Nutr. Prev. Health” 2020, vol. 3, e000085; E.V. Bandera et al., *op. cit.*

16 A. Pal et al., Zinc and COVID-19: Basis of current clinical trials, „Biol. Trace Elem. Research” 2021, no. 199(8), pp. 2882–2892.

17 N.Z. Gammoh, L. Rink, Zinc in infection and inflammation, „Nutrients” 2017, vol. 9, p. 624; H. Hemilä, E.J. Petrus, J.T. Fitzgerald, A. Prasad, Zinc acetate lozenges for treating the common cold: an individual patient data meta-analysis, „Br. J. Clin. Pharmacol.” 2016, vol. 82, pp. 133–139; S.A. Read, S. Obeid, C. Ahlenstiel, G. Ahlenstiel, The role of zinc in antiviral immunity, „Adv. Nutr.” 2019, vol. 10, no. 4, pp. 696–710.

18 H. Kuchanowicz, B. Przygoda, I. Nadolna, K. Iwanow, *op. cit.*

lenium is a micronutrient that is a component of over 30 selenoproteins, also called seleno-dependent enzymes, including glutathione peroxidases (GPx), thioredoxin reductase, selenoprotein P, or iodothyronine 5-deiodinase.[19] GPx enables the reduction of peroxides and the deactivation of free oxygen radicals, which has a strong antioxidant effect and reduces the risk of inflammatory, autoimmune, cancer, cardiovascular, and viral diseases. This nutrient occurs, among others, in fish, seafood, meat, mushrooms, and garlic; Brazil nuts are exceptionally rich in selenium.[20] Magnesium is one of the most important macronutrients in the human body; it has preventive and healing properties in cardiovascular diseases, neuroses, cancer, and diabetes. This nutrient lowers the concentration of lipids in the blood, dilates blood vessels, regulates blood pressure, has antiarrhythmic and antiatherosclerotic properties, and also plays a significant role in bone mineral homeostasis.[21] It also has an anti-stress effect, and its concentration in the body decreases significantly under stress.[22] Magnesium deficiency is quite common because many nutritional factors adversely affect its bioavailability from food.[23] The source of this macronutrient is primarily food of plant origin, including buckwheat, cocoa, legumes, spinach, wholemeal bread, and nuts.[24] Calcium, in turn, is one of the main components of bones and teeth; it also performs important physiological functions in body fluids, mainly maintaining the proper sensitivity of synapses to nerve stimuli, heart function, and blood coagulation. It is a component of biological membranes and substances that integrate cell cohesion; it also plays a role in permeability, mainly of capillaries. Its deficiency may cause skin inflammation, allergies, osteoporosis, tetany, and hypertension.[25] The best-absorbable sources of calcium are milk and its products; among plant products,

19 M.P. Rayman, The importance of selenium to human health, „The Lancet" 2000, vol. 356, no. 9225, pp. 233–241.

20 E.C. Silva Junior et al., Natural variation of selenium in Brazilian nuts and soils from the Amazon region, „Chemosphere" 2017, vol. 188, pp. 650–658.

21 S.M. Glasdam, S. Glasdam, G.H. Peters, The importance of magnesium in the human body: A systematic literature review, „Adv. Clin. Chem." 2016, vol. 73, pp. 169–193; U. Gröber, J. Schmidt, K. Kisters, Magnesium in Prevention and Therapy, „Nutrients" 2015, vol. 7, no. 9, pp. 8199–8226.

22 N.B. Boyle, C. Lawton, L. Dye, The Effects of Magnesium Supplementation on Subjective Anxiety and Stress-A Systematic Review, „Nutrients" 2017, vol. 9, no. 5, p. 429.

23 A.A.A. Ismail, Y. Ismail, A.A. Ismail, *op. cit.*

24 H. Kuchanowicz, B. Przygoda, I. Nadolna, K. Iwanow, *op. cit.*

25 L. Song, Calcium and bone metabolism indices, „Adv. Clin. Chem." 2017, vol. 82, pp. 1–46; R.A.G. Khamssa, J. Fourie, M.H. Motswaledi, R. Ballyram, J. Lemmer et al., The biological activities of Vitamin D and its receptor in relation to calcium and bone homeostasis, cancer, immune and cardiovascular systems, skin biology, and oral health, „Biomed Res. Int." 2018, 9276380; M.C. Houston, K.J. Harper, Potassium, magnesium, and calcium: their role in both the cause and treatment of hypertension, „J. Clin. Hypertens. (Greenwich)" 2008, vol. 10(7 Suppl 2), pp. 3–11.

good sources of this macronutrient are oxalates found in legumes, lettuce, cabbage, and cauliflower.[26]

The n-3 and n-6 polyunsaturated fatty acids (PUFAs) are essential components of the diet vital for the construction of cell membranes and proper functioning of the nervous and cardiovascular systems, mainly through a beneficial effect on the lipid profile. They have anti-inflammatory, anticancer, antiallergic, and antidepressant properties, inhibit the development of type 2 diabetes, and prevent obesity.[27] PUFA sources are primarily vegetable oils (including linseed, rapeseed, and olive oil), nuts, and long-chain PUFAs (LC-PUFAs): fatty sea fish.[28] Reducing the consumption of omega-3 fatty acids is associated with weakening cognitive functions that deteriorate with age and with an increased risk of dementia. LC-PUFAs constitute 25–30% of total fatty acids (FAs) in the human brain, including docosahexaenoic acid (DHA) and arachidonic acid (AA).[29]

Amino acids are essential components for the synthesis of proteins, enzymes, hormones, peptides, neurotransmitters, and other mediators, consisting of an amino group and a carboxyl group. There are twenty amino acids found in many natural polypeptides, which can be classified based on their side chain and physiological function. Based on the side chain, amino acids can be divided into three groups, namely, amino acids with nonpolar and uncharged side chains, amino acids with polar and uncharged side chains, and amino acids with charged side chains. Based on their physiological functions, amino acids are also divided into three groups, i.e., exogenous amino acids, which cannot be synthesized in the body; endogenous amino acids, which can be produced in the body; and conditionally essential amino acids, which can be synthesized in the body using essential amino acids as precursors, but in limited quantities.[30]

In addition to being a component of proteins, several amino acids also play a role in regulating key metabolic pathways necessary for maintaining health, growth, reproduction, and immunity. These are functional amino acids, which include L-arginine, cysteine, glutamine, leucine, proline,

26 H. Kuchanowicz, B. Przygoda, I. Nadolna, K. Iwanow, *op. cit.*

27 A.A. Spector, H.Y. Kim, Discovery of essential fatty acids, „J. Lipid. Res." 2015, vol. 56(1), pp. 11–21; G. Deacon, C. Kettle, D. Hayes, C. Dennis, J. Tucci, Omega 3 polyunsaturated fatty acids and the treatment of depression, „Crit. Rev. Food Sci. Nutr." 2017, vol. 57, no. 1, pp. 212–223; U.N. Das, Essential Fatty acids–a review, „Curr. Pharm. Biotechnol." 2006, vol. 7, no. 6, pp. 467–482.

28 H. Kuchanowicz, B. Przygoda, I. Nadolna, K. Iwanow, *op. cit.*

29 P.S. Sastry, Lipids of Nervous Tissue: Composition and Metabolism, „Prog. Lipid Res." 1985, vol. 24, pp. 69–176.

30 I. Nugrahani, M.A. Jessica, Amino acids as the potential co-former for co-crystal development: A review, „Molecules" 2021, vol. 26, 3279, https://doi.org/10.3390/molecules26113279.

and tryptophan.[31] Amino acids perform various important functions in the human body. They play a role in nutrition, sensory perception, and biological regulation, influencing exercise, energy expenditure, and glucose metabolism.[32] They are essential for maintaining overall body functions and well-being.[33] Amino acids are key regulators in maintaining blood vessel homeostasis by modulating endothelial cell functions such as proliferation, migration, and survival, thereby influencing vascular health and function.[34] They are involved in modulating signal transduction pathways that regulate mRNA translation; some amino acid-regulated signaling pathways overlap with pathways typically associated with cellular response to hormones such as insulin and insulin-like growth factors.[35] They also have a vital role in immune responses by regulating the activation of T cells, B cells, NK cells, and macrophages and participating in the production of antibodies, cytokines, and other cytotoxic substances.[36] An imbalance of amino acids can lead to metabolic disorders, insulin resistance, and diabetes.[37] Amino acid metabolism involves numerous metabolic networks and is closely related to intracellular redox balance and epigenetic regulation. Reprogrammed metabolism is commonly observed in cancer cells.[38]

Phenolic acids are a class of bioactive compounds of plant origin of great interest due to their diverse biological activities and therapeutic potential. They play a key role in plant defense mechanisms, acting as antioxidants, signaling molecules, and protective compounds against various stress conditions and pathogens. They are synthesized in response to abiotic stresses such as light, temperature, salinity, and heavy metals, as well as biotic stresses caused by microbial pathogens, nematodes, insects, and herbivores.[39] They create a chemical barrier against pathogens and insects, and their accumulation is greater in resistant and moderately resist-

31 *Ibid.*

32 Y. Kamei, Y. Hatazawa, R. Uchitomi, R. Yoshimura, S. Miura, Regulation of skeletal muscle function by amino acids, „Nutrients” 2020, vol. 12, 261, https://doi.org/10.3390/ nu12010261.

33 N.F. Zakaria, M. Hamid, M.E. Khayat, Amino acid-induced impairment of insulin signaling and involvement of G-protein coupling receptor, „Nutrients” 2021, vol. 13, 2229, https://doi.org/10.3390/nu13072229.

34 M. Li, Y. Wu, L. Ye, The Role of Amino Acids in Endothelial Biology and Function, „Cells” 2022, vol. 11, 1372, https://doi.org/10.3390/cells11081372.

35 S.R. Kimball, L.S. Jefferson, Amino acids as regulators of gene expression, „Nutr. Metab.” 2004, vol. 1, https://doi.org/10.1186/1743–7075-1–3.

36 P. Li, Y.L. Yin, D. Li, S.W. Kim, G. Wu, Amino acids and immune function, „Br. J. Nutr.” 2007, vol. 98, pp. 237–252, https://doi.org/10.1017/S000711450769936X.

37 N.F. Zakaria, M. Hamid, M.E. Khayat, *op. cit.*

38 X. Li, H.S. Zhang, Amino acid metabolism, redox balance and epigenetic regulation in cancer, „FEBS J.” 2024, vol. 291, pp. 412–429, https://doi.org/10.1111/febs.16803.

39 S. Hamid, A.M. Yatoo, M.Y. Mir, S. Ali, H.I. Mohamed, Historical Perspective of Plant Phenolics, in: Plant Phenolics in Abiotic Stress Management, Springer, Singapore, 2023, pp. 1–22, https://doi. org/10.1007/978–981-19–6426-8_1.

ant genotypes compared to susceptible genotypes.[40] These compounds are derivatives of hydroxybenzoic and hydroxycinnamic acids. Among the derivatives of hydroxybenzoic acid, the most known are gallic, ellagic, protocatechuic, p-hydroxybenzoic, vanillic, and syringic acids, while among the derivatives of hydroxycinnamic acid–caffeic, ferulic, sinapic, and p – Coumaric acids.[41] They are known for their antioxidant properties, which make them valuable in fighting diseases such as cancer, diabetes, inflammation, and others.[42] Moreover, they have cardioprotective, antiatherosclerotic, immunoregulatory, antiallergic, antithrombotic, and antimicrobial effects.[43] Phenolic acids from medicinal plants have also shown promise in alleviating symptoms of depression through their antioxidant and anti-inflammatory effects by regulating molecular pathways associated with depression.[44] Additionally, phenolic acids can bioconjugate to form sulfate derivatives, which expands their potential applications in metabolic studies and biological activity assessment.[45] Phenolic acids are common in all plant food sources and in various parts of plants, such as seeds, stems, leaves, and roots. Their uneven distribution in plants depends on various factors such as stress, temperature, and abiotic conditions.[46]

Dietary fiber, as a substrate for the transformation of intestinal bacteria (prebiotic effect) and by lowering the pH in the intestine, contributes to the development of beneficial intestinal microflora and supporting immune processes.[47] It also increases fecal mass and improves the motility of the digestive tract, preventing constipation.[48] The anticancer effect of

40 A. Stiller et al., From fighting critters to saving lives: Polyphenols in plant defense and human health, „Int. J. Mol. Sci." 2021, vol. 22, 8995, https://doi.org/10.3390/ijms22168995.

41 E. Rosa-Martínez, A. Bovy, M. Plazas, Y. Tikunov, J. Prohens, L. Pereira–Dias, Genetics and breeding of phenolic content in tomato, eggplant and pepper fruits, „Front. Plant Sci." 2023, vol. 14, 1135237, https://doi.org/10.3389/fpls.2023.1135237.

42 H.P. Devkota, A. Adhikari–Devkota, Phenolic acids, in Antioxidants Effects in Health: The Bright and the Dark Side, „Elsevier" 2022, pp. 427–436, https://doi.org/10.1016/B978–0-12–819096-8.00014–8; M.N. Saqib, M.R.T. Rahman, Phenolic acids, „Nutraceuticals and Health Care", Academic Press, 2021, pp. 303–316, https://doi.org/10.1016/B978–0-323 – 89779–2.00014–4; R. Sehrawat et al., Phenolic Acids –Versatile Natural Moiety with Numerous Biological Applications, „Curr. Top. Med. Chem." 2022, vol. 22, pp. 1472–1484, https://doi.org/10.2174/1568026622666220623114450.

43 A. Saleem et al., Anticancer, Cardio-Protective and Anti-Inflammatory Potential of Natural-Sources-Derived Phenolic Acids, „Molecules" 2022, vol. 27, 7286, https://doi.org/10.3390/molecules27217286.

44 M.L. da S. Cordeiro et al., Phenolic Acids as Antidepressant Agents, „Nutrients" 2022, vol. 14, 4309, https://doi.org/10.3390/nu14204309.

45 V. Kolaříková et al., Sulfation of Phenolic Acids: Chemoenzymatic vs. Chemical Synthesis, „Int. J. Mol. Sci." 2022, vol. 23, 15171, https://doi.org/10.3390/ijms232315171.

46 Afnan et al., Anticancer, Cardio-Protective and Anti-Inflammatory Potential of Natural-Sources-Derived Phenolic Acids, „Molecules" 2022, vol. 27, 7286, https://doi.org/10.3390/molecules27217286.

47 C. Venter, S. Eyerich, T. Sarin, K.C. Klatt, Nutrition and the immune system: A complicated tango, „Nutrients 2020, vol. 12, 818.

48 S. Adams et al., Interactions of dietary fiber with nutritional components on gut microbial composition, function and health in monogastrics, „Curr. Protein Pept Sci." 2018, vol. 19, no. 10, pp. 1011–1023.

dietary fiber is documented primarily in the case of colorectal cancer. Numerous scientific studies have shown a link between low fiber intake and this type of cancer. In turn, doubling the total dietary fiber intake reduces the risk of colorectal cancer by 40%.[49] Bacteria and other microorganisms present in the human large intestine (intestinal microbiota) also play a crucial role in regulating the functions of the immune system. The appropriate amount of probiotic microorganisms (including *Bifidobacterium* and *Lactobacillus)* has a beneficial effect on many functions in the intestine and the entire body by creating a barrier protecting the large intestine against colonization by pathogenic microorganisms and strengthening innate immunity.[50] Products with probiotic properties constitute the largest share of the functional food market. As far as probiotics are concerned, it is worth paying attention to the development of psychobiotics, a group of probiotics that influence the functions of the central nervous system via the gut-brain axis through immune, humoral, nervous, and metabolic pathways, having antidepressant and anxiolytic effects.[51] It has been shown that dysbiosis of intestinal microflora is associated with various diseases of the nervous system, such as depression, dementia, attention deficit hyperactivity disorder (ADHD), and autism.[52]

Functional food can be produced using generally used methods, but in order to have specific health-promoting properties, raw materials from special farms and crops, e.g., organic farms, are used for production to obtain the optimal content of desirable components and reduce undesirable ones.[53]

49 S.J. O'Keefe et al., Fat, fiber and cancer risk in African Americans and rural Africans, „Nat. Commun." 2015, vol. 6, 6342; S.A. Bingham et al., Dietary fiber in food and protection against colorectal cancer in the European Prospective Investigation into Cancer and Nutrition (EPIC): an observational study, „Lancet" 2003, vol. 361, no. 9368, pp. 1496–501.

50 P.C. Calder, *op cit.*; H. Kaur et al., Therapeutic and preventive role of functional foods in the process of neurodegeneration, „IJPSR" 2020, vol. 11, no. 6, pp. 2882–2891; W.–T. Lei et al., Effect of probiotics and prebiotics on immune response to influenza vaccination in adults: a systematic review and meta-analysis of randomized controlled trials, „Nutrients" 2017, vol. 9, 1175; M.C. Mentella, A. Scaldaferri, A. Gasbarrini, G.A.D. Miggiano, The role of nutrition in the COVID-19 pandemic, „Nutrients" 2021, vol. 13, 1093; R. Vignesh et al., Could perturbation of gut microbiota possibly exacerbate the severity of COVID-19 via cytokine storm?, „Front. Immunol." 2021, vol. 11, 607734.

51 See A. Sarkar, S.M. Lehto, S. Harty et al., *Psychobiotics and the Manipulation of Bacteria-Gut-Brain Signals,* „Trends Neurosci." 2016, 39, pp. 763–81.

52 See E. Aizawa et al., Possible Association of Bifidobacterium and Lactobacillus in the Gut Microbiota of Patients with Major Depressive Disorder, „J. Affect. Disord." 2016, vol. 202, pp. 254–7; N.M. Vogt et al., Gut Microbiome Alterations in Alzheimer's Disease, „Sci. Rep." 2017, vol. 7, 13537; D.W. Kang et al., Reduced Incidence of Prevotella and Other Fermenters in Intestinal Microflora of Autistic Children, „PLoS One" 2013, vol. 8, e68322.

53 F. Świderski, *op. cit.*

A dynamically developing direction in functional food is technologically modified food at the stage of its production, including food enriched with individual bioactive substances, which can be helpful in supplementing the most common nutrient deficiencies in the diet, as well as food containing substitutes for undesirable components, e.g., fat, cholesterol, salt, or sugar. Fortified food may be helpful in supplementing essential nutrients in people following a monotonous, unvaried diet, eliminating certain products (e.g., fish), in the elderly or children who are picky eaters, where products enriched with vitamins, calcium, or omega-3 fatty acids may be used. Consuming such foods may have a beneficial effect on health by inhibiting degenerative changes in the body, supporting the treatment of certain diseases, and increasing the supply of nutrients in physiological states of increased demand, e.g., during intensive growth, pregnancy, and recovery, while practicing sports, as well as contributing to improving mood and increasing psychophysical efficiency.[54] Thanks to the availability of such products, it is easier to tailor a diet to various diseases, e.g., obesity, food allergies and intolerances, diabetes, insulin resistance, or hypertension. This type of food may reduce the risk of lifestyle diseases and slow down aging. The 21st-century consumers face increased threats from environmental pollution, stress, social challenges, and health concerns. Functional products can help improve physical and mental health, leading to a higher quality of life. Research by Polish scientists has shown that the greatest interest and motivation to consume this type of food are among women and older adults who are ready to compromise on taste in favor of the health-promoting properties of functional food. Regardless of socio-demographic factors, inadequate nutritional knowledge may limit the acceptance of such products, which is why it is vital to launch appropriate educational programs. It has also been indicated that health issues of family members increase consumer interest in functional products.[55]

The concept of healthy food is inextricably linked to aspects related to food safety. Under Article 3(3)(5) of the Act of August 25, 2006, on safety of food and nutrition (hereinafter referred to as the Act on safety of food and nutrition),[56] food safety covers all activities that must be undertaken at all stages–from obtaining raw materials and food production, to transport and sale so that the food that reaches consumers is safe and does not pose a health risk.

54 *Ibid.*

55 K. Topolska, A. Florkiewicz, A. Filipiak–Florkiewicz, Functional Food-Consumer Motivations and Expectations, „Int. J. Environ. Res. Public Health" 2021, vol. 18, no. 10, 5327

56 Act of August 25, 2006, on safety of food and nutrition (Journal of Laws of 2023, item 1448).

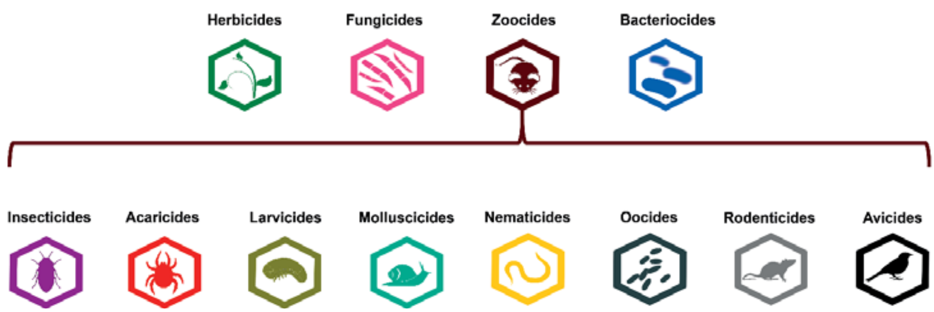
Issues related to food health safety include environmental pollutants, e.g., toxic elements, residues of fertilizers and plant protection products, compounds resulting from food processing, and additional substances intentionally added to food. With the increase in environmental pollution, industrial development, and high availability of processed food, consumed products may also contain components that adversely affect the central nervous system, including heavy metals, pesticides, acrylamide, mycotoxins, and bisphenol A.

Pesticides

Pesticides are a wide group of chemical or biological agents that protect crops against agrophages (pathogens, weeds, pests). Pesticides in food of plant origin and honey result from their use inconsistent with the manufacturer's label (exceeding the dose, failure to comply with the withdrawal period, use of pesticides not registered for specific crops), as well as application in strong winds, causing the working liquid to be carried to adjacent fields, and application in sunny weather and during the peak activity of pollinating insects.

The largest groups of chemical pesticides are zoocides, fungicides, and herbicides.[57] Zoocides, which include insecticides, are the most complex group, which also include acaricides, larvicides, molluscicides, nematicides, ovicides, rodenticides, and avicides (fig. 1).

Fig. 1. Division of pesticides according to the targeted organisms.



Pesticides can act selectively, controlling only specific species, or nonselectively, killing many species, including those that do not pose a threat to a given crop. Moreover, in terms of their action, plant protection products are divided into contact (they do not penetrate the plants and remain on

57 J. Popp, K. Peto, J. Nagy, Pesticide productivity and food security. A review, „Agron. Sustain. Develop." 2013, vol. 33, pp. 243–255, https://doi.org/10.1007/s13593–012-0105-x.

their surface), translaminar (at the point of application, they penetrate only a few cell layers and do not move to new growths), and systemic (penetrate deep into the plants).[58]

Insecticides are used to control populations of insects that feed on crops, causing damage and making agricultural crops unsuitable for human consumption.[59] The most commonly used include organophosphorus insecticides, carbamates, neonicotinoids, and pyrethroids. The mechanisms of action of insecticides involve disturbances in the functioning of the insects' nervous system, inhibition of growth and fat synthesis, and disturbances in energy metabolism, ultimately leading to their death.[60]

Fungicides are used to combat pathogenic fungi in plant crops and limit the spread of fungal diseases. They constitute a large and diverse group of substances with different mechanisms of action, residence time in the environment, and physicochemical properties.[61] They are most often used in vegetable crops (e.g., lettuce, spinach), soft fruit (e.g., strawberries, grapes, currants), and cereal crops. The most commonly used fungicides represent the chemical groups of triazoles, imidazoles, phenylpyrroles, carboxamides, dithiocarbamates, and strobilurins. Moreover, fungicides are often applied in seed dressings, which helps limit the development of soil-borne fungal diseases. The typical modes of action of fungicides involve inhibiting cellular respiration, protein, nucleic acid, and lipid biosynthesis.[62] Despite the usage of fungicides, pathogenic fungi are responsible for 7–24% of crop losses, which can be partially attributed to the development of resistance to commonly used fungicides, even within several years of their application.[63]

Another group of pesticides of great importance in agriculture is herbicides, which are used to combat weeds. They currently constitute about 60% of plant protection products used worldwide, mainly in field crops of cereals and vegetables, and most large-scale crop production systems rely

58 R. Bundschuh, M. Bundschuh, M. Otto, R. Schulz, Food-related exposure to systemic pesticides and pesticides from transgenic plants: evaluation of aquatic test strategies, „Environ. Sci. Eur." 2019, vol. 31, no. 87, https://doi.org/10.1186/s12302–019-0266–1.

59 M.F. Araújo, E.M.S. Castanheira, S.F. Sousa, The Buzz on Insecticides: A Review of Uses, Molecular Structures, Targets, Adverse Effects, and Alternatives, „Molecules" 2023, vol. 28, 3641.

60 P. Rezende–Teixeira et al., What Can We Learn from Commercial Insecticides? Efficacy, Toxicity, Environmental Impacts, and Future Developments, „Environmental Pollution" 2022, vol. 300, 118983.

61 M.S. Ayesha et al., Seed treatment with systemic fungicides: Time for review, „Front. Plant Sci." 2021, vol. 12, 654512

62 J.P. Zubrod et al., Fungicides: An Overlooked Pesticide Class?, „Environ. Sci. Technol." 2019, vol. 53, pp. 3347–3365.

63 F. van den Bosch et al., Mixtures as a Fungicide Resistance Management Tactic, „Phytopathol." 2014, vol. 104, pp. 1264–1273.

on synthetic herbicides.[64] Weed infestation is an important factor in yield reduction due to the competition of weeds with crop plants for nutrients, water, and light sources. Frequently employed herbicides include triazolopyrimidines, sulfonylureas, phenoxycarboxylic acids, and benzoic acid.[65] Depending on the date of application, herbicides can be divided into pre-emergence and post-emergence, depending on the method of use – foliar and soil-applied, and based on the scope of action – total herbicides, combating monocotyledonous and dicotyledonous plants, and selective herbicides, combating specific groups or species of weeds. The mechanism of action of herbicides most often involves inhibiting the biosynthesis of proteins, photosynthetic pigments, lipids, and disturbing hormonal balance.[66]

The group most exposed to pesticides are farmers when spraying is carried out incorrectly. They usually suffer from chronic cough, shortness of breath, wheezing and expectoration, reduced lung capacity, asthma, bronchitis, burning eyes, rash, blisters, and deaths have been reported.

Consuming food containing high concentrations of pesticides can lead to acute poisoning, which manifests as skin irritation, rash, nausea, dizziness, and diarrhea.[67]

Chronic effects of contact and oral exposure to pesticides include cancer, damage to the reproductive system, neurological and developmental toxicity, congenital defects, immunotoxicity, and endocrine system disorders. The chronic effects of pesticides are divided into four main groups: endocrine, neurotoxic, genotoxic and carcinogenic, and reproductive.[68]

Many pesticides can affect the functioning of the endocrine system. They have the potential to act as tumor promoters and increase the risk of breast cancer. Some insecticides, fungicides, and herbicides, including dimethoate, diazinon, cypermethrin, and heptachlor, have been linked to breast cancer in women.[69] In men, over 95% of prostate cancers are androgen-dependent. The increased incidence of prostate cancer was, at least in

64 F.E. Dayan, Current Status and Future Prospects in Herbicide Discovery, „Plants" 2019, vol. 8, p. 341.

65 B. Łozowicka et al., Impact of Diversified Chemical and Biostimulator Protection on Yield, Health Status, Mycotoxin Level, and Economic Profitability in Spring Wheat (Triticum aestivum L.) Cultivation, „Agronomy" 2022, vol. 12, no. 2:258.

66 M.N. Gandy, M.G. Corral, J.S. Mylne, K.A. Stubbs, An Interactive Database to Explore Herbicide Physicochemical Properties, „Org. Biomol. Chem." 2015, vol. 13, pp. 5586–5590.

67 W. Benka–Coker et al., The Joint Effect of Ambient Air Pollution and Agricultural Pesticide Exposures on Lung Function Among Children with Asthma, „Environ. Res." 2020, 190, 109903.

68 *Ibid.*

69 L.V. Zarate et al., Angiogenesis Signaling in Breast Cancer Models is Induced by Hexachlorobenzene and Chlorpyrifos, Pesticide Ligands of the Aryl Hydrocarbon Receptor, „Toxicol. Appl. Pharmacol." 2020, vol. 401, 115093.

part, related to endocrine-disrupting pesticides. Possible correlations have also been reported between prostate cancer and pesticide exposure, including lindane, endosulfan, prochloraz, deltamethrin, and chlorpyrifos.[70] Exposure to endocrine-disrupting pesticides may disrupt the balance of thyroid hormones and result in attention disorders in children with autism and cognitive and behavioral dysfunctions.[71]

Neurotoxicity can be defined as any adverse effect on the central or peripheral nervous system caused by chemical, biological, or physical agents. The developing nervous system in children (during replication, migration, differentiation, neuronal myelination, and synapse formation) is more susceptible to neurotoxic chemicals, including pesticides.[72] They can cause nerve cell death by disrupting the cytoskeleton, causing oxidative stress, calcium overload, or damaging the mitochondria. Most currently used synthetic insecticides, some fungicides, and herbicides are neurotoxins for children.[73] Neuropsychiatric disorders such as anxiety and depression have been observed in patients with acute and long-term organophosphate insecticide poisoning. They may also cause intermediate syndrome and delayed polyneuropathy 1–3 weeks after a single exposure. Carbamates, on the other hand, temporarily inhibit the activity of acetylcholine. Mitochondrial dysfunction and oxidative stress induced by chronic exposure to organophosphate insecticides can lead to neurological diseases, including Parkinson’s disease, seizures, cognitive impairment, attention and memory deficits, dementia, depression, and childhood Alzheimer’s disease.[74] Exposure to type I pyrethroids causes tremor syndrome (behavioral arousal, increased startle response, and mild body tremors progressing to whole body tremor and prostration), while exposure to type II pyrethroids causes sialorrhea syndrome (abundant salivation, gross tremor progressing to choreoathetosis and clonic convulsions).[75] The poisoned cerebral cortex limits the process of learning, memory, emotions, and movement. Pyrethroid ex-

70 P. Thomas, J. Dong, Novel Mechanism of Endocrine Disruption by Fungicides Through Binding to the Membrane Androgen Receptor, ZIP9 (SLC39A9), and Antagonizing Rapid Testosterone Induction of the Intrinsic Apoptotic Pathway, „Steroids” 2019, vol. 149, 108415.

71 L. Zuniga–Venegas et al., Exposición a Plaguicidas en Chile y Salud Poblacional: Urgencia para la Toma de Decisiones, „Gac. Sanit.” 2020, vol. 35, no. 5.

72 J.R. Richardson, V. Fitsanakis, R.H.S. Westerink, A.G. Kanthasamy, Neurotoxicity of Pesticides, „Acta Neuropathol.” 2020, vol. 138, no. 3, pp. 343–362.

73 P. Kaur, B. Radotra, R. Minz, K. Gill, Impaired Mitochondrial Energy Metabolism and Neuronal Apoptotic Cell Death After Chronic Dichlorvos (OP) Exposure in Rat Brain, „Neurotoxicology” 2007, vol. 28, no. 6, pp. 1208–1219.

74 *Ibid.*

75 I. Hołyńska–Iwan, K. Szewczyk–Golec, Pyrethroids: How Do They Affect Human and Animal Health?, „Medicina” (Kaunas) 2020, vol. 56, no. 11.

posure has been positively associated with hearing loss in American adolescents and has been suggested to be a mechanism underlying cognitive impairment. Paraquat, triazine, and pyrazole (herbicides) cause cognitive impairment[76] through oxidative stress, increased calcium supply, stimulation of nitric oxide forms, and increased amyloidogenesis.

Pesticides causing genotoxic effects may interact with the genetic material (DNA), causing changes, damage, or breaks, and interfere with the enzymatic processes of repair, genesis, or polymerization of proteins involved in chromosome segregation. These changes may lead to impaired embryonic development or be the first step in cancer development. Exposure to pesticides can cause genome damage.[77] Non-Hodgkin's lymphoma is a diverse group of malignancies whose incidence has increased worldwide. Patients with immune system dysfunctions are at high risk of developing it. Studies have shown an increased risk of non-Hodgkin's lymphoma when exposed to the herbicide glyphosate, terbufos (organophosphate nematicide), dimethoate, malathion, and chlorpyrifos (organophosphate insecticides), and 2,4-D and dichloroprop (chlorophenoxy herbicides).[78] The risk of chronic myeloid leukemia and acute myeloblastic leukemia has been found to be higher in women. Children whose parents used insecticides in the garden and home or whose mothers were exposed to them during pregnancy had an increased incidence of all types of leukemia.[79] There was also a positive correlation between parental exposure to organophosphate insecticide dichlorvos and pyrethroid preparations and brain tumors in their children.[80] Additionally, a relationship was found between hepatocellular carcinoma and increased exposure to endosulfan, fluopyram, carbendazim, or dicamba.[81]

Fertility disorders result from impaired testosterone production in Leydig cells and spermatogenesis. Some pesticides have been shown to reduce testosterone levels, which are required for the final stages of sperm maturation, e.g., vinclozolin, chlorpyrifos, p,p'-DDE, fenvalerate, and atra-

76 C.A. Sukumar, V. Shanbhag, A.B. Shastry, Paraquat: The Poison Potion, „Indian J. Crit. Care Med.” 2020, vol. 23, pp. S263–S266.

77 G.A. Anguiano–Vega et al., Risk of Genotoxic Damage in Schoolchildren Exposed to Organochloride Pesticides, „Sci. Rep.” 2020, vol. 10, 17584.

78 L. Latifovic et al., Pesticide Use and Risk of Hodgkin Lymphoma: Results from the North American Pooled Project (NAPP), „Cancer Causes Control” 2020, vol. 31, no. 6, pp. 583–99.

79 S. Koutros et al., Occupational Exposure to Pesticides and Bladder Cancer Risk, „Int. J. Epidemiol.” 2016, vol. 45, no. 3, pp. 792–805.

80 P. Kaur et al., *op. cit.*

81 C.C. Lerro et al., Dicamba Use and Cancer Incidence in the Agricultural Health Study: An Updated Analysis, „Int. J. Epidemiol.” 2020, vol. 49, no. 4, pp.1326-1337.

zine.[82] Endosulfan may pass through the placenta and into milk in exposed mothers, which poses a risk to breastfed children. Menstrual disorders, endometriosis, fetal growth retardation, and pregnancy loss due to endosulfan exposure have also been observed in women.[83]

Toxic Elements

Elements that have toxic effects on the human body include cadmium (Cd), lead (Pb), arsenic (As), and mercury (Hg). Due to their common occurrence in the environment, these elements may constitute a significant food contaminant. Cadmium is found in small amounts as a natural component of Earth's crust, but its amount in the environment increases significantly as a result of human activity. In the case of non-smokers and people not at risk of occupational exposure, food is the source of 90% of exposure to cadmium, of which approximately 80% is of plant origin: cereal products (groats, rice, pasta), vegetables, mushrooms, and sea algae. Among animal products, offal accumulates most of this toxic element; increased content was also recorded in fish and seafood.[84] The toxic effect of cadmium on the body is multidirectional. Its strong embryotoxic, teratogenic, mutagenic, and genotoxic effects have been confirmed. This element has been classified by the International Agency for Research on Cancer (IARC) as group 1 of compounds with a confirmed carcinogenic effect on the human body. It has also been shown to have neurotoxic effects, especially on the central nervous system. Exposure to cadmium causes impairment of memory and learning.[85] Cadmium may be a factor causing autoimmune diseases, inducing lipid peroxidation, and influencing the formation of atherosclerotic plaque, increasing the risk of cardiovascular diseases, including hypertension. One of the critical organs at risk of chronic exposure to cadmium is the kidneys–the metabolism of calcium and vitamin D is disturbed, and, as a result, the skeletal system is damaged.[86]

82 D. Xia et al., Paternal Fenvalerate Exposure Influences Reproductive Functions in the Offspring, „Reprod. Sci." 2013, vol. 20, no. 11, pp. 1308–15.

83 M.M. Milesi et al., Postnatal Exposure to Endosulfan Affects Uterine Development and Fertility, „Mol. Cell. Endocrinol." 2020, vol. 511, 110855.

84 M. Wojciechowska–Mazurek, M. Mania, K. Starska, Kadm w środkach spożywczych – celowość obniżenia limitów, „Przemysł Spożywczy" 2010, no. 64, pp. 45–48.

85 W. Zheng, Toxicology of Choroid Plexus: Special Reference to Metal-Induced Neurotoxicities, „Microsc. Res. Tech." 2001, vol. 52, pp. 89-103.

86 H. Wu et al., Environmental exposure to cadmium: health risk assessment and its associations with hypertension and impaired kidney function, „Sci. Rep." 2016, vol. 6, 29989.

The toxic effect of lead is mainly manifested in the disruption of the functioning of the hematopoietic, nervous, and cardiovascular systems.[87] Due to exposure to this element, liver and kidney damage may occur, and its negative impact on the functions of the immune system and its proven pro-oxidant effect may lead to the induction of cancer. IARC classified lead as group 2A, i.e. probably carcinogenic compounds. The mechanism of lead's carcinogenic action is not fully explained. It probably disrupts nuclear DNA synthesis and repair in cells, which results in their damage.[88] Some studies suggest that lead may be carcinogenic in concentrations lower than those generally considered toxic. Therefore, efforts should be made to keep lead content in foodstuffs as low as possible, especially those that are supposed to have health-promoting effects. Moreover, even exposure to low concentrations may be associated with a reduced level of intelligence, attention deficit hyperactivity disorder, as well as deterioration of executive and language functions.[89] In people not at risk of occupational exposure, approximately 80% of lead enters the body through food. The source of exposure to lead in the diet is mainly food of plant origin; leafy and root vegetables, potatoes, fruits, and cereal products accumulate the most of this element, and less often, legumes, pumpkins, and tomatoes. Technological processes, packaging, and substances intentionally added to food may be an additional source of lead exposure. Among products of animal origin, increased amounts of lead were found in milk, offal, game, and meat of slaughtered animals, as well as in fish from polluted waters.[90] Arsenic is widespread in nature. Industrial pollution can introduce it into the environment and thus into food, while it can enter the human body through food, inhalation, and the skin. The toxic effect of arsenic is primarily associated with its strong carcinogenic effect. IARC classified it as a carcinogen group 1, as a compound with epidemiologically proven carcinogenic effects. It most often causes cancer of the respiratory system, bladder, and skin due to its strong affinity for keratin. Moreover, it causes anemia, damages blood vessels, causes pathological changes in the myocardium, and also adversely affects the metabolic processes of liver and kidney cells. Exposure to this element may also

87 S. Asgary, A. Movahedian, M. Keshvari, Serum levels of lead, mercury and cadmium in relation to coronary artery disease in the elderly: A cross-sectional study, „Chemosphere" 2017, vol. 180, pp. 540-544.

88 E.K. Silbergeld, M. Waalkes, J.M. Rice, Lead as a carcinogen: experimental evidence and mechanisms of action, „Am. J. Ind. Med." 2000, vol. 38, no. 3, pp. 316-323.

89 J.K. Goodlad, D.K. Marcus, J.J. Fulton, Lead and Attention-Deficit/Hyperactivity Disorder (ADHD) Symptoms: A Meta-Analysis, „Clin. Psychol. Rev." 2013, vol. 33, pp. 417–425; L. H. Mason, J. P. Harp, D. Y. Han, Pb Neurotoxicity: Neuropsychological Effects of Lead Toxicity, „BioMed Res. Int." 2014, 840547.

90 I. Krzywy, E. Krzywy, M. Pastuszak–Gabinowska, A. Brodkiewicz, Ołów – czy jest się czego obawiać? „Roczniki Pomorskiej Akademii Medycznej w Szczecinie" 2010, no. 56, pp. 118-128.

result in nervous system disorders. High concentrations of arsenic were found mainly in fish and crustaceans. Rice also easily accumulates this toxic element. In recent years, there have been reports of significant arsenic contamination in rice bread. Research has shown that some species of mushrooms can also accumulate significant amounts of this toxic element; high contents were recorded, for example, in dried bolete.[91] Mercury compounds enter the environment mainly as a result of human activities, including coal-fired power plants, waste incineration, chemical, paper, pharmaceutical industries, and gold mining. High mercury content is recorded in marine organisms, especially in predatory fish (e.g., tuna, halibut), crabs, snails, and game birds. When mercury compounds enter the aquatic environment, microorganisms methylate it, which is why mercury in fish occurs mainly in the most toxic form, methylmercury.[92] There is a close relationship between methylmercury accumulated in the human body and the severity of toxic symptoms. The first symptoms of poisoning (Minamata disease) involve paresthesia (numbness of the lips and tongue, tingling, and spontaneous shaking of the limbs and head). Deepening symptoms of poisoning manifest as ataxia; then, progressive motor inertia develops, followed by speech and hearing disorders, and higher doses may cause death. Other neurological symptoms of exposure to mercury include sleep disorders, depression, and memory loss.[93] Some studies suggest a link between mercury exposure and multiple sclerosis, Alzheimer's disease, and Parkinson's disease. Mercury can also accumulate in bone tissue.[94]

Mycotoxins

Other compounds with a negative impact on health are mycotoxins, which are biological contaminants of food. Mycotoxins are toxic secondary metabolites produced by various filamentous fungi, mainly *Aspergillus, Fusarium*, and *Penicillium* species, commonly found in agricultural products,

91 K. Kulik–Kupka et al., Arsen – trucizna czy lek?, „Med. Pr." 2016, vol. 67, no. 1, pp. 89–96; K. Rydzyński, M. Stępnik, Genetyczne efekty narażenia na arsen i kadm; interakcje z innymi czynnikami, „Med. Pr." 2001, vol. 52 (Supl.14), pp. 5–10; W. Seńczuk, Toksykologia współczesna, Warsaw 2016.

92 M. Mania, M. Wojciechowska–Mazurek, K. Starska, Ryby i owoce morza jako źródło narażenia człowieka na metylortęć, „Rocz. Panstw. Zakl. Hig." 2012, vol. 63, pp. 257-264; H. Okyere, R.B. Voegborlo, S.E. Agorku, Human exposure to mercury, lead and cadmium through consumption of canned mackerel, tuna, pilchard and sardine, „Food Chem." 2015, vol. 179, pp. 331-335.

93 B.F. Azevedo, L.B. Furieri, F.M. Pec, Toxic effects of mercury on the cardiovascular and central nervous systems, „J. Biomed Biotechnol." 2012, 949048.

94 M. Cyran, Wpływ środowiskowego narażenia na rtęć na funkcjonowanie organizmu człowieka, „Med. Środ." 2013, no. 16, pp. 55–58; E. Ha, N. Basu, S. Bose–O'Reilly, Current progress on understanding the impact of mercury on human health, „Environ. Res." 2017, no. 152, pp. 419–433; KH Kim, E. Kabir, S.A. Johan, A review on the distribution of Hg in the environment and its human health impacts, „J. Hazard. Mater." 2016, no. 306, pp. 376–385.

especially cereals and nuts, and products of their processing.[95] They are also found in meat, cold cuts, fish, dairy products, and processed vegetables and fruit. Mycotoxins, including aflatoxins, fumonisins, trichothecenes, zearalenone, ochratoxin A, patulin, and others, pose significant risks to human and animal health, leading to acute and chronic diseases, mutagenic, teratogenic, and carcinogenic effects.[96] Exposure to mycotoxins through contaminated food can cause inflammation, hormonal imbalances, and disruptions in metabolic pathways, affecting enzymes and receptors critical to the proper functioning of the body. Moreover, they may cause kidney damage, growth disorders in children, or suppression of the immune system. Mycotoxins cause DNA damage, disruption of protein synthesis and cell cycle, induction of programmed cell death, tissue necrosis, and damage to chromosomes and proteins caused by the action of reactive oxygen species.[97] Mycotoxins exert a neurotoxic effect by freely passing through the blood–brain barrier, accumulating mainly in the hippocampus, and this mechanism is associated with the pathogenesis of Alzheimer's disease, Huntington's disease, Parkinson's disease, and schizophrenia.[98] Moreover, it is suspected that mycotoxins may interact with drugs, potentially altering their pharmacokinetics and pharmacodynamics.[99]

Due to the complex nature of consumer motivation and expectations, an appropriate strategy for designing health-promoting food and its marketing and technological development is important.[100] The key direction of development seems to be new recipes for functional products with properties confirmed, also in clinical trials, where the high quality of raw materials is vital. These products should have optimal content of beneficial components, be completely free of chemical and biological impurities, or have the lowest possible content of undesirable components.

95 R.A. El–Sayed, A.B. Jebur, W. Kang, F.M. El–Demerdash, An Overview on the Major Mycotoxins in Food Products: Characteristics, Toxicity, and Analysis, „J. Futur. Foods" 2022, vol. 2, pp. 91–102; C. Gurikar et al., Impact of Mycotoxins and Their Metabolites Associated with Food Grains, „Grain Oil Sci. Technol." 2023, vol. 6, pp. 1–9; A.K. Pandey et al., Fungal Mycotoxins in Food Commodities: Present Status and Future Concerns, „Front. Sustain. Food Syst." 2023, vol. 7, 1162595.

96 MS Azam et al., Critical Assessment of Mycotoxins in Beverages and Their Control Measures, „Toxins" (Basel) 2021, vol. 13, 323; R. Xu et al., Nutritional Impact of Mycotoxins in Food Animal Production and Strategies for Mitigation, „J. Animation Sci. Biotechnol." 2022, vol. 13, pp. 1–19.

97 Zhu L, Zhang B, Dai Y et al., A review: epigenetic mechanism in ochratoxin and toxicity studies, „Toxins" 2017, vol. 9, no. 4, 113.

98 A. Caccamo et al., CBP gene transfer increases BDNF levels and ameliorates learning and memory deficits in a mouse model of Alzheimer's disease, „Proc. Natl. Acad. Sci." US 2010, vol. 107, pp. 22687–22692.

99 O. Lootens et al., Possible Mechanisms of the Interplay Between Drugs and Mycotoxins–Is There a Possible Impact?, „Toxins" (Basel) 2022, vol. 14, 873.

100 K. Topolska, A. Florkiewicz, A. Filipiak–Florkiewicz, *op. cit.*

To achieve the above goals, effective cooperation between the scientific community and the food industry is necessary.

2. Healthy Food in the Social Science Literature

From the perspective of medical and health sciences, various aspects of food can be used to analyze whether a given food is healthy or not. From a legal perspective, it is possible to examine whether and under what conditions the concept of healthy food exists (can function) on the market.[101] However, despite various studies on this topic, it is not entirely clear how consumers evaluate the healthiness of individual food products and meals.

Ronteltap et al.'s „Constructive levels of healthy eating. Exploring consumers' interpretation of health in the food context"[102] draws attention to the fact that thinking about healthy eating can involve various levels of abstraction. An example of the operationalization of a low level of representation of perceived healthiness was the question, „How healthy is it?" Or „What do you think is product X?" The equivalent of this question at a high level of representation was, „Do you think product X fits into a healthy lifestyle?" For example, products considered unhealthy, such as potato chips, were rated as less unhealthy when assessed more abstractly.

Mötteli et al.'s „Consumers' practical understanding of healthy food choices: a fake food experiment" examines consumers' ideas about a healthy diet. Using an artificial food buffet, they studied how people defined healthy and sustainable food choices compared to typical choices and dietary guidelines.[103]

The control group participants were asked to choose products they would normally eat, while the healthy group participants were asked to choose products that represented a healthy diet. The latter selected significantly more nutritious foods, such as fruits, vegetables, wholemeal bread, fish, and meatless protein sources. At the same time, they chose significantly fewer products considered unhealthy, such as sausages, croissants, sweets, fast foods, and sugar-sweetened drinks, compared to the control group. Participants' dietary choices reflect at least a basic understanding of the Healthy Eating and Physical Activity Pyramid, which recommends eat-

101 See subsection 1.3.

102 A. Ronteltap et al., Construal levels of healthy eating. Exploring consumers' interpretation of health in the food context, „Appetite" 2012, vol. 59, no. 2, pp. 333-340, https://doi.org/10.1016/j.appet.2012.05.023.

103 S. Mötteli et al., Consumers' practical understanding of healthy food choices: a fake food experiment, „British Journal of Nutrition" 2016, no. 116(3), pp. 559–566, https://doi.org/ 10.1017/S0007114516002130.

ing larger amounts of foods at the lower levels of the pyramid compared to foods at the higher levels.

The experiment results are consistent with previous research showing that national dietary guidelines strongly influence an average person's perceptions of healthy eating. Against this background, a significantly higher amount of protein was reported in the healthy group and a lower than recommended amount of available carbohydrates in both experimental conditions, which the authors attribute to the growing popularity of the low-carbohydrate diet in recent years.

Haws, Reczek, and Sample's „Healthy Diets Make Empty Wallets: The Healthy = Expensive Intuition" examines consumers' intuition about the relationship between healthiness and food prices.[104] The study found that consumers often believe healthier food is pricier, which influences their purchasing decisions. While this intuition may be true in some cases, consumers tend to overgeneralize it. It acts as a bias, shaping how consumers process health and price information and influencing their perceptions of the healthfulness of components.

Ditlevsen, Sandře, and Lassen's „Healthy food is nutritious, but organic food is healthy because it is pure: The negotiation of healthy food choices by Danish consumers of organic food" is a qualitative analysis showing consumers define healthy food products as ecological.[105] The study revealed three main concepts of health in the existing literature: health as purity, health as pleasure, and a holistic approach to health. The most common understanding among the participants was health as purity. It should be emphasized that purity is understood here as naturalness and the lack of foreign substances rather than the absence of superficial dirt. However, in a broader discussion about healthy food, disconnected from the ecological context, health was understood mainly as nutritional value, and biomedical arguments gained importance.

Lusk's „Consumer beliefs about healthy foods and diets" shows that consumers are divided on whether a food is considered healthy based on its nutritional value (52.1%) or other factors (47.9%). Similarly, 47.9% of respondents believed that a single product could be healthy, while 52.1% considered healthiness to be a feature of the entire diet. The study indi-

104 K.L. Haws, R.W. Reczek, K.L. Sample, Healthy Diets Make Empty Wallets: The Healthy = Expensive Intuition, „Journal of Consumer Research" 2017, no. 43(6), pp. 992–1007, https://doi.org/ 10.1093/jcr/ucw078.

105 K. Ditlevsen, P. Sandøe, J. Lassen, Healthy food is nutritious, but organic food is healthy because it is pure: The negotiation of healthy food choices by Danish consumers of organic food, „Food Quality and Preference" 2019, vol. 71, pp. 46–53, https://doi.org/10.1016/j.foodqual.2018.06.001.

cated that the perception of healthiness is complex and includes, among others, animal origin, preservation, and freshness/processing. According to respondents, the healthiness of food decreased with the fat, sodium, and carbohydrate content and increased with the protein content.[106]

Plasek, Lakner, and Temesi's „Factors that Influence the Perceived Healthiness of Food–Review" identifies six categories that influence the perceived healthiness of food products: the impact of communicated information,[107] product category, shape and color of packaging, product components, organic origin of the product, taste, and other sensory characteristics of the product.[108] The review shows that the organic origin of a product has a positive impact on its perceived healthiness.

Gaspar, Garcia, and Larrea–Killinger's „How would you define healthy food? Social representations of Brazilian, French and Spanish dietitians and young laywomen" analyzes the social perception of healthy food in Brazil, Spain, and France.[109] This study reveals that the concept of healthy food is ambiguous. There are two main ways of categorizing healthy foods: the physiological, nutritional, and functional approach and the „eco-ideological" approach, which takes into account production, cultural, and distribution methods.

Hagen's „Pretty Healthy Food: How and When Aesthetics Enhance Perceived Healthiness" examines how aesthetics influence the perception of food healthiness.[110] The author suggests that prettier foods are perceived as healthier, mainly because classic aesthetic features make them appear more natural. The study found that people rated nicer versions of the same products as more nutritious, even though the price was perceived to be the same. Perceptions of naturalness mediated this effect, and reminders of artificial modifications attenuated these perceptions. Expressive aesthetics that do not evoke naturalness had no impact on perceived health, even though they were pretty. The results suggest that food styling may mislead consumers.

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106 J.L. Lusk, Consumer beliefs about healthy foods and diets, „PLoS One" 2019, vol. 14, no. 10, e0223098, doi: 10.1371/journal.pone.0223098.

107 Some ways of informing consumers about the nutritional value of food and its impact on health have a positive impact on the perceived healthiness of that food.

108 B. Plasek, Z. Lakner, Á. Temesi, Factors that Influence the Perceived Healthiness of Food–Review, „Nutrients" 2020, vol. 12, no. 6, p. 1881, doi: 10.3390/nu12061881.

109 M.C.M.P. Gaspar, A.M. Garcia, C. Larrea–Killinger, How would you define healthy food? Social representations of Brazilian, French and Spanish dietitians and young laywomen, „Appetite" 2020, vol. 153, p. 104728, https://doi.org/10.1016/j.appet.2020.104728.

110 L. Hagen, Pretty Healthy Food: How and When Aesthetics Enhance Perceived Healthiness, „Journal of Marketing" 2021, vol. 85, no. 2, pp. 129–145, https://doi.org/10.1177/0022242920944384.

It is also worth noting review studies focused on marketing, such as those by Chan and Zhang.[111] This study examined how people evaluate the nutritiousness of food and how their perceptions influence dietary choices and the amount of food consumed.

The authors point out that people often have difficulty processing health information about foods, so they rely on intuition or common beliefs to make judgments. This article analyzes recent empirical research, highlighting how individuals use sensory (e.g., visual, gustatory) and cognitive (e.g., nutrition labels, price) cues to infer the healthfulness of foods and how these perceptions influence their consumption.

Sensory beliefs are based on highly visible cues, such as packaging color, shape, or aesthetics, that may suggest the healthiness of food. For example, food in blue or green packaging is often perceived as healthier than red. Packaging with a mat surface is considered healthier than a shiny one. Additionally, people believe that „pretty = healthy", which means that aesthetically pleasing foods are perceived as more natural and healthy.

Cognitive cues such as nutrition labels and price also influence perceptions of healthfulness. Foods labeled „organic" or „low-fat" are often considered healthier. More expensive foods are frequently perceived as more nutritious, leading to the belief that „healthy = expensive".

The study also highlights the paradoxical effects of food health perceptions. People often consume larger amounts of foods they consider healthy, which can lead to overconsumption of calories and problems such as obesity.

According to the Awuh study conducted in the Dutch province of Flevoland, the prevailing understanding of healthy food in that region was largely based on nutritional value, which is consistent with government recommendations.[112] The study claims that official guidelines (issued by Voedingscentrum–a public entity providing information on food and nutrition) significantly impact people's perception of healthy and unhealthy food.[113]

111 E. Chan, L.S. Zhang, Is this food healthy? The impact of lay beliefs and contextual cues on food healthiness perception and consumption, „Current Opinion in Psychology" 2022, vol. 46, p. 101348, https://doi.org/10.1016/j.copsyc.2022.101348.

112 H.E. Awuh, Meanings and Visions of Healthy and Unhealthy Food in Flevoland, the Netherlands, in H. Esam Awuh, S. Agyekum (eds.), Geographies of Food: Global Visions of Healthy and Unhealthy Food, Cham, https://doi.org/10.1007/978–3-031–49873-2_2.

113 *Ibid.*

3. Healthy Food in Legal Regulations

Countries often use legal regulations to take action to improve public health, including through interventions in the area of food and nutrition. However, despite these activities, considerations regarding the definition of healthy food in legal provisions can be summarized in one sentence: Polish, European, and international laws do not define it. However, this should not be viewed as a lack of interest in healthy food, and leaving the considerations at that would be a significant understatement. We can talk about the considerable impact of the law on the concept of healthy food.[114]

Food law is of key importance in this respect. In EU law, and consequently also in Polish law, it is defined in Article 3(1) of Regulation 178/2002.[115] This provision states, „'food law' means the laws, regulations and administrative provisions governing food in general, and food safety in particular, whether at Community or national level". This definition covers all stages of production, processing, and distribution of food and feed manufactured for or used to feed farm animals. The rights and obligations that make up the overall food law can be divided into three basic categories, following van der Meulen: interests of consumers, regulations regarding requirements for food businesses, and regulations regarding the powers of public authorities.[116] Van der Meulen further divides the EU food law requirements for food businesses into product-focused provisions, process-focused provisions, presentation, and miscellaneous provisions.[117] It appears that the impact of the law on the concept of healthy food can be discussed in at least two cases: in relation to provisions focusing on the product itself and provisions regulating product presentation.

Product-focused regulations contain standards related to the food, specifying its features, such as composition, additives, or permissible levels of contaminants. Regulations in this category cover, among other things, food quality. As Taczanowski notes, Polish law recognizes two basic types of food quality regulated by food law. These are the commercial quality of

114 See J.A. Farhan, M. Perkowski, Pojęcia zdrowej żywności i zdrowego odżywiania w polityce i prawie Unii Europejskiej, „Przegląd Prawa Rolnego" 2023, no. 2(33), pp. 109–124. doi:10.14746/ppr.2023.33.2.6.

115 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 (OJ L 31, 01/02/2002, page 1 as amended) (hereinafter referred to as „Regulation 178/2002").

116 B.M.J. van der Meulen, The Structure of European Food Law, „Laws" 2013, vol. 2, no. 2, p. 72. The author presented this stratification in relation to EU food law, but it seems that mutatis mutandis may also apply to food law in general.

117 *Ibid.*

food and the health quality of food (health requirements).[118] Under Article 3(5) of the Act on commercial quality of agri-food products, the commercial quality of food covers the features of an agri-food product regarding its organoleptic, physicochemical, and microbiological properties in terms of production technology, size, or weight, as well as requirements resulting from the method of production, packaging, presentation, and labeling, not covered by sanitary, veterinary, or phytosanitary requirements.[119] As Korzycka points out, the legislator, by introducing this concept, „distinguished the features of an agri-food product and, by excluding features strictly related to consumer health protection, considered the features of commercial importance to be those resulting from the method of production and 'externalization' of the product on the market (packaging, presentation, marking)".[120]

On the other hand, the legislation specifies health requirements for food, which replaced the previously used food health quality. Some remnants of the transition to the new terminology can still be found. For example, Article 22(1)(5) of the Act on government administration departments states that the agriculture department covers matters of supervision over the health quality of foodstuffs of animal origin in the places of their acquisition, production, processing, and storage, as well as in direct sales, agricultural retail trade and marginal, local and limited, as well as food containing both foodstuffs of non-animal origin and products of animal origin in agricultural retail trade.[121]

Food health requirements are a statutory concept used in the Act on safety of food and nutrition. Although this Act does not contain a legal definition of this concept, it is used, among other things, in the title of the relatively short Chapter II of this Act (Articles 5–8): Health requirements and food labeling. The content of this section leaves no doubt that it concerns food safety standards. This is indicated, for example, by Article 6(1), stating that foodstuffs not meeting the requirements specified in the provisions of this section implementing EU directives and the requirements of EU regulations regarding food safety may not be placed on the market in the territory of the Republic of Poland. Paragraph 2 of this article contains a similar regulation, although it does not refer to EU law but to the „provisions of

118 M. Taczanowski, Prawo żywnościowe, ed. 2, Warsaw 2017, p. 88.

119 Article 3(5) of the Act of December 21, 2000, on commercial quality of agri-food products (Journal of Laws of 2023, item 1980).

120 M. Korzycka, Jakość żywności in: M. Korzycka, P. Wojciechowski (eds.), System prawa żywnościowego, Warsaw 2017, p. 267.

121 Article 22(1)(5) of the Act of September 4, 1997, on government administration departments (Journal of Laws of 2022, item 2512, of 2023, item 2029 and of 2024, items 834 and 862).

this section", which only cover food safety. This is a certain difference from the health quality of food, which, in accordance with Article 3(13) of the Act on health conditions of food and nutrition, meant all the features and criteria by which food is characterized in terms of nutritional value, organoleptic quality, and safety for the consumer's health.[122] Therefore, it referred to a broader catalog of aspects, including not only safety but also other quality features, such as nutritional value and organoleptic quality (taste, smell, consistency).

As can be seen above, the concept of healthy food has not been legally defined, but the „healthiness" of food is understood narrowly in the law, and in this purely definitional and terminological approach, it refers to food safety. It can only be emphasized that there is no doubt that food safety standards have a significant impact on the perception of food, especially in the context of the historical development of food law. In the EU, a particular acceleration and turnaround in the development of food law occurred as a result of bovine spongiform encephalopathy, commonly known as mad cow disease. Until the 1990s, EU food law served primarily to integrate the internal market through the harmonization of national standards. The introduction of restrictive food safety standards as a result of the crisis was primarily aimed at regaining consumer trust.[123] These standards were originally intended to influence the perception of food, guaranteeing consumers that the products they consume are safe and meet the highest health standards. The implementation of the policies outlined in the White Paper on Food Safety, announced by the European Commission in January 2000, was a response to the need to guarantee a high level of food safety and not only to focus on internal market issues. These dynamic changes in EU food legislation have been crucial to rebuilding consumer confidence and ensuring a high level of food safety in the EU.[124]

On the other hand, emphasizing that these considerations focus on nominal issues, the functioning of the concept of healthy food is much more influenced by regulations on labeling, presentation, and advertising of food, i.e., related to the commercial quality of food. The regulations concerning this matter are important in terms of consumer access to information necessary to make a purchase decision and may also limit advertising and pro-

122 Article 3(13) of the Act of May 11, 2001, on health conditions of food and nutrition (Journal of Laws of 2005, *items* 265 and 1480).

123 B.M.J. van der Meulen, The System of Food Law in the European Union, „Deakin Law Review" 2009, vol. 14, no. 2, p. 313, https://doi.org/10.21153/dlr2009vol14no2art145.

124 White Paper on Food Safety of 12 January 2000, COM/99/0719 final.

motional practices. Under EU law, regulations in this area developed dynamically, in particular after the judgment in the *Cassis de Dijon* case.

The case concerned the introduction of a liqueur called Cassis de Dijon to the German market. The ruling concluded that „There is therefore no valid reason why, provided that they have been lawfully produced and marketed in one of the Member States, alcoholic beverages should not be introduced into any other Member State".[125] Thus, the principle of mutual recognition was created not only for alcoholic beverages but also for all products available on the market. In the communication of the Commission of the European Communities from 1985 on the completion of the internal market, it was held that the principles developed by the ECJ following the *Cassis de Dijon* judgment enable the Community to define a system of food law that contains only provisions justified as necessary to meet essential requirements in the general interest. The necessity of these additional provisions is measured by compliance with the principle of proportionality.[126]

This is the basis of the consumer concept developed by the CJEU based on the information paradigm reflected in food law. The information paradigm is based on the belief that if consumers are provided with sufficient and appropriate information, they will generally be sufficiently protected and make good decisions, including regarding their health and life. This paradigm assumes that the average consumer will be sufficiently „well-informed", „cautious", and „observant". Each of these characteristics has its implications: Being informed refers to the consumer's assumed level of knowledge; being careful refers to attention and information absorption; and being prudent refers to the degree of criticality a consumer should have when processing information.[127]

Detailed regulations on the provision of food information to consumers are regulated primarily in Regulation 1169/2011[128] (which will be dis-

125 Paragraph 14 of the Judgment of the Court of 20 February 1979, Rewe–Zentral AG v Bundesmonopolverwaltung für Branntwein. Reference for a preliminary ruling: Hessisches Finanzgericht.

126 Commission of the European Communities, Completion of the internal market: Community legislation on foodstuffs. Communication from the Commission to the Council and the European Parliament, Brussels 1985, COM (85) 603 final, point 8.

127 C.G. Stanescu, The Responsible Consumer in the Digital Age: On the Conceptual Shift from 'Average' to 'Responsible' Consumer and the Inadequacy of the 'Information Paradigm' in Consumer Financial Protection, Rochester, NY 2019, p. 51.

128 Regulation (EU) No 1169/2011 of the European Parliament and of the Council of 25 October 2011 on the provision of food information to consumers, amending Regulations (EC) No 1924/2006 and (EC) No 1925/2006 of the European Parliament and of the Council, and repealing Commission Directive 87/250/EEC, Council Directive 90/496/EEC, Commission Directive 1999/10/EC, Directive 2000/13/EC of the European Parliament and of the Council, Commission Directives 2002/67/EC and 2008/5/EC and Commission Regulation (EC) No 608/2004 (OJ EU L 304, 22/11/2011, p. 18 as amended) (hereinafter referred to as „Regulation 1169/2011").

cussed in greater detail in section 3.4), as well as specific provisions applicable to specific categories of food. What should be signaled at this stage is that, in addition to the mandatory information, foodstuffs may bear nutrition or health claims.

A mere claim in food law is understood to mean any communication or representation that is not mandatory under Community or national law, including a pictorial, graphic, or symbolic representation in any form that states, suggests, or implies that a food has special properties.[129]

A nutrition claim is any claim that states, suggests, or implies that a food has particular nutritional properties by virtue of providing, being in a reduced or increased amount of, or not providing energy, or by containing, being in a reduced or increased amount, or not containing nutrients or other substances.[130] The catalogue of nutritional claims permitted for use and the conditions for their use can be found in the annex to Regulation 1924/2006. It includes claims such as:

- low energy value, which may only be used if the product does not contain more than 40 kcal (170 kJ)/100 g for solid products or no more than 20 kcal (80 kJ)/100 ml for liquid products. In the case of table sweeteners, the limit is 4 kcal (17 kJ)/portion, with a sweetening intensity equivalent to 6 g of sucrose (approx. 1 teaspoon of sucrose);
- low fat content, which may only be used if the product contains no more than 3 g of fat per 100 g for solid products or 1.5 g of fat per 100 ml for liquid products (1.8 g of fat per 100 ml of semi-skimmed milk);
- low sugar content, which can only be used if the product contains no more than 5 g of sugars per 100 g for solid products or 2.5 g of sugars per 100 ml for liquid products.

A health claim is defined in Article 2, paragraph 2, point 5 of Regulation 1924/2006. This term means any claim that states, suggests or implies that there is a relationship between a food category, a given food or one of its ingredients and health.[131] In accordance with Article 13(3) of Regulation 1924/2006, the European Commission, after obtaining the opinion of the relevant authority, had to adopt, by 31 January 2010, a Community list

129 Article 2(2)(1) of Regulation (EC) No 1924/2006 of the European Parliament and of the Council of 20 December 2006 on nutrition and health claims made on foods (OJ EU L 150 of 14/06/2018, p. 1 as amended) (hereinafter referred to as „Regulation 1924/2006").

130 Article 2(2)(4) of Regulation 1924/2006.

131 Article 2(2)(5) of Regulation 1924/2006.

of permitted health claims in accordance with the regulatory procedure with scrutiny referred to in Article 25(3). The list has been adopted, but it is not immutable. On the basis of Article 15 of Regulation 1924/2006, it is possible to submit an application for authorisation to enter a new claim in this list. In accordance with Article 13(1) of Regulation 1924/2006, the list may include claims that refer to: the effect of nutrients or substances on growth, development and body functions; the effect on psychological or behavioural functions; weight control, including weight loss, reducing the sense of hunger, increasing the sense of satiety or reducing the available energy in the diet.

In addition, in accordance with Article 14(1) of Regulation 1924/2006, the list may include claims concerning the reduction of the risk of diseases and the promotion of children's development and health. In addition to the claims included in the register, Article 10(1) 3 Regulation 1924/2006 allows for the possibility of referring to the „general, non-specific benefits of a nutrient or food for general health and well-being" if accompanied by a registered health claim. Such general health claims were controversial even at the drafting stage. The European Commission even proposed introducing a ban on such claims referring to general health or well-being.[132]

These general health claims are particularly noteworthy in the context of the lack of nutrient profiles in EU food law. By 19 January 2009, nutrient profiles and exemptions that food products must meet in order to make nutrition or health claims were to be developed. The conditions for the use of these claims for different product categories were also established.[133] Nutrient profiles for foods or certain food categories were to be established taking into account elements such as: the amounts of specific nutrients and other substances contained in the food, such as fat, saturated fatty acids, trans fatty acids, sugars and salt/sodium; the role and importance of a given food (or food category) and its contribution to the diet of the general population or, where appropriate, certain risk groups, including children; the overall nutritional composition of the food; and the presence of nutrients that have been scientifically recognised as having an effect on health.[134] The aim of establishing nutrient profiles was to „avoid situations where nutrition or health claims mask the overall nutritional status of a food product,

132 A. Balicki, Art. 10, in: A. Balicki, D. Szostek, A. Szymecka–Wesołowska (eds.), Oświadczenia żywieniowe i zdrowotne w oznakowaniu, prezentacji i reklamie żywności. Komentarz, Warszawa 2015, p. 230.

133 Article 4 of Regulation 1924/2006.

134 *Ibid.*

which could mislead consumers when trying to make health-related choices in the context of a balanced diet".[135]

This goal is undoubtedly justified, but nutrient profiles have not yet been established. The lack of such profiles means that products can be labeled with claims such as „Source of vitamin C" and „Vitamin C contributes to the normal function of the immune system"[136], if they contain sufficient amounts of this vitamin, regardless of other nutrients in the product, such as high levels of salt.[137]

According to Article 10(3) of Regulation No. 1924/2006, such a claim may be accompanied by a more general statement, such as „health-promoting product" or „part of a healthy diet". As a consequence of this regulatory shortcoming, a product labelled by the manufacturer as „healthy" may in fact contain ingredients that are not beneficial to health, such as high fat or sugar content, and may not necessarily meet the criteria for a healthy food according to the studies cited above[138]

4. Healthy Food – Analysis of Differences and Relationships between Individual Concepts of Healthy Food

Even a cursory preliminary study and a short scientific discussion in an interdisciplinary group indicate that healthy food is an ambiguous term. It may be interpreted differently by different people. For some, it may mean low-calorie food, especially if they think about the health problems of modern societies in the context of the growing incidence of obesity; for others, it means food free from artificial additives and less processed, and for still others, it will mean functional food.

Based on the discussed perspectives on the concept of healthy food, significant differences in individual approaches can be observed. Despite its commonness in society, this concept causes skepticism, especially in the context of chemical and medical sciences. It is not possible to separate the category of healthy food. The possible content of this concept is analyzed only through the prism of two main characteristics of food–the con-

135 Recital 10 of Regulation 1924/2006.

136 Annex to Commission Regulation (EC) No 983/2009 of 21 October 2009 on the authorisation and refusal of authorisation of certain health claims made on food and referring to the reduction of disease risk and to children's development and health (OJ L 277, p. 3 as amended).

137 Article 28 of Regulation 1924/2006.

138 See J.A. Farhan, M. Perkowski, *op. cit.*

tent of nutrients and chemical and biological contaminants present in food, which are critical determinants of food quality and safety.

Unlike common thinking about healthy food, which may be shaped not only by well-conducted scientific research but also by dietary trends and marketing activities, the scientific approach focuses on a strict assessment of food. Food safety is an integral element of the assessment of its healthiness, including official control of pesticide residues, nitrates III and nitrates V, nitrosamines, nitrofurans, alkaloids, dioxins, polycyclic aromatic hydrocarbons, acrylamide, mycotoxins, microorganisms, and toxic elements such as cadmium and lead, which negatively affect consumers' health.[139]

In turn, the perspective resulting from the research discussed in section 1.2 presents a less strict approach to the concept of healthy food. From the perspective of food consumers, there is also a connection between healthy food and its nutrients and potential contaminants that may be contained in it. However, research shows that consumers often associate healthy food with factors that may be irrelevant from a scientific point of view. For example, the aesthetics of the packaging and the impression of naturalness, or even a higher price, may influence the perception of the healthiness of food, even though they have no direct connection with its nutritional value or safety.

As for the legal standpoint, it should be emphasized that the law shapes many features of food that influence consumers' perception, as well as their assessment of whether a specific product is considered healthy. However, at a nominal level, there are significant limitations in the definition and application of healthy food in legal practice. The regulations that influence what can be defined as healthy food contain obvious shortcomings. „Healthy food" as a general health claim in its current form does not take into account issues such as high salt, fat, or sugar content, which are crucial from the perspective of health sciences.

139 EFSA, Contaminants in the Food Chain, accessed: August 8, 2024, https://www.efsa.europa.eu/en/science/scientific-committee-and-panels/contam.

Chapter 2

HEALTHY FOOD IN THE LIGHT OF SURVEY RESULTS

1. Research Assumptions

As follows from the considerations presented in the previous chapter, determining the meaning of healthy food is not an easy task. Depending on the perspective adopted, it may undergo certain changes, leading to a shift in emphasis to various food features. Nevertheless, it can be clearly stated that „healthy food" is a real social phenomenon. There is no doubt that this concept is part of the common language. An internet search yields many results related to its use.

When developing the assumptions of this project, it was known that an accurate and unambiguous definition of healthy food, especially with an interdisciplinary approach, would be impossible, based only on a literature review and analysis of legal regulations. However, this does not make the study of healthy food and its social perception pointless. We must bear in mind that in common parlance, people constantly use concepts that are not clearly defined. Therefore, we found it necessary to conduct a survey. It aimed to determine specific designations that, in social assessment, correspond to the concept of healthy food. The authors assumed the following:

- On the one hand, the survey will enable verification of the coherence of scientific literature and legal regulations to the extent enabling defining healthy food, with the actual application of this concept in society, and
- On the other hand, it will constitute the basis for further research on food actually considered healthy by society.

Since people consider some foods to be healthy and others do not, and healthy food does not have one precise definition, when examining the social perception of healthy food, it is necessary to focus on specific foods that society considers healthy. Only after identifying these foods (processed, partially processed, or unprocessed foods) or their characteristics can we assess whether their perception as healthy is justified by applying the lens of „scientific certainty".

For analysis, the definition of food (or foodstuff) in Article 2 of Regulation 178/2002 is applied:

„Food" (or „foodstuff") means any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be ingested by humans. „Food" includes drink, chewing gum and any substance, including water, intentionally incorporated into the food during its manufacture, preparation or treatment. It includes water after the point of compliance as defined in Article 6 of Directive 98/83/EC and without prejudice to the requirements of Directives 80/778/EEC and 98/83/EC.

„Foodstuff" shall not include:

a) *feed;*

b) *live animals unless they are prepared for placing on the market for human consumption;*

c) *plants prior to harvesting;*

d) *medicinal products within the meaning of Council Directives 65/65/EEC and 92/73/EEC;*

e) *cosmetics within the meaning of Council Directive 76/768/EEC;*

f) *tobacco and tobacco products within the meaning of Council Directive 89/622/EEC;*

g) *narcotic or psychotropic substances within the meaning of the United Nations Single Convention on Narcotic Drugs, 1961, and the United Nations Convention on Psychotropic Substances, 1971;*

h) *residues and contaminants;*

i) *medical devices within the meaning of Regulation (EU) 2017/745 of the European Parliament and of the Council.*

The survey was divided into two parts. In the first, the respondents were a random sample of the general population. In the second, the respondents were narrowed down to include only the food industry representatives.

Due to the specific conditions in which both groups of respondents interact on the market, it could be assumed that there are significant differences in what potentially influences their perception of healthy food. Consumers evaluate products based on individual health needs, taste preferences, and financial availability, while business owners must take these into account while adapting to market requirements, consumer trends, and industry regulations. Using these two groups was intended to allow for a better understanding of the specificity and dynamics of the social and business dimensions of healthy food.

2. Research Description

The Pollster Research Institute (hereinafter referred to as „Pollster"), which specializes in research using new technologies, was responsible for the survey.[1] It not only conducted and compiled the survey results but also provided expert services involving methodological correctness and optimization of the questionnaires provided by the researchers. The results were provided to the research team as a database in .xls format. After transforming the survey results into transparent tables and charts, the research team developed an abridged open-access report, which was published in March 2023 in two language versions, Polish[2] and English[3], on the website https://zdrowazywnosc.edu.pl. It contains a description of the survey methodology, demographic data of the respondents, and visualized

1 The Pollster Research Institute specializes in market and organizational research using new technologies; see https://pollster.pl/. Its portfolio includes many studies. Recently, it demonstrated the lowest error rate of election polls compared to the results of the parliamentary elections in Poland in 2023; see https://sprawdzamysondaze.pl/parlamentarne-2023/wybory/sondaz/#instytut-badan-pollster. Pollster was selected due to the most advantageous offer, based on the price–quality ratio and scope of services provided, from eight entities providing similar services to which requests for proposals were sent.

2 J.A. Farhan, P. Kaczyński, M. Perkowski, Społeczna percepcja zdrowej żywności w świetle interdyscyplinarnej pewności naukowej. Raport z wynikami badania ankietowego, Białystok 2023, https://doi.org/10.15290/spzzsipn.2023.

3 J.A. Farhan, P. Kaczyński, M. Perkowski, Public Perception of Healthy Food in The Light of Interdisciplinary Scientific Certainty. Survey report, Białystok 2023, https://doi.org/10.15290/pphflisc.2023.

survey results. The report does not discuss the results of this study. For this reason, we wanted to include here the most important information about the research methodology, which was described in the reports published in 2023. They constitute an important introduction to the preliminary analysis of the research results.

The survey of a representative sample of the general population was conducted using computer-assisted web interviewing (CAWI), which involves collecting information by asking the respondents to complete an electronic survey on the ReaktorOpinii.pl research panel created by Pollster. The respondents were over 18 years of age, and the answers were collected on January 26–31, 2023. The research sample, which included 1,041 people, is representative of the population of adult Poles in terms of age, gender, size of place of residence, and education.[4]

In order to improve the quality of the responses received, respondents were registered in the research panel in two stages. In the first step, the respondents provided their basic demographic data, then were obliged to complete an extensive „initial" survey covering additional demographic data and confirming the previously provided information; in each project, respondents were asked questions about demographic variables, which were then randomly compared with variables provided in the initial survey. In case of inaccuracies, the respondent received a message asking for clarification. The final verification of the correctness of demographic data was done on payment of the remuneration for participation in the research. This ensures each respondent provides accurate personal data related to their bank account. Double questions about the same issues are used, e.g., year of birth and age range. Pollster regularly updates data that may change (e.g., education, place of residence, etc.).

The questionnaire was developed by the entire research team involved in the project and then consulted with Pollster experts. It consisted of 10 specific questions and 4 thematic sections: I. General

4 The survey standards are described, for example, in E. Babbie, Badania społeczne w praktyce, Warsaw 2013; M. Szreder, Metody i techniki sondażowych badań opinii, Warsaw, 2010; J. Sztumski, Wstęp do metod i technik badań społecznych, Katowice 2020; A. Haber, M. Szałaj (eds.), Ewaluacja wobec wyzwań stojących przed sektorem finansów publicznych, Warsaw 2009, pp. 97–188.

information about food; II. Using the healthy food category; III. General opinions about food; and IV. Food knowledge. In section I, all respondents were asked 4 multiple-choice questions and 1 Likert-scale question (a set of five statements) regarding general information about healthy food. In section II, respondents were asked 3 closed-ended questions, 2 Likert-scale questions, and 4 open-ended questions. Due to the number of questions and the time required to complete the questionnaire, sections III and IV were divided into modules A and B. Respondents were divided into two representative samples and assigned to one of the two modules. It should be emphasized that the allocation to modules was not random and was based on the sociodemographic characteristics of respondents to ensure the representativeness of the results from both modules. In module A, section III consisted of 4 Likert-scale questions and 1 closed-ended question, and section IV consisted of 8 multiple-choice questions and 2 closed-ended questions. However, in module B, section III consisted of 4 Likert-scale questions and 1 open-ended question, and section IV consisted of 1 closed-ended question, 1 Likert-scale question, and 7 multiple-choice questions.

The survey of the food industry was carried out using computer-assisted telephone interviewing (CATI), during which the interviewer reads the questions and notes the answers using a computer script.[5] The respondents were business people from the database of companies purchased by Pollster whose activities are related to catering, food production, or food processing. The business profile was determined based on the Polish Classification of Activities (PKD) codes. The study was carried out from January 30 to February 7, 2023, from 11:00 a.m. to 9:00 p.m. Only people with prior appointments were called before 11:00 a.m.

The questionnaire consisted of 4 specific questions, and the main questionnaire included 9 closed-ended questions, 9 open-ended questions, and 3 multiple-choice questions. The study involved

5 See W. Jabłoński, Wywiad telefoniczny ze wspomaganiem komputerowym (CATI). Działania ankieterskie w call centers, Łódź 2016; P.B. Sztabiński, Wywiad telefoniczny ze wspomaganiem komputerowym (CATI): co zyskujemy, co tracimy?, „Research and Methods" 1999, no. 8(1), pp. 51–66; D. Mider, Jak badać opinię publiczną w internecie? Ewaluacja wybranych technik badawczych, „Przegląd Socjologiczny" 2013, vol. 62, no. 1, pp. 209–224.

100 business owners, of which 91 were involved in catering, 4 in processing, and 5 in primary production.[6] This cross-section, to some extent, reflects the cross-section of entities in the national economy, where there are definitely fewer producers and processors, and gastronomy dominates.[7] The size of the enterprises was as follows: 78 businesses employed from 2 to 9 people, 19 employed from 10 to 49 people, 1 employed from 50 to 249 people, 1 employed over 250 people, and 1 was unable to specify the number of employees. There were 24 businesses operating in the countryside, 26 in towns up to 20,000 inhabitants, 17 in cities between 20,000 and 50,000 inhabitants, 6 in cities between 50,000 and 100,000 inhabitants, 7 in cities between 100,000 and 500,000 inhabitants, and 20 in cities over 500,000 inhabitants. All respondents were decision-makers in their companies.

The research aimed to determine the characteristics that cause a given type of food to be assigned to the „healthy food" category in the public's perception. This was necessary for further legal and analytical research. In legal research, determining which features influence the social perception of food as healthy is a starting point for determining which legal acts should ultimately be analyzed regarding the relevance of the standards they contain with society's expectations. In turn, food of plant origin and honey, indicated by respondents, were selected for analytical research, including the presence of chemical (pesticides, toxic elements) and biological (mycotoxins) contaminants and the content of minerals.

6 „Primary production" means the production, cultivation, or breeding of primary products, including the harvesting, milking, and rearing of livestock before slaughter. It also means hunting and fishing and collecting forest undergrowth; see Article 3(17) of Regulation 178/2002.

7 According to the statistical data available in the Local Data Bank of Statistics Poland, analyzing the number of national economy entities (public and private) by REGON, in accordance with the sections and divisions of the PKD (2007), in 2023, it was as follows: 72,164 entities in section A „Agriculture, forestry, hunting and fishing" (all sections); 33,609 entities in section C „Industrial processing" (section 10: production of food products); 115,270 entities in section I „Activities related to accommodation and catering services" (division 56: service activities related to catering); see Local Data Bank, Statistics Poland, Category K25, Group G439, Subgroup P3001, https://bdl.stat.gov.pl/bdl/dane/podgrup/tablica.

3. Research Results

In the general population survey, the questions and the conclusions drawn from the answers can be divided into four categories as follows:

1) General approach to healthy food–Are respondents interested in healthy food?
2) Obtaining information and opinions about food:
   a) Where do they look for information about food, and what are their food preferences?
   b) What factors influence their choice of specific food products?
3) Determinants of purchasing and dietary decisions:
   a) How do they make decisions about purchasing and consuming food?
   b) What factors are key in making nutritional decisions, and what are the barriers?
4) Food concerns and confidence:
   a) What are their concerns about food, and what actions are they taking about it?
   b) What factors influence their trust in food products and producers?
5) General food knowledge–What knowledge do they have about the nutrients and nutritional value of various food products?

It is worth emphasizing that respondents were asked about foodstuffs and general food characteristics without receiving a prior definition of what researchers understand by healthy food. Thanks to this approach, respondents were not influenced by researchers' assumptions or guidelines, and researchers could independently infer which features of food make respondents consider a given food to be healthy. When analyzing the research results, tenths of the obtained percentage results were rounded up or down in accordance with generally accepted rules to improve readability.

3.1. General Approach to Healthy Food

Nowadays, there appears to be a growing interest in leading a healthy lifestyle, an integral element of which is eating healthy and appropriate eating habits. Although the majority of the respondents expressed interest in healthy food, this majority constituted just over half of them, i.e., 62%.

On the other hand, despite the declared lack of general interest in healthy food, a significantly larger group of respondents (88%) indicated that they sometimes buy healthy food. It seems that healthy food interests the respondents, and many of them have come across it, but it is not constantly present in their daily diet. Moreover, respondents agreed with the following statement: „If someone wants to have a healthy mind, they must take care of proper nutrition" (45% – „Somewhat agree", 36% – „Strongly agree"). Therefore, most are aware of the importance of diet in maintaining cognitive skills.

Searching for a general definition of what society considers healthy food, respondents were presented with three statements. The largest group somewhat and strongly agreed with the statement that healthy food includes any food product that, when consumed in reasonable quantities, has a positive effect on the consumer's health (55%). However, the smallest group of respondents somewhat and strongly agreed with the statement that healthy food is any food purchased in a health food store (36%), which indicates the need to promote knowledge and information about it. There was also a statement that healthy food is „any food product produced on a farm" (40%). For each of these statements, the largest group of respondents chose the answer „Somewhat agree", which accounted for 40%, 30%, and 30% of the responses, respectively. The second largest group of respondents in all three cases answered „Neither agree nor disagree", and the third largest group in all three cases replied „Somewhat disagree". This also demonstrates that not all respondents are convinced that the place of purchase (health food store) or the place of food production (farm) makes food healthy or unhealthy.

The most common places where respondents buy healthy food are supermarkets/hypermarkets (45%) and farmers markets (39%). Only about a quarter of respondents (26%) shop at health food stores, and 10% buy online. This is surprising considering that for 77% of respondents, the Internet is the main source of information about food. However, this does not mean purchasing healthy food.

The vast majority of respondents interested in healthy food (83%) agree or somewhat agree with the statement that they are interested in the impact of healthy food on improving life functions. This coincides with the fact that the vast majority of respondents (62%) indicate concern for their health as a source of motivation to choose healthy food. This is important in the context of promoting wholesome food.

For a significant number of respondents, important motivators for buying healthy food are the concern for the natural environment and a sense of responsibility for their food choices. In addition, 70% of respondents agreed or somewhat agreed that „By consuming healthy food, I achieve greater psychological comfort knowing that I care about the environment and am responsible." This leads to the conclusion that any connections with environmental protection and natural values of the area where a given food was produced may cause associations to designate this food as healthy. Therefore, appropriate and precise markings, etc., should be the subject of concern for the creators of legal provisions, bodies applying the law, and scientists dealing with these issues.

The compatibility of healthy food consumption with personal values and lifestyle as a manifestation of beliefs is a motive for 64% of respondents. Therefore, it appears that for a significant number of respondents, choosing healthy food is not only a matter of health but also an element of their identity or worldview. On the other hand, a very small proportion of respondents indicated choosing healthy food because it is fashionable (2%). The latter does not necessarily reflect reality, as fashion-driven people may not be willing to admit it directly. In the future, in-depth research is needed on „healthy food fashion" and what it entails. It seems that broadly understood fashion can have a strong impact on identity and worldview, especially among young people (e.g., because of influencers).[8]

However, it should be noted that a significant number of respondents point to the composition and nutritional value of products as the main factors for selecting healthy food (55%). Thus, it can be stated that the classification of foodstuffs as healthy is made, among other things, based on composition and nutritional value. It is also worth highlighting that a considerable proportion of respondents indicated „quality" (49%) and „taste" (38%) – the interviewees appear to associate healthy food with higher quality with special taste values.

An interesting conclusion is that most respondents confuse the concepts of healthy food and safe food (58%), believing them to mean the same or to have at least some similarities. At the same time, most respondents think that safe food is free from pesticides, fertilizers, preservatives, and additives (42% strongly agree with this position, and the same percentage somewhat agree). A significant proportion of respondents also agreed

8 See D. Marzec, Znaczenie influencer marketingu w kształtowaniu decyzji współczesnych konsumentów, „Media i Społeczeństwo" 2022, no. 16, pp. 154–174, https://doi.org/10.53052/MiS.2022.16.10, and the literature cited there.

that safe food comes from organic farming and breeding (36% strongly agreed and 45% somewhat agreed) and has the least amount of fats and sugars (24% strongly agreed and 44% somewhat agreed). Paradoxically, the smallest percentage of respondents agreed that safe food has contaminant contents below that specified in the standards (11% strongly agreed and 36% somewhat agreed).

3.2. Information about Food and Desired Food Characteristics

As already mentioned, the Internet is the main source of information about food products for the majority of respondents (77%). This is consistent with the general trend to seek all information primarily online. A significant group of respondents (63%) obtain information through conversations with family and friends (63%). Personal experiences and recommendations from loved ones are important factors shaping their knowledge about food. Although television and radio still play a prominent role in finding information about food, they were indicated considerably less often than the Internet (45%). A small number of respondents point to professionals, e.g., dietitians, doctors, or pharmacists, as their main source of knowledge about food products (21%). Health science experts are undoubtedly a reliable and valuable source of information, but they are not the primary source for respondents. Perhaps this is because they are more difficult to access compared to other options provided. This is also an important finding for our research team to widely disseminate information about our project and its results in order to raise public awareness of healthy food, emphasizing the contribution of experts in its development.

Packaging is a major source of information about specific products. Therefore, respondents were asked what type of packaging would encourage them to buy healthy food. Most respondents (78%) are interested in packaging containing information about the impact of individual food components on health, i.e., which can be legally described as a health claim.[9] Packaging with a general statement about the content of health-promoting components arouses the interest of over 70% of respondents. This indicates that general information about the content of health-promoting components may also influence purchasing decisions. It is vital for consumers to highlight the health benefits of a product, which may influence their willingness to purchase it. In turn, 12% of respondents declare that attractive,

9 Under Article 2(2)(5a) of Regulation (EC) No 1924/2006 of the European Parliament and of the Council of 20 December 2006 on nutrition and health claims made on foods (OJ L 404, 30/12/2006, p. 9 as amended, a „'health claim' means any health claim that states, suggests or implies that a relationship exists between a food category, a food or one of its constituents and health".

aesthetic packaging would not encourage them to make a purchase, while 52% of respondents claim that such packaging would encourage them to make a purchase.

Respondents consider micro – and macronutrients, vitamins and minerals, and unsaturated fatty acids to be particularly important to a healthy diet. This is consistent with commonly known facts about their role in maintaining health and well-being. It is important, however, that a significant number of respondents have limited knowledge about polyphenolic compounds, phenolic acids, phytosterols, and glucosinolates, which manifests itself in considering these components unimportant or in the lack of knowledge about them. This suggests that education about the role of these components, including their antioxidant properties and importance, among other things, in preventing cardiovascular diseases, may be crucial for improving society's health awareness. The lack of understanding of their role may be due to the limited availability of information or lack of education in this area, highlighting the need for greater overlap in education about healthy eating. The tendency to select answers „Not important" or „Don't know/ Hard to say" may be due to uncertainty or unfamiliarity with the components, highlighting the need to provide more accessible and transparent information about their role and importance for health. This suggests that education and reliable information about various food components can be key to promoting healthy eating and improving public understanding of a healthy diet.

Respondents believe that the high quality of food products is mainly related to their naturalness. When asked about what proves the high quality of food products, the most common answers were: no artificial additives (67%), only natural ingredients (60%), and low processing (50%). The two most frequent answers directly refer to naturalness. A low degree of processing is also related to this because less processed food may contain more natural ingredients, and it certainly does not contain artificial food additives typical of highly processed foods, so, in general, it can be treated as close to natural food. This is reflected in the question about food labels, which particularly encourage choosing a given product. The three most frequently indicated labels by respondents were: „no artificial colors" (66.4%), „natural" (61%), and „GMO-free" (34%). In the case of the latter, it is worth noting that 56% of respondents agree with the statement that non-genetically modified food is healthier than food with the GMO marking, and 55% of respondents agree that food from animals fed with GMO feed is less healthy and healthy from animals fed with non-GMO feed.

When it comes to respondents' approach to macronutrients, sugar has the worst reputation. As many as 75% of respondents agree that low-sugar food is healthier than standard food. In turn, 59% of respondents believe that low-fat food is healthier than standard food. However, only 20% of respondents think that low-protein foods are healthier than standard foods. As many as 71% of respondents consider food with high dietary fiber content to be healthier than standard food. Therefore, it appears that as far as macronutrients are concerned, sugar and fat are associated with unhealthy food, while protein and dietary fiber are much more often perceived as health-promoting nutrients. It can be assumed that information about the harmful effects of sugar and fat reaches the average person more effectively than in the case of the previously discussed food contaminants that do not exceed the standards.

Products with labels designed to entice consumers by referring to the reduced content of a specific component, such as „low calorie", are becoming increasingly common. However, only 21% of respondents agreed with the statement that such markings are particularly persuasive. However, the use of a label (sometimes synonyms are used), such as „lite", to designate food healthier than standard food motivates the choice of such a product (33% of respondents). However, 20% of respondents had no opinion about this label, and 34% of respondents said that such food is neither healthier nor less healthy. By far, the most health-promoting label is „reduced sodium/salt". In turn, 65% of respondents somewhat or strongly agree that food labeled with it would be healthier than standard food.

More and more often, food producers use labeling systems, such as GDA or Nutri-Score. They are intended to make it easier for consumers to make purchasing decisions by choosing foodstuffs with the most favorable nutritional composition/adapted to the needs of a given consumer. It was found that 25% of respondents somewhat use such markings, and 5% of respondents definitely use them. It can be assumed that most consumers do not have much knowledge about food labeling systems. This can be seen in the largest group of respondents who have an ambivalent approach to these labels, i.e., they do not use them, but they do not discourage them from buying specific foodstuffs.

In addition to the above information, food businesses use certain standardized markings intended to provide consumers with information about the characteristics of food that distinguish specific products. These include markings such as „Organic", „Discover good food", „Polish product", „Quality Tradition", and „Quality Assurance for Food Products". When asked if labels such as the above guarantee the quality and safety of foodstuffs, most respondents agree with this statement (9% strongly agree, but as many as 43% somewhat agree). Still, 32% of respondents have no opinion on this matter. However, only 11% somewhat or strongly disagreed with this statement. A designation with a special role, at least because of its place in the legal system, is the protected designation of origin (PDO). The PDO label does not seem to have a clear impact on health according to 43% of respondents (neither agree nor disagree and don't know/ hard to say), but 32% agree that it denotes healthier food (27% somewhat agree and 5% strongly agree), which seems logical because no region would like to be associated with food that is of little value or even harmful to health. For a while, superfoods seemed quite popular. However, in public opinion, such a label has not been associated with health in most cases. Only 21% of respondents believe that foods labeled superfoods have specific health-promoting properties.

The Fairtrade label intended to determine whether respondents understood what function it was supposed to perform. Only 4% of respondents strongly agreed with the statement that food marked with it is healthier than food without it. The vast majority (correctly[10]) answered: „Neither agree nor disagree" (40%), „Don't know/ Hard to say" (24%), „Somewhat disagree" (10%), and „Strongly disagree" (3%).

A noteworthy and relatively unexpected result is that as many as 68% of respondents believe that locally produced food is healthier than mass-produced food. Only 7% strongly (3%) and somewhat (4%) disagreed with this statement. It seems that the trend of focusing on local products is to some extent related to choosing organic products, which are also a permanent fixture on „healthy food shelves" at stores. Therefore, it was reasonable to examine the respondents' approach to pesticides in food production. When asked how to produce fruits and vegetables, respondents overwhelmingly chose synthetic pesticides, using technology consistent with sustainable development (76%). Only 9% supported synthetic pesticides, using technology inconsistent with sustainable development. The remaining 15% had no opinion. A large proportion of respondents do not know, cannot say, or have no opinion on whether the use of pesticides reduces the risk of mycotoxins (33% – „Don't know/ Hard to say" 28% – „Neither agree nor disagree"). It appears that consumers are not aware of the role of plant protec-

10 This label denotes products and raw materials originating only from countries in the Global South; therefore, it is not related to healthy food, and the standards are based on compliance with the provisions of the International Labor Organization convention; see Oznakowania o charakterze społecznym, „Public Procurement Office", pp. 4–6, https://www.uzp.gov.pl/__data/assets/pdf_file/0027/39564/Oznaczenia-spoleczne.pdf.

tion products in food production and that they are used in both organic and conventional agriculture. This is one of the ways to protect plants and plant products against harmful factors (including weeds and fungi) and improve agricultural production.

Although they raise some concerns and are often presented in a negative light, pesticides play a significant role in the production of food of plant origin. However, only 26% of respondents agree that their use is needed to produce enough food. Only 27% disagree with this statement. The largest group neither agreed nor disagreed (33%). This is further evidence that consumers have little knowledge about pesticides. However, opinions are divided as to whether pesticides are completely unnecessary and whether agricultural production without their use would yield enough food (10% strongly agreed and 26% somewhat agreed, while 6% strongly disagreed, 14% somewhat disagreed, and 29% neither agreed nor disagreed) and whether they are main factors causing various diseases (20% strongly agreed, 36% somewhat agreed, 2% strongly disagreed, 9% somewhat disagreed, and 21% neither agreed nor disagreed). It is worth pointing out that residues of plant protection products and other pesticides are dangerous, exceeding permissible concentrations and posing a threat to consumers' health. The Supreme Audit Office drew attention to this in 2020, pointing out that the main problem of the safety system of trade in plant protection products is the excessively long time needed to test for pesticides–both in agricultural produce and in food sold in stores.[11] Further, respondents primarily express great concern about the impact of pesticides on the natural environment. And 24% strongly agreed that pesticides pose a huge threat to the environment, and 37% somewhat agreed with this statement. It is worth noting that in the Farm to Fork Strategy, one of the pillars of the European Green Deal, the European Commission has committed to reducing the use of chemical and more hazardous pesticides in the EU and the risks associated with them by 50% by 2030.[12] However, due to the EU farmers' protests in recent months, limiting the use of plant protection products has been dropped.[13] There is a discrepancy between the expectations and concerns of respondents and producers.

11 See System bezpieczeństwa obrotu środkami ochrony roślin. Informacja o wynikach kontroli, „Supreme Audit Office", LLO.430.004.2019, Registration no. 174/2019/P/19/086/LLO, Warsaw 2020, https://www.nik.gov.pl/plik/id,22046,vp,24713.pdf.

12 See Pesticides and plant protection, European Commission, https://agriculture.ec.europa.eu/sustainability/environmental-sustainability/low-input-farming/pesticides_pl.

13 See Wojciechowski: ugorowanie gruntów będzie dobrowolne, ograniczenie środków ochrony roślin nie wejdzie w życie „PAP" March 7, 2024, https://www.pap.pl/aktualnosci/wojciechowski-ugorowanie-gruntow-bedzie-dobrowolne-zdrowie-srodkow-ochrony-plant.

The issue of organic food is closely related to the respondents' opinions on pesticides.[14] This term seems to be widely known now, and the number of foodstuffs marked as organic food available in stores is growing. Therefore, respondents were presented with several statements about what organic food is. They were asked to what extent they agreed or disagreed with individual statements. The following statements were presented: Organic food is produced in organic farming without the use of artificial fertilizers, pesticides, and other chemicals; Organic food is produced on family farms with minimal use of artificial fertilizers, pesticides, and other chemicals; Organic food is produced/grown in a home or family garden; Organic food is produced according to traditional recipes; Organic food is produced in areas considered clean and with an unpolluted environment. It will not be surprising that the largest percentage of respondents agreed with the statement that organic food is produced in organic farming without the use of ar-

14 Under Article 3(2) of Regulation (EU) 2018/848 of the European Parliament and of the Council of 30 May 2018 on organic production and labelling of organic products and repealing Council Regulation (EC) No 834/2007 (OJ EU L 150 of 14/06/2018, page 1 as amended), „organic product" means a product resulting from organic production, other than a product produced during the conversion period referred to in Article 10 [conversion means the transition from non-organic production to organic production within a specified period, during which the provisions of this Regulation relating to organic production apply]. Hunting or fishing products are not considered organic products. Chapter II of the regulation specifies the goals and principles of organic production. It is worth quoting here Article 4 of the Regulation: Organic production is based on the following principles:

a) appropriate design and management of biological processes that are based on ecological systems using intra-system natural resources using methods that:

(i) use living organisms and mechanical production methods;

(ii) they grow crops on agricultural land and carry out animal production or aquaculture that meets the principle of sustainable exploitation of fisheries resources;

(iii) exclude the use of GMOs and products produced from or using GMOs, with the exception of veterinary medicinal products;

(iv) are based on risk assessment and the application, where necessary, of precautionary and preventive measures;

b) limiting the use of external funds. If internal measures are required or if appropriate management methods and methods referred to in point (a) do not exist. (a), they are limited to:

(i) inputs from organic production;

(ii) natural substances or substances derived from them;

(iii) slowly soluble mineral fertilizers;

(c) strictly limiting the use of chemically synthesized agents to exceptional cases where:

(i) appropriate management practices do not exist; and

(ii) external funds referred to in point (a). b), are not available on the market; or

(iii) the use of external measures referred to in point (a), (b) contributes to an unacceptable impact on the environment;

(d) adapting, where necessary, within the framework of this Regulation, the rules of organic production to the sanitary situation, regional differences in climate and local conditions, the stage of development and particular breeding practices.

See also M. Korzycka–Iwanow, P. Wojciechowski, Żywność ekologiczna w prawie USA i Unii Europejskiej, „Studia Iuridica Agraria" 2015, vol. 13, pp. 19–38, https://doi.org/10.15290/sia. 2015.13.02.

tificial fertilizers, pesticides, and other chemicals (40% strongly agreed and 46% somewhat agreed). However, most respondents tended to agree with all the above statements (over 65%).

In order to determine the differences in the perception of organic food and conventional food, respondents were presented with a number of food terms and asked to indicate which food category this term fits better. The largest percentage of organic food was matched with the following terms: natural (79% – organic food; 26% – conventional food; Don't know/ hard to say 6%, and no 5%), organic (79% – organic food; 31% – conventional food; Don't know/ hard to say 9%, no 3%), tasty (69% – organic food; 62% – conventional food; Don't know/ hard to say 9%, no 1%), safe (71% – organic food; 33% – conventional food; Don't know/ hard to say 12%, none 8%), environmentally friendly (78% – organic food; 18% – conventional food; Don't know/ hard to say 12%, none 4%), free from pesticides and GMOs (70% – organic food; 16% – conventional food; Don't know/ hard to say 16%, and no 8%), contains vitamins (76% – organic food; 55% – conventional food; Don't know/ hard to say 10%, no 1%), it contains micro – and macronutrients (63% – organic food; 49% – conventional food; Don't know/ hard to say 21%, no 2%). In the case of conventional food, it was most often chosen with the terms: contains amino acids (46% – conventional food; up to 45% – organic food; Don't know/ hard to say 35%, and no 4%), rich in fatty acids (49% – food conventional; 42% – organic food; Don't know/ hard to say 28%, no 5%), contains pesticides (49% – conventional food; 32% – organic food; Don't know/ hard to say 16%, no 8%), contains heavy metals (39% – conventional food; 34% – organic food; Don't know/ hard to say 26%, and no 5%). „Don't know/ hard to say" was the most common answer to questions about the presence of polyphenolic compounds (60%) and alkaloids (64%). Unlike organic food, the terms associated with conventional food are not so clear. However, it is apparent that consumers attribute it primarily to the presence of pesticides. This may indicate that consumers are more aware of organic food and less aware of conventional food. A high response rate of „Don't know/ hard to say" in the case of polyphenolic compounds and alkaloids indicates a low level of knowledge about them and their connection with food.

3.3. Shopping and Dietary Decisions and Their Determinants

Consumers who declared that they buy healthy food when asked about the frequency of purchasing these products most often do so several times a month (32%). Significant groups of respondents indicated the options several times a week (25%) and once a week (23%). These results suggest that healthy foods regularly appear in the diet of respondents. Only a small percentage declared that they buy such products less frequently, i.e., once a month (9%) or even less often (8%). This also indicates that most people who declare an interest in healthy foodstuffs make regular efforts to include them in their daily diet.

The most frequently purchased healthy foods are vegetables (65%) and fruit (61%). More than half of respondents (54%) indicated eggs as frequently bought products, while only 31% chose fish. Notably, arelatively low number of respondents indicated nuts (23%) and legumes (18%) as the products they buy most often. This may be due to their relatively high prices, discouraging their purchase. Due to their nutritional values emphasized in many studies,[15] it is worth verifying their healthiness, and if it is confirmed, start recommending them accordingly.

When choosing food, respondents are most often guided by price–it plays a key role in purchasing decisions for 79%. More than half of respondents pay attention to the expiration date (72%) and the composition/labels of products (63%). The content of additives is also important, which is confirmed by almost half of the respondents (48%). However, advertising, at least when it comes to declarations, has a relatively small impact on purchasing decisions, as indicated by only 10% of respondents. The challenge is to develop health-promoting indicators with economic features so that consumers are informed about health and medical costs in addition to the price. Potentially spending more money on a product rich in nutrients gives an opportunity to limit or abandon the purchase of, for exam-

15 See, e.g., R. Blomhoff, M.H. Carlsen, L.F. Andersen, D.R. Jacobs, Health benefits of nuts: potential role of antioxidants, „British Journal of Nutrition” 2006, vol. 96(S2), pp. S52–S60, https://doi.org/10.1017/BJN20061864; J. Mukuddem–Petersen, W. Oosthuizen, J.C. Jerling, A Systematic Review of the Effects of Nuts on Blood Lipid Profiles in Humans, „The Journal of Nutrition” 2005, vol. 135, no. 9, pp. 2082–2089, https://doi.org/10.1093/jn/135.9.2082; S.D. Nash, D.T. Nash, Nuts as part of a healthy cardiovascular diet, „Current Atherosclerosis Reports” 2008, vol. 10, pp. 529–535, https://doi.org/10.1007/s11883–008-0082–3; N. Gorji, R. Moeini, Z. Memariani, Almond, Hazelnut and Walnut, Three Nuts for Neuroprotection in Alzheimer’s Disease: A Neuropharmacological Review of Their Bioactive Constituents, „Pharmacol. Res.” 2018, vol. 129, pp. 115–127, https://doi.org/10.1016/j.phrs.2017.12.003; K. Kulik, B. Waszkiewicz–Robak, E. Biller, Deklarowana a oznaczona analitycznie zawartość składników odżywczych w różnych rodzajach orzechów, „Postępy Techniki Przetwórstwa Spożyczego” 2019, no. 2, pp. 49–56; M. Woźniak, A. Waśkiewicz, I. Ratajczak, The Content of Phenolic Compounds and Mineral Elements in Edible Nuts, „Molecules” 2022, vol. 27(14), https://doi.org/10.3390%2Fmolecules27144326; R. Amarowicz, Legume Seeds as an Important Component of Human Diet, „Foods” 2020, vol. 9, no. 12, https://doi.org/10.3390/foods9121812; M.C. Vaz Patto, R. Amarowicz, A.N.A. Aryee, J.I. Boye, H.–J. Chung, M.A.M.–Cabrejas, C. Domoney et al., Achievements and Challenges in Improving the Nutritional Quality of Food Legumes, „Critical Reviews in Plant Sciences” 2018, vol. 34, no. 1–3, pp. 105–143, https://doi.org/10.1080/07352689.2014.897907; T.L. Wang, C. Domoney, C.L. Hedley, R. Casey, MA Grusak et al., Can We Improve the Nutritional Quality of Legume Seeds?, „Plant Physiology” 2003, vol. 131, no. 3, pp. 886–891, https://doi.org/10.1104/pp.102.017665; P. Grdeń, A. Jakubczyk, Health benefits of legume seeds, „Journal of the Science of Food and Agriculture” 2023, vol. 103, pp. 5213–5220, https://doi.org/10.1002/jsfa.12585.

ple, dietary supplements while achieving a similar or better effect. This is, of course, a highly imprecise postulate, but it is directionally justified and worth reviewing.

The respondents' responses concerning the major barriers to purchasing organic food are consistent with the above results. For respondents, the main barrier to purchasing organic food is price (75%). Organic products are often more expensive than their conventional counterparts, which can be a challenge for those on a budget. Additionally, some respondents notice a potentially shorter shelf life (26%), the habit of buying conventional products (20%), or a lack of knowledge about where they can be purchased (16%). A small percentage (8%) believe that buying organic food is unjustified. While the habit of purchasing conventional products may change, it is difficult to expect that consumers will decide to buy a more expensive product with a shorter shelf life when they can choose one that is cheaper, has a longer shelf life, and is more widely available. The development of health-promoting indicators with the economic features proposed above and the establishment of effective distribution channels for these products to increase their availability and visibility could help break this habit. There is a clash between the potential health benefits of organic products and the economic benefits resulting from the purchase of conventional products.

3.4. Food Concerns

In order to determine respondents' concerns related to food, they were asked how they were influenced by media-publicized irregularities in the food sector (e.g., road salt used in the meat industry or horsemeat in beef burgers, etc.). Only 19% of respondents were unaware of these irregularities, so it can be assumed that they resonated with the public. The largest number of respondents said that the publicized irregularities made them aware of the health risks associated with food choices (45%). In addition, 35% said it made them learn more about the product, its origin, and its label, and 32% realized that food could negatively impact their health or worsen it in the future. And 17% of respondents changed their consumer attitudes. This reflects the important role of the media in shaping consumer opinions–journalists expose problems and provide information that reaches the public more effectively, encouraging caution in making consumer decisions.

To identify which common concerns about purchased food are of key importance to respondents, they were presented with examples and asked to rate which each of the following issues aroused their concern: 1. Pesticides in food; 2. Heavy metal content in food; 3. Dyes and flavors in food;

4. Antibiotics and hormones in meat; 5. Mycotoxins and alkaloids in food. The vast majority of respondents answered that all these issues caused concern. Most affirmative answers were given to the issue specified in point 2 (87%), and least in the case of the issue specified in point 5 (73%). The lowest number of affirmative answers to point 5 correlates with the highest percentage of „Don't know/hard to say" (9%) responses. The last indication causes concern and calls for better dissemination of scientific recommendations (understandable to the average consumer) among consumers–respondents are aware that these are undesirable but may not distinguish between them or know their effects on health.

3.5. General Food Knowledge

The shelves with healthy food often hold products from the functional food category. Therefore, respondents were asked what functional food is. The largest percentage of respondents somewhat (43%) or strongly (24%) agreed with the position that functional food has a positive impact on health. The respondents also agreed that it is rich in fiber, oligosaccharides, glycosides, polyphenols, flavonoids, essential fatty acids, vitamins, lactic acid bacteria, and minerals (42% somewhat agreed, 18% strongly agreed); and they also believed that it fulfills more than just nutritional functions (42% somewhat agreed, 15% strongly agreed). According to 20% of respondents, it is food intended only for athletes, and 32% believe that one or several components have been eliminated.

The Polish system of official food control is highly dispersed.[16] Respondents were asked about the institutions responsible for food quality and safety in Poland. The two most frequently indicated institutions were the Agricultural and Food Quality Inspection and the State Sanitary Inspection (50% and 47%, respectively). Other institutions received between 20% and 29%, including the National Veterinary Research Institute, the Office of Competition and Consumer Protection, the Trade Inspection, the Chief Inspectorate of Environmental Protection, the General Veterinary Inspectorate, and the State Plant Health and Seed Inspection Service. It is worth noting that a relatively large number of respondents did not know any such

16 See System kontroli bezpieczeństwa żywności w Polsce – stan obecny i pożądane kierunki zmian, „Supreme Audit Office", LLO.034.001.2020, Registration No. 198/2020/megainfo/LLO, Warsaw 2020, https://www.nik.gov.pl/ file/id,25232,vp,27982.pdf; Integracja czy połączenie. Analiza możliwości zwiększenia efektywności działania inspekcji weterynaryjnej oraz ochrony roślin i nasiennictwa, EFRWP Development Initiatives Forum and the Jagiellonian Club, https://efrwp.pl/publikacje/integracja-czy-polaczenie-analization-mozliwosci-zwiekczenia-zdrowiewnosci-dzialania-inspekcji-weterynarejj – and-protection-of-plants-and-seeds/; Raport o polskim systemie kontroli bezpieczeństwa żywności, „Polish Chamber of Commerce", May 30, 2022, https://kig.pl/raport-o-polskim-systemie-kontroli-bezpieczenstwa-zywnosci/.

institution (20%), which may indicate a low level of public awareness of official food control. The largest proportion of respondents agreed with the statement that the food quality and safety supervision system in Poland ensures compliance with legal standards (37% somewhat agreed, 6% strongly agreed), but many were undecided (as many as 31% neither agreed nor disagreed). Similar results were found when the respondents were asked if they trusted in food quality due to the legal limits of specific contaminants in foodstuffs (34% somewhat agreed, 8% strongly agreed, and 33% neither agreed nor disagreed). If the food control system is left unchanged, more effort should be made to promote the activities of individual institutions so that consumers know who to turn to and where to receive reliable information on food safety. However, this would not solve the fundamental problem – the food control system in Poland requires changes[17]. It seems that the above-mentioned institutions can be combined, which would also facilitate the internal flow of information on food safety and external communication about potential problems and threats. Both consumers and producers would benefit from this.

The presence of toxic elements/heavy metals is an important problem. However, the respondents indicate that they do not know which fruits accumulate them – over 69% gave this answer – nor do they know which fish show the highest concentration of such elements (40%). It can be assumed that this is related to the low consumption of fruit and fish by Poles and, therefore, also to the awareness of their properties.[18] In the case of fish, however, respondents chose one answer other than „Don't know" more often. According to 41% of respondents, pangasius has the highest concentration of toxic elements. This is information about high concentrations of toxic elements/heavy metals in pangasius meat due to the breeding conditions of this species. It is also one of the most popular fish species in the Polish diet (due to its low price).[19]

When asked where most pesticides are used, respondents were also very unsure. The largest group did not know this (29%). Others indicated orchards (21%) and cereal crops (16%). Potato crops came last (5%). Perhaps this suggests low consumer awareness of modern agricultural produc-

17 See M. Korzycka, P. Wojciechowski (eds.), Urzędowa kontrola żywności: teoria i praktyka, Warsaw 2019.

18 See e.g., A. Zimny–Zając (ed.), Narodowy Test Żywienia Polaków – raport 2023, „Medonet" Warsaw 2023, pp. 36–38.

19 See e.g., A. Iwańczuk, Źródło toksyn i metali ciężkich. Może też zawierać rakotwórcze związki, February 2, 2024, https://zyczenie.abczdrowie.pl/uloveana-prze-polakow-jest-zrodlem-toxin-i-metali-ciezkich-moze-tez-zawierac-rakotworcze-zwiazki; P. Nowak, Nie podawaj dziecku pangi. Jest bardzo szkodliwa, June 26, 2021, https://parenting.pl/nie-podaj-dziecku-pangi-jest-zdrowie-szkodliwa; K. Dzięcielak, Wszystkie blaski i cienie popularnej ryby, June 1, 2021, https://dietetyki.org.pl/panga/.

tion. It may be recommended to carry out broader awareness campaigns on this topic; this is particularly important in the context of the effective implementation of the EU's Farm to Fork Strategy.[20]

To get rid of pesticides, respondents generally simply wash fruits and vegetables, usually under running tap water (45%); they also use water with vinegar, lemon juice, or baking soda (20%); 19% did not know how to do it; 14% indicated short immersion in boiling water; and 2% use special detergents. This practice is consistent with the guidelines of the Chief Sanitary Inspectorate, although the length and intensity of washing are arguable.[21]

Respondents were also presented with several questions about foods containing beneficial nutrients. When asked which fruits had the highest vitamin C content, the vast majority indicated kiwifruit and citrus fruits (72%). In second place, respondents chose berries (38%), while apples and pears, stone fruits, other tropical fruits, dried fruits, avocados, bananas, olives, sweet fruit, and candied products scored under 20%. The results reflect the common belief about the high content of vitamin C in citrus fruits, although it is not consistent with the available data.[22] It can be said that consumers are still insufficiently informed about the vitamin C content in other products.

In the opinion of the respondents, the most beneficial content of minerals is found in green leafy vegetables (47%) and root and other vegetables (43%). Potatoes in various forms (11%) and fresh and canned legumes (21%) came last. Vegetables are rich in various minerals. The particular advantages of legumes are highlighted, as they show an exceptionally high nutritional density and provide many nutrients present in seafood

20 See Farm to Fork Strategy, European Council and Council of the European Union, https://www.consilium.europa.eu/pl/policies/from-farm-to-fork/.

21 The Chief Sanitary Inspectorate recommends washing fruits and vegetables under running tap water, even if they are peeled later, thoroughly by rubbing or scrubbing their surface under a stream of water. In the case of products with a more resistant, thick rind, they can be scalded with boiling water or scrubbed with a clean brush under running tap water. It also indicates that you can also use water with table salt, lemon juice, citric acid, or vinegar to rinse fruit and vegetables; see Proste sposoby na mycie owoców i warzyw, „Chief Sanitary Inspectorate", June 19, 2023, https://www.gov.pl/web/gis/proste-osoby-na-mycie-owocow-i-warzyw.

22 According to data from the National Center for Nutrition Education, the best source of ascorbic acid (vitamin C) in fruit is sea buckthorn, which contains up to 900 mg of ascorbic acid per 100 g of fresh product. Then, the highest content of vitamin C is found in rose hips (250–800 mg/100g), blackcurrants (150–300 mg/100g), strawberries (46–90 mg/100g), kiwifruit (84 mg/100g), grapefruit (30–70 mg/100g), and lemon (40–60 mg/100g); see P. Nagel, Czy cytrusy to główne źródło witaminy C?, „National Center for Nutrition Education", https://ncez.pzh.gov.pl/abc-zywienia/czy-cytrusy-to-glowne-zrodlo-witaminy-c/. See also K. Janda, M. Kasprzak, J. Wolska, Witamina C – budowa, właściwości, funkcje i występowanie, „Pomeranian Journal of Life Sciences" 2015, vol. 61, no. 4, pp. 419–425, https://ojs.pum.edu.pl/pomjlifesci/article/view/427/326; B. Bobrowska–Korczak, A. Wójcik, A. Tokarz, Zawartość witaminy C w warzywach i owocach pochodzących z upraw konwencjonalnych i ekologicznych, „Bromatologia i Chemia Toksykologiczna" 2016, vol. XLIX, no. 3, pp. 225–228.

and various types of meat.[23] Perhaps awareness of this fact is not common among consumers, or they consider canned vegetables to be less beneficial to health – it needs further research.

When asked about nuts with the highest content of minerals, cashews were most often chosen by respondents (33%), followed by „Don't know" (29%). Hazelnuts (23%) and almonds (21%) also scored high. Pine nuts were indicated least frequently (9%). These results correspond to the low consumption of nuts (discussed above), which may translate into low awareness of their properties. A similar question regarding cereal products saw buckwheat (49%), oat flakes (41%), and millet (36%) indicated most often, and corn flakes (12%) scoring lowest. It is also worth noting that most respondents agreed with the statement that wholemeal bread is healthier than white bread (44% somewhat agreed and 35% strongly agreed). It can be said that the respondents are generally aware of the advantages of individual cereal products, which is consistent with their knowledge about cereal mineral content.[24] Nevertheless, the answers did not indicate high consumer awareness in this respect.

Most respondents probably do not know what glucosinolates and alkaloids are. Glucosinolates, found in cruciferous vegetables, among other things, are classified as antinutrients. They are natural compounds of plants that may limit or prevent the use of nutrients or have a harmful effect on humans. On the other hand, they have anticarcinogenic properties[25] and are used in cancer prevention.[26] Alkaloids are natural toxins; the most common alkaloids are atropine and scopolamine (found in cereal products, herbal teas, and legumes).[27] When asked about the source of glucosinolates in the human diet, the vast majority of respondents did not know the

23 K. Rutkowski (ed.), Wartości odżywcze i zdrowotne owoców i warzyw, „Instytut Ogrodnictwa - Państwowy Instytut Badawczy" Skierniewice 2017, p. 27.

24 J. Jaczewska–Schuetz, Produkty zbożowe w żywieniu dzieci i młodzieży. Praktyczne wskazówki, „National Center for Nutrition Education", https://ncez.pzh.gov.pl/zyczenie-w-placowkach/produkty-zbozowe-w-zywieniu-dzieci-i-mlodziezy-praktyczne-wskazowki/; see A. Winiarska–Mieczan, E. Zaricka, M. Kwiecień et al., Can Cereal Products Be an Essential Source of Ca, Mg and K in the Deficient Diets of Poles?, „Biological Trace Element Research" 2020, vol. 195, pp. 317–322, https://doi.org/10.1007/s12011–019-01826-z.

25 A. Sikorska, M. Gugała, K. Zarzecka, Ł. Domański, Substancje antyżywieniowe w wybranych roślinach rolniczych, „Herbalism" 2022, vol. 8, no. 1, pp. 119–129, https://doi.org/ 10.12775/HERB.2022.009.

26 J. Szwejda–Grzybowska, Antykancerogenne składniki warzyw kapustnych i ich znaczenie w profilaktyce chorób nowotworowych, „Bromatologia i Chemia Toksikologiczna" 2011, vol. 44, no. 4, pp. 1039–1046; S.A. McNaughton, G.C. Marks, Development of a food composition database for the estimation of dietary intakes of glucosinolates, biologically active constituents of cruciferous vegetables, „British Journal of Nutrition„ 2003, vol. 90, no. 3, pp. 687–697.

27 M. Jankowska, B. Łozowicka, Naturalne i syntetyczne substancje toksyczne występujące w roślinach rolniczych i ich produktach, „Progress in Plant Protection" 2021, vol. 61 no. 1, pp. 24–30, http://dx.doi. org/10.14199/ppp-2021–003.

answer (70%). When asked about the source of alkaloids, 61% of respondents gave the same answer. It is clear that this area requires wider dissemination of knowledge about the presence of these compounds in food and an explanation of their impact on the human body.

Unsaturated fatty acids have a reputation as „good" fatty acids.[28] When asked where they are most abundant, the largest percentage of respondents indicated fish (38%), followed by vegetable oils and oil plants (36%), legumes (14%), meat and cold cuts (13%), milk and dairy products (7%), vegetables (6%) fruit (4%), and herbs and spices (3%). As many as 34% could not give their source. Similarly, as in the case of glucosinolates and alkaloids, actions should also be taken to disseminate knowledge about the presence of unsaturated fatty acids in products (especially essential fatty acids (EFAs), without which the human body cannot function properly) and their properties.[29]

Respondents' views on sugar, potato chips, and alcohol are also worth discussing. A significant number of respondents believe that cane sugar is healthier than white sugar – 34% somewhat agreed, 15% strongly agreed, and 24% neither agreed nor disagreed with this statement. It would be necessary to verify why such a discrepancy occurs and whether it is justified. Moreover, less than half of the respondents agreed with the statement that they know the caloric value of typical alcoholic drinks (a shot of vodka, a glass of wine, and a half liter of beer) – 30% somewhat agreed, and 10% strongly agreed with it. This may be due to the fact that people talk more often about the social effects of alcohol consumption and addiction than about calorie consumption. In turn, 30% somewhat agreed, 16% strongly agreed, and almost 25% neither agreed nor disagreed with the statement that frequent consumption of potato chips may contribute to poor memory and mood disorders. It can be assumed that the respondents do not have extensive knowledge about the impact of potato chip components (e.g., fat and saturated fatty acids) on memory, which should be scientifically examined.[30]

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28 See e.g., J. Lunn, H.E. Theobald, The health effects of dietary unsaturated fatty acids, „Nutrition Bulletin" 2006, vol. 31, pp. 178–224, https://doi.org/10.1111/j.1467–3010.2006.00571. x; H.M. Roche, Unsaturated Fatty Acids, „Proceedings of the Nutrition Society" 1999, vol. 58, no. 2, pp. 397–401, https://doi.org/10.1017/S002966519900052X; S. Coniglio, M. Shumskaya, E. Vassiliou, Unsaturated Fatty Acids and Their Immunomodulatory Properties, „Biology" 2023, vol. 12 no. 2, pp. 1–17. https://doi.org/10.3390/biology12020279.

29 L. Szponar, H. Mojska, M. Ołtarzewski, Czy wiesz, ile potrzebujesz tłuszczów?, „Institute of Food and Nutrition", Warsaw 2019.

30 Some studies indicate that just one meal containing a large amount of saturated fatty acids significantly decreases the ability to concentrate; see A. Annelise, M.A. Madison Belury, R. Andridge et. al., Afternoon distraction: a high-saturated-fat meal and endotoxemia impact postmeal attention in a randomized crossover trial,

3.6. Survey of Food Industry

Due to the differences among respondents in the food industry group, as well as the higher cost of conducting a survey using CATI, the questions asked in this part of the study differ significantly from those discussed earlier.

First of all, it should be noted that 85% of respondents affirmed that their company/enterprise produces/distributes/serves food that could be described as healthy. However, of those who gave an affirmative answer, 53% said they did not plan to develop their activities in this area. This is interesting, given a growing interest in healthy food among consumers, as shown by the survey results discussed earlier. It would seem that business owners try to meet the expectations of potential customers. However, this study cannot determine whether it is a downward, upward, or permanent trend; in-depth research on this topic is needed. Noteworthy, 51% responded to the increase in demand for healthy food (primarily by expanding their offers with such products). Analysis of the responses suggests that this is related to customer expectations. As consumers' needs for access to healthy food increase, the offer of businesses producing, processing, or serving food will have to include more of them.

The largest percentage of respondents (71%) said that the healthy food they produce, distribute, and serve is lightly processed food (e.g., flour, groats, dried fruit, tea, juice, puree). Other common answers were processed food from raw materials of natural origin (64%); processed food produced without/with little use of preservatives, enhancers, salt, sugar, and other sweeteners (62%); unprocessed, packaged food from organic production/natural origin (55%); dietary supplements (10%); highly processed food, e.g., ready-to-eat (RTE) products, healthy snacks, etc. (9%); other (3%). It is clear that businesses pay attention to the quality of the products or services offered, producing, distributing, or serving mainly slightly processed food. However, some businesses still offer highly processed products, but their number is small. More than half of the respondents offer unprocessed, packaged food from organic production/natural origin; however, it would be worth examining what percentage this represents compared to the rest of the offer of a given business.

None of the respondents used financial support to incorporate healthy food into their activities. It should be noted that businesses are also very independent when implementing the production/distribution/serving of

„The American Journal of Clinical Nutrition” 2020, vol. 111, no. 6, pp. 1150–1158, https://doi.org/10.1093/ajcn/nqaa085.

healthy food. Only 2% of respondents conducted R&D in laboratories, 6% purchased ready-made technologies/patents, and 6% used the services/support of research units (domestic or foreign). It is difficult to determine if the respondents do not see the need for financial and scientific support when incorporating healthy food into their activities or if they miss out on the opportunities to receive such support. However, considering that 47% of respondents plan to develop their healthy food portfolios, this may be an opportunity for researchers to come up with a specific offer. It is also in the interest of research units (universities, institutes) to provide an opportunity to obtain additional external funds and commercialize research results.

Only 19% of respondents label their products with a quality mark, health or nutritional claims. The majority of respondents saw no benefit in using any such label. Those who saw benefits said they were internal rather than commercial. This may be due to the fact that consumers have a low awareness of quality marks and health or nutritional claims. Therefore, this does not directly translate into commercial advantage. It is, therefore, not surprising that when respondents who did not mark their products were asked whether they were considering certifying/marking their products, as many as 93% gave a negative answer. It can be assumed that without raising consumer awareness of product labeling, it is impossible to expect a change in attitudes to this problem. It seems that consumers do not see the connection between product certification/labeling and their quality or other advantages. This also poses a challenge for certification/accreditation organizations themselves, which should become more involved in popularizing knowledge on this subject.

4. Research Conclusions

Based on the survey responses, four food characteristics can be abstracted, which made the respondents classify a given food as healthy. They are as follows:

- Naturalness and purity: respondents prefer food whose production does not involve GMOs and plant protection products. Purity focuses on the method of food production and the technology used rather than on superficial cleanliness, for example, food hygiene.
- Food produced using ecological methods without artificial fertilizers and antibiotics is particularly appreciated. Ecological certificates additionally increase consumer confidence. This study shows that for many respondents, the lack of artificial additives and low degree of processing are key indicators of high-quality food products.

- Simple composition: Consumers prefer products with short and understandable compositions. Labels claiming no artificial additives in the context are particularly motivating to choose a given product.
- Nutritional values: The importance of nutritional values is crucial in assessing the healthfulness of food products. Important components include vitamins, minerals, and low levels of fats and sugars. Respondents are particularly critical of products high in salt, sugar, and fat while positively viewing foods rich in protein and dietary fiber.
- Local production: Local production refers to the production of food in close proximity to where it is sold and consumed. Local products may be considered fresher because the time from production to hitting the shelf of the local store may potentially be relatively short, and the fact that they are usually produced by smaller farms may be associated with assigning other desirable characteristics.

In general, the results of consumer surveys indicate the need to educate society about the properties, nutrients, and risks associated with the consumption of various food products, such as pesticides, mycotoxins, and heavy metals. Even though the Internet is the main source of knowledge for 77% of respondents, a low percentage of purchases of healthy food online in favor of a high percentage of purchases in supermarkets and at farmers markets may indicate the willingness to evaluate the goods in person and the lack of waiting for delivery in the case of physical stores/markets.

Consumers are aware of the impact of dietary macronutrients (proteins, fats, carbohydrates) on health, but their knowledge regarding individual markings of the food labeling system is insufficient. In addition to research on which labels are the most effective and informative (e.g., whether Nutri-Score is the optimal solution for helping consumers make food choices that have a positive impact on their health), it is necessary to conduct parallel educational campaigns on existing labels.

Public education about the negative role of mycotoxins and alkaloids in food and the sources of these contaminants is also insufficient. Respondents believe that products they view as healthy (e.g., organic products) are particularly safe, but an organic food certificate does not make such food safer in terms of mycotoxin contamination. There is also low public awareness of official food control and the complexity of the food control system from primary and secondary production sites.

Education on the use of various pesticides in agricultural produce is necessary. The largest percentage of respondents claim that washing under running tap water is an effective way to remove pesticides from fruits and vegetables. Failure to choose other methods, such as washing with vinegar, lemon juice, baking soda, or special detergents, may result from ignorance as to the effectiveness of these methods and may be related to the reluctance to carry out a more time-consuming process and purchase additional cleaning agents.

Chapter 3

HEALTHY FOOD IN THE LIGHT OF LEGAL REGULATIONS

1. Research Assumptions

In order to examine the social perception of healthy food in the legal context, a formal and dogmatic analysis of EU food law was planned in the areas of food law regulations that influence the social perception of food in such a way that they lead to classifying foodstuffs as healthy. The starting point for defining these areas is the synthesis of parallel levels of understanding the concept of healthy food, which was presented in section 1.4, and the survey results discussed in section 2.4.

As shown in section 1.3, the concept of healthy food is ambiguous under the law. However, even when adopting different research perspectives, it is possible to isolate certain food characteristics that consumers use to classify specific foodstuffs as healthy.[1] This multiplicity of research approaches is reflected in the diversity of public opinion, as indicated by the survey results discussed in Chapter 2. Based on all the responses from the survey, four characteristics were abstracted. These are: 1) naturalness and purity; 2) „simple composition"; 3) nutritional values; 4) local production.

2. Research Description

The study required the identification of key legal acts affecting the food characteristics indicated in the previous section. It should be noted that food law is comprehensive. This makes an in-depth analysis of each legal act on food law impractical. Therefore, an adequate approach was planned,

1 See section 1.4.

taking into account the research assumptions; what is crucial is not a specific regulation but the functioning of the mechanisms by which the law influences food and its social perception. Through these mechanisms, it is possible to incorporate knowledge about food and nutrition from other fields of science into law.

At this point, it should be noted that food law is harmonized within the EU and even internationalized due to the influence of the Codex Alimentarius.[2] However, when it comes to dogmatic and legal analysis, in the context of examining the social perception of healthy food among respondents from Poland, the most interesting perspective and potentially most valuable is the EU perspective. Due to the free movement of goods, EU food law is largely defined in EU regulations, which are directly and directly binding in the member states.[3] Therefore, an analysis focused primarily on the EU will be valuable not only from the perspective of Poland but also from the perspective of all EU member states.

The starting point for research for each of the analyzed aspects was Regulation 178/2002, known as the General Food Law Regulation, due to its horizontal impact on all food laws. Then, key legal solutions were analyzed in the context of individual characteristics with which consumers classify food as healthy.

For the characteristics of naturalness and purity, the key areas of influence of food law include regulations on foreign substances in food, organic food and genetically modified food (hereinafter referred to as „GM food"). The following EU legal acts have been identified and analyzed as fundamental for the identified areas of impact.

In terms of GM food:

– Regulation (EC) No 1829/2003 of the European Parliament and of the Council of 22 September 2003 on genetically modified food and feed (OJ EU L 268 of 18/10/2003, p. 1 as amended; Polish special edition: chapter 13, vol. 032, page 432) (hereinafter referred to as „Regulation 1829/2003");
– Regulation (EC) No 1830/2003 of the European Parliament and of the Council of 22 September 2003 concerning the traceability and labelling of genetically modified organisms and the traceability of food and feed products produced from genetically modified organisms

2 See T. Srogosz, Międzynarodowe prawo żywnościowe, Warszawa 2020.

3 Treaty on the Functioning of the European Union (OJ EU C 202 of 07/06/2016, p. 1).

and amending Directive 2001/18/EC (OJ L 268 of 18/10/2003, p. 24 (hereinafter referred to as „Regulation 1830/2003").

- In terms of foreign substances:
- Regulation (EC) No 396/2005 of the European Parliament and of the Council of 23 February 2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin and amending Council Directive 91/414/EEC (OJ L 70 of 16/03/2005, p. 1 as amended) (hereinafter referred to as „Regulation 396/2005");
- Commission Regulation (EC) No 2073/2005 of 15 November 2005 on microbiological criteria for foodstuffs (OJ EU L 338 of 22/12/2005, p. 1 as amended);
- Commission Regulation (EU) No 37/2010 of 22 December 2009 on pharmacologically active substances and their classification regarding maximum residue limits in foodstuffs of animal origin (OJ EU L 015, 20/01/2010, p. 1 as amended);
- Regulation (EC) No 470/2009 of the European Parliament and of the Council of 6 May 2009 laying down Community procedures for the establishment of residue limits of pharmacologically active substances in foodstuffs of animal origin, repealing Council Regulation (EEC) No 2377/90 and amending Directive 2001/82/EC of the European Parliament and of the Council and Regulation (EC) No 726/2004 of the European Parliament and of the Council (OJ EU L 152, 16/06/2009, p. 11);
- Council Regulation (Euratom) 2016/52 of 15 January 2016 laying down the maximum permitted levels of radioactive contamination of food and feed following a nuclear accident or other radiological emergency and repealing Regulation (Euratom) No 3954/87 and Commission Regulation (Euratom) No 944/89 and (Euratom) no. 770/90 (OJ EU L 13, 20/01/2016, p. 2) (hereinafter referred to as „Regulation 2016/52");
- Commission Regulation (EU) 2023/915 of 25 April 2023 on maximum levels for certain contaminants in food and repealing Regulation (EC) No 1881/2006 (OJ EU L 119, 05/05/2023, p. 103 as amended).

In terms of organic food: Regulation (EU) 2018/848 of the European Parliament and of the Council of 30 May 2018 on organic production and labelling of organic products and repealing Council Regulation (EC) No 834/2007 (OJ L 150 of 14/06/2018, page 1 as amended) (hereinafter referred to as „Regulation 2018/848").

For the „simple composition", the key areas of influence of food law include regulations on substances added to food. The following EU legal acts have been identified as fundamentally important for the identified areas of impact and have been analyzed.

- Regulation (EC) No 1333/2008 of the European Parliament and of the Council of 16 December 2008 on food additives (OJ EU L 354 of 31/12/2008, p. 16 as amended) (hereinafter referred to as „Regulation 1333/2008");
- Regulation (EC) No 1334/2008 of the European Parliament and of the Council of 16 December 2008 on flavourings and certain food ingredients with flavouring properties for use in and on foods and amending Council Regulation (EEC) No 1601/91, Regulations (EC) No 2232/96 and (EC) no. 110/2008 and Directive 2000/13/EC (OJ EU L 354, 31/12/2008, p. 34 as amended) (hereinafter referred to as the „Regulation 1334/2008").

For the nutrition criterion, key impact areas include requirements for food information regarding nutritional values and the intentional addition of substances to food intended to influence its nutritional value. The following EU legal acts have been identified as fundamental for the identified areas of impact and have been analyzed.

Regarding food information requirements:

- Regulation 1169/2011;
- Regulation 1924/2006.

In terms of modifying the nutritional value of foodstuffs: Regulation (EC) No 1925/2006 of the European Parliament and of the Council of 20 December 2006 on the addition of vitamins and minerals and of certain other substances to foods (OJ EU L 404 of 30/12/2006, p. 26 as amended) (hereinafter referred to as „Regulation 1925/2006").

In terms of local production under EU food law: Regulation (EU) 2024/1143 of the European Parliament and of the Council of 11 April 2024 on geographical indications for wine, spirit drinks and agricultural products, as well as traditional specialities guaranteed and optional quality terms for agricultural products, amending Regulations (EU) No 1308/2013, (EU) 2019/787 and (EU) 2019/1753 and repealing Regulation (EU) No 1151/2012 (OJ EU L 1143 of 23/04/2024, 2024/1143) (hereinafter referred to as „Regulation 2024/1143").

Of course, many more legal acts generally relate to the issues specified above.[4] Nevertheless, the legal acts indicated above were considered the „strict core" of food regulations.

3. Research Results

3.1. Naturalness and Purity of Food

First of all, it should be emphasized that Regulation 178/2002 in Article 5 states that one of the general objectives of food law is to ensure a high level of protection of human health and life while taking into account, where appropriate, the protection of animal health and living conditions, plant health, and the environment. It is worth noting that the protection of human health and life is a priority in the doctrine of food law. Moreover, human health and life are the only objectives that need to be protected at a „high level". The protection of animal health and well-being, plant health, and the environment are objectives that should only be taken into account where appropriate. This results in a clear prioritization of objectives within food law.

When analyzing food characteristics related to its naturalness and purity, it should be noted that food law, through the above-mentioned objectives, has a significant impact on these characteristics. Purity, understood as the absence of food contamination, is a basic requirement for achieving the goal of a high level of protection of human health and life. A high level of food contamination may lead to it being considered dangerous, which, under Article 14 of Regulation 178/2002, means that such a product cannot be placed on the market.

A food is considered dangerous if it is harmful to health or unfit for human consumption.[5] When assessing whether a food is unsafe, account should be taken of the normal conditions of use by consumers, its use at each stage of production, processing, and distribution, as well as information intended for the consumer, including labeling and other publicly available information on how to avoid adverse effects, and health issues related to a given food.[6]

4 For example, M. Korzycka indicates seven EU regulations on the status of organic food alone. See M. Korzycka, Wybrane obszary szczegółowej regulacji prawa żywnościowego, in: M. Korzycka, P. Wojciechowski, System prawa żywnościowego, Warsaw 2017, p. 359.

5 Article 14(2) of Regulation 178/2002.

6 Article 14(3) of Regulation 178/2002.

The decision on whether food is harmful to health should take into account not only the likely immediate, short-term, and long-term effects of consumption on the consumer but also the potential effects on subsequent generations, the possibility of cumulative toxicity, and the particular sensitivity of certain categories of consumers if the food is intended for them.[7]

This means that the minimum level of purity, understood as the absence of contamination at a level that would be harmful to health, is secured based on provisions that are general but fundamental for food law, such as those specified in Article 14 of Regulation 178/2002. Similar rules apply to food containing GMOs. Despite social skepticism toward GMOs, which was reflected in the results of the survey discussed in Chapter 2, such food, in accordance with the regulations cited above, cannot be placed on the market if it would be harmful to health.

The basic safeguard in EU food law is the early warning system for notifying about the direct or indirect danger to human health originating from food or feed using the Rapid Alert System for Food and Feed (hereinafter referred to as „RASFF"). RASFF includes member states, the European Commission, and the European Food Safety Authority (EFSA). Each member state, the Commission, and EFSA designate a contact point as a member of the network, and the Commission is responsible for managing the network.[8] Under Article 50 (2) of Regulation 178/2002, if a network member becomes aware of a direct or indirect risk to human health arising from food or feed, it must immediately notify the Commission using the early warning system. The Commission immediately transmits this information to the other members of the network, and EFSA may supplement the notification with scientific or technical information supporting prompt and appropriate risk management actions by member states.[9]

Article 53 of Regulation 178/2002 deals with protecting human health and life from food containing contaminants at a level that poses a risk. It provides that where it is evident that food or feed originating in the Community or imported from a third country is likely to present a serious risk to human health, animal health, or the environment and that such risk cannot be sufficiently contained by measures taken by the member state or states concerned, the Commission is obliged to take immediate preventive measure, depending on the gravity of the situation.[10] Regardless of the origin of the

7 Article 14(4) of Regulation 178/2002.

8 Article 50(1) of Regulation 178/2002.

9 Article 50(2) of Regulation 178/2002.

10 Article 53(1) of Regulation 178/2002.

food or feed, the main intervention measures are suspension of the placing on the market or consumption of the food in question, laying down special conditions for the food or feed in question, and any other appropriate interim measure. These activities aim to manage risks quickly and effectively to protect human health, animal health, and the environment. Therefore, food that contains contaminants at a level that poses a risk to human health does not reach the market.

Article 19 of Regulation 178/2002 covers situations where such food reaches the market. It imposes an obligation on food business operators to act immediately in the event of suspicion that food placed on the market does not meet safety requirements. This operator must immediately initiate the procedure to withdraw such food from the market and inform the competent authorities (as part of RASFF). If the product has already reached consumers, the operator must effectively inform them of the reasons for the withdrawal and, if necessary, arrange for the product to be taken back from consumers to ensure a high level of health protection. Information about food withdrawals from the market often takes the form of announcements in the traditional media or online, which may particularly influence public perception of food because this type of information is memorable and may raise concerns among consumers. Public awareness of such incidents may have long-term consequences for the perception of a given company and the entire food industry.

At the same time, however, it should be emphasized that food that complies with specific Community rules governing food safety is considered safe with respect to factors covered by specific Community rules.[11] These specific provisions, like all other provisions of food law, in order to achieve the general objective of a high level of protection of human health and life, food law should, in principle, be based on a risk analysis.[12]

Risk analysis consists of three interrelated elements: risk assessment, risk management, and risk communication.[13] Risk assessment includes four steps: hazard identification, hazard characterization, exposure assessment, and risk characterization[14] Risk management involves weighing policy alternatives in consultation with interested parties, considering risk assessment and other legitimate factors, and, if need be, selecting ap-

11 Article 14(7) of Regulation 178/2002.

12 Article 6(1) of Regulation 178/2002.

13 Article 3(1) of Regulation 178/2002.

14 Article 3 (11) of Regulation 178/2002.

propriate prevention and control options.[15] Risk communication means interactive exchange of information and opinions throughout the risk analysis process as regards hazards and risks, risk-related factors and risk perceptions, among risk assessors, risk managers, consumers, feed and food businesses, the academic community and other interested parties, including the explanation of risk assessment findings and the basis of risk management decisions.[16]

The concept of risk is fundamental to the above process. Defined in Article 3(9) of Regulation 178/2002, „risk" in the Polish version is defined as the danger (niebezpieczeństwo) of negative health effects and the severity of such effects as a result of the threat.[17] In turn, a hazard referred to in the definition of risk in the context of food means biological, chemical or physical agent in, or condition of, food or feed with the potential to cause an adverse health effect.

Szajkowska presented the essence of risk with a concise equation: „Risk = danger * probability". The greater the danger, understood here as the severity of the threat, and the greater the probability of that danger occurring, the higher the total risk will be. The condition for risk to occur is the existence of danger.[18]

Taking into account the above, it can be said that a certain minimum of purity and naturalness of food law is determined by risk analysis, within which the legislator pursues the goal of achieving a high level of protection of human life and health. This minimum is due to the fact that a certain level of foreign substances in food or, in some cases, changes related to genetic modification of food may pose a significant risk.

It is necessary to move here from general food law, defined primarily in the provisions of Regulation 178/2002, to more specific solutions that de-

15 Article 3(12) of Regulation 178/2002.

16 Article 3(13) of Regulation 178/2002.

17 It is also worth quoting the English equivalent of this definition, i.e. „a function of the probability of an adverse health effect and the severity of that effect, consequential to a hazard", where instead of the word „danger", the phrase „function of the probability" is used. In the Polish doctrine of food law, it is commonly noted that the Polish equivalent is an imprecise translation. We should agree with M. Korzycka that the word „danger" should be read rather as „probability", and as a result, risk in EU food law should be treated as the probability of occurrence of specific negative health effects as a result of the threat and the probability of the severity of these effects as a result of threats. M. Korzycka, in: B. Dziliński et al., Komentarz do rozporządzenia nr 178/2002 ustanawiającego ogólne zasady i wymagania prawa żywnościowego, powołującego Europejski Urząd ds. Bezpieczeństwa Żywności oraz ustanawiającego procedury w zakresie bezpieczeństwa żywności, Lex/el. 2018, Art. 3.

18 A. Szajkowska, Regulating Food Law: Risk Analysis and the Precautionary Principle as General Principles of EU Food Law, „European Institute for Food Law" series 7 (Wageningen Academic Publishers, 2012), p. 39.

fine and develop these general assumptions and have a significant impact on aspects of food law related to naturalness and purity of food.

With regard to GM food, Regulation 1829/2003 is of fundamental importance, laying down rules for the approval and supervision of genetically modified organisms (GMOs) and the labeling of genetically modified food and feed, the primary purpose of which is to establish a basis for ensuring a high level of protection of human life and health, animal health and welfare, and the environment and consumer interests in relation to genetically modified food and feed, while ensuring the effective functioning of the internal market. Article 4(1) of Regulation 1829/2003 sets out key requirements for GM food that must not: a) have harmful effects on human health, animals, or the natural environment; b) mislead the consumer; c) differ from the food intended to be replaced to such an extent that its normal consumption does not result in adverse nutritional effects for consumers.

The above objectives and assumptions are achieved by two basic regulations. At the stage before placing GM foods on the market, they undergo formal authorization procedures, which include the submission of an application containing detailed scientific and technical data, an assessment of these data by EFSA, and consultations with member states. Only after obtaining a positive opinion and meeting all safety requirements can GMOs be released into circulation.[19] After meeting a number of formal requirements by GM food for placing on the market, the general rule is to use appropriate labels, such as „contains genetically modified (name of organism)" or „contains (name of component) produced from genetically modified (name of component or organism)", or „genetically modified" depending on whether it is a product containing GMO or a component derived from GMO.[20] Although GM food, in accordance with the previously mentioned regulations, must be safe and have no harmful effects on health, one may wonder whether this specific labeling deters consumers. Since such food must be specifically labeled, consumers may wonder whether there is something wrong with it. This thinking can lead to fear of GMO products, even if they have passed rigorous safety inspections. As a consequence, legal regulations regarding the labeling of GM foods may increase consumer concerns and negatively affect the perception of this category of food.

In turn, Regulation 1830/2003 introduces specific requirements related to the control of GM food in the supply chain and plays a key role in ensuring safety and transparency in the area of GM food. Tracking and labeling

19 Article 4(2–4) and Articles 6 and 7 of Regulation 1829/2003.

20 Article 13(1)(b) of Regulation 1829/2003.

mechanisms, inspections, checks, and a system of penalties for infringements aim to protect consumer health and the environment. However, these regulations may also influence the perception of GM food by consumers, which may lead to concerns and a negative perception of such products.

Korzycka states that the fact that the legislator introduces provisions regulating the technique of genetic modification is a form of „producing risk by law". This is due to the fact that even despite numerous legal safeguards involving restrictive procedures for introducing GMOs into the environment and on the market, there will remain an unknown risk due to the short use of these organisms, which may become apparent later.[21] The skepticism toward these foods noticed in the survey is probably based, to some extent, on the same assumptions.

With regard to foreign substances, it seems safe to say that the basic instrument of EU food law is the establishment of maximum permissible concentrations of foreign substances in food.[22] Each of the analyzed legal acts listed in section 3.2 focuses on different foreign substances potentially present in food and whose presence is undesirable. This catalog covers a very wide range – residues of plant protection products and veterinary drugs, microorganisms, and the maximum permitted levels of radioactive contamination. These standards aim to protect public health by controlling and limiting levels of substances that may be harmful. The legal perspective alone on the established levels does not allow us to determine to what extent the applicable standards in this area are sufficient. It should be emphasized, however, that regulations regarding individual aspects of food safety were analyzed during laboratory tests described in Chapter 4. It is worth paying particular attention to the potentially dangerous underregulation of mycotoxins in the EU food law, which were present in alarming concentrations in the nuts tested. Maximum levels are established for some mycotoxins in selected food categories, but gaps exist, particularly for mycotoxins such as HT-2 toxin.[23]

Several instruments are used to ensure compliance with these standards, including the following:

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21 M. Korzycka, Bezpieczeństwo żywności, in: M. Korzycka, P. Wojciechowski, System prawa żywnościowego, Warsaw 2017, p. 241.

22 For example, according to the Annex to Regulation 2016/52, the sum of strontium isotopes, in particular Sr-90, cannot exceed 75 Bq/kg in baby food.

23 B. Łozowicka., P. Kaczyński, P. Iwaniak, E. Rutkowska, K. Socha, K. Orywal, J.A. Farhan, M. Perkowski, Nutritional compounds and risk assessment of mycotoxins in ecological and conventional nuts, „Food Chemistry" 2024, 140222.

- Obligation to inspect and monitor foodstuffs and to report the inspection results to the appropriate authorities.[24] In addition to the provisions set out in specific regulations, Regulation 2017/625, which establishes common rules on official controls in the EU, is of key importance. Regulation 2017/625 harmonizes the EU system of official controls and enforcement measures across the entire agri-food chain;
- EU food law also includes provisions related to sanctions, which are, however, regulated primarily at the national level. Under Article 139(2) of Regulation 2017/625, member states ensure that financial penalties in the event of infringements of this Regulation and the provisions referred to in Article 1(2) (a broad catalog of food and food safety regulations) resulting from unfair or deceptive practices reflect, in accordance with national law, an economic advantage to the entity or, where applicable, a percentage of its turnover;
- Member states and EU bodies cooperate with each other. One of the forms of cooperation most widely discussed in the doctrine is the previously mentioned RASFF.

Organic food enjoys a good reputation in society. The survey shows that consumers are more willing to attribute positive characteristics to it, such as a higher content of vitamins and micro – and macronutrients, compared to conventional food. At the same time, consumers indicated that the label „contains heavy metals" applies more to conventional food than to organic food.

However, when it comes to legal matters, under Regulation 2018/848, „organic food" should simply be understood as foodstuffs bearing the term referring to organic production.[25] A product may be marked as organic – on labels, advertisements, or commercial documents – if it was produced in accordance with the principles of organic production. This also includes the use of derived terms relating to organic production and abbreviations such as „bio" and „eco".[26] The principles of organic production indicated in the regulation do not apply to the content of heavy metals, vitamins, or micro – and macronutrients. The research discussed later also does not confirm the assumptions made by the respondents. It is also worth noting that medical literature generally states that current scientific evidence

24 For example, according to Article 26(1) of Regulation 396/2005, member states carry out official controls on pesticide residues to ensure compliance with the regulation in accordance with the relevant provisions of Community law on official controls on food and feed.

25 See Article 30 of Regulation 2018/848.

26 *Ibid.*

does not allow for a clear conclusion about the health benefits of consuming organic food.[27]

However, this consumer attitude is not surprising considering that organic food is often found on shelves labeled „healthy food" or (in the case of online shopping) in a special tab with the same label. This type of labeling and in-store placement suggests to consumers that organic products are more beneficial to health, and advertising and marketing campaigns also reinforce this message. It is, therefore, worth noting that there may be a certain discrepancy between social expectations regarding organic food and legal regulations relating to organic production. The social perception of organic food goes beyond what would result solely from legal regulations.

3.2. „Simple Composition"

Although the surveyed consumers attributed qualities to organic food that they do not actually need to have, such as higher vitamin content or lack of heavy metals, the desired quality of „simple composition" is highly likely to appear in this type of food. Organic products, in accordance with the principles of organic production, usually contain a minimum amount of components, often from natural sources, which corresponds to the desired quality of „simple composition".

„Simple composition" on food reflects the expectations of consumers who want products with a small number of ingredients, preferably natural, understandable, and easily identifiable. A simple composition is often associated with higher quality, safety, and transparency of the product. In the context of EU food law, key areas of influence include regulations regarding requirements relating primarily to food additives and flavors. These are food improvement agents[28], which also include enzymes and substances that aid processing but seem to be of secondary importance to social perception of food.[29]

The indication in section 3.1 of two main regulations covering substances added to food results from the fact that flavorings and food ingredients with flavoring properties are not on an equal footing with food additives in EU food law.

27 V. Vigar, S. Myers, C. Oliver, J. Arellano, S. Robinson, C. Leifert., A Systematic Review of Organic Versus Conventional Food Consumption: Is There a Measurable Benefit on Human Health?, „Nutrients" 2019, vol. 12, no. 7, doi: 10.3390/nu12010007.

28 M. Taczanowski, „Prawo żywnościowe", Warsaw 2017, p. 120.

29 Even a cursory online search shows that there is no such an abundance of articles with an alarmist overtone.

Regulation 1333/2008 concerns food additives, which cover a wide range of substances used for technological purposes, such as preservatives, dyes, emulsifiers, antioxidants, and other substances intended to improve the durability, appearance, consistency, and other characteristics of foodstuffs.[30]

Under the Regulation, a food additive may be included in Annexes II and III (which contain the Community list of authorized additives and the conditions of their use) if it meets the following conditions:

a) at the level of use proposed, does not constitute, on the basis of available scientific evidence, a risk to the health of consumers;

b) there is a justified technological requirement that cannot be met in another way that is economically and technologically acceptable; and

c) its use does not mislead the consumer.[31]

At the same time, the food additive must benefit consumers by fulfilling one or more of the following purposes:

a) preserves the nutritional value of a given food;

b) provides essential ingredients or elements of foodstuffs produced for groups of consumers with special nutritional needs;

c) increases the shelf life or stability of a food or improves its organoleptic properties, provided that the nature, essence, and quality of the food are not changed in such a way as to mislead the consumer;

d) assists in the production, processing, preparation, handling, packaging, transportation, or storage of food, including food additives, food enzymes, and flavorings, provided that the food additive is not used to conceal the effects of using wasted raw materials or of use while performing any of these activities or any other undesirable practices or techniques, including unhygienic practices or techniques.[32]

Meeting the above conditions is the basis for including a given additive in the lists that are an integral part of the Regulation. These annexes contain detailed information on approved additives and the conditions of their use in various food products, food additives, food enzymes, and flavorings.

30 The types and functions of additives are described in Annex I to Regulation 1333/2008.

31 Article 6(1) of Regulation 1333/2008.

32 Article 6(2) of Regulation 1333/2008.

Under Article 10(2) of Regulation 1333/2008, each entry for a food additive included in these lists specifies:

a) the name of the food additive and its E number[33],

b) foodstuffs to which this food additive may be added,

c) conditions under which this food additive may be used[34],

d) possible restrictions on the sale of this food additive directly to final consumers.

All „E" markings that consumers find on food labels come from this list. Even a cursory online search confirms a reluctance to eat food with an „E" label.[35] On the one hand, for a given additive to be approved for use in food, it must have a health safety assessment by EFSA. On the other hand, the Supreme Audit Office in Poland points out that the law requires ensuring the safety of each additive used separately. They do not address the risk arising from the presence of more than one additive in foodstuffs or their accumulation from different sources.[36] A number of online publications and reports, such as the one from the Supreme Audit Office, certainly have a negative impact on the perception of food that contains a lot of additives marked „E". Regardless of whether a given substance is actually harmful or what it actually is, the average consumer is unlikely to know what is hidden under each of the over 300 „E" markings.

Regulation 1334/2008 applies to flavorings and food components with flavoring properties. Flavorings are used not for technological purposes but to improve or change the smell or taste of foodstuffs for the benefit of the consumer.[37] Under Article 4 of Regulation 1334/2008, only flavorings or food ingredients with flavoring properties may be used in and on foodstuffs which, according to available scientific information, do not pose a threat to the health of consumers, and their use does not mislead the consumer.[38] As in the case of food additives, a Community list of flavorings and source

33 The letter E is an alphanumeric code that uniquely identifies the additive. This is the standard marking used throughout the European Union; for example, E100 is curcumin, and E200 is sorbic acid.

34 Detailed conditions regarding the use of the additive, such as maximum permitted concentrations, specific situations of use, etc.

35 Szkodliwe dodatki do żywności – lista szkodliwych „E", https://masterdieta.pl/szkodliwe-dodatki-do-zywnosci-lista-szkodliwych-e; Dodatki do żywności E. Czy należy się ich bać?, https://www.apo-discounter.pl/blog/zdrowie-w-kuchni/dodatki-do-zywnosci-e-czy-nalezy-sie-ich-bac; „E", które szkodzą najbardziej. Czytaj etykiety i wystrzegaj się tych dodatków do żywności, https://pysznosci.pl/jakie-jest-najgorsze-e-szkodliwe-dodatki-do-zywnosci,6919175202945153a all abovementioned accesed 10 September 2024.

36 „E" w żywności bez kontroli, https://www.nik.gov.pl/aktualnosci/e-w-zywnosci-bez-kontroli.html.

37 Recital 7 of Regulation 1334/2008.

38 Article 4(a) and (b) of Regulation 1334/2008.

materials approved for use in and on foods has been established under Regulation 1334/2008.[39] Flavorings are classified based on their chemical properties and use without assigning E numbers.

It should be emphasized that the use of food additives or flavors has consequences for information provided to the consumer on a voluntary basis, in accordance with Article 36 of Regulation 1169/2011. In particular, this may prevent the use of labels that attract consumers, such as „traditional", „homemade", „natural", „clean", or „rural".[40]

3.3. Nutritional Values

Nutritional values play an important role in classifying foods as healthy. This is not surprising, especially considering the fact that one of the greatest challenges of the 21st century is non-communicable diseases, whose most important risk factors include excessive salt consumption and metabolic risks related to nutrition, i.e., increased blood pressure, overweight and obesity, hyperglycemia, and hyperlipidemia.[41]

However, given that the EU food law system focuses on food safety, virtually any food can be placed on the market, regardless of issues such as salt, sugar, fat content, etc., and the legislator generally does not interfere with the composition of the food itself. EU food law is based in this respect on the information paradigm, which is based on the belief that if consumers are provided with a sufficient and appropriate amount of information, they will generally be sufficiently protected and will make good decisions, including regarding their health and life. This paradigm assumes that the average consumer is „reasonably well-informed and reasonably observant and circumspect".[42]

A certain exception to the legislator's refraining from interfering in the composition of food (to the extent beyond issues related to food safety) and introducing regulations affecting the nutritional value of food is Regulation 1925/2006, which harmonizes the EU countries' regulations regarding the addition of vitamins, minerals, and certain other substances to food in order to guarantee the effective functioning of the internal market while ensur-

39 Article 1(a) of Regulation 1334/2008.

40 See K. Jędrych, Art. 36, in: A. Szymecka–Wesołowska (ed.) Znakowanie, prezentacja, reklama żywności. Komentarz do rozporządzenia Parlamentu Europejskiego i Rady (UE) no. 1169/2011, Warsaw 2018, p. 462.

41 World Health Organization, „Noncommunicable diseases", https://www.who.int/news-room/fact-sheets/detail/noncommunicable-diseases, 2018 (accessed June 17, 2024).

42 Judgment of the Court (Fifth Chamber) of 16 July 1998, Gut Springenheide GmbH and Rudolf Tusky v Oberkreisdirektor des Kreises Steinfurt – Amt für Lebensmittelüberwachung, reference for a preliminary ruling: Bundesverwaltungsgericht – Germany, Case C-210/96.

ing a high level of consumer protection.[43] This introduces a number of legal mechanisms specifying the conditions for adding vitamins and minerals and certain other substances to food, such as establishing a register of permitted substances[44], maximum and minimum amounts of vitamins and minerals that may be added to food[45] and specific standards for labeling and informing consumers.[46]

However, as previously indicated, food law affects the public perception of food in relation to its nutritional value primarily through food information regulations. Regulation 1169/2011 is of fundamental importance in this respect, as it is the basis for ensuring a high level of consumer protection in food information, taking into account differences in consumer perception and information needs while ensuring the smooth functioning of the internal market.[47] It imposes an obligation on food producers to provide consumers with product information that is reliable, clear, easy to understand[48] and not misleading.[49]

Article 9 of Regulation 1169/2011 contains a catalog specifying the particulars that must be provided to the consumer. This also includes nutritional information.[50] For beverages containing more than 1,2 % alcohol by volume, the actual alcoholic strength by volume.[51] At the same time, in the case of beverages with an alcohol content higher than 1.2%, an exception was introduced from the obligation to provide a list of ingredients and nutritional information.[52]

The nutritional information includes the following information: energy content and the amount of fats (including saturated fatty acids), carbohydrates (including sugars), protein, and salt.[53] The labeling may also include information on the content of other nutrients that may have health significance, e.g., fiber, vitamins, or minerals.[54] This legal regulation is of fundamental importance when it comes to consumers navigating the nutritional values of individual foods.

43 Article 1(1) of Regulation 1925/2006.
44 Article 9(1)(1) of Regulation 1925/2006.
45 Article 9(1)(2)(c) of Regulation 1925/2006.
46 Article 7 of Regulation 1925/2006.
47 Article 1(1) of Regulation 1169/2011.
48 Article 7(2) of Regulation 1169/2011.
49 Article 7(1) of Regulation 1169/2011.
50 Article 9(1)(1)(l) of Regulation 1169/2011.
51 Article 9(1)(1)(k) of Regulation 1169/2011.
52 Article 16(4) of Regulation 1169/2011.
53 Article 30(1) of Regulation 1169/2011.
54 Article 30(2) of Regulation 1169/2011.

As a rule, the energy value and the amount of nutrients referred to in Article 30(1–5) are expressed per 100 g or per 100 ml.[55] In some cases, it is possible to express it on a per portion basis or per unit amount of food instead of or in addition to 100 g or 100 ml.[56] In the context of shaping food perception, the additional forms of expressing and presenting information are referred to in Article 35(1) of Regulation 1169/2011. The energy value and the amount of nutrients referred to in Article 30(1–5) may be expressed or presented, in addition to words and numbers, graphically or symbolically, provided that certain requirements are met. An example of this is the increasingly popular Nutri-Score system, which assesses the nutritional value of products using colors and letters, although it should be emphasized that it is controversial.[57]

When talking about voluntary information provided to consumers, it is necessary to emphasize the role of nutrition and health claims that shape the perception of food, among other things, through references to the nutritional value of given foodstuffs. Nutrition claims are intended to encourage consumers to purchase a given food by emphasizing its specific nutritional properties. Health claims, in turn, are intended to encourage consumers to make purchases based on the association of a given food or its components with good health. These instruments are discussed in more detail in section 1.3.

3.4. Local Production

Locally produced food, as shown by the survey, enjoys a good reputation among consumers, and at the same time, supporting the development of local production can contribute to shaping more sustainable and healthy patterns of food consumption and production, improving food security, and thus strengthening the resilience of local food systems.[58] EU food law can contribute to a positive perception of local food through quality systems that refer to the local production of foodstuffs.

Over the years, the EU has established quality systems for products with specific characteristics, covering geographical indications for wine, spirits, and agricultural products, including foodstuffs, as well as tradition-

55 Article 32(2) of Regulation 1169/2011.

56 Article 33 of Regulation 1169/2011.

57 See S. Peters, H. Verhagen, Publication bias and Nutri-Score: A complete literature review of the substance of the effectiveness of the front-of-pack logo Nutri-Score, „Pharma Nutrition" 2024, vol. 27, 100380, doi: 10.1016/j.phanu.2024.100380.

58 See A. Kapała, Zamówienia publiczne na żywność lokalną w prawie Unii Europejskiej, „Przegląd Prawa Rolnego" 2022, vol. 1, no. 30, pp. 93–106, doi:10.14746/ppr.2022.30.1.7.

al specialties guaranteed and optional quality terms for agricultural products, including foodstuffs.[59] EU rules have protected designations of origin and geographical indications for wine since the early 1970s, for spirit drinks since 1989, and for agricultural products and foodstuffs since 1992. They enable the registration of valued names for products produced in accordance with a product specification on a defined geographical area by producers with recognized expertise.[60]

In the current legal status, the relevant laws are specified primarily in Regulation 2024/1143. It establishes two registers–the EU register of geographical indications for products with the protected designation of origin (PDO) and protected geographical indication (PGI) labels[61] and the EU register of traditional specialties guaranteed.[62] An agricultural product's designation of origin refers to a product that must come from a specific place, region, or, in exceptional cases, country.[63] Its quality or characteristics are essentially or exclusively the result of a particular geographical environment, including both natural and human factors[64] and all stages of production take place in the defined geographical area.[65] A geographical indication refers to a product that also comes from a specific place, region, or country[66] and whose quality, reputation, or other characteristic is mainly due to that geographical origin.[67] In the case of a geographical indication, it is sufficient that at least one stage of production takes place in the defined geographical area.[68] Traditional specialty guaranteed applies to products that are obtained using traditional methods of production, processing, or composition, following traditional practices.[69] Such a product must be made from traditional raw materials or ingredients.[70]

The protection of geographical indications and traditional specialties guaranteed in the EU is primarily about preventing misuse of names, imi-

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59 Recital 1 of Regulation 2024/1143.

60 Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on geographical indications of the European Union in relation to wine, spirits and agricultural products and on agricultural product quality schemes, amending Regulations (EU) No 1308/2013, (EU) 2017/1001 and (EU) 2019/ 787 and repealing Regulation (EU) No 1151/2012, COM/2022/134 final.

61 Article 22 section 1 of Regulation 2024/1143.

62 Article 65(1) of Regulation 2024/1143.

63 Article 46(1) of Regulation 2024/1143.

64 Article 46(1)(b) of Regulation 2024/1143.

65 Article 46(1)(c) of Regulation 2024/1143.

66 Article 46(2) of Regulation 2024/1143.

67 Article 46 2(b) of Regulation 2024/1143.

68 Article 46(1)(c) of Regulation 2024/1143.

69 Article 53(1) of Regulation 2024/1143.

70 Article 53(1)(b) of Regulation 2024/1143.

tations, false designations, and any practice that could mislead consumers as to the origin or nature of the product.[71]

It should be noted that despite many benefits, this protection does not necessarily support the consumption of local food in the strict sense. Most registered geographical indications and traditional specialties guaranteed concern products from southern Europe, such as Parmigiano Reggiano or Prosciutto di Parma. For the Polish consumer, these products are not local, even though they are protected and recognized as high quality. Nevertheless, quality schemes in the EU help maintain the diversity of food available on the market, countering the dominance of industrial production.

On the other hand, it is worth noting that EU law may also be problematic in some aspects for its members that would like to stimulate demand for local food. Kapała notes that „According to the principle of the single market, public procurement that would favor national or local suppliers is not allowed". Similarly, it is not possible to discriminate against a product because it comes from another member state. This position was expressed by the European Court of Justice (ECJ, currently the Court of Justice of the EU) in many judgments in public procurement cases, indirectly and directly based on the relevant provisions of the Treaty of Rome.[72] It should be emphasized, however, that Kapała points out that there are possibilities to circumvent this strict position.

4. Research Conclusions

This chapter analyzes the impact of legal regulations on the perception of food, focusing on the classification of products as healthy or unhealthy. Various regulations and guidelines are reviewed that shape consumers' perceptions of the nutritional and health values of food products.

Legal regulations play an important role in all aspects of consumers' assessment of food healthiness. In the context of characteristics such as purity and naturalness of food, after the BSE crisis, increased consumer confidence has been partially restored thanks to stringent food safety standards. These trends often lead to international trade disputes, as in the case of disputes before the World Trade Organization between the USA and the European Community relating to the introduction to the common

71 See, for instance, Article 26 or 68 of Regulation 2024/1143.

72 A. Kapała, *op. cit.*, p. 97.

market of meat from animals bred using growth hormones[73] or differences regarding GM food. As Korzycka and Wojciechowski emphasize, while the precautionary principle prevails in the EU, and the lack of scientific certainty as to possible risks associated with a specific type of food is the basis for taking preventive measures, in the USA, only scientific demonstration of risks is the basis for taking action.[74]

The legal structure of mechanisms ensuring food safety is not controversial. Nevertheless, analyses regarding the permissible concentrations of individual substances and their classification require in-depth research that goes beyond the framework of standard legal research.

In the context of organic food, EU law effectively protects consumers. Comparing regulations between the United States and the EU, Korzycka and Wojciechowski note that EU regulations are more restrictive in the context of using terms related to organic production, which increases consumer protection.[75] However, it should be noted that in light of the guidelines and goals of organic production, it is interesting that the survey shows that consumers attribute such characteristics to organic food as lower concentration of heavy metals, higher mineral content, or higher vitamin content. Such a relationship does not result directly from legal regulations.

In the context of „simple composition", EU food law is also restrictive, and legal mechanisms in this area do not create legal doubts. Nevertheless, consumer concerns about food additives and flavors, especially those marked „E", are apparent. Even natural and health-promoting additives such as E100 (curcumin) can suffer from the negative PR associated with the „E" symbol.

In the context of nutritional values, attention should be paid to providing information about the energy value of alcohol. Although research is inconclusive as to whether information about the energy value of alcohol would impact public health, and the majority of respondents in a sociological study stated that they knew how many calories a particular alcoholic beverage contained, it is doubtful that this clearly unhealthy food is treated in a special way in the context of limiting full information to the consumer.

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73 See T. Srogosz, Globalne zarządzanie bezpieczeństwem żywności. Aspekty prawne, Warsaw 2022, pp. 249–258.

74 M. Korzycka, P. Wojciechowski, Regulacja prawna żywności genetycznie zmodyfikowanej w USA i UE w kontekście planowanego Transatlantyckiego Porozumienia Handlowo-Inwestycyjnego (TTIP), „Studia Iuridica Lublinensia" 2017, vol. 26, no. 1, p. 467.

75 M. Korzycka–Iwanow, P. Wojciechowski, Żywność ekologiczna w prawie USA i Unii Europejskiej, „Studia Iuridica Agraria" 2015, vol. 13, p. 29.

In the area of information about the nutritional value of food, however, the most important activities seem to be related to the establishment of nutrient profiles and information on nutritional values provided on a voluntary basis. Various voluntary nutrition labeling schemes operate in this context. WHO suggests the need to develop a uniform system to increase the effectiveness of the labeling system.[76]

76 WHO, Guiding principles and framework manual for front-of-pack labeling for promoting healthy diets, 2019.

Chapter 4

HEALTHY FOOD – ANALYTICAL RESEARCH

1. Research Assumptions

In recent years, more and more attention has been paid to the quality and safety of plant-based products. Chemical contaminants of food, including residues of pesticides and toxic elements, are referred to as critical determinants of food quality and safety. Pesticide residues in crops are primarily a consequence of their use to protect plants against pests. Moreover, failure to comply with the withdrawal period, application of pesticides in strong winds causing them to be carried away to adjacent fields, use of pesticides not registered for specific crops, exceeding the recommended doses, and application of pesticides in sunny weather and during the peak activity of pollinating insects are the causes of the presence of these compounds in the marketed fruit, agricultural products, and honey, especially in concentrations exceeding the maximum permissible levels (MRLs).

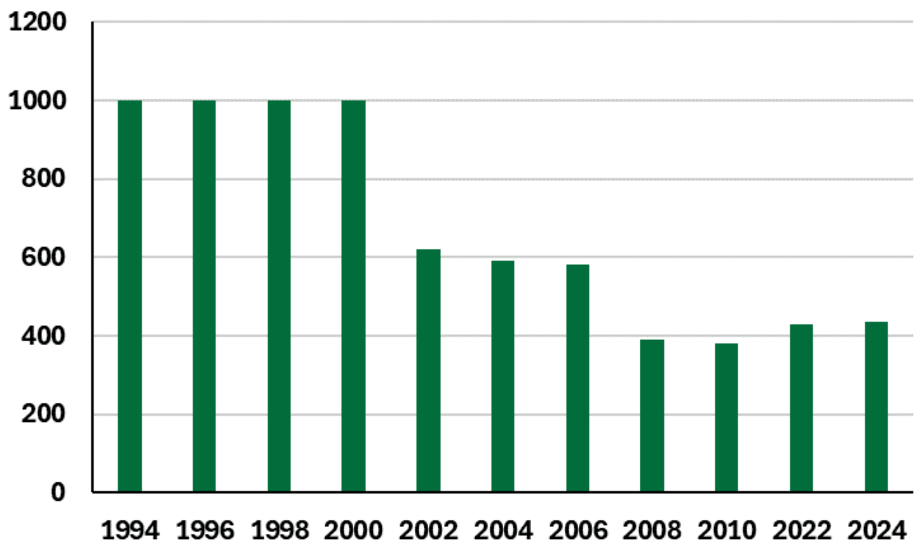
The most frequently detected pesticides in food of plant origin are insecticides, fungicides, and herbicides.[1] In 2022, a total of 110,829 food samples were analyzed in the EU as part of coordinated monitoring, of which 59% showed no pesticide residues, 37.3% found their presence below the MRLs, and 3.7% of the samples exceeded the MRLs. Compared to 2019 and 2016, the rate of exceedance of MRLs for pesticides has decreased for apples, peaches, and strawberries, while this value has been decreasing in spinach since 2019. Exceedances of permissible pesticide limits have increased for head cabbage, tomatoes, lettuce, barley, and oats. In turn, the percentage of multi-residue samples accounted for 23%.

1 EFSA, National summary reports on pesticide residue analyses performed in 2022, „EFSA Support Publ." 2024, vol. 21, pp. 1–270.

Systematic research in the EU to ensure the safety of consumers, animals, pollinators, and the environment results in the withdrawal of many dangerous pesticides. The European Commission decides to authorize or withdraw pesticides in Europe based on the opinion of the European Food Safety Authority (EFSA). In the last twenty years, there has been a significant decrease in the active substances of pesticides registered in the EU, from over 1,000 in 2000 to 436 in 2024 (fig. 2).

It should be emphasized that the maximum permissible levels of pesticides in the EU are established by the European Commission on the basis of EFSA reports and opinions. In the countries outside the community, MRLs are included in the Codex Alimentarius, developed by the FAO/WHO Codex Alimentarius Commission. Often, the pesticide MRLs set by EFSA for foods of plant origin are more restrictive than those in Codex Alimentarius. For example, according to EFSA, the MRL for tebuconazole in lettuce is 0.5 mg/kg, and according to the Codex Alimentarius–5 mg/kg.

Fig. 2. Number of registered active substances in pesticides in the EU in 1994–2024



Based on EFSA reports, the European Commission updates the MRLs for pesticides in food, which are among the lowest compared to countries outside the community. Pesticides withdrawn in Europe are still used in other parts of the world (North and South America, Asia, and Africa), which leads to the problem of importing food with their residues to EU countries.

Examples of such compounds detected in food of plant origin imported to Europe include chlorpyrifos, chlorothalonil, buprofezin, and pyridaben.[2]

Fruits, vegetables, and cereal products are essential components of the human diet – they provide carbohydrates, protein, vitamins, dietary fiber, and minerals, mainly copper, manganese, magnesium, and iron. They contain a wide range of bioactive phytochemicals, such as anthocyanins, carotenoids, flavanols, phytoestrogens, terpenoids, limonoids, phytosterols, and phenolic compounds, which can prevent chronic diseases, such as cancer, hypercholesterolemia, and hypertension.[3] They are relatively low in calories, which is particularly important considering the epidemic of obesity, overweight, and diabetes. Moreover, they are believed to have antibacterial, immunomodulating, hepato – and cardioprotective and anti-amnestic properties.[4]

The key role of products of plant origin in human life is reflected in the increasing popularity of vegetarian diets, especially in developed countries. Reducing meat consumption has become an important sustainable development goal, and initiatives to discourage consumers from eating animal products, especially meat, have increased around the world. It is estimated that vegetarians constitute between 1 and 10% of the population of the EU, the United States, and Canada. In the world, the number of people with such dietary preferences is estimated at approximately 1.5 billion. However, it should be noted that there are two categories of vegetarianism–vegetarians by choice, for whom meat is easily available but avoided, and vegetarians by necessity, who have limited access to meat, for example, for economic reasons. The reasons for the increase in the consumption of plant products and the elimination of animal products also include health, cultural, philosophical, religious, and ecological reasons or simply taste preferences.[5,6]

Taking into account that nutrition experts encourage the daily consumption of vegetables and fruit, or other products of plant origin, as a source of valuable minerals, vitamins, and fiber, determining exposure to pesti-

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2 EFSA, The 2022 European Union report on pesticide residues in food, „EFSA J." 2024, vol. 22, e8753.

3 S. Kaur, U. Rani, P.S. Panesar, Functional and nutraceutical potential of fruits and vegetables, in: Microbes in the Food Industry, „John Wiley & Sons, Ltd" 2023, pp. 275–320.

4 S.S. Moni, Functional Vegetables and Medicinal Uses: Cure and Curse, in: S. Mohan, S. Abdollahi, Y. Pathak (eds.), Applications of Functional Foods and Nutraceuticals for Chronic Diseases, „CRC Press" 2023, pp. 117–135.

5 C. McEvoy, J.V. Woodside, Vegetarian and Vegan Diets: Weighing the Claims, in: N.J. Temple, T. Wilson, G.A. Bray (eds.), Nutrition Guide for Physicians, „Human Press" 2010, pp. 81–93.

6 J.B. Nezlek, C.A. Forestell, Vegetarianism as a social identity, „Curr. Opin. Food Sci." 2020, vol. 33, pp. 45–51.

cides and toxic elements in food seems to be particularly important in the context of health benefits and risks of consuming vegetables and fruit. Moreover, legal regulations oblige EU countries to monitor the concentrations of active substances of pesticides in food and to report any irregularities detected.[7]

Consumers are also paying more and more attention to the origin of food products. Local products, often, although not always rightly, associated with ecological production, are often associated with better sensory values, quality and freshness, environmental friendliness and support of local rural communities, as well as with sustainable development.[8] Due to the qualities attributed to local food, customers are willing to pay more for it.[9] Conscious consumers see the benefits of reducing the physical distance between buyer and producer and shortening the supply chain to reduce the environmental impact of transporting food. Moreover, the local origin of a product is not only associated with space but also with time, referring to the tradition and culture of food production that give it a distinctive identity.[10] This may involve, for example, limiting the use of pesticides in growing, storing, and transporting fruit, vegetables, and cereals. On the other hand, consumers also notice obstacles to purchasing local food, including seasonal availability of products and limited choice, as well as a potential economic barrier.[11]

Food of plant origin is necessary for proper nutrition, but it can also be an important source of chemical (pesticides and toxic elements) and biological (mycotoxins) pollutants in the diet. The increase in social awareness of healthy food as products free from chemical and biological contamination brings about an increase in interest in ecological foodstuffs whose production does not involve pesticides and mineral fertilizers. Consumer choices translate into the share of organic farms and the area of agricultural land managed in the organic system in Poland over the years. Farmers were most interested in organic production in 2012–2014, and despite the

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7 See Article 10 et seq. of Regulation 396/2005.

8 K. Ditlevsen, S. Denver, T. Christensen, J. Lassen, A taste for locally produced food–Values, opinions and sociodemographic differences among ‘organic’ and ‘conventional’ consumers, „Appetite” 2020, vol. 147, 104544.

9 I. Printezis, C. Grebitus, Marketing Channels for Local Food, „Ecological Economics” 2018, vol. 152, pp. 161–171.

10 M.C. Aprile, V. Caputo, R.M. Nayga, Consumers’ Preferences and Attitudes Toward Local Food Products, „J. Food Prod. Mark.” 2016, vol. 22, pp. 19–42.

11 S. Godrich, K. Kent, S. Murray, S. Auckland, J. Lo, L. Blekkenhorst, B. Penrose, A. Devine, Australian consumer perceptions of regionally grown fruits and vegetables: Importance, enablers, and barriers, „Int. J. Environ. Res. Public Health” 2020, vol. 17, 63.

decline in the number of farms and land area in the organic system in subsequent years, an upward trend is currently observed again.

The National Center for Nutrition Education recommends eating five portions of vegetables and fruit a day.[12] Vegetables should predominate because they can be eaten without restrictions, while fruit, especially those with high fructose content, should be limited by diabetics. These products are a valuable source of vitamins, polyphenol compounds, and dietary fiber and contain a relatively high water content. Vegetables and fruits are mostly a moderate source of minerals, and they also contain components that hinder their bioavailability (e.g. dietary fiber, polyphenols, oxalates, phytates) and thus their ability to be used by the body. Nevertheless, food of plant origin is an important source of some macro- and micronutrients, for example, magnesium, potassium, selenium, and zinc.[13]

The most popular drinks are tea infusions. The availability of many types of tea and various brewing methods mean that this aromatic drink is consumed for its taste, but it also meets the human need for fluids and has a refreshing effect. Many varieties of tea, due to the presence of valuable components, have health-promoting qualities confirmed by research, including antioxidant, anti-inflammatory, calming, or stimulating properties, supporting the digestive tract or warming.[14]

Coffee, like tea, is one of the most popular drinks. There are various types available on the market, and there are many ways of preparing it, depending on preferences and culture. It is consumed primarily due to its taste and functional properties, including stimulation and improving mood and concentration. For many years, it was considered a dangerous stimulant, causing, e.g., hypertension and heart disease. Recent studies on its health-promoting properties proved that coffee does not cause hypertension when consumed moderately. Studies have also shown that coffee has antioxidant properties and can reduce the risk of diabetes, has a beneficial effect on neurodegenerative diseases (Parkinson’s and Alzheimer’s disease), and accelerates fat burning. The myth that coffee leaches out miner-

12 K. Wolnicka, Talerz zdrowego żywienia, National Center for Nutrition Education, accessed: August 8, 2024, https://ncez.pzh.gov.pl/abc-zywienia/talerz-zdrotego-zywienia.

13 K. Platel, K. Srinivasan, Bioavailability of Micronutrients from Plant Foods: An Update, „Crit. Rev. Food Sci. Nutr.” 2016, vol. 56, no. 10, pp. 1608–1619, doi: 10.1080/10408398.2013.781011.

14 G.Y. Tang et al., Health Functions and Related Molecular Mechanisms of Tea Components: An Update Review, „Int. J. Mol. Sci.” 2019, vol. 20, no. 24, 6196.

als has also been debunked by studies showing that some types of coffee can provide significant amounts of minerals.[15]

Nuts represent another group of plant-based foods with a positive impact on health. They are a valuable snack and a source of essential fatty acids, dietary fiber, vitamin E, some B vitamins, and minerals.[16]

The analytical research aimed to assess the occurrence of chemical and biological contaminants as well as minerals and selected nutritional and antioxidant compounds in various types of food of plant origin and honey purchased in European retail chains. The analyzed food groups included commonly consumed fruits, vegetables, teas, coffees, hummus, smoothies, honey, nuts, groats, and cereal products. Some of the tested products came from the EU, and the rest were imported from non-EU countries.

2. Research Description

As part of the project, various groups of food of plant origin and honey were tested for the presence of chemical contaminants (pesticide residues and toxic elements), biological contaminants (mycotoxins), and the content of beneficial components (minerals, amino acids, vitamins, and phenolic acids). The products selected were those commonly regarded as healthy, recommended in the diet due to the presence of important health-promoting components (vegetables, fruit, cereals and cereal products, nuts, and honey), and other frequently consumed products, including hummus, smoothies, tea, and coffee, due to their functional properties and taste.

2.1. Food of Plant Origin, Honey, and Country of Origin

In total, 479 samples of food of plant origin and honey were analyzed, of which 130 came from crops declared as organic.

The sampled groups included fruits (44 samples), vegetables (38), herbs (1), teas (64), coffees (30), humus (22), smoothies (35), honey (41), groats and cereal products (90), and nuts (114).

15 K. Nieber, The Impact of Coffee on Health, „Planta Med.” 2017, vol. 83 no. 16, pp. 1256–1263; B.B. Gökcen, N. Şanlier, Coffee consumption and disease correlations, „Crit. Rev. Food Sci. Nutr.” 2019, vol. 59, no. 2, pp. 336–348; E. Olechno, A. Puścion–Jakubik, K. Socha, M.E. Zujko, Coffee Brews: Are They a Source of Macroelements in Human Nutrition?, „Foods 2021”, vol. 10, no. 6, 1328.

16 B. Gonçalves et al., Composition of Nuts and Their Potential Health Benefits – An Overview, „Foods” 2023, vol. 12, no. 5, 942.

The research covered a total of 44 fruit samples from 20 countries; 13 commonly consumed species belonging to six groups were examined, i.e., citrus fruits, exotic fruits, berries, stone fruits, wild strawberries, and vine fruits. The only product for which all samples were produced in Poland was apples. One species contained 1 to 6 samples: pineapple – 1 sample from Costa Rica; avocado – 4 samples from Colombia, Spain, Mexico, and South Africa; bananas – 4 samples from Colombia and Ecuador; kiwifruit – 2 samples from Italy and Greece; mango – 1 sample from Peru; blueberries – 3 samples from Morocco, Peru, and South Africa; lemons – 4 samples from Spain and Uruguay; grapefruit – 5 samples from Turkey, France, South Africa, and the USA; oranges – 3 samples from Italy and Spain; pears – 5 samples from Poland, Belgium, and Portugal; apples – 5 samples from Poland; strawberries – 1 sample from Greece; purple grapes – 6 samples from Spain, Portugal, Italy, India, and Peru.

The research covered a total of 38 vegetable samples from 12 countries and included 14 commonly consumed species belonging to 6 main groups: Solanaceae, Cucurbitaceae, Amaryllidaceae, Brassicaceae, Asteraceae, and Apiaceae. Each species contained from 1 to 8 samples: eggplant – 1 sample from Spain; broccoli – 3 samples from Spain and Italy; onion – 5 samples from Poland, India, the Netherlands, France, and Spain; garlic – 1 sample from Spain; Chinese cabbage – 1 sample from Poland; parsley – 1 sample from Spain; cucumber – 4 samples from Poland and Turkey; red pepper – 1 sample from Turkey; tomato – 7 samples from Poland, Spain, Italy, Morocco, Germany, and the Netherlands; leek – 1 sample from Belgium; radish – 3 samples from Italy; romaine lettuce – 1 sample from Spain; celery – 1 from Spain; potato – 5 samples from Poland and Cyprus and 3 samples from the USA and Spain. In addition, 1 sample of Polish basil was tested.

In addition, 22 samples of classic hummus based on chickpeas and hummus with additions of tomatoes, garlic, dates, black cumin, olive oil, pumpkin and ginger, tofu with peppers, and guacamole were tested.

The study included a total of 35 smoothie samples from Poland (24 samples), Spain (6), and Germany (5). The smoothie types tested had 1 to 6 ingredients, including blackcurrant, cherry, strawberry, banana, grape, apple, acerola, mango, orange, passion fruit, pineapple, melon, coconut, blackberry, raspberry, lime, asparagus, carrot, peach, ginger, pomegranate, blueberries, baobab, sea buckthorn, moringa, flax seeds, pumpkin, tangerine, cranberry, wild rose, spinach, kale, aloe, chia seeds, maqui berries, turmeric, chokeberry, ashwagandha, kiwifruit, and pear.

The study covered 90 samples of groats and cereal products, including buckwheat (17), millet (18), barley (14), oatmeal (20), and rice (21). Samples from Poland predominated (62%). Additionally, samples from Pakistan (8%), Ukraine (5%), Cambodia (3%), Lithuania (2%), Italy (2%), and other countries (9%) were examined.

The research covered a total of 64 tea samples from 9 countries, including 5 types: black, black fruit, white, red, and green, and 2 herbal teas: lemon balm and mint. Each had from 4 to 17 samples analyzed: black tea – 17 samples from Sri Lanka, India, China, Kenya, United Arab Emirates; black fruit tea – 4 samples from China; white tea – 7 samples from Sri Lanka and China; tea red – 4 samples from China; green tea – 16 samples from Sri Lanka, China, Japan, Vietnam; lemon balm tea – 7 samples from Poland and Greece; and mint tea – 9 samples from Poland and Greece.

The research included 30 coffee samples from 15 countries: Brazil (3), Ethiopia (2), France (2), the Netherlands (2), Honduras (3), Indonesia (1), Kenya (1), Colombia (1), Congo (1), Peru (5), Germany (2), Mexico (1), Poland (4), Portugal (1), and Italy (1).

Testing also covered 114 samples of nuts from 25 countries, including peanuts – 10 samples from India, USA, Nigeria, Argentina, and Brazil; Brazil nuts – 10 samples from Peru, Bolivia, and Brazil; hazelnuts – 12 samples from Spain, Georgia, Turkey, and Azerbaijan; macadamia nuts – 11 samples from Côte d'Ivoire, Vietnam, and Kenya; almonds – 14 samples from Spain, the USA, Cyprus, and Italy; cashew nuts – 13 samples from Brazil, Burkina Faso, Côte d'Ivoire, and Vietnam; pecan nuts – 10 samples from Mexico, South Africa, and the USA; pine nuts – 9 samples from Cyprus, Turkey, Spain, Kazakhstan, and China, pistachio nuts – 14 samples from Turkey, the USA, Spain, and Iran; and walnuts – 11 samples from Bulgaria, Turkey, Poland, the USA, and Chile.

Moreover, the testing covered a total of 41 samples of Polish honey.

Representative samples of each product were purchased in 4 nationwide retail chains. Each was properly marked and stored at 4˚C until analysis.

The representative sample consisted of approximately 1 kg of fruit, vegetables, groats, cereal products, and nuts, as well as 4 packages of 100 g or 250 g of each type of tea and coffee, 4 packages of 100 g of each type of hummus, 4 packages of 250 ml of each type of smoothie and 41 packages 400 g of Polish honey. The contents of individual samples were combined into a collective sample.

The content of pesticides was analyzed in all products; the content of toxic elements and minerals was tested in vegetables, fruits, coffees, teas, and nuts; the concentration of mycotoxins was analyzed in coffees and nuts; and the concentration of amino acids, vitamins, and phenolic acids was tested in nuts.

2.2. Chemical Pollutants

Analytical Studies of Pesticide Residues in Food of Plant Origin and Honey

The study covered 583 pesticides, including herbicides (193), fungicides (146), and insecticides (244). The concentrations of the detected compounds were checked for compliance with the maximum permitted levels (MRLs) and approval for use in the EU.

The procedure for extracting pesticides from food products was carried out using QuEChERS in accordance with the applied methodologies.[17,18]

Instrumental pesticide analysis used liquid chromatography (Eksigent Ultra LC-100; Eksigent Technologies, Dublin, CA, USA) coupled with tandem mass spectrometry (MS/MS 6500 QTRAP; AB Sciex Instruments, Foster City, CA, USA) (LC–MS/MS) and gas chromatography (Agilent 7890A GC; Agilent Technologies, Palo Alto, CA, USA) coupled with tandem mass spectrometry (MS/MS 7000B; Agilent Technologies, Palo Alto, CA, USA) (GC–MS/MS) according to the developed methodologies.[19]

Analytical Studies of Toxic Elements in Food of Plant Origin

The content of cadmium, lead, and arsenic, after prior mineralization of the samples using microwaves, was determined by inductively coupled plasma mass spectrometry (ICP–MS) in the standard mode (Cd, Pb) and using kinetic energy discrimination (KED) (Nexion 300D, PerkinElmer, USA).

17 B. Łozowicka, E. Rutkowska, M. Jankowska, Influence of QuEChERS modifications on recovery and matrix effect during the multi-residue pesticide analysis in soil by GC/MS/MS and GC/ECD/NPD, „Environ. Sci. Pollut. Res." 2017, vol. 24, pp. 7124–7138.

18 B. Łozowicka, G. Ilyasova, P. Kaczyński, M. Jankowska, E. Rutkowska, I. Hrynko, P. Mojsak, J. Szabuńko, Multi-residue methods for the determination of over four hundred pesticides in solid and liquid high sucrose content matrices by tandem mass spectrometry coupled with gas and liquid chromatograph, „Talanta" 2016, vol. 151, pp. 51–61.

19 E. Rutkowska, B. Łozowicka, P. Kaczyński, Modification of Multiresidue QuEChERS Protocol to Minimize Matrix Effect and Improve Recoveries for Determination of Pesticide Residues in Dried Herbs Followed by GC-MS/MS, „Food Anal. Methods" 2018, vol. 11, pp. 1–16; P. Kaczyński, B. Łozowicka, One-Step QuEChERS-Based Approach to Extraction and Cleanup in Multiresidue Analysis of Sulfonylurea Herbicides in Cereals by Liquid Chromatography–Tandem Mass Spectrometry, „Food Anal. Methods" 2017, vol. 10, pp. 147–160.

Mercury content was determined directly with a mercury analyzer using the ASA method with amalgamation after pre-combustion of the sample in an oxygen atmosphere (MA–3 Solo, Nippon Instruments Corporation, Japan).

2.3. Biological Contaminants

Analytical Studies of Mycotoxin Content in Nuts and Coffee

Nut and coffee samples (5 g) were extracted with 10 ml of 1% formic acid in acetonitrile (1:1, v/v). Then, 4 g of magnesium sulfate, 1 g of sodium chloride, 1 g of sodium citrate, and 0.5 g of dibasic sodium citrate sesquihydrate were added. The samples were shaken (1 min) and centrifuged for 5 min at 4500 rpm. The supernatant was collected and stored at −60 ˚C for 30 min. Then, 150 mg of magnesium sulfate, 25 mg of primary amine, and 25 mg of C15 ketones were added. The samples were shaken (1 min) and centrifuged at 4500 rpm for 10 min. The final extract (1 ml) was filtered through a hydrophilic PTFE filter with a pore diameter of 0.45 μm and analyzed using LC–MS/MS according to the developed protocol.[20]

2.4. Beneficial Components in Food of Plant Origin

Analytical Studies of Mineral Content in Food of Plant Origin

Food samples of plant origin were wet mineralized in concentrated nitric acid V using microwaves in a closed system (SpeedWave Berghof, Germany). The content of calcium, magnesium, iron, zinc, and copper was determined by atomic absorption spectrometry (ASA) with atomization in an acetylene–air flame (Ca, Mg, Fe, Zn) and electrothermal atomization in a graphite cuvette (Cu), with Zeeman background correction (Z–2000 Hitachi, Japan).

Analytical Studies of Selected Nutritional Compound Content in Nuts

To determine the concentration of 20 amino acids, ground nut samples (1 g) were combined with 10 ml of water and methanol solution (8:2, v/v) with 0.1% formic acid. The samples were shaken for 5 min and centrifuged at 10,000 rpm for 10 min. Extracts (1 ml) were filtered through a 0.22 μm hydrophilic PTFE filter and analyzed by liquid chromatography coupled with

20 B. Łozowicka, P. Iwaniak, R. Konecki, P. Kaczyński, N. Kuldybayev, Y. Dutbayev, Impact of Diversified Chemical and Biostimulator Protection on Yield, Health Status, Mycotoxin Level, and Economic Profitability in Spring Wheat (Triticum aestivum L .) Cultivation, „Agronomy" 2022, vol. 12, 258.

tandem mass spectrometry (LC–MS/MS). Instrumental LC–MS/MS was performed according to previously developed methodologies. [21,22]

To determine the concentration of 8 vitamins, 1 g of nut sample was combined with 10 ml of 50% acetonitrile in acidified water (1% formic acid) and shaken for 10 min. After centrifugation (for 5 min. at 4500 rpm), the supernatant was filtered through a hydrophilic PTFE filter with a pore diameter of 0.2 µm, transferred to an automatic sample feeder vial and analyzed by LC–MS/MS, according to the previously developed protocol.[23]

Analytical Studies of Selected Antioxidant Content in Nuts

To determine the concentration of 11 phenolic acids, 5 ml of water was added to 5 g of ground nuts. Then, 100 µl of the internal standard solution of atrazine-d5 (0.5 µg /ml) was added, followed by 10 ml of 1% formic acid in acetonitrile. The tubes were shaken for 1 mi. Then, 4 g of anhydrous magnesium sulfate, 1 g of sodium chloride, 1 g of trisodium citrate dihydrate, and 0.5 g of hemihydrate were added to hydrogen citrate disodium. The sample was shaken for 5 min and then centrifuged for 5 min at 4500 rpm. Then, 6 ml of supernatant acetonitrile was transferred to a polypropylene centrifuge tube containing: 150 mg PSA, 150 mg C18, and 900 mg anhydrous magnesium sulfate. The tubes were shaken for 1 min and then centrifuged at 4500 rpm for 5 min. One ml of the final extract was filtered through a hydrophilic PTFE filter with a pore diameter of 0.2 µm, transferred to an autosampler vial, and analyzed by LC–MS/MS according to the specified methodology.[24]

2.5. Validation of Analytical Methods

Validation of chromatographic methods for the determination of pesticide residues, mycotoxins, and nutrients was carried out for linearity, recovery, precision, limit of detection (LOD), limit of quantification (LOQ), matrix effect (ME), and uncertainty (U) (SANTE/11312/2021). LOD was calculated in all cases using the following signal-to-noise (S/N) criteria: LOD = 3 S/N. Analytical standards of 583 pesticides, 20 amino acids, 11 phenol-

21 B. Łozowicka, P. Kaczyński, P. Iwaniak, Analysis of 22 free amino acids in honey from Eastern Europe and Central Asia using LC-MS/MS technique without derivatization step, „J. Food Compos. Anal." 2021, vol. 98, 103837.

22 P. Iwaniak, R. Konecki, P. Kaczyński, A. Rysbekova, B. Łozowicka, Influence of seven levels of chemical/biostimulator protection on amino acid profile and yield traits in wheat, „Crop J." 2022, vol. 10, pp. 1198–1206.

23 B. Łozowicka, P. Kaczyński, P. Iwaniak, E. Rutkowska, K. Socha, K. Orywal, J.A. Farhan, M. Perkowski, Nutritional compounds and risk assessment of mycotoxins in ecological and conventional nuts, „Food Chem." 2024, vol. 458, 140222.

24 *Ibid.*

ic acids, 8 vitamins, and 14 mycotoxins, with a purity of >98%, were purchased from LGC Standards Dr. Ehrenstorfer (LGC Standards GmbH, Wesel, Germany) and Sigma-Aldrich (St. Louis, MO, USA).

Validation of the analytical methods used for determining toxic elements and beneficial minerals (ICP–MS and ASA) was carried out using matrix reference materials (Simulated Diet D–Reference material, Livsmedelsverket National Food Administration, Uppsala Sweden; Tea Leaves–INCT-TL-1, Institute of Nuclear Chemistry and Technology, Warsaw, Poland; Mixed Polish Herbs–INCT-MPH-2, Institute of Nuclear Chemistry and Technology, Warsaw, Poland).

2.6. Statistical Analysis

Statistical analysis was performed using Statistica v.13.1. The normality of data distribution was checked using the Shapiro–Wilk and Kolmogorov–Smirnov tests. The Mann–Whitney U test and the Kruskal–Wallis test were used to calculate statistically significant differences. Differences were considered statistically significant at the significance level of $p < 0.05$. The contents of the above components in conventional food samples were also compared to selected food samples certified as organic products.

3. Research Results

3.1 Chemical Contaminants in Food of Plant Origin and Honey

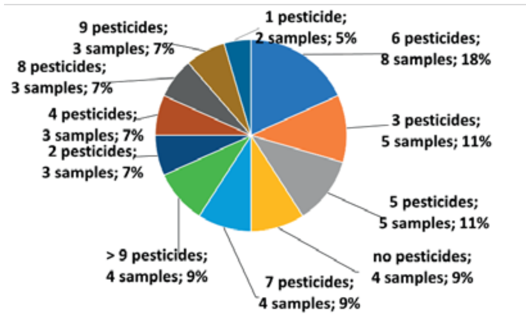
3.1.1. Pesticides

Fruit

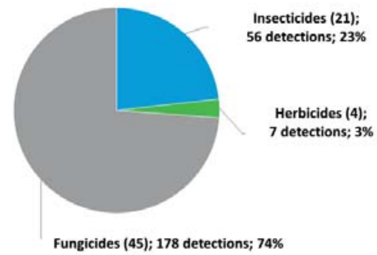
Of the total number of fruit samples tested, 4 were free from any residue, representing 9% of all fruit. Particularly noteworthy is the fact that 3 avocado samples (out of 4 tested) and 1 sample of blueberries from South Africa did not contain pesticides. In the vast majority of the analyzed products, i.e., 86%, residues below MRLs were detected. Unacceptable exceedances of MRLs were recorded for two compounds (5% of samples, 2 samples).

Fig. 3. (a) Share of pesticide-free, single-compound, and multi-residue fruit samples; (b) Summary of detected pesticide groups (numbers in brackets indicate the number of detected compounds)

a



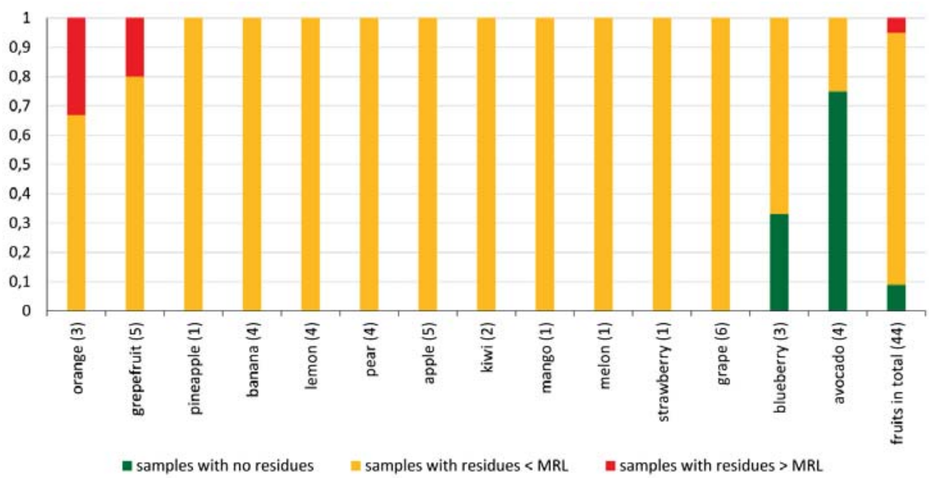
b



Of the 70 pesticides detected in fruit samples, 16 (23%) are not approved for use in the EU. These compounds were present in fruit from third countries: Peru, Costa Rica, Ecuador, Colombia, and the USA, and the EU countries: Portugal, Greece, Italy, and Spain. The withdrawn compounds included 1 herbicide, 10 fungicides, and 10 insecticides. This group included trifluralin, found in 1 mango sample from Peru; thiamethoxam and flutriafol, detected in a melon sample from Costa Rica; epoxiconazole in a pineapple sample from Costa Rica; triflumuron and fenoxycarb, detected in pears from Portugal; flutriafol and carbendazim in purple grapes from Portugal; and spiromesifen in strawberries from Greece. Imidacloprid, bromopropylate, oxadixyl, and chlorpyrifos were found in two samples of green grapefruits from the USA. Carbendazim was present in orange samples from Spain, and chlorpyrifos was found in a sample of this fruit from Italy. Exotic fruit samples, i.e., bananas from Ecuador, contained bifenthrin (0.005 mg/kg), while the remaining three samples from Colombia had diafenthiuron (0.002 mg/kg), bifenthrin and fenpropimorph, myclobutanil, and fenbutatin oxide.

Of the 241 detected compounds, the most frequent were fungicides (74%; 178 detections) and insecticides (23%; 56), while herbicides were detected sporadically (3%; 7) (fig. 3). Two compounds–the insecticide chlorpyrifos-methyl and the herbicide beflubutamid–did not meet safety standards. The tested fruit included samples with one pesticide residue (5%) and multi-residues, containing from 2 to 15 active substances. The most numerous samples (18%) contained 6 pesticides, while residues of 3 and 5 compounds were found in 11% of the samples, and 9% of the analyzed samples contained 9 to 15 compounds. The sample of purple grapes from Portugal had the highest number of pesticides and contained 18 compounds with a total concentration of 1,700 mg/kg. The most frequently detected fungicides were fludioxonil (8.7%), pyrimethanil (5.8%), and imazalil (5%). The dominant insecticides were acetamiprid (4.1%) and spirotetramat (3.7%), while chlorpyrifos exceeded the MRL in 0.4% of the tested samples. The most frequently detected herbicide was beflubutamid (1.6%), the concentration of which exceeded the safe MRL in 0.4% of the tested fruit samples. In citrus fruits, exotic fruits, berry fruits, stone fruits, wild strawberries, and vine fruits, exceedances of the maximum permissible levels were recorded for compounds in citrus fruits. In this group, 18% of samples did not meet safety standards, and 82% of samples contained pesticide residues. No residues were found in exotic fruits (22% of samples) and berries (20%). All stone fruits, wild strawberries, and vine fruits were contaminated with pesticides (100%, 100%, 100%) (fig. 4).

Fig. 4. Pesticides in fruit samples (number of samples in brackets) and their concentrations with maximum permissible levels (MRLs)



Citrus fruits

The citrus fruit group was represented by 3 samples of oranges from Italy and Spain, 5 samples of grapefruits from Turkey, South Africa, the USA, and France, and 4 samples of lemons from Spain and Uruguay. All tested citrus fruits contained pesticides ranging from 2 to 11 compounds. In a sample of grapefruits from the USA, the herbicide beflubutamid was detected at a concentration of 0.040 mg/kg, i.e., twice the norm. In addition, the same sample contained three active substances withdrawn from use in the EU: the insecticides bromopropylate and chlorpyrifos, the fungicide oxadixyl, and two other compounds authorized for use in the EU: the fungicides imazalil and thiabendazole. The total content of all residues in this sample was 1.372 mg/kg. A sample of red oranges from Italy contained chlorpyrifos at a concentration five times higher than the MRL, set at 0.05 mg/kg. This compound is not approved for use in the EU. In addition, three other substances were present: acetamiprid and fungicides imazalil and pyrimethanil. The total content of all residues in this sample is 0.796 mg/kg.

Table 1. Detailed summary of detected pesticides in citrus fruit samples

No	AsAssort-ment	Country of origin		Pestycyd	Concentration (mg/kg)	No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)
15	lemon	Spain	F	Fludioxonil	0.001	12	grapefruit	Türkiye	I	Acetamiprid	0.001
			I	Hexythiazox	0.006				F	Fludioxonil	0.001
			F	Imazalil	1.143				F	Imazalil	0.542
			I	Pyriproxyfen	0.035				I	Malathion	0.022
17	lemon	Spain	F	Fludioxonil	1.060				F	Pyrimethanil	0.842
			F	Imazalil	0.565				I	Pyridaben	0.009
29	lemon	Uruguay	F	Imazalil	0.634				I	Spirotetramat	0.022
			F	Pyrimethanil	0.670				F	Thiabendazole	0.052
31	lemon	Spain	F	Azoxystrobin	0.200	34	green grape-fruit	USA	H	Beflubutamid	0.017
			F	Fludioxonil	0.005				F	Imazalil	0.481
			F	Imazalil	0.007				**I**	**Imidacloprid**	**0.004**
			I	Malathion	0.011				F	Pyrimethanil	0.012
			F	Pyrimethanil	0.690				I	Pyriproxyfen	0.011
			I	Spirotetramat	0.005				F	Thiabendazole	0.166
			F	Thiabenda-zole	0.011	26	green grape-fruit	USA	*H*	*Beflubutamid*	*0.044*
38	orange	Spain	F	Imazalil	1.606				**I**	**Bromopropylate**	**0.012**
			F	Pyraclostrobin	0.012				**I**	**Chlorpyrifos methyl**	**0.008**
			F	Pyrimethanil	1.014				F	Imazalil	1.015
			I	Pyriproxyfen	0.012				**F**	**Oxadixyl**	**0.008**
			I	Spirotetramat	0.005				F	Thiabendazole	0.286
			I	Tau-fluval-inate	0.020	25	red grapefruit	South Africa	F	Azoxystrobin	0.004

24	orange	Spain	H	2.4-D	0.165
			F	Azoxystrobin	0.022
			F	Imazalil	0.001
			F	**Carbendazim**	**0.001**
			F	Thiabenda-zole	0.416
11	red orange	Italy	I	Acetamiprid	0.006
			I	**Chlorpyrifos methyl**	0.052
			F	Imazalil	0.385
			F	Pyrimethanil	0.353
			H	Beflubutamid	0.027
			F	Fludioxonil	0.011
			F	Imazalil	0.002
			I	Malathion	0.020
			F	Pyrimethanil	0.078
			I	Pyridaben	0.005
			I	Spirotetramat	0.010
37	red grapefruit	France	F	2-phenylphenol	1.220
			H	Beflubutamid	0.018
			I	Flonicamid	0.075
			F	Imazalil	0.938
			I	Malathion	0.044
			F	Pyrimethanil	0.341
			I	Spirotetramat	0.031
			I	Sulfoxaflor	0.004
			F	Tebuconazole	0.011
			F	Thiabendazole	0.334
			F	Trifloxystrobin	0.015

H: herbicide; F: fungicide; I: insecticide; the bold name of the compound indicates that it is withdrawn in the EU; the name of the compound in italics indicates that the MRL value is exceeded

Exotic fruits

The exotic fruits were represented by 4 avocado samples, of which three came from Mexico, Colombia, and South Africa, and one from the EU, i.e, Spain; pineapple from Costa Rica, 3 samples of bananas from Costa Rica, Ecuador, and Colombia; mango from Peru; melon from Costa Rica; and 2 samples of kiwifruit from the EU, i.e., Italy and Greece. Of the 13 samples tested, three (avocado; 23%) were free of contaminants. The presence of 1 compound was reported in a sample of avocados from Colombia and bananas from Ecuador, and three different compounds in kiwifruit and mango. Three banana samples from Colombia contained 5 to 6 pesticides, while melons from Costa Rica had 9 residues. The highest concentration of all compounds was determined in a sample of kiwifruit from Italy (2.451 mg/kg) and bananas from Colombia (1.358 mg/kg) (table 2).

Table 2. Detailed summary of detected pesticides in exotic fruit samples

No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)	No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)
4	avocado	Colombia	F	Thiabendazole	0.168	8	kiwi	Italy	F	Boscalid	0.001
27	avocado	Spain		bdl	bdl				I	Etofenprox	0.025
23	avocado	South Africa		bdl	bdl				F	Fludioxonil	2.426
32	avocado	Mexico		bdl	bdl	36	kiwi	Greece	F	Boscalid	0.559
16	pineapple	Costa Rica	**F**	**Epoksykonazol**	**0.001**				F	Fludioxonil	0.012
			F	Fludioxonil	0.288				F	Pyraclostrobin	0.018
6	banana	Colombia	F	Azoxystrobin	0.267	1	mango	Peru	F	Difenoconazole	0.001
			I	**Bifenthrin**	**0.009**				F	Fludioxonil	0.220
			F	Fenpropimorph	0.003				**H**	**Trifluralin**	**0.001**
			F	Myclobutanil	0.238	3	melon	Costa Rica	I	Acetamiprid	0.046
			F	Pyrimethanil	0.001				F	Azoxystrobin	0.015
			I	Pyriproxyfen	0.031				F	Difenoconazole	0.001
30	banana	Ecuador	**I**	**Bifenthrin**	**0.005**				F	Famoxadone	0.011
33	banana	Colombia	F	Azoxystrobin	0.173				F	Fludioxonil	0.013
			I	**Diafenthiuron**	**0.001**				F	Fluxapyroxad	0.007
			F	**Fenpropimorph**	**0.096**				F	Flutriafol	0.003
			I	Spirotetramat	0.029				F	Kresoxim methyl	0.001
			F	Thiabendazole	0.082				**F**	**Thiamethoxam**	**0.002**
			I	**Fenbutatin oxide**	**0.001**						
18	banana	Colombia	F	Azoxystrobin	0.650						
			I	**Bifenthrin**	**0.026**						
			F	**Myclobutanil**	**0.460**						
			I	Pyriproxyfen	0.220						
			F	Spiroxamine	0.002						

H: herbicide; F: Fungicide; I: Insecticide; bdl: below detection limit; the bold name of the compound indicates that it is withdrawn in the EU

Berries

In three blueberry samples, two contained residues of 8 pesticides (66.6% of samples). Blueberries from Morocco and Peru had 6 compounds each, with a total of 0.501 mg/kg and 0.313 mg/kg. Boscalid and fenhexamid were tested twice. Acetamiprid, clopyralid, cyantraniliprole, cyprodinil, difenoconazole, fludioxonil, kresoxim-methyl, and pyraclostrobin were assayed once, and no compound exceeded the safe MRLs (table 3).

Table 3. Detailed summary of detected pesticides in berry fruit samples

No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)	No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)
9	blueberry	Morocco	F	Boscalid	0.065	21	blueberry	Peru	I	Acetamiprid	0.022
			I	Cyantraniliprole	0.040				F	Boscalid	0.120
			F	Cyprodinil	0.022				H	Clopyralid	0.034
			F	Fenhexamid	0.270				F	Difenoconazole	0.017
			F	Fludioxonil	0.022				F	Fenhexamid	0.117
			F	Kresoxim methyl	0.082				F	Pyraclostrobin	0.007
22	blueberry	South Africa		bdl	bdl						

H: Herbicide; F: Fungicide; I: Insecticide; bdl: below detection limit

Stone Fruits

Ten stone fruit samples were tested, including 5 apple samples (Poland) and 5 pear samples (Belgium, Portugal, and Poland). All fruit had pesticide residues below the maximum permitted levels. The presence of 1 to 9 compounds, mainly fungicides, was detected. A sample of Rocha pear from Portugal had the highest number of 9 pesticides and the highest concentration of 2.563 mg/kg. Eight compounds were found in pear samples from Poland (0.576 mg/kg). Pear samples from Belgium contained 7 pesticides with a total concentration of 0.326 mg/kg. The highest number of pesticides (7) was determined in a sample of Polish green apples (total 0.367 mg/kg) (table 4).

Table 4. Detailed summary of detected pesticides in stone fruit samples

No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)	No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)
13	pear konferencja	Belgium	I	Acetamiprid	0.006	41	red apple	Poland	F	Boscalid	0.023
			F	Azoxystrobin	0.001				F	Fludioxonil	0.010
			F	Cyprodinil	0.185				F	Captan	0.257
			F	Difenoconazole	0.009				F	Pyraclostrobin	0.007
			F	Fludioxonil	0.067	42	green apple	Poland	I	Acetamiprid	0.018
			F	Fluxapyroxad	0.002				F	Boscalid	0.046
			F	Pyrimethanil	0.057				F	Cyprodinil	0.021
2	pear rocha	Portugal	F	Boscalid	0.002				I	Flonicamid	0.035
			I	**Fenoxycarb**	**0.019**				F	Fludioxonil	0.015
			F	Fludioxonil	0.676				F	Captan	0.221
			F	Fluxapyroxad	0.001				F	Pyraclostrobin	0.011
			F	Fluopyram	0.003	43	red apple	Poland	F	Cyprodinil	0.098
			F	Captan	0.170				F	Fludioxonil	0.005
			F	Pyrimethanil	1.680				F	Captan	0.833
			F	Tebuconazole	0.005	44	green apple	Poland	I	Acetamiprid	0.019
			F	Trifloxystrobin	0.006				F	Difenoconazole	0.009
3	pear	Portugal	**I**	**Triflumuron**	**0.003**				F	Fluopyram	0.005
39	pear	Poland	F	Cyprodinil	0.023				F	Captan	0.141
			F	Fludioxonil	0.036				F	Penthiopyrad	0.004
			F	Pyrimethanil	0.021	14	apple jonagold	Poland	I	Acetamiprid	0.003
40	pear	Poland	I	Acetamiprid	0.003				F	Boscalid	0.001
			F	Boscalid	0.023				F	Fludioxonil	0.001
			F	Cyprodinil	0.050				F	Fluxapyroxad	0.001
			I	Fenpyroximate	0.002				F	Fluopyram	0.049
			I	Flonicamid	0.138				F	Tebuconazole	0.022
			F	Fludioxonil	0.053						
			F	Pyraclostrobin	0.010						
			F	Pyrimethanil	0.298						

F: Fungicide; I: Insecticide; the bold name of the compound indicates that it is withdrawn in the EU

Strawberries

Wild strawberries tested included one sample of strawberries from Greece, which contained 5 compounds with a total amount of 0.290 mg/kg. These included four fungicides and one insecticide. All compounds were determined in the concentration range of 0.016– 0.135 mg/kg, one exceeded the MRL (table 5).

Table 5. Detailed summary of detected pesticides in strawberry fruit samples

No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)
10	strawberry	Greece	F	Bupirimate	0.135
			F	Ethirimol	0.016
			F	Fluxapyroxad	0.049
			F	Penconazole	0.034
			I	**Spiromesifen**	**0.056**

F: Fungicide; I: Insecticide; the bold name of the compound indicates that it is withdrawn in the EU

Vine Fruits

Six vine fruit samples were tested, including 2 from third countries: white grapes (India) and red (Peru), and four from the EU: green (Italy), purple (Portugal), and pink (Spain and Portugal). All samples (100%) contained pesticide residues. The highest concentrations were recorded for cyprodinil (1.360 mg/kg), fludioxonil (1.200 mg/kg), cyazofamid (1.042 mg/kg), and azoxystrobin (0.870 mg/kg). A total of 34 compounds were detected, mostly fungicides. All samples were defined as multi-residue because they contained 5, 7, 9, 9, 15, or 18 pesticide residues. The sum of the concentrations of pesticides detected in grape samples is as follows, from the highest: pink grapes (Spain)–6.425 mg/kg; pink grapes (Portugal)–2.098 mg/kg; purple grapes (Portugal) –1.700 mg/kg, white grapes (India)–0.153 mg/kg; green grapes (Italy)–1.080 mg/kg; and red grapes (Peru)–0.090 mg/kg (table 6).

Table 6. Detailed summary of detected pesticides in grape fruit samples

No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)	No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)
7	red grape	Peru	F	Boscalid	0.070	5	white grape	India	I	Cyantraniliprole	0.004
			F	Cyprodinil	0.001				F	Cyazofamid	0.021
			F	Fluopyram	0.008				F	Difenoconazole	0.005
			I	Spirotetramat	0.005				F	Dimethomorph	0.041
			F	Tebuconazole	0.003				F	Fluopyram	0.003
19	green grape	Italy	I	Emamectin benzoate	0.009				F	Mandipropamid	0.004
			F	Cymoxanil	0.003				I	Spirotetramat	0.076
			F	Dimethomorph	0.280	28	pink grape	Spain	I	Acetamiprid	0.209
			F	Fluxapyroxad	0.013				F	Boscalid	2.150
			F	Metalaxyl	0.110				I	Chlorantraniliprole	0.010
			F	Spiroxamine	0.122				F	Cyazofamid	1.042
			I	Spirotetramat	0.003				F	Cyprodinil	1.360
			I	Tau-fluvalinate	0.016				I	Deltamethrin	0.013
			F	Trifloxystrobin	0.530				I	Fenpyroximate	0.030
20	violet grape	Portugal	F	Ametoctradin	0.086				F	Fludioxonil	1.200
			F	Azoxystrobin	0.870				F	Fluxapyroxad	0.002
			I	Emamectin benzoate	0.001				F	Fluopyram	0.208
			F	Cymoxanil	0.019				F	Mandipropamid	0.001
			I	Deltamethrin	0.010				F	Metalaxyl	0.016
			F	Difenoconazole	0.240				I	Spinosad	0.175
			F	Dimethomorph	0.013				F	Spiroxamine	0.001
			F	Fluxapyroxad	0.006				F	Zoxamide	0.008
			F	Fluopicolide	0.005	35	pink grape	Portugal	F	Cyazofamid	0.510
			F	**Flutriafol**	**0.013**				F	Cymoxanil	0.003
			F	**Carbendazim**	**0.002**				F	Cyprodinil	0.485
			F	Metalaxyl	0.220				F	Fludioxonil	0.653
			F	Metrafenone	0.075				F	Fluxapyroxad	0.243
			F	Penconazole	0.026				F	Fluopyram	0.012

F	Pyrimethanil	0.011	I	Flupyradifurone	0.111
F	Proquinazid	0.087	F	Metrafenone	0.077
I	Spinosad	0.006	I	Spinosad	0.003
F	Zoxamide	0.010			

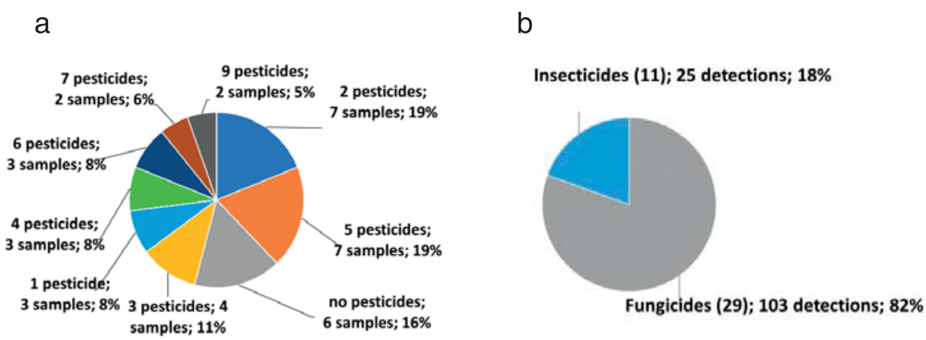
F: Fungicide; I: Insecticide; the bold name of the compound indicates that it is withdrawn in the EU

Vegetables

Of the total number of vegetable samples tested, no pesticide residues were found in 6, which constitutes 16% (fig. 5). Onion and potato samples from India, Spain, the Netherlands, and Poland did not contain any pesticides.

Pesticide residues below the maximum permissible limits were detected in most analyzed vegetables (81%). Unacceptable exceedances of the MRLs were recorded for one compound (flonicamid) in a sample of Chinese cabbage from Poland at a concentration of 0.102 mg/kg, which constitutes 3% of all tested vegetable samples. Boscalid was also present in this sample at a concentration of 0.001 mg/kg.

Fig. 5 (a) Share of pesticide-free, single-compound, and multi-residue vegetable samples; (b) Summary of detected pesticides (numbers in brackets indicate the number of detected compounds)



Of the 40 pesticides detected in vegetable samples, 7 (18%) are not approved for use in the EU. These compounds were present primarily in vegetables imported from the EU, originating from Italy, Cyprus, Spain, and Germany, but also in one potato sample from Poland. The withdrawn compounds include 4 fungicides and 3 insecticides. Among withdrawn fungicides, benthiavalicarb isopropyl was recorded in a tomato sample from Italy at a concentration of 0.095 mg/kg, flutriafol in a potato sample from Cyprus, prochloraz in a garlic sample from Spain, and dichloran in a sweet potato sample from the USA. Among the insecticides withdrawn in the EU, diafenthiuron and fenbutatin oxide were found in a tomato sample from Germany with a total concentration of 0.014 mg/kg, and imidacloprid in potatoes from Poland.

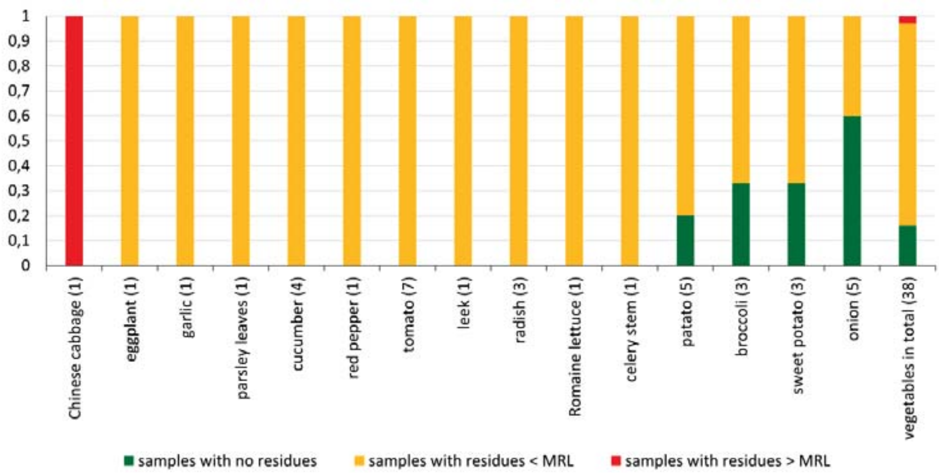
Of the 128 detected compounds, fungicides were the most common (82%), while insecticides accounted for 18%. In vegetable samples, single and multiple pesticides were detected in one sample. The largest number of pesticides detected was in a leek sample from Belgium, which contained 9 compounds with a total concentration of 0.188 mg/kg; these were ametoctradin, boscalid, propamocarb, dimethomorph, fludioxonil, fluopicolide, pyrimethanil, prothioconazole, and tebuconazole.

The most abundant vegetable samples (19%) contained 2 and 5 pesticides, 3 compounds were found in 11% of the samples, while 1, 4, and 6 pesticides were detected in 8% of the samples each, 7 residues were recorded in 6% of the samples, and 9 compounds were detected in 5% of vegetable samples.

Among the 11 insecticides, the most frequently detected were spirotetramat (4%; 0.002–0.044 mg/kg), flonicamid (3.2%; 0.020–0.127 mg/kg), and acetamiprid (2.4%; 0.034–0.109 mg/kg). Imidacloprid exceeded the MRL in 0.8% of vegetables. Among the 29 fungicides, the most frequently detected were boscalid (10.3%; 0.001–0.355 mg/kg), propamocarb (9.5%; 0.001–0.872 mg/kg), and fludioxonil (7.9%; 0.001–1.09 mg/kg). The concentrations of compounds detected in vegetables did not exceed the MRLs.

Detailed laboratory test results for individual vegetables are presented in fig. 6. The most pesticide residues were detected in leeks, tomatoes, and potatoes.

Fig. 6. Pesticides in vegetable samples (number of samples in brackets) and their concentrations with maximum permissible levels (MRLs)



In the 6 groups of vegetables tested (Solanaceae, Cucurbitaceae, Amaryllidaceae, Brassicaceae, Asteraceae, and Apiaceae), exceedance of the maximum permissible levels was recorded for flonicamid present in Brassicaceae (Chinese cabbage). In this group, 14% of the samples did not meet safety standards, and 86% contained pesticide residues. Among the vegetables tested, only the broccoli sample did not contain any pesticides. All Solanaceae, Cucurbitaceae, Amaryllidaceae, Asteraceae, and Apiaceae vegetables were contaminated with pesticides (100%).

Solanaceae

The Solanaceae were represented by 1 eggplant sample from Spain; 1 red pepper sample from Turkey; 7 tomato samples from Italy, Poland, Spain, Germany, the Netherlands; and Morocco; 5 potato samples from Poland and Cyprus, and 3 samples from the USA and Spain (table 7).

Of the 17 samples, two (potatoes from Poland and sweet potatoes from Spain) were free of contaminants, which constitutes 12% of all samples tested. The detected pesticides were primarily fungicides. The highest number of pesticides (9) was recorded in a sample of tomatoes from Poland, 7 in two samples of tomatoes from Morocco and Italy, and 6 in Polish tomatoes. Three pesticides were recorded in the eggplant sample, and one pesticide was detected in two potato samples from Poland. The highest concentration of all pesticides was determined in a 9-residue sample of tomatoes from Poland (1.034 mg/kg), as well as in a sample of sweet potatoes from the USA (1.091 mg/kg).

The most frequently detected pesticide was fludioxonil, found in 7 samples, which constitutes 41% of all samples. This compound was present in 2 potato samples from Poland and Cyprus, 2 sweet potato samples from the USA, 2 tomato samples from Poland and Morocco, and red peppers from Turkey.

All pesticides were below the MRLs, but benthiavalicarb isopropyl in cherry tomatoes from Italy, flutriafol in potatoes from Cyprus, and diafenthiuron and fenbutatin oxide in tomatoes from Germany and the Netherlands have been withdrawn in the EU. The withdrawn pesticides accounted for 17% of all detected.

Table 7. Detailed summary of detected pesticides in nightshade vegetable samples

No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)	No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)
4	plum tomato	Spain	F	Propamocarb	0.002	8	red pepper	Türkiye	I	Boscalid	0.001
			F	Cyazofamid	0.003				I	Flonicamid	0.106
6	cherry tomato	Italy	**F**	**Benthiavalicarb isopropyl**	**0.095**				F	Fludioxonil	0.003
			I	Emamectin	0.001				I	Pirydalil	0.092
			F	Boscalid	0.001	13	eggplant	Spain	I	Abamectin	0.006
			F	Difenoconazole	0.031				I	Acetamiprid	0.083
			F	Fluopyram	0.027				F	Metrafenone	0.004
			F	Penconazole	0.020	7	potato	Poland	F	Fludioxonil	0.004
			F	Tetraconazole	0.001	9	sweet potato	USA	F	Boscalid	0.001
22	raspberry tomato	Poland	F	Boscalid	0.229				F	Fludioxonil	1.090
			F	Cyprodinil	0.001	12	potato	Cyprus	F	Propamocarb	0.005
			F	Fludioxonil	0.001				F	Difenoconazole	0.001
			F	Fluopyram	0.065				F	Fludioxonil	0.001
			F	Pyraclostrobin	0.014				F	Fluopicolide	0.001
			F	Pyrimethanil	0.013				**F**	**Flutriafol**	**0.005**
26	tomato	Morocco	F	Cyprodinil	0.021	25	sweet potato	Spain		bdl	bdl
			I	Flonicamid	0.020	36	potato	Poland	F	Propamocarb	0.001

			F	Fludioxonil	0.022	37	potato	Poland		bdl	bdl
			F	Fluopyram	0.018		potato	Poland	F	Propamocarb	0.007
			F	Mandipropamid	0.001				F	Fluxapyroxad	0.010
			F	Tebuconazole	0.021				**I**	**Imidacloprid**	**0.006**
			F	Trifloxystrobin	0.031	39	sweet potato	USA	**F**	**Dicloran**	**0.010**
									F	Fludioxonil	0.330
30	tomato	Germany	**I**	**Diafenthiuron**	**0.003**	23	tomato	Poland	F	Azoxystrobin	0.082
			I	Sulfoxaflor	0.009				F	Propamocarb	0.405
			I	**Fenbutatin oxide**	**0.002**				I	Deltamethrin	0.003
34	tomato	Netherlands	F	Fluopyram	0.008				I	Flonicamid	0.037
			I	Pyridalyl	0.005				F	Captan	0.131
			I	Spinosad	0.036				F	Penthiopyrad	0.284
									F	Pyrimethanil	0.007
									I	Spirotetramat	0.004
									F	Tebuconazole	0.082

F: Fungicide; I: Insecticide; bdl: below detection limit; the bold name of the compound indicates that it is withdrawn in the EU

Cucurbitaceae

The Cucurbitaceae were represented by 4 samples of cucumbers from Poland and Turkey. Primarily fungicide residues were detected in 100% of the samples. In three samples of Polish cucumbers, 2, 3, and 4 pesticides were recorded, respectively, with a total concentration of 0.070 mg/kg, 0.054 mg/kg, and 0.019 mg/kg. In turn, in a sample of Turkish cucumbers, 6 were found, the total concentration of which was 0.186 mg/kg. Propamocarb was detected three times, cyprodinil and fluopyram were detected twice, and the remaining pesticides were detected once (table 8).

Table 8. Detailed summary of detected pesticides in cucurbit vegetable samples

No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)	No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)
3	cucumber	Poland	F	Boscalid	0.001	5	cucumber	Türkiye	I	Acetamiprid	0.034
			F	Cyprodinil	0.001				F	Propamocarb	0.016
			F	Fluopyram	0.003				I	Chlorpyrifos methyl	0.003

			F	Pyrimethanil	0.015				F	Cyjazolamid	0.005
27	cucumber	Poland	F	Azoxystrobin	0.006				F	Cyprodinil	0.001
			F	Propamocarb	0.043				I	Flonicamid	0.127
			F	Fluopicolide	0.005	24	cucumber	Poland	F	Propamocarb	0.003
									F	Fluopyram	0.067

F: Fungicide; I: Insecticide

Amaryllidaceae

The Amaryllidaceae were represented by one leek sample from Belgium, 5 onion samples from India, Poland, the Netherlands, France, and Spain, and a garlic sample from Spain (table 9). Of the 7 samples, no residues were recorded in the sample of garlic onion from India, organic white onion from the Netherlands, and pink onion from Spain, which constitutes 43% of all sampled vegetables. The detected pesticides were primarily fungicides. The largest number (9) was recorded in a leek sample from Belgium with a total concentration of 0.188 mg/kg. Then, in a sample of shallots from France, 6 pesticides with a total concentration of 0.098 mg/kg were recorded, 5 pesticides were found in a sample of garlic from Spain (0.463 mg/kg), and 2 in a sample of red onion from Poland (0.010 mg/kg). Boscalid was detected four times (0.002–0.355 mg/kg), while azoxystrobin, propamocarb, fluopicolide, pyraclostrobin, and tebuconazole were detected twice. No compound exceeded the MRL, but prochloraz (0.014 mg/kg) recorded in a garlic sample from Spain has been withdrawn in the EU.

Table 9. Detailed summary of detected pesticides in onion vegetable samples

No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)	No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)
15	leek	Belgium	F	Ametoctradin	0.137	19	garlic	Spain	F	Azoxystrobin	0.004
			F	Boscalid	0.002				F	Boscalid	0.355
			F	Propamocarb	0.007				F	Pyraclostrobin	0.086
			F	Dimethomorph	0.029				**F**	**Prochloraz**	**0.014**
			F	Fludioxonil	0.001				F	Tebuconazole	0.004
			F	Fluopicolide	0.007	18	white onion	Netherlands		bdl	bdl
			F	Pyrimethanil	0.001	28	shallot onion	France	F	Azoxystrobin	0.012
			F	Prothioconazole	0.004				F	Boscalid	0.048

			F	Tebuconazole	0.002				F	Propamocarb	0.009
17	red onion	Poland	F	Boscalid	0.004				F	Cyjazolamid	0.002
			I	Spirotetramat	0.006				F	Fluopicolide	0.013
35	pink onion	Spain		bdl	bdl				F	Pyraclostrobin	0.014

F: Fungicide; I: Insecticide; bdl: below detection limit; the bold name of the compound indicates that it is withdrawn in the EU

Brassicaceae

The tested Brassicaceae were 3 samples of broccoli from Spain and Italy, a sample of Chinese cabbage from Poland, and 3 samples of radish from Italy (table 10). Of the tested vegetables, only the broccoli sample from Spain had no pesticides, which represents 14% of all samples. Fungicides were detected most often. The highest number of pesticides (4) with a total concentration of 0.042 mg/kg was found in radishes from Italy, followed by 2 detected in two samples of broccoli with a total concentration of 0.045 mg/kg and 0.037 mg/kg, as well as in a sample of Chinese cabbage (0.103 mg/kg). Among the recorded residues, dimethomorph and fluopyram were detected twice, while spirotetramat, chlorpyrifos, fludioxonil, and flonicamid were found once. Flonicamid present in Chinese cabbage from Poland (0.102 mg/kg) exceeded the applicable MRL and may pose a potential health hazard. All detected pesticides were registered for use in the EU.

Table 10. Detailed summary of detected pesticides in cabbage vegetable samples

No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)	No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)
1	broccoli	Spain	F	Fluopyram	0.001	2	radish	Italy	I	Chlorpyrifos	0.008
			I	Spirotetramat	0.044				F	Dimethomorph	0.033
33	broccoli	Italy	F	Azoxystrobin	0.025				F	Fludioxonil	0.001
			F	Difenoconazole	0.012				F	Fluopyram	0.002
11	Chinese cabbage	Poland	F	Boscalid	0.001	29	radish	Italy	F	Dimethomorph	0.005
			I	*Flonicamid*	*0.102*	31	broccoli	Spain		bdl	bdl
						32	radish	Italy	F	Mandipropamid	0.020

F: Fungicide; I: Insecticide; bdl: below detection limit; the name of the compound in italics indicates that the MRL value is exceeded

Asteraceae

The only representative of the Asteraceae was a sample of romaine lettuce from Spain (table 11). The presence of 2 insecticides (acetamiprid and spirotetramat) and 2 fungicides (ametoctradin and fluopicolide) with a total concentration of 0.159 mg/kg was recorded. These compounds are registered in the EU and did not exceed MRLs.

Table 11. Detailed summary of detected pesticides in asteraceae vegetable samples.

No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)
14	Romaine lettuce mini	Spain	I	Acetamiprid	0.109
			F	Ametoctradin	0.012
			F	Fluopicolide	0.003
			I	Spirotetramat	0.036

F: Fungicide; I: Insecticide

Apiaceae

The Apiaceae included a sample of celery and parsley from Spain (table 12). In both samples, 5 compounds were detected, mainly fungicides, with a total concentration of 0.029 mg/kg in celery and 1.34 mg/kg in parsley. Azoxystrobin, boscalid, and difenoconazole were detected twice in the tested vegetables, and the remaining compounds (fluopicolide, spirotetramat, propamocarb hydrochloride, and fludioxonil) were found in one sample. The pesticides recorded are registered in the EU and did not exceed the MRLs.

Table 12. Detailed summary of detected pesticides in celery vegetable samples

No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)	No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)
10	celery stalk	Spain	F	Azoxystrobin	0.002	21	parsley leaves	Spain	F	Azoxystrobin	0.220
			F	Boscalid	0.001				F	Boscalid	0.001
			F	Difenoconazole	0.024				F	Propamocarb	0.872
			F	Fluopicolide	0.001				F	Difenoconazole	0.247
			I	Spirotetramat	0.002				F	Fludioxonil	0.001

F: Fungicide; I: Insecticide

Herbs

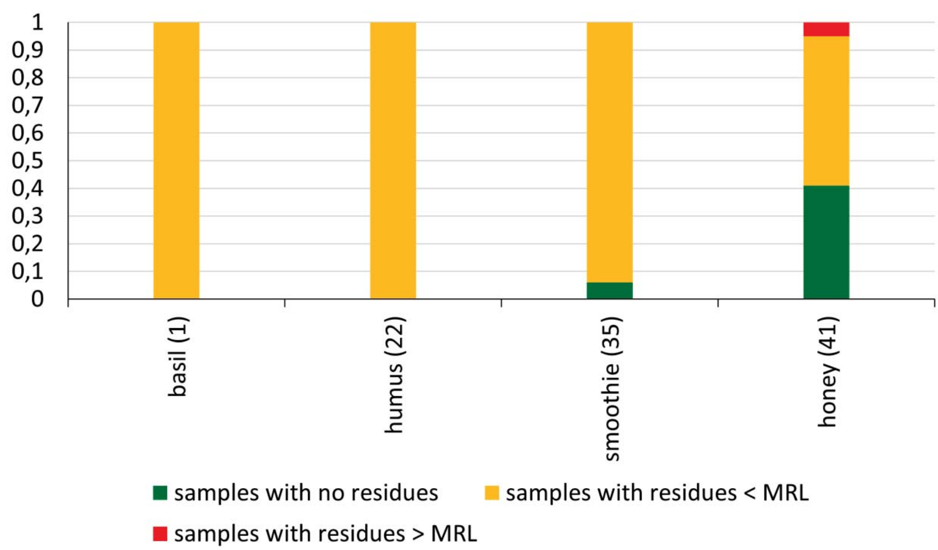
The only herb tested was basil from Poland (table 13), which contained 5 fungicides with a total concentration of 0.007 mg/kg: azoxystrobin, boscalid, propamocarb hydrochloride, fluopicolide, and pyrimethanil. The detected compounds are registered in the EU and did not exceed the established MRLs (fig. 7).

Table 13. Detailed summary of detected pesticides in herb samples

No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)
20	basil	Poland	F	Azoxystrobin	0.001
			F	Boscalid	0.001
			F	Propamocarb	0.003
			F	Fluopicolide	0.001
			F	Pyrimethanil	0.001

F: Fungicide

Fig. 7. Pesticides in samples of herbs (basil), humus, smoothies, and honey (number of samples in brackets) and their concentrations with the maximum permissible levels (MRLs)



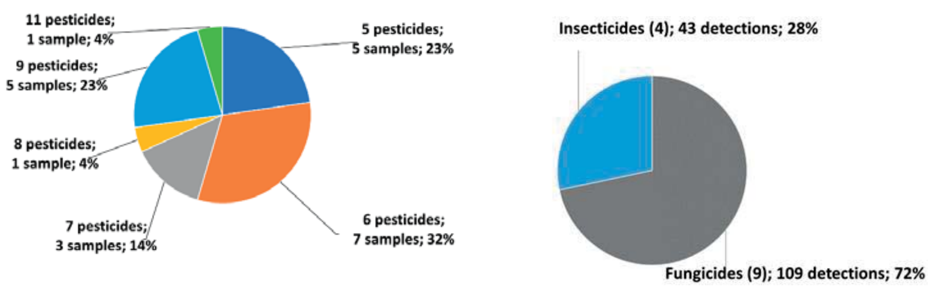
Hummus

All humus samples contained pesticides (100%) and prohibited substances (100%). Moreover, the tested humus samples had multiple residues – the smallest number of pesticides detected was 5 (5 samples, 23%), 6 were present in seven samples (32%), 7 pesticides were found in three samples (14%), 8 in one sample (4%), 9 in five samples (23%), and 11 in one sample (4%) (fig. 8).

In total, 13 compounds were found, including four insecticides which accounted for 28% of detections: spirotetramat was detected 19 times, acetamiprid – 12, imidacloprid – 10, and thiamethoxam – 1, nine fungicides which accounted for 72% of detections were ametoctradin (22), carbendazim (21), mandipropamid (21), fluxapyroxad (18), propamocarb (9), fluopyram (7), thiophanate-methyl (7), boscalid (3), and thiabendazole (1).

Fig. 8. (a) Share of multi-residue samples in humus;
(b) Summary of detected pesticides (numbers in brackets indicate the number of detected compounds)

a b



The total concentrations of individual pesticides, despite their significant abundance, were within very low limits: from 0.002 mg/kg to 0.352 mg/kg. The largest number of samples had a total pesticide concentration in the range of 0.2–0.4 mg/kg (6 samples), five samples had a pesticide content of 0.2–0.3 mg/kg (5 samples), three samples of 0.1–0.2 mg/kg and two samples 0.35 and 0.6 mg/kg (table 14).

However, the presence of residues of pesticides banned in the EU is worrisome. In total, 39 such compounds were found, including neonicotinoid insecticide and benzimidazole fungicide imidacloprid/carbendazim (9 samples).

Table 14. Detailed summary of detected pesticides in humus samples

No	Assortment	Country of origin		Pesticide	Concentration (mg/kg)
1	chickpea + sesame	Poland	I	Acetamiprid	0.004
			F	Ametoctradin	0.002
			F	Propamocarb	0.003
			F	Fluxapyroxad	0.002
			I	**Imidacloprid**	**0.003**
			F	Mandipropamid	0.001
			I	Spirotetramat	0.084
			F	**Thiophanate methyl**	**0.002**
2	chickpea	Poland	I	Acetamiprid	0.003
			F	Ametoctradin	0.002
			F	Propamocarb	0.003
			F	Fluxapyroxad	0.002
			I	**Imidacloprid**	**0.002**
			F	**Carbendazim**	**0.001**
			F	Mandipropamid	0.001
			I	Spirotetramat	0.054
			F	**Thiophanate methyl**	**0.002**
3	chickpea +sesame pepper+ curry	Poland	I	Acetamiprid	0.002
			F	Ametoctradin	0.001
			F	Propamocarb	0.002
			F	Fluxapyroxad	0.002
			F	**Carbendazim**	**0.001**
			F	Mandipropamid	0.001
			I	Spirotetramat	0.219
4	avocado	Spain	F	Ametoctradin	0.001
			F	**Carbendazim**	**0.001**
			F	Mandipropamid	0.001
11	tomato+ garlic	Serbia	I	Acetamiprid	0.001
			F	Ametoctradin	0.001
			F	Boscalid	0.005
			F	Fluxapyroxad	0.002
			I	**Imidacloprid**	**0.001**
			F	**Carbendazim**	**0.002**
			F	Mandipropamid	0.001
			I	Spirotetramat	0.047
			I	**Thiamethoxam**	**0.002**
12	grilled egg-plant	Netherlands	I	Acetamiprid	0.002
			F	Ametoctradin	0.001
			F	Fluxapyroxad	0.002
			F	Fluopyram	0.002
			F	**Carbendazim**	**0.001**
			F	Mandipropamid	0.001
13	oriental	Netherlands	F	Ametoctradin	0.001
			F	Fluxapyroxad	0.001
			F	Fluopyram	0.001
			F	**Carbendazim**	**0.001**
			F	Mandipropamid	0.001
			I	Spirotetramat	0.351
14	oriental	Netherlands	F	Ametoctradin	0.001
			F	Fluxapyroxad	0.002
			F	Fluopyram	0.001
			F	**Carbendazim**	**0.001**
			F	Mandipropamid	0.001
			I	Spirotetramat	0.048

			I	Spirotetramat	0.048
			F	Thiabendazole	0.010
5	pepper	Poland	I	Acetamiprid	0.003
			F	Ametoctradin	0.001
			F	Boscalid	0.010
			F	Propamocarb	0.002
			F	Fluxapyroxad	0.002
			F	Fluopyram	0.001
			I	**Imidacloprid**	**0.002**
			F	**Carbendazim**	**0.001**
			F	Mandipropamid	0.001
			I	Spirotetramat	0.037
			F	**Thiophanate methyl**	**0.002**
6	tomato	Poland	I	Acetamiprid	0.003
			F	Ametoctradin	0.002
			F	Propamocarb	0.002
			F	Fluxapyroxad	0.002
			I	**Imidacloprid**	**0.002**
			F	**Carbendazim**	**0.001**
			F	Mandipropamid	0.001
			I	Spirotetramat	0.157
			F	**Thiophanate methyl**	**0.002**
7	bio classic	Poland	F	Ametoctradin	0.001
			I	**Imidacloprid**	**0.005**
			F	**Carbendazim**	**0.001**
			F	Mandipropamid	0.001
			I	Spirotetramat	0.047
8	with black cumin	Poland	I	Acetamiprid	0.004
			F	Ametoctradin	0.001
			F	Propamocarb	0.003
			F	Fluxapyroxad	0.002
15	with olive oil	Netherlands	F	Ametoctradin	0.001
			F	Fluxapyroxad	0.002
			F	Fluopyram	0.001
			F	**Carbendazim**	**0.001**
			F	Mandipropamid	0.001
			I	Spirotetramat	0.064
16	pumpkin	Netherlands	F	Ametoctradin	0.001
			F	Fluxapyroxad	0.002
			F	Fluopyram	0.001
			F	**Carbendazim**	**0.001**
			F	Mandipropamid	0.001
			I	Spirotetramat	0.002
17	dried omato+basil	Netherlands	F	Ametoctradin	0.002
			F	Propamocarb	0.007
			F	Fluxapyroxad	0.002
			F	Fluopyram	0.001
			F	**Carbendazim**	**0.001**
			F	Mandipropamid	0.002
			I	Spirotetramat	0.056
18	classic	Poland	I	Acetamiprid	0.004
			F	Ametoctradin	0.002
			F	Propamocarb	0.003
			I	**Imidacloprid**	**0.003**
			F	**Carbendazim**	**0.001**
			F	Mandipropamid	0.001
			F	**Thiophanate methyl**	**0.002**
19	with dates	Poland	F	Ametoctradin	0.001
			F	Fluxapyroxad	0.002
			F	**Carbendazim**	**0.001**
			F	Mandipropamid	0.001
			I	Spirotetramat	0.095

			I	**Imidacloprid**	**0.002**
			F	**Carbendazim**	**0.002**
			F	Mandipropamid	0.001
			I	Spirotetramat	0.181
			F	**Thiophanate methyl**	**0.002**
9	tomato	Poland	I	Acetamiprid	0.003
			F	Ametoctradin	0.001
			F	Propamocarb	0.002
			F	Fluxapyroxad	0.002
			I	**Imidacloprid**	**0.002**
			F	**Carbendazim**	**0.002**
			F	Mandipropamid	0.001
			I	Spirotetramat	0.090
			F	**Thiophanate methyl**	**0.002**
10	humus spicy	Serbia	F	Ametoctradin	0.001
			F	Boscalid	0.022
			I	**Imidacloprid**	**0.007**
			F	**Carbendazim**	**0.001**
			F	Mandipropamid	0.001
			I	Spirotetramat	0.108
20	tofu+pepper	Poland	F	Ametoctradin	0.001
			F	Fluxapyroxad	0.002
			F	**Carbendazim**	**0.001**
			F	Mandipropamid	0.001
			I	Spirotetramat	0.270
21	classic	Poland	I	Acetamiprid	0.001
			F	Ametoctradin	0.001
			F	Fluxapyroxad	0.002
			F	**Carbendazim**	**0.001**
			F	Mandipropamid	0.001
			I	Spirotetramat	0.215
22	pumpkin+ginger	Poland	I	Acetamiprid	0.001
			F	Ametoctradin	0.001
			F	Fluxapyroxad	0.002
			F	**Carbendazim**	**0.001**
			I	Spirotetramat	0.202

F: Fungicide; I: Insecticide; bdl: below detection limit; the bold name of the compound indicates that it is withdrawn in the EU

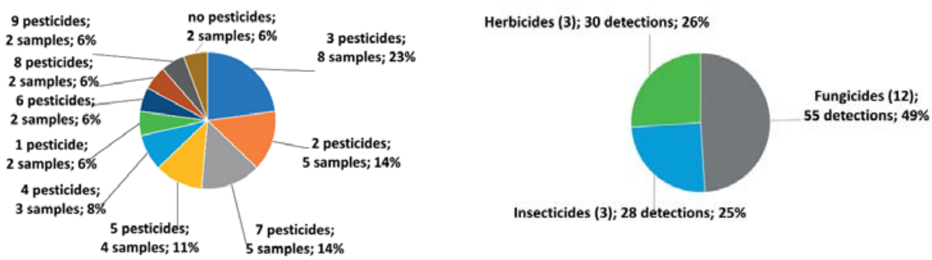
Smoothies

Of the 35 smoothie samples tested, 94% (33) contained pesticides. Due to the complex composition of smoothies, there are no maximum permissible levels of pesticides for this group of products.

Of the 18 pesticides found in smoothies, 4 (22%) are banned in the EU. These compounds were present in 3 samples from Germany, 4 from Spain, and 6 from Poland. The withdrawn compounds include 2 herbicides, 1 fungicide, and 1 insecticide. Among the withdrawn herbicides, haloxyfop was found in the highest concentration (0.033 mg/kg) in the coconut–pineapple–banana–orange smoothie sample from Spain, and fluazifop was found in the highest concentration (0.033 mg/kg) in the banana–apple–strawberry smoothie sample from Poland. Among the withdrawn fungicides, carbendazim was detected in 2 smoothie samples from Poland (banana–apple–strawberry and blackcurrant–cranberry–blackberry–apple–wild rose). The only banned insecticide was imidacloprid, recorded in 2 smoothie samples from Poland (banana–apple and blackcurrant–cranberry–blackberry–apple–rose hip).

Fig. 9. (a) Share of pesticide-free, single-pesticide, and multi-residue smoothie samples; (b) Summary of detected pesticide groups (numbers in brackets indicate the number of detected compounds)

a b



Of the 113 pesticides, fungicides were the most common (49%), herbicides accounted for 26%, and insecticides accounted for 25% of detections (fig. 9). In smoothie samples containing pesticides, at least 2 compounds were usually recorded, and only 1 sample had a single pesticide. The largest number of pesticides was found in the smoothie sample from Spain (blackberry–apple–raspberry–blackcurrant), which contained 9 compounds with a total concentration of 0.039 mg/kg, and the smoothie from Poland (banana–apple–strawberry) with 9 pesticides with a total content of 0.151 mg/kg. However, the highest total concentration (0.215 mg/kg) was found in a six-residue smoothie sample from Poland (black currant–cranberry–blackberry–apple–rose hip), including pesticides such as acetamiprid, imidacloprid, captan, carbendazim, pyrimethanil, and thiabendazole (table 15).

Most smoothie samples (23%) contained 3 pesticides; 2 and 7 were found in 14% of the samples; 5 residues were recorded in 11% of the samples, while 1, 6, 8, and 9 pesticides were found in 6% of the tested samples.

Among the three insecticides, acetamiprid was the most frequently detected (20.4%; 0.001–0.01 mg/kg). Among the three herbicides, 2,4-D was the most frequently detected (14.2%; 0.001–0.007 mg/kg), and fluopyram was the most common among the 12 fungicides found (14.2%; 0.001–0.005 mg/kg).

Table 15. Detailed summary of detected pesticides in smoothie samples

No	Assortment		Pesticide	Concentration (mg/kg)	No	Assortment		Pesticide	Concentration (mg/kg)	No	Assortment		Pesticide	Concentration (mg/kg)
1	coconut – pineapple-banana-orange	H	2.4-D	0.002	14	apple-orange-strawberry	H	2.4-D	0.007	10	pineapple-banana-coconut	H	2.4-D	0.001
		I	Acetamiprid	0.001			I	Acetamiprid	0.001			**H**	**Haloxyfop**	**0.001**
		H	**Haloxyfop**	**0.033**			F	Fluopyram	0.002			I	Spirotetramat	0.002
		I	Spirotetramat	0.005			**H**	**Haloxyfop**	**0.009**	11	pomegranate-acai berries	H	2.4-D	0.001
2	blackberry-apple-raspberry-blackcurrant	H	2.4-D	0.002			F	Imazalil	0.012			I	Acetamiprid	0.002
		I	Acetamiprid	0.001			F	Captan	0.056			I	Bifenazate	0.009
		I	Bifenazate	0.011			F	Thiabendazole	0.007			F	Fluxapyroxad	0.001
		F	Fenhexamid	0.002	15	pineapple-melon-mango	H	2.4-D	0.005			F	Fluopyram	0.001
		H	**Fluazifop**	**0.002**			F	Fluopyram	0.001			**H**	**Haloxyfop**	**0.001**
		F	Fluxapyroxad	0.001			**H**	**Haloxyfop**	**0.004**			F	Imazalil	0.001
		F	Fluopyram	0.002	16	banana-apple	H	2.4-D	0.003			I	Spirotetramat	0.001
		H	**Haloxyfop**	**0.016**			I	Acetamiprid	0.003	12	apple-banana-mango	I	Acetamiprid	0.001
		I	Spinosad	0.003			**I**	**Imidacloprid**	**0.001**			F	Fluopyram	0.001
3	mango-apple-banana-marakuja	H	2.4-D	0.003			F	Captan	0.127			F	Imazalil	0.002
		I	Acetamiprid	0.004			I	Spirotetramat	0.002			F	Captan	0.082
		F	Fluxapyroxad	0.001	17	banana-apple-strawberry	H	2.4-D	0.005			F	Thiabendazole	0.001
		F	Fluopyram	0.001			I	Acetamiprid	0.002	13	orange – mango – passion fruit	H	2.4-D	0.003
		H	**Haloxyfop**	**0.001**			**H**	**Fluazifop**	**0.033**			F	Imazalil	0.017

		F	Imazalil	0.001			F	Fluopyram	0.005			F	Thiabendazole	0.004
		I	Spirotetramat	0.006			**H**	**Haloxyfop**	**0.001**	28	strawberry – banana – maqui berries	I	Acetamiprid	0.008
4	asparagus-apple-banana-lime	I	Acetamiprid	0.007			F	Isofetamid	0.003			F	Captan	0.059
		F	Fluxapyroxad	0.001			F	Captan	0.096			F	Pyrimethanil	0.021
		F	Fluopyram	0.002			**F**	**Carbendazim**	**0.001**			I	Spirotetramat	0.003
5	carrot-pineapple-peach-orange	H	2.4-D	0.001			I	Spirotetramat	0.005	29	baobab – orange – mango	I	Acetamiprid	0.001
		F	Boscalid	0.008	18	baobab	H	2.4-D	0.001			F	Captan	0.05
		F	Fludioxonil	0.019			I	Acetamiprid	0.006			F	Pyrimethanil	0.019
		F	Fluxapyroxad	0.001			F	Captan	0.063			I	Spirotetramat	0.048
		F	Fluopyram	0.002			F	Methfuroxam	0.001	30	pineapple – acerola – turmeric	I	Acetamiprid	0.002
		F	Imazalil	0.001			F	Pyrimethanil	0.026			F	Captan	0.101
		I	Spinosad	0.002	19	sea buckthorn	H	2.4-D	0.002	31	chokeberry – blackcurrant – ashwagandha	I	Acetamiprid	0.001
6	ginger-apple-banana-coconut	H	2.4-D	0.002			I	Acetamiprid	0.002			F	Captan	0.049
		I	Acetamiprid	0.005			F	Captan	0.073	32	pineapple – kiwi-spinach	F	Propamocarb	0.001
		H	**Fluazifop**	**0.002**			F	Pyrimethanil	0.012			F	Fludioxonil	0.048
		F	Fluxapyroxad	0.001			I	Spirotetramat	0.002	33	pear-banana-kiwi		bdl	-
		F	Fluopyram	0.001	20	moringa	I	Acetamiprid	0.010	34	banana-apple-pineapple-orange	F	Captan	0.029

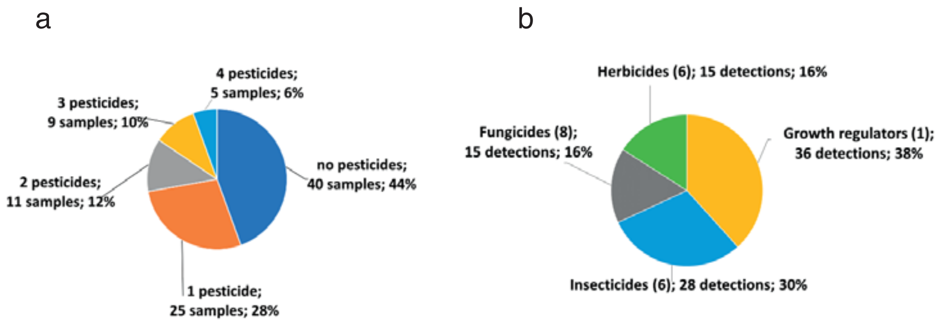
		H	**Haloxyfop**	**0.016**			F	Captan	0.127	35	banana-mango-orange		bdl	-
		I	Spirotetramat	0.002			F	Pyrimethanil	0.013	9	strawberry-banana	H	2.4-D	0.001
7	blackcurrant-cherry-strawberry-banana-grape-apple	I	Acetamiprid	0.002	21	flax-mango-pumpkin-apple-ginger – banana-pineapple-	F	Captan	0.030			I	Acetamiprid	0.001
		F	Fenhexamid	0.002			F	Pyrimethanil	0.023			I	Bifenazate	0.016
		F	Fluxapyroxad	0.001	22	blackcurrant-cranberry-blackberry-apple-briar	I	Acetamiprid	0.005			**H**	**Fluazifop**	**0.003**
		F	Fluopyram	0.001			**I**	**Imidacloprid**	**0.001**			F	Fluxapyroxad	0.001
		F	Captan	0.060			F	Captan	0.180			F	Fluopyram	0.002
		I	Spirotetramat	0.002			**F**	**Carbendazim**	**0.003**			F	Isofetamid	0.001
8	acerola-mango-orange-banana-apple	H	2.4-D	0.003			F	Pyrimethanil	0.027			I	Spirotetramat	0.001
		I	Acetamiprid	0.002			F	Thiabendazole	0.001	25	strawberry – orange – banana	F	Fluopyram	0.001
		F	Fluxapyroxad	0.001	23	orange-banana-peach	F	Fluopyram	0.001			F	Captan	0.029
		F	Fluopyram	0.001			F	Captan	0.062	26	orange – mango – passion fruit	F	Captan	0.045
		H	**Haloxyfop**	**0.029**			F	Thiabendazole	0.001	27	passion fruit – mango – chia seeds	I	Acetamiprid	0.006
		F	Captan	0.06	24	apple-spinach-kale-aloe	I	Acetamiprid	0.001			F	Captan	0.045
		I	Spirotetramat	0.001			F	Fluopyram	0.001			F	Pyrimethanil	0.044

H: Herbicide; F: Fungicide; I: Insecticide; bdl: below detection limit; the bold name of the compound indicates that it is withdrawn in the EU

Groats and Cereal Products

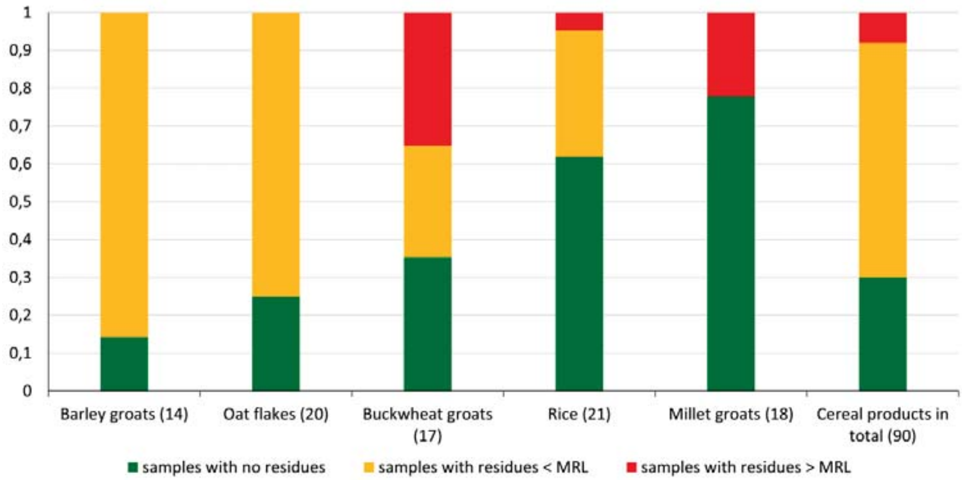
Pesticide residues below MRLs were detected in 43% of samples (39); 44% of samples (40) were free from contaminants, while 13% (11) contained compounds inconsistent with safety standards. Twenty-one pesticides were detected in groats, including 13 approved for use in the EU (62%) and 8 (38%) banned in the EU. Of the 90 groats samples, most had one residue (25 samples; 28%), two (11; 12%), three (9; 10%), and four (5; 6%) (fig. 10). The highest number of detections were recorded for growth regulators, i.e., chlormequat (36 samples; 38%), and insecticides (28; 30%). Fungicides (15; 16%) and herbicides (15; 16%) had an analogous level of detection.

Fig. 10. (a) Share of samples free from pesticides, containing single pesticide and multi-residues in groats and cereal products; (b) Summary of detected pesticides and growth regulators (numbers in brackets indicate the number of detected compounds)



The largest number of groat samples did not contain any contaminants (78%). There were no samples with residues below the MRLs, while 22% of the samples contained pesticides above the MRLs. The second product with a high percentage of samples without residues was rice (62%), while 33% of the samples contained residues below the MRLs and 5% above the MRLs (fig. 11). The pesticide residues in individual species are as follows: barley groats (12/14; 85% with residues), oatmeal (13/20; 65%), buckwheat groats (13/17; 76%), rice (8/21; 38%), and millet (4/18; 22%).

Fig. 11. Pesticides in samples of groats and cereal products (number of samples in brackets) and their concentrations with the maximum permissible levels (MRLs)



Buckwheat Groats

In the case of buckwheat (14 samples from Poland, 1 from Kazakhstan, and 2 from Lithuania), 35% of samples had no residues (6 samples), 29% with residues ≤ MRL, and the highest percentage with residues ≥ MRL, i.e., 35%. The exceedances (2, 3, and 4 times) were found for chlormequat, for which strict MRLs were set at 0.01 mg/kg. The presence of banned compounds was also recorded–chlorpyrifos and imidacloprid; fluazifop and haloxyfop were detected in buckwheat produced in Poland, while haloxyfop was also found in buckwheat from Lithuania (table 16). Chlormequat, a growth regulator, was detected most frequently (7 samples) in the concentration range from 0.01 to 0.04 mg/kg. Additionally, herbicides such as haloxyfop (3 samples; 0.001–0.006 mg/kg), MCPA (2; 0.002–0.034 mg/kg), clomazone (1; 0.001 mg/kg), glyphosate (1; 0.04 mg /kg), fluazifop (1; 0.007 mg/kg), mecoprop (1; 0.036 mg/kg), and insecticides: pirimiphos-methyl (2; 0.001–0.022 mg/kg), chlorpyrifos (1; 0.002 mg/kg), and imidacloprid (1; 0.017 mg/kg) were found.

Table 16. Detailed summary of detected pesticides in buckwheat groats samples

No	Country of origin		Pesticide	Concentration (mg/kg)	No	Country of origin		Pesticide	Concentration (mg/kg)
1	Poland	**H**	**Fluazifop**	**0.007**	7	Poland	GR	Chlormequat	*0.030*
		H	MCPA	0.034	8	Poland	GR	Chlormequat	*0.040*
		H	Mecoprop-P	0.036	9	Poland	GR	Chlormequat	*0.040*
		I	Pirimiphos methyl	0.001	10	Kazakhstan		bdl	bdl
2	Poland		bdl	bdl	11	Poland	GR	Chlormequat	*0.030*
3	Poland	H	Clomazone	0.001	12	**Lithuania**	**H**	**Haloxyfop**	**0.001**
		I	**Chlorpyrifos**	**0.002**	13	Poland		bdl	bdl
		H	MCPA	0.002	14	Lithuania	GR	Chlormequat	0.010
		I	Pirimiphos methyl	0.002	15	Poland		bdl	bdl
4	Poland	GR	Chlormequat	*0.030*	16	**Poland**	**H**	**Haloxyfop**	**0.002**
5	Poland		bdl	bdl			**I**	**Imidacloprid**	**0.017**
6	**Poland**	**H**	**Haloxyfop**	**0.006**	17	Poland		bdl	bdl
		GR	Chlormequat	*0.020*					
		H	Glyphosate	0.040					

H: Herbicide; I: Insecticide; GR: Growth regulator; bdl: below detection limit; the bold name of the compound indicates that it is withdrawn in the EU; the name of the compound in italics indicates that the MRL value is exceeded

Barley Groats

Barley groats (14 samples) from Poland had a high percentage of pesticides within the permissible limits, with residues ≤ MRL (86%). Samples without residues constituted 14% of all barley groats. There were no samples found to be inconsistent with safety standards. However, one sample contained a compound not approved for use in the EU, i.e., chlorpyrifos. The samples included fungicides: bixafen (4 samples; 0.001–0.003 mg/kg), cyprodinil (2; 0.005–0.009 mg/kg), fluxapyroxad (1; 0.006 mg/kg), fluopyram (1; 0.002 mg/kg), and spiroxamine (1; 0.005 mg/kg); insecticides: chlorpyrifos (1; 0.003 mg/kg) and pirimiphos-methyl (4; 0.006–0.024 mg/kg); the growth regulator chlormequat (10; 0.01–0.9 mg /kg), and the herbicide glyphosate (4; 0.002–0.016 mg/kg) (table 17).

Table 17. Detailed summary of detected pesticides in barley groats samples

No	Country of origin		Pesticide	Concentration (mg/kg)	No	Country of origin		Pesticide	Concentration (mg/kg)
36	Poland	**I**	**Chlorpyrifos**	**0.003**	43	Poland	GR	Chlormequat	0.030
	Poland	I	Pirimiphos methyl	0.024			I	Cyprodinil	0.009
	Poland	H	Glyphosate	0.005			I	Fluxapyroxad	0.006
37	Poland	GR	Chlormequat	0.010	44	Poland	GR	Chlormequat	0.010
38	Poland		bdl	bdl			I	Cyprodinil	0.005
39	Poland	GR	Chlormequat	0.030	45	Poland	GR	Chlormequat	0.050
		I	Pirimiphos methyl	0.009			I	Bixafen	0.001
40	Poland	GR	Chlormequat	0.060			I	Pirimiphos methyl	0.006
		I	Bixafen	0.003	46	Poland	GR	Chlormequat	0.040
		I	Pirimiphos methyl	0.006			I	Bixafen	0.002
		H	Glyphosate	0.016			I	Fluopyram	0.002
41	Poland	GR	Chlormequat	0.070	47	Poland	I	Bixafen	0.003
42	Poland		bdl	bdl			I	Spiroxamine	0.005
48	Poland	GR	Chlormequat	0.900			H	Glyphosate	0.002
					49	Poland	GR	Chlormequat	0.020
							H	Glyphosate	0.014

H: Herbicide; I: Insecticide; GR: Growth regulator; bdl: below detection limit; the bold name of the compound indicates that it is withdrawn in the EU

Oat Flakes

For the oat flake samples (18 from Poland, one from Germany, and one from Latvia), those with residues ≤ MRL (75%) and without residues (25%) were found. No non-compliant samples were recorded. In four Polish samples, a withdrawn insecticide, diafenthiuron, was detected in the concentration range of 0.001–0.005 mg/kg. Additionally, the growth regulator chlormequat (12 samples; 0.01–7.89 mg/kg) and pirimiphos-methyl (5; 0.01–0.029 mg/kg) were detected (table 18).

Table 18. Detailed summary of detected pesticides in oat flakes samples

No	Country of origin		Pesticide	Concentration (mg/kg)	No	Country of origin		Pesticide	Concentration (mg/kg)
50	Poland	GR	Chlormequat	7.890	61	Latvia		bdl	bdl
51	Poland	GR	Chlormequat	0.470	62	Poland		bdl	bdl
52	Poland	GR	Chlormequat	0.350	63	Poland	GR	Chlormequat	0.110
53	Poland	GR	Chlormequat	0.580			I	Pirimiphos methyl	0.019
		I	Pirimiphos methyl	0.010	64	Ukraine		bdl	bdl
54	Poland		bdl	bdl	65	Poland		bdl	bdl
55	Poland	GR	Chlormequat	0.010	66	Poland	GR	Chlormequat	0.010
56	Poland	GR	Chlormequat	0.020			**I**	**Diafenthiuron**	**0.005**
57	Poland	GR	Chlormequat	0.640	67	Poland	**I**	**Diafenthiuron**	**0.003**
58	Poland	GR	Chlormequat	1.870	68	Poland	**I**	**Diafenthiuron**	**0.002**
59	Poland	GR	Chlormequat	1.150	69	Poland	GR	Chlormequat	0.570
		I	Pirimiphos methyl	0.029			**I**	**Diafenthiuron**	**0.001**
60	Poland	I	Pirimiphos methyl	0.020			I	Pirimiphos methyl	0.025

I: Insecticide; GR: Growth regulator; bdl: below detection limit; the bold name of the compound indicates that it is withdrawn in the EU

Millet Groats

Millet samples came from Poland (14) and Ukraine (4). Four samples included insecticides such as pirimiphos-methyl (1 sample; 0.012 mg/kg) and chlorpyrifos (1; 0.017 mg/kg), the herbicide glyphosate (2; 0.014–0.021 mg/kg), and the growth regulator chlormequat (4; 0.02–0.04 mg/kg) (table 19).

Table 19. Detailed summary of detected pesticides in millet groats samples

No	Country of origin	Pesticide	Concentration (mg/kg)	No	Country of origin		Pesticide	Concentration (mg/kg)
18	Ukraine	bdl	bdl	28	Ukraine		bdl	bdl
19	Poland	bdl	bdl	29	Ukraine		bdl	bdl
20	Poland	bdl	bdl	30	Ukraine		bdl	bdl
21	Poland	bdl	bdl	31	Poland	*GR*	*Chlormequat*	*0.020*
22	Poland	bdl	bdl	32	Poland	*GR*	*Chlormequat*	*0.040*

23	Poland		bdl	bdl			H	Glyphosate	0.014
24	Poland		bdl	bdl	33	Poland	*GR*	*Chlormequat*	*0.020*
25	Poland	*GR*	*Chlormequat*	*0.030*			**I**	**Chlorpyrifos**	**0.017**
		H	Glyphosate	0.021			I	Pirimiphos methyl	0.012
26	Poland		bdl	bdl	34	Poland		bdl	bdl
27	Poland		bdl	bdl	35	Poland		bdl	bdl

H: Herbicide; I: Insecticide; GR: Growth regulator; bdl: below detection limit; the bold name of the compound indicates that it is withdrawn in the EU; the name of the compound in italics indicates that the MRL value is exceeded

Rice

The 21 rice samples came from ten countries: Myanmar, Pakistan, Vietnam, Italy, Pakistan, Argentina, Cambodia, Thailand, Guyana, and India. The rice samples included the following insecticides: acetamiprid (3 samples; 0.001–0.003 mg/kg), clothianidin (3; 0.001–0.003 mg/kg), chlorpyrifos (1; 0.008 mg/kg), imidacloprid (1; 0.007 mg/kg); fungicides: tebuconazole (4; 0.003–0.008 mg/kg), tricyclazole (1; 0.003 mg/kg), and isoprothiolate (1; 0.010 mg/kg), and the growth regulator chlormequat (3; 0.01–0.12 mg/kg). Compounds prohibited for use in the EU were detected seven times: Clothianidin was detected in samples from Pakistan, isoprothiolate and clothianidin in rice from Vietnam, chlorpyrifos and clothianidin from Pakistan, tricyclazole from Myanmar, and imidacloprid in rice from Guyana (table 20).

The maximum levels for chlormequat in Vietnamese rice have been exceeded.

Table 20. Detailed summary of detected pesticides in rice samples

No	Country of origin		Pesticide	Concentration (mg/kg)	No	Country of origin		Pesticide	Concentration (mg/kg)
70	Mjanmar		bdl	bdl	79	Pakistan	I	Tebuconazole	0.007
71	Pakistan	**I**	**Clothianidin**	**0.001**	80	Pakistan		bdl	bdl
72	Vietnam	*GR*	*Chlormequat*	*0.120*	81	Cambodia		bdl	bdl
		I	**Isoprothiolane**	**0.010**	82	Italy		bdl	bdl
		I	**Clothianidin**	**0.003**	83	Pakistan	I	Tebuconazole	0.008
		I	Tebuconazole	0.003	84	Thailand		bdl	bdl
73	Italy		bdl	bdl	85	Vietnam		bdl	bdl

74	Pakistan	I	Acetamiprid	0.003	86	Mjanmar	GR	Chlormequat	0.010
		I	**Chlorpyrifos**	**0.008**			I	Acetamiprid	0.002
		I	**Clothianidin**	**0.001**			**I**	**Tricyclazole**	**0.003**
		I	Tebuconazole	0.008	87	Cambodia	GR	Chlormequat	0.010
75	Argentina		bdl	bdl			I	Acetamiprid	0.001
76	Cambodia		bdl	bdl	88	Guiana	**I**	**Imidacloprid**	**0.007**
77	Pakistan		bdl	bdl	89	India		bdl	bdl
78	Pakistan		bdl	bdl	90	Mjanmar		bdl	bdl

I: Insecticide; GR: Growth regulator; bdl: below detection limit; the bold name of the compound indicates that it is withdrawn in the EU; the name of the compound in italics indicates that the MRL value is exceeded

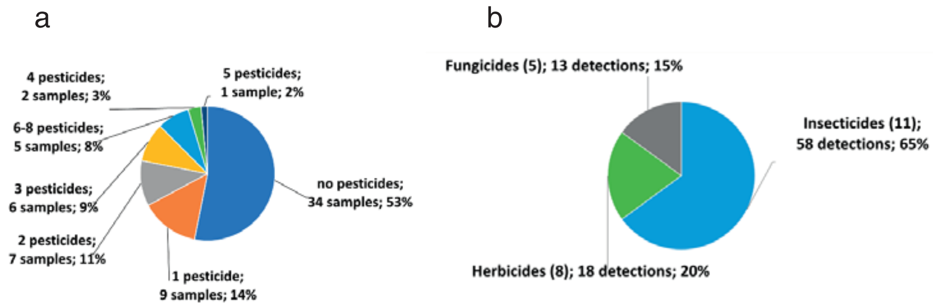
Tea

No residues were found in 34 tea samples, which constitutes 53% of all samples. Pesticide-free samples were reported for all tea varieties except black fruit tea, in which 100% of the samples contained residues (fig. 12).

Pesticides below the highest MRLs were detected in less than half of the analyzed tea varieties (45%). Unacceptable exceedances of the MRLs were recorded for one pesticide (linuron) in a sample of mint tea from Poland at a concentration of 0.336 mg/kg (2% of all tested tea samples), which may pose a potential health hazard (fig. 13).

Of the 24 pesticides detected, 8 (47%) are not approved for use in the EU. These compounds were present primarily in teas imported from China, but they were also found in 6 samples of herbal teas from Poland (lemon balm and mint). The banned pesticides include carbendazim in a black tea sample from India, 2 lemon balm tea samples from Poland, and 3 black fruit tea samples from China. Additionally, linuron was reported in 3 samples of mint tea from Poland, and 6 insecticides (thiacloprid, thiamethoxam, imidacloprid, flufenoxuron, lufenuron, and chlorpyrifos) were also found.

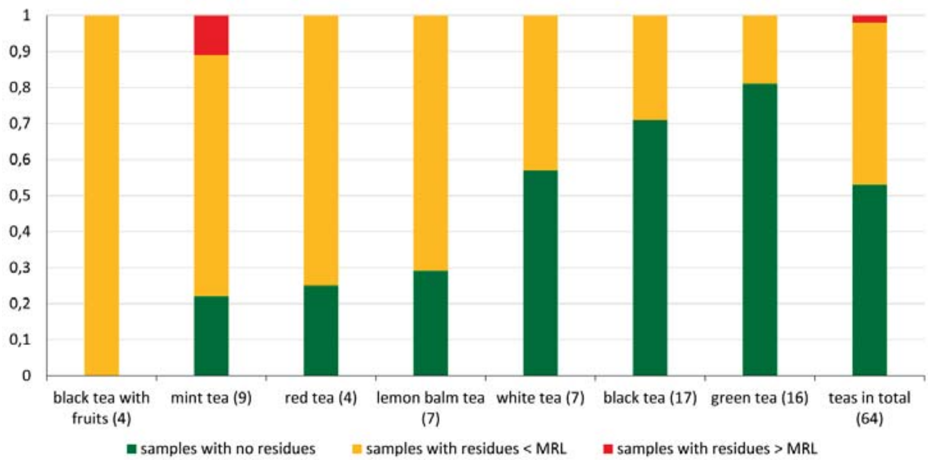
Fig. 12. (a) Share of pesticide-free, single-pesticide, and multi-residue tea samples; (b) Summary of detected pesticide groups (numbers in brackets indicate the number of detected compounds)



Of the 89 detected pesticides, insecticides were the most common (65%, 58 detections), herbicides accounted for 20% (18 detections), and fungicides accounted for 15% (13 detections). Single and multiple pesticides were found in tea samples. The highest number of pesticides detected was found in 2 samples of black fruit tea from China, which contained 8 compounds with total concentrations of 0.129 mg/kg and 0.160 mg/kg. Most samples contained 1 pesticide (14%); 2 were found in 11% of the samples, and 3 pesticides were detected in 9% of the samples.

Among the 11 insecticides, the most frequently detected were acetamiprid (17%; 0.001–0.064 mg/kg), thiacloprid (10%; 0.001–0.084 mg/kg), and fenpyroximate (8%; 0.001–0.008 mg/kg). Of the 8 herbicides, the most frequently detected were glyphosate (7%; 0.027–0.092 mg/kg), linuron (7%; 0.002–0.336 mg/kg), and clomazone (2%; 0.002–0.003 mg/kg). Among the fungicides, the most frequently found were carbendazim (7%; 0.001–0.004 mg/kg) and azoxystrobin (4%; 0.012–0.071 mg/kg).

Fig. 13. Pesticides in tea samples (number of samples in brackets) and their concentrations with maximum permissible levels (MRLs)



Black Tea

The black tea study covered 3 samples from China, 9 samples from Sri Lanka, 3 samples from India, 1 sample from Kenya, and 1 sample from the United Arab Emirates. Of the 17 samples, 12 were free from contaminants, which constitutes 71% of all samples (table 21). The highest number of pesticides (4), with a total concentration of 0.116 mg/kg, was recorded in a sample of black tea from the United Arab Emirates. Three pesticides with a total concentration of 0.090 mg/kg were detected in a tea sample from India, 2 pesticides with a total concentration of 0.033 mg/kg were detected in a tea sample from Kenya, and one pesticide each was recorded in tea from Sri Lanka (glyphosate, 0.045 mg/kg) and China (thiacloprid, 0.022 mg/kg). The most frequently detected pesticide in black tea was thiacloprid, found in a total of 4 samples in the concentration range of 0.001–0.022 mg/kg, which constitutes 24% of all tested samples. Additionally, glyphosate was also detected in 4 black tea samples in the concentration range of 0.032–0.078 mg/kg. All pesticides in the black tea samples were below the MRLs, but carbendazim, thiacloprid, and thiamethoxam have been withdrawn in the EU. The banned pesticides accounted for 60% of all compounds detected in black tea.

Table 21. Detailed summary of detected pesticides in black tea samples

No	Country of origin		Pesticide	Concentration (mg/kg)	No	Country of origin		Pesticide	Concentration (mg/kg)
1	Sri Lanka		bdl	bdl	13	India	H	Glyphosate	0.078
2	India		bdl	bdl			F	**Carbendazim**	**0.004**
3	China		bdl	bdl			I	**Thiacloprid**	**0.008**
4	Sri Lanka		bdl	bdl	14	China	I	**Thiacloprid**	**0.022**
5	Sri Lanka		bdl	bdl	15	Kenya	H	Glyphosate	0.032
6	India		bdl	bdl			I	**Thiacloprid**	**0.001**
7	Sri Lanka		bdl	bdl	16	Sri Lanka		bdl	bdl
8	Sri Lanka		bdl	bdl	17	UAE	I	Acetamiprid	0.002
9	Sri Lanka		bdl	bdl			I	**Thiamethoxam**	**0.076**
10	Sri Lanka		bdl	bdl			H	Glyphosate	0.032
11	Sri Lanka	H	Glyphosate	0.045			I	**Thiacloprid**	**0.006**
12	China		bdl	bdl					

H: Herbicide; I: Insecticide; bdl: below detection limit; the bold name of the compound indicates that it is withdrawn in the EU

Black Fruit Tea

The black fruit tea analyzed included 4 samples from China, all of which were contaminated with pesticides, mainly insecticides (table 22). Most (8) with a total concentration of 0.129 mg/kg and 0.160 mg/kg were recorded in 2 samples. Moreover, 4 pesticides with a total concentration of 0.176 mg/kg were found in another sample, and one sample included only spirotetramat (0.081 mg/kg). The most frequently detected pesticides were acetamiprid, thiamethoxam, carbendazim, and thiacloprid, found in 3 samples. All pesticides detected were below the MRLs. Carbendazim, thiacloprid, thiamethoxam, flufenoxuron, lufenuron, and imidacloprid have been withdrawn in the EU yet accounted for 67% of all compounds detected.

Table 22. Detailed summary of detected pesticides in samples of black tea with fruits

No	Country of origin		Pesticide	Concentration (mg/kg)	No	Country of origin		Pesticide	Concentration (mg/kg)
64	China	I	Acetamiprid	0.064	63	China	I	Acetamiprid	0.007
		I	Fenpyroximate	0.008			I	Fenpyroximate	0.002

		I	**Imidacloprid**	**0.013**			**I**	**Imidacloprid**	**0.002**
		I	**Flufenoxuron**	**0.043**			**I**	**Thiamethoxam**	**0.064**
		I	**Thiamethoxam**	**0.011**			**I**	**Flufenoxuron**	**0.008**
		F	**Carbendazim**	**0.003**			**F**	**Carbendazim**	**0.001**
		I	**Lufenuron**	**0.010**			**I**	**Lufenuron**	**0.029**
		I	**Thiacloprid**	**0.008**			**I**	**Thiacloprid**	**0.016**
61	China	I	Acetamiprid	0.033	62	China	I	Spirotetramat	0.081
		I	**Thiamethoxam**	**0.121**					
		F	**Carbendazim**	**0.001**					
		I	**Thiacloprid**	**0.021**					

F: Fungicide; I: Insecticide; bdl: below detection limit; the bold name of the compound indicates that it is withdrawn in the EU

White Tea

The white tea study included 7 samples from China and Sri Lanka, 4 of which did not contain any pesticides. In one sample, 3 insecticides with a total concentration of 0.090 mg/kg were recorded: acetamiprid, imidacloprid, and thiacloprid; in two more, 1 compound each was found: acetamiprid and glyphosate. All pesticides detected were below the MRLs. Thiacloprid and imidacloprid have been withdrawn in the EU, yet they accounted for 50% of all detected pesticides (table 23).

Table 23. Detailed summary of detected pesticides in white tea samples

No	Country of origin	Pesticide	Concentration (mg/kg)	No	Country of origin		Pesticide	Concentration (mg/kg)
54	Sri Lanka	bdl	bdl	56	China	I	Acetamiprid	0.002
55	China	bdl	bdl	57	China	I	Acetamiprid	0.002
58	China	bdl	bdl			**I**	**Imidacloprid**	**0.004**
60	China	bdl	bdl			**I**	**Thiacloprid**	**0.084**
				59	Sri Lanka	H	Glyphosate	0.027

H: Herbicide; I: Insecticide; bdl: below detection limit; the bold name of the compound indicates that it is withdrawn in the EU

Red Tea

The red tea study covered 4 samples from China, of which 75% were contaminated with pesticides, mainly insecticides (table 24). The largest number of pesticides (3, i.e., acetamiprid, fenpyroximate, and glyphosate) with a total concentration of 0.095 mg/kg was recorded in one sample. Acetamiprid, which was the most frequently reported (3 samples), was detected in the remaining two contaminated samples. All pesticides detected in red teas were below the MRLs and registered in the EU.

Table 24. Detailed summary of detected pesticides in red tea samples

No	Country of origin		Pesticide	Concentration (mg/kg)	No	Country of origin		Pesticide	Concentration (mg/kg)
50	China	I	Acetamiprid	0.001	51	China	I	Acetamiprid	0.002
52	China	I	Acetamiprid	0.002			I	Fenpyroximate	0.001
53	China		bdl	bdl			H	Glyphosate	0.092

H: Herbicide; I: Insecticide; bdl: below detection limit

Green Tea

The green tea study included 3 samples from China, 9 samples from Sri Lanka, 3 from India, 1 from Kenya, and 1 from the United Arab Emirates. Of the 16 samples, 3 contained residues, which constitute 19% of the total (table 25). They contained 2 insecticides (flufenoxuron and thiamethoxam) with a total concentration of 0.014 mg/kg, 0.172 mg/kg, and 0.162 mg/kg. Both pesticides have been withdrawn in the EU.

Table 25. Detailed summary of detected pesticides in green tea samples

No	Country of origin	Pesticide	Concentration (mg/kg)	No	Country of origin		Pesticide	Concentration (mg/kg)
19	China	bdl	bdl	18	Sri Lanka		bdl	bdl
20	China	bdl	bdl	21	Sri Lanka		bdl	bdl
23	China	bdl	bdl	22	Sri Lanka		bdl	bdl
24	China	bdl	bdl	26	China	**I**	**Flufenoxuron**	**0.012**
25	Japan	bdl	bdl			**I**	**Thiacloprid**	**0.002**
27	China	bdl	bdl	28	China	**I**	**Flufenoxuron**	**0.134**
29	China	bdl	bdl			**I**	**Thiamethoxam**	**0.038**
30	China	bdl	bdl	32	Sri Lanka	**I**	**Flufenoxuron**	**0.127**

31	China		bdl	bdl			**I**	**Thiamethoxam**	**0.034**
33	Vietnam		bdl	bdl					

I: Insecticide; bdl: below detection limit; the bold name of the compound indicates that it is withdrawn in the EU

Lemon Balm Tea

The lemon balm tea study covered 6 samples from Poland and 1 from Greece, of which 5 contained pesticides, i.e., 71% of all samples (table 26). The highest number of residues (6) with a total concentration of 0.068 mg/kg was recorded in a sample from Poland containing acetamiprid, azoxystrobin, chlorpyrifos, fenpyroximate, permethrin, and carbendazim. In another sample, 3 pesticides (azoxystrobin, carbendazim, MCPA) were detected with a total content of 0.151 mg/kg. In the next study, 2 (acetamiprid and azoxystrobin) were found, and in two samples, only fenpyroximate was detected. The most common was azoxystrobin, which was found three times. All pesticides were below the MRLs. However, carbendazim and chlorpyrifos have been withdrawn in the EU yet accounted for 29% of all pesticides found.

Table 26. Detailed summary of detected pesticides in lemon balm tea samples

No	Country of origin		Pesticide	Concentration (mg/kg)	No	Country of origin		Pesticide	Concentration (mg/kg)
34	Poland	F	Azoxystrobin	0.040	36	Poland	I	Acetamiprid	0.001
		F	**Carbendazim**	**0.002**			F	Azoxystrobin	0.012
		H	MCPA	0.108			**I**	**Chlorpyrifos**	**0.029**
37	Poland	I	Fenpyroximate	0.007			I	Fenpyroximate	**0.007**
38	Poland	I	Acetamiprid	0.001			I	Permethrin	0.017
		F	Azoxystrobin	0.027			**F**	**Carbendazim**	**0.002**
	Poland	I	Fenpyroximate	0.001	40	Greece		bdl	bdl
35	Poland		bdl	bdl					

H: Herbicide; F: Fungicide; I: Insecticide; bdl: below detection limit; the bold name of the compound indicates that it is withdrawn in the EU

Mint Tea

The mint tea study included 8 samples from Poland and 1 sample from Greece; pesticide residues were detected in 7, which constitutes 78% of all samples and included herbicides, insecticides, and fungicides (table 27).

The highest number of pesticides (7), with a total concentration of 0.077 mg/kg, was recorded in Polish mint tea. In the next 2 samples, 6 pesticides with a total content of 0.114 mg/kg and 5 pesticides with a total concentration of 0.121 mg/kg were detected. Three residues were recorded in 2 samples. Detected pesticides included aclonifen, quizalofop-P-ethyl, linuron, clomazone, fenazaquin, and linuron. In the next 2 samples, 2 pesticides were found (acetamiprid and imidacloprid), with a total concentration of 0.018 mg/kg and 0.020 mg/kg.

Linuron was the most common and detected in 5 samples at concentrations of 0.002–0.045 mg/kg, acetamiprid in 4, and fenazaquin in 3 samples.

Linuron in a sample of mint tea from Poland (0.336 mg/kg) exceeded the MRL, which could harm the health of consumers. Additionally, linuron, chlorpyrifos, and imidacloprid have been withdrawn in the EU but accounted for 20% of all pesticides found.

Table 27. Detailed summary of detected pesticides in mint tea samples

No	Country of origin		Pesticide	Concentration (mg/kg)	No	Country of origin		Pesticide	Concentration (mg/kg)
41	Poland		bdl	bdl	46	Poland	H	Aclonifen	0.010
43	Poland	H	Bentazone	0.029			H	Quizalofop	0.336
		F	Benzovindiflupyr	0.009			H	Linuron	0.336
		H	Clomazone	0.002	47	Poland	I	Acetamiprid	0.016
		I	**Chlorpyrifos**	**0.013**			**I**	**Imidacloprid**	**0.003**
		I	Fenazaquin	0.015	48	Poland	I	Acetamiprid	0.001
		F	Fluopyram	0.006			F	Azoxystrobin	0.071
		H	**Linuron**	**0.002**			**I**	**Chlorpyrifos**	**0.026**
44	Poland	I	Acetamiprid	0.014			I	Fenpyroximate	0.008
		I	**Imidacloprid**	**0.004**			**H**	**Linuron**	**0.002**
45	Poland	I	Acetamiprid	0.018			F	Tebuconazole	0.006
		I	**Chlorpyrifos**	**0.028**	49	Poland	H	Clomazone	0.003
		I	Fenazaquin	0.015			I	Fenazaquin	0.014

		H	**Linuron**	**0.045**			**H**	**Linuron**	**0.006**
		H	Napropamide	0.015	52	Greece		bdl	

H: Herbicide; F: Fungicide; I: Insecticide; bdl: below detection limit; the bold name of the compound indicates that it is withdrawn in the EU; the name of the compound in italics indicates that the MRL value is exceeded

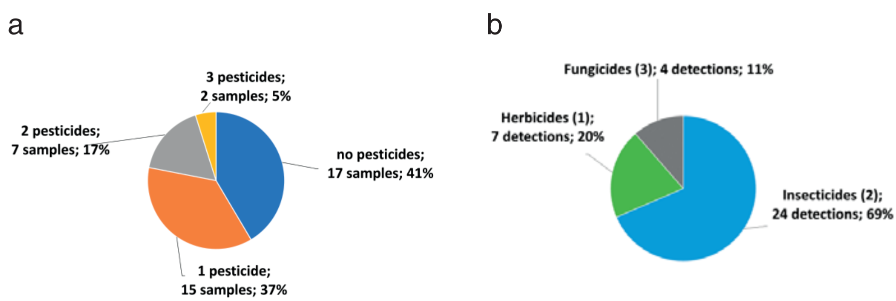
Honey

The study analyzed a total of 41 samples of Polish honey, and no pesticide residues were found in 17, which constitutes 41% of all samples (fig. 14).

Most had residues below the maximum permissible limits. Unacceptable exceedances of the MRLs were detected in two cases (acetamiprid and thiacloprid), which constitute 5% of all tested samples.

Of the 6 pesticides detected, 4 (67%) were prohibited in the EU. These include a herbicide (tebutrion) detected in 7 samples (0.003–0.015 mg/kg), 2 fungicides detected in 3 samples (cyproconazole and carbendazim at concentrations of 0.002–0.003 mg/kg and 0.029 mg/kg), and an insecticide (thiacloprid) detected in 12 samples in the concentration range of 0.001–0.528 mg/kg.

Fig. 14. (a) Share of pesticide-free, single-pesticide, and multi-residue honey samples; (b) Summary of detected pesticides (numbers in brackets indicate the number of detected compounds)



Of the 35 detected pesticides, insecticides were the most common (69%), herbicides accounted for 20%, and fungicides for 11%. Single and multiple pesticides were recorded in honey samples. The highest number of pesticides (3) were recorded in 2 samples, with total concentrations of 0.028 mg/kg and 0.032 mg/kg. They included acetamiprid, cyproconazole, and thiacloprid. Another 7 samples contained 2 compounds (17%) in combinations: acetamiprid and tebutrion, acetamiprid and thiacloprid, fluopyram and tebutrion, acetamiprid and carbendazim, and tebutrion and thiacloprid, while the remaining 15 samples had 1 pesticide (37%).

Of the 2 insecticides, acetamiprid and thiacloprid were detected in 2.9% of samples with the same frequency (34.3%; at concentrations of 0.001–0.146 mg/kg and 0.001–0.528 mg/kg) and above the safe MRL, which could pose a potential threat to the consumers. The only herbicide found in honey was tebutrion (20%; 0.003–0.015 mg/kg), and the fungicide was cyproconazole (5.7%; 0.002–0.003 mg/kg) (table 28).

Table 28. Detailed summary of detected pesticides in polish honey samples

No		Pesticide	Concentration (mg/kg)	No		Pesticide	Concentration (mg/kg)	No		Pesticide	Concentration (mg/kg)
1		bdl	bdl	13	I	Acetamiprid	0.028	28	**I**	**Thiacloprid**	**0.002**
2	**I**	**Thiacloprid**	**0.001**		**F**	**Cyproconazole**	**0.003**	29	**I**	**Thiacloprid**	**0.005**
3	**I**	**Thiacloprid**	**0.060**		**I**	**Thiacloprid**	**0.001**	30		bdl	bdl
4	I	Acetamiprid	0.006	14	*I*	*Acetamiprid*	0.146	31	**H**	**Tebuthiuron**	**0.005**
	H	**Tebuthiuron**	**0.015**		**H**	**Tebuthiuron**	0.004	32		bdl	bdl
5	I	Acetamiprid	0.006	15	I	Acetamiprid	0.005	33		bdl	bdl
	H	**Tebuthiuron**	**0.011**	16		bdl	bdl	34	I	Acetamiprid	0.006
6		bdl	bdl	17		bdl	bdl		**I**	**Thiacloprid**	**0.006**
7	**H**	**Tebuthiuron**	**0.003**	18		bdl	bdl	35		bdl	bdl
8		bdl	bdl	19	I	Acetamiprid	0.001	36	I	Acetamiprid	0.026
9		bdl	bdl	20	**I**	**Thiacloprid**	0.006	37	I	Acetamiprid	0.024
10	**I**	**Thiacloprid**	**0.009**	21		bdl	bdl	38	F	Fluopyram	0.002
11		bdl	bdl	22		bdl	bdl		**H**	**Tebuthiuron**	**0.004**
12	I	Acetamiprid	0.020	23		bdl	bdl	39	I	Acetamiprid	0.028
	F	**Cyproconazole**	**0.002**	24	**I**	**Thiacloprid**	0.002	40	I	Acetamiprid	0.008
	I	**Thiacloprid**	**0.005**	25		bdl	bdl		**F**	**Carbendazim**	**0.029**
				26		bdl	bdl	41	**H**	**Tebuthiuron**	**0.010**
				27	**I**	**Thiacloprid**	0.001		I	Thiacloprid	0.528

H: Herbicide; F: Fungicide; I: Insecticide; bdl: below detection limit; the bold name of the compound indicates that it is withdrawn in the EU; the name of the compound in italics indicates that the MRL value is exceeded

Nuts and Coffee

The analyzed 114 nut samples included 10 groups (peanut, Brazil nut, hazelnut, macadamia nut, almond, cashew, pecan, pine nut, pistachio, walnut); 57 nut samples came from conventional farming and 57 from organic farming.

In the case of the 30 coffee samples analyzed, 15 came from conventional cultivation and 15 from organic cultivation.

No pesticide residues were found in any of the nut and coffee samples.

3.1.2. Detected Pesticides

Herbicides

The most frequently detected herbicides were phenoxy acids, found in 21 product samples, i.e., 4.3% of the tested products. The most common phenoxy acid was 2,4-D, present in 16 smoothie samples at a concentration of 0.001–0.007 mg/kg and 1 orange sample (0.165 mg/kg) (fig. 15). Another herbicide from this group was MCPA, found in lemon balm teas (0.108 mg/kg) and 2 buckwheat samples (0.002–0.034 mg/kg). Additionally, mecoprop-P (0.036 mg/kg) was detected in the buckwheat sample. Noteworthy, 2,4-D, MCPA, and mecoprop-P are approved for use in the EU, and their MRLs in the tested ranges are 1, 0.1, and 0.05 mg/kg, respectively. Therefore their MRLs were not exceeded. Smoothies are not subject to regulations specifying MRLs; therefore, in the case of these products, pesticide concentrations cannot be exceeded. In case of chronic exposure, 2,4-D may cause endocrine problems. The acute toxicity of this substance toward birds, fish, bees, and earthworms is moderate. The compound is characterized by mobility in ecosystems and high leachability into groundwater (table 29).

Other frequently detected herbicides were phosphonates, the only representative of which was glyphosate, present in 1.5% of samples (fig. 15). Glyphosate was detected in 4 samples of black tea, 1 red and white tea, 4 samples of barley, 2 millet and 1 buckwheat samples. The highest concentrations of glyphosate were found in tea (0.026–0.092 mg/kg) compared to groats (0.002–0.04 mg/kg). However, the concentrations were below the MRLs (0.1–20 mg/kg, depending on the product range). In case of contact exposure, glyphosate may irritate the eyes, and in case of chronic exposure, it may cause endocrine problems. Glyphosate is also associated with DNA damage. Its chronic toxicity to birds and earthworms is moderate. In the environment, it has moderate permeability to groundwater and moderate transport potential with soil particles (table 29).

Herbicides from the propionic acid group (haloxyfop) were detected in 13 products, which constituted 1.5% of all tested products. Most cases of detection of this herbicide were found in smoothies (10 samples) in the concentration range of 0.001–0.033 mg/kg and in 3 samples of buckwheat (0.001–0.006 mg/kg). Haloxyfop has been withdrawn in the EU. In the case of acute toxicity, haloxyfop irritates the skin and eyes. Acute toxicity of haloxifop to *Daphnia magna* is moderate. In the environment, it has high leachability into groundwater (table 29).

Another herbicide is tebuthiuron, a carbamide, which was detected in 7 honey samples, which constituted 0.8% of all samples tested (fig. 15). The concentration of this compound was in the range of 0.004–0.015 mg/kg. This herbicide has been withdrawn in the EU. Tebuthiuron irritates the eyes in case of contact. The acute toxicity of tebuthiuron to fish, bees, and earthworms is moderate, as is its chronic toxicity to fish. In soil, tebuthiuron shows very high durability and high leachability in groundwater (table 29).

A representative of the amide herbicides, beflubutamid, was detected in 4 grapefruit samples. Its concentration range was 0.017–0.044 mg/kg. Beflubutamid is an EU-approved herbicide with an MRL of 0.02 mg/kg. In 1 grapefruit sample, its concentration exceeded the MRL (0.044 mg/kg). Beflubutamid causes negative reproductive and developmental effects and is toxic to the thyroid gland in case of chronic exposure. Its chronic toxicity to fish, earthworms, and *Daphnia magna* is moderate. Beflubutamid has a high transport potential associated with soil particles (table 29).

In the case of Aryloxyphenoxypropionic acid herbicides, fluazifop was detected in 4 fruit smoothie samples at concentrations of 0.002–0.033 mg/kg and in a sample of Polish buckwheat at a level of 0.007 mg/kg. Fluazifop has been banned in the EU. Smoothies are not subject to regulations specifying MRLs, and in the case of these products, the concentration of this herbicide cannot be exceeded. Currently, there is no information on the impact of this pesticide on human health; only the likelihood of negative reproductive and developmental effects is indicated. Fluazifop is characterized by mobility in ecosystems and high leachability into groundwater and transfer to groundwater (table 29).

Among phenylurea herbicides, linuron was detected in 5 samples of Polish mint teas at the concentrations of 0.002–0.336 mg/kg. Linuron has been banned in the EU. Linuron is responsible for negative reproductive and developmental effects, as well as endocrine problems in case of chronic exposure. Contact exposure causes eye and skin irritation. Its acute toxicity toward birds, fish, bees, earthworms, and *Daphnia magna* is moderate, as is its chronic toxicity. Linuron has moderate persistence in ecosystems, low leachability into groundwater, and moderate transport potential with soil particles (table 29).

Fig. 15. Concentrations of detected herbicides (mg/kg) in more than 5 samples of the tested products

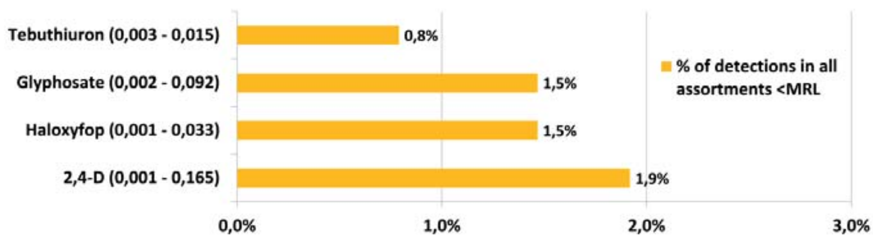


Table 29. Herbicides most frequently detected in tested foods of plant origin and their potential health and environmental effects

	Chemical group	Pesticide	Environmental fate	Ecotoxicity	Human health	Cancers	Mutagen	Hormonal system	development	Neurotoxicity	Respiratory system	Skin irritant	Skin sensitizer	Eye irritant
Herbicides	Phenoxy acids	2.4-D	🟥	🟨	🟥	?	A3; B0; C0; D0; E3	+	+	+	+	?	?	-
		MCPA	🟥	🟨	🟨	-	A3; B0; C0; D0; E2	-	?	-	?	-	-	+
		Mecoprop-P	🟥	🟨	🟥	-	A3; B0; C0; D0; E2	-	+	-	+	-	-	+
	Phosphonates	Glyphosate	🟨	🟨	🟥	?	A3; B1; C3; D0; E3	?	?	-	-	-	-	+
	Propionic acids	Haloxyfop	🟥	🟨	🟨	-	A3; B0; C0; D0; E0	n.d.	?	n.d.	n.d.	+	n.d.	+
	Carbamides	Tebuthiuron	🟥	🟨	🟨	-	A3; B0; C0; D0; E3	n.d.	?	n.d.	n.d.	-	n.d.	+
	Amides	Beflubutamid	🟥	🟨	🟥	-	A3; B0; C0; D0; E3	n.d.	+	-	-	-	-	-
	Arylphenoxy acids	Fluazifop	🟥	n.d.	🟨	n.d.	A0; B0; C0; D0; E0	n.d.	?	n.d.	n.d.	n.d.	n.d.	n.d.
	Phenylureas	Linuron	🟨	🟨	🟥	?	A3; B0; C0; D0; E3	?	+	-	?	+	n.d.	+

🟩 – *Low risk* 🟨 – *Moderate risk* 🟥 – *High risk*

+ – *yes. it is known to cause problems;* **–** – *no. it is known that it does not cause problems;*
? – *probably the status was not identified;* **n.d.** – *no scientific data*

A – *Chromosomal aberration (EFSA database);* **B** – *DNA damage/repair (EFSA database);* **C** – *Gene mutation (EFSA database);* **D** – *Genome mutation (EFSA database);* **E** – *Unspecified type of genotoxicity (different data source)*

0 – *No data;* **1** – *Positive;* **2** – *Mixed/ambiguous results;* **3** – *Negative*

Compounds in red font are withdrawn in the EU

Fungicides

The most frequently detected fungicides were benzimidazoles, the presence of which was found in a total of 53 products, constituting 11% of all products (fig. 16). In this group, the most common was carbendazim, present mainly in humus (21 samples; 0.001–0.002 mg/kg). The second was thiabendazole, present in 4 smoothie samples (0.001–0.004 mg/kg), a humus sample (0.01 mg/kg), and 8 fruit samples (avocados, grapefruits, oranges, lemons, bananas) in the concentration range of 0.011–0.416 mg/kg. Moreover, thiophanate-methyl was also detected in 7 humus samples (0.002–0.002 mg/kg). Carbendazim and thiophanate-methyl are banned in the EU, while thiabendazole is approved for use. The concentrations of the above pesticides did not exceed the established MRLs. Carbendazim causes negative reproductive and developmental effects, disrupts hormonal balance, and may cause genetic defects in case of chronic exposure. Its acute toxicity toward fish and *Daphnia magna* is high, as is its chronic toxicity to earthworms. Carbendazim has moderate leachability into groundwater. In turn, thiabendazole may have a toxic effect on the thyroid gland. Its chronic toxicity to birds, fish, bees, earthworms, and *Daphnia magna* is moderate, as is its chronic toxicity. Its durability in the environment and transport potential with soil particles is high. However, thiophanate-methyl may cause chromosomal aberrations and other genotoxic effects in case of chronic exposure. It shows chronic toxicity toward birds and moderate mobility in transfer to groundwater. The U.S. Environmental Protection Agency (EPA) considers carbendazim, thiabendazole, and thiophanate-methyl as possible human carcinogens (table 30).

Carboxamide fungicides were detected in 46 samples (9.6% of all tested). The most common was fluxapyroxad found in 9 fruit samples (pears, melon, strawberries, apples, and grapes) in the concentration range of 0.001–0.243 mg/kg, 18 humus samples (0.001 mg/kg), 9 smoothies (0.001 mg /kg), as well as in barley (0.006 mg/kg) and sweet potatoes (0.01 mg/kg). Additionally, bixafen (0.001–0.003 mg/kg) was found in 4 samples of barley groats, penthiopyrad in tomatoes and apples (0.004–0.284 mg/kg), as well as benzovindiflupyr in mint tea (0.009 mg/kg) and metfuroxam in smoothie (0.001 mg/kg). The detected carboxamide fungicides are registered in the EU, and their concentrations did not exceed the MRLs. Chronic and acute toxicity of fluxapyroxad to birds, fish, earthworms, and *Daphnia magna* is moderate. Fluxapyroxad is highly persistent in the environment. In turn, bixafen causes negative effects related to reproduction and development. It has high chronic and acute toxicity to fish and is persistent in the environment. Penthiopyrad causes negative reproductive and developmental effects in the case of chronic exposure. Its acute toxicity toward fish, earthworms, and *Daphnia magna* is moderate. In the environment, it leaches slightly into groundwater, but its transport potential with soil particles is moderate. Benzovindiflupyr is characterized by high acute toxicity toward fish and *Daphnia magna*. This fungicide is persistent in the environment and has a high potential for transport associated with soil particles (table 30).

In turn, benzamides were present in 43 tested products (8.9% of all products). The main one was fluopyram (41 samples), recorded in fruits (pears, grapes, and apples) in the concentration range of 0.003–0.208 mg/kg, vegetables (broccoli, radish, tomatoes, and cucumbers) in concentrations of 0.001–0.067 mg/kg, humus (0.001 mg/kg), smoothies (0.001–0.005 mg/kg), honey (0.002 mg/kg), mint tea (0.006 mg/kg), and barley groats (0.002 mg/kg) (fig. 16). Moreover, zoxamide was also detected in 2 grape samples (0.008–0.01 mg/kg). These benzamide fungicides are approved in the EU, and their concentrations were within the applicable MRLs. Fluopyram is suspected of being neurotoxic. It causes negative reproductive and developmental effects in humans with chronic exposure. It has high acute toxicity toward birds, is persistent in the environment, and has a high ability to penetrate groundwater. Zoxamide is a skin sensitizer and causes eye irritation upon contact. It has high chronic toxicity to fish. Zoxamide has a low ability to move with drainage water in the soil, but its transport potential with soil or sediment particles is moderate (table 30).

At the same time, anilinopyrimidine fungicides were detected in 42 samples, mainly in fruits and vegetables, which constituted 8.7% of all tested products. These included pyrimethanil (19 samples) in the concentration range of 0.001–1.68 mg/kg in fruit and 0.0010.015 mg/kg in vegetables, and cyprodinil (13) at 0.001–1.36 mg/kg in fruit and at 0.001 –0.021 mg/kg in vegetables. Moreover, pyrimethanil was detected in 8 smoothie samples (0.012–0.044 mg/kg), and cyprodinil in 2 barley samples (0.005–0.009 mg/kg) (fig. 16). The detected anilinopyrimidine fungicides are approved in the EU, and their concentrations did not exceed the MRLs. Pyrimethanil is likely to be a thyroid toxicant, and the EPA lists it as a possible human carcinogen under chronic exposure. It has moderate acute toxicity to fish, *Daphnia magna*, earthworms, and birds. Pyrimethanil is moderately persistent in the environment. However, cyprodinil irritates the respiratory tract, skin, and eyes and is also a sensitizer when in contact with the skin. It has high chronic toxicity toward *Daphnia magna* and shows high mobility in the environment (table 30).

However, the presence of triazole fungicides was confirmed in 38 samples, constituting 7.9% of all products analyzed. They were the most diverese, with 9 different compounds in total (cyproconazole, difenoconazole, epoxiconazole, flutriafol, myclobutanil, penconazole, prothioconazole-desthio, tebuconazole, and tetraconazole). Triazoles were detected in 18 fruit samples (mango, melon, pears, grapes, bananas, strawberries, apples, pineapple, blueberries, and grapefruit) in the concentration range of 0.001–0.46 mg/kg and in 13 vegetable samples (tomatoes, celery, leek, garlic, potatoes, parsley, and broccoli) at 0.001–0.247 mg/kg, as well as in 4 rice samples (0.003–0.008 mg/kg), 2 honey samples (0.002–0.003 mg/kg), and mint tea (0.006 mg/kg). Flutriafol, myclobutanil, epoxiconazole, and cyproconazole have been withdrawn in the EU. Cyproconazole disrupts hormonal balance, causes negative reproductive and developmental effects in case of chronic exposure, and irritates the respiratory tract as a result of contact exposure. The EPA classifies cyproconazole as a probable human carcinogen. Difenoconazole irritates the skin and eyes through contact exposure and is classified by the EPA as a possible carcinogen. In turn, epoxiconazole is responsible for negative reproductive and developmental effects and shows liver toxicity as a result of chronic exposure. According to CLP and EPA data, epoxiconazole is a probable human carcinogen. However, flutriafol may cause endocrine problems and irritation to the respiratory tract (table 30).

Strobilurin fungicides were detected in 36 samples. Azoxystrobin was recorded in 21 samples, mainly fruits (9; 0.001–0.87 mg/kg), vegetables (8; 0.001–0.22 mg/kg), and mint tea (0.071 mg/kg) (fig. 16). The presence of pyraclostrobin was confirmed in 6 fruit samples (0.007–0.018 mg/kg) and 3 groups of vegetables (garlic, tomato, blueberry) in the concentration range of 0.014–0.086 mg/kg. In turn, trifloxystrobin was detected in 3 fruit samples (pear, grape, grapefruit) at concentrations of 0.006–0.53 mg/kg and in tomatoes (0.031 mg/kg). Kresoxim-methyl was recorded in a sample of blueberries (0.082 mg/kg) and melons (0.001 mg/kg). These fungicides are approved for use in the EU, and their concentrations were below the MRLs. Pyraclostrobin irritates the respiratory tract and skin by contact and is responsible for negative reproductive and developmental effects in case of chronic exposure, while kresoxim-methyl irritates the skin, respiratory tract, and eyes. According to the EPA, kresoxim-methyl is a probable human carcinogen (table 30).

Phenylpyrrole fungicides were found in 33 product samples (3.2% of all tested products). Fludioxonil was present in 10 groups of fruit (pears, mango, melon, kiwifruit, pineapple, apples, lemons, blueberries, grapes) in the concentration range of 0.001–2.42 mg/kg, and 10 samples of vegetables (radish, potato, sweet potato, red pepper, leek, tomatoes, parsley) at concentrations of 0.001–1.09 mg/kg, and in 2 smoothie samples (0.019–0.048 mg/kg). Fludioxonil is approved for use in the EU and was detected in concentrations below the MRL (fig. 16). However, it irritates the skin and eyes due to contact exposure. It has high acute toxicity toward *Daphnia magna.* Fludioxonil has a moderate potential to move with soil or sediment particles (table 30).

As for the aniline fungicides, boscalid was found in 28 samples, which constitutes 3.2% of the analyzed products (fig. 16). This fungicide was mostly found in domestic and imported fruits (apples, pears, grapes, kiwifruit, blueberries) in the range of 0.001–2.15 mg/kg and vegetables (cucumbers, tomatoes, sweet potatoes, leeks, celery, onion, garlic, Chinese cabbage, pepper, parsley, and basil) at a level of 0.005–0.355 mg/kg. Moreover, it was found in 3 humus samples (0.005–0.022 mg/kg). Boscalid is approved in the EU, and its concentrations were within the MRLs for individual products (1.5–50 mg/kg). Boscalid is suspected of possible negative reproductive and developmental effects in case of chronic exposure. This pesticide can be very persistent in both soil and water systems, depending on local conditions (table 30).

Phthalimide fungicides were detected in 27 product samples. Only captan was found, mainly in 21 smoothie samples (0.029–0.18 mg/kg), 5 fruit samples (pears and apples, 0.141–0.833 mg/kg), and tomatoes (0.131 mg/kg). Captan is approved in the EU, and its concentrations were below the applicable MRLs. It disrupts the hormonal balance in case of chronic exposure, may cause contact dermatitis, and irritates the skin. According to the EPA, it is a probable carcinogen. It is not persistent in soil or water systems (table 30).

Amide fungicides included mandipropamid found in 25 product samples, contituting 2.8% of the analyzed products. This fungicide was detected primarily in 21 humus samples at a concentration of 0.001 mg/kg. Moreover, it was found in 2 samples of grapes from India and Spain and in tomatoes and radishes (0.001–0.02 mg/kg). Mandipropamid is approved in the EU, and its concentration did not exceed the MRL (0.3–2 mg/kg). Mandipropamid is a skin sensitizer by contact and is toxic to the liver in case of chronic exposure and acute poisoning. It has moderate acute and chronic toxicity to birds, fish, *Daphnia magna*, and earthworms. Mandipropamid has a moderate tendency to move with drainage water into the soil (table 30).

In the group of pyrimidineamine fungicides, ametoctradin was detected in 25 samples. This fungicide was found in 22 humus samples (0.001 mg/kg) and 2 vegetable samples (leek, lettuce) at the level of 0.012–0.137 mg/kg and in grapes (0.086 mg/kg). Ametoctradin is permitted in the EU, and its concentration did not exceed the MRL. In general, ametoctradin has low to moderate toxicity to most organisms but has high acute toxicity to fish. This pesticide is usually not persistent in the soil. Taking into account its chemical properties, the risk of its release into groundwater is low (table 30).

Carbamic acids were detected in 22 samples, and the only representative of this group was propamocarb hydrochloride found in 12 samples of vegetables (tomatoes, cucumbers, potatoes, leek, basil, parsley, onion, potatoes) in the concentration range of 0.001–0.872 mg/kg, 9 samples of humus (0.001–0.003 mg/kg), and a smoothie sample (0.001 mg/kg). Propamocarb hydrochloride is permitted in the EU, and its concentrations were below the MRL. However, it is classified as an endocrine-disrupting chemical in case of chronic exposure and is irritating and sensitizing to the skin as a result of contact exposure. It has moderate acute and chronic toxicity to fish and birds. Propamocarb hydrochloride has a moderate tendency to move with drainage water into the soil (table 30).

Fig. 16. Concentrations of detected fungicides (mg/kg)
in more than 5 samples of the tested products

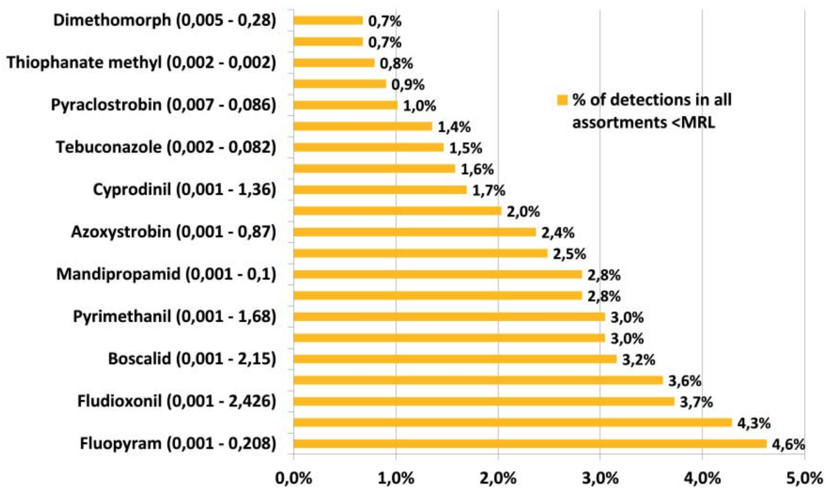


Table 30. Fungicides most frequently detected in tested foods
of plant origin and their potential health and environmental effects

	Chemical group	Pesticide	Environmental fate	Ecotoxicity	Human health	Cancers	Mutagen	Hormonal system	Reproduction/devel-opment	Neurotoxicity	Respiratory system	Skin irritant	Skin sensitizer	Eye irritant	Phototoxicity
Fungicides	Benzimidazoles	Carbendazim	yellow	red	red	?	A2; B3; C3; D0; E1	+	+	-	-	-	n.d.	-	n.d.
		Thiabendazole	red	yellow	yellow	?	A2; B3; C3; D0; E3	n.d.	?	-	?	-	n.d.	-	n.d.
		Thiophanate methyl	yellow	red	red	?	A1; B0; C0; D0; E1	-	+	n.d.	+	?	+	-	-
	Carboxamides	Fluxapyroxad	red	yellow	yellow	-	A3; B3; C3; D0; E0	n.d.	?	-	n.d.	-	n.d.	?	n.d.
		Bixafen	red	red	red	-	A3; B0; C0; D0; E3	n.d.	+	n.d.	n.d.	-	n.d.	-	n.d.
		Penthiopyrad	yellow	yellow	red	-	A3; B3; C3; D0; E3	n.d.	+	?	-	-	n.d.	-	n.d.
		Benzovindi-flupyr	red	red	red	-	A0; B0; C0; D0; E0	-	?	-	n.d.	-	-	-	n.d.
		Methfuroxam	n.d.	n.d.	yellow	n.d.	A0; B0; C0; D0; E0	n.d.	b	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	Benzamides	Fluopyram	red	red	yellow	-	A3; B0; C3; D0; E0	n.d.	?	?	n.d.	-	n.d.	-	n.d.

Fungicides		Zoxamide	[yellow]	[red]	[green]	-	A0; B0; C0; D0; E3	n.d.	-	-	-	?	+	+	-
Fungicides	Anilinopyrimidines	Pyrimethanil	[yellow]	[yellow]	[yellow]	?	A3; B3; C3; D0; E3	?	?	-	-	-	-	-	-
Fungicides	Anilinopyrimidines	Cyprodinil	[red]	[red]	[yellow]	-	A3; B3; C3; D0; E3	n.d.	?	-	+	+	+	+	n.d.
Fungicides	Triazoles	Cyproconazole	[red]	[red]	[red]	?	A3; B3; C3; D0; E0	+	+	-	+	-	-	-	-
Fungicides	Triazoles	Difenoconazole	[red]	[red]	[yellow]	?	A2; B3; C3; D0; E0	-	?	-	-	+	n.d.	+	n.d.
Fungicides	Triazoles	Epoxiconazole	[yellow]	[red]	[red]	?	A3; B0; C0; D0; E0	+	+	-	-	-	?	-	-
Fungicides	Triazoles	Flutriafol	[red]	[yellow]	[red]	-	A3; B3; C3; D0; E2	+	?	-	+	?	?	+	n.d.
Fungicides	Triazoles	Myclobutanil	[yellow]	[yellow]	[red]	-	A3; B3; C3; D0; E3	+	?	-	-	-	n.d.	+	n.d.
Fungicides	Triazoles	Penconazole	[red]	[yellow]	[red]	-	A3; B3; C3; D0; E0	+	?	-	n.d.	-	n.d.	-	n.d.
Fungicides	Triazoles	Prothioconazole-destio	[yellow]	[yellow]	[red]	-	A2; B3; C3; D0; E3	-	+	?	-	-	-	-	-
Fungicides	Triazoles	Tebuconazole	[yellow]	[red]	[red]	?	A3; B3; C3; D0; E0	+	?	-	-	-	n.d.	+	n.d.
Fungicides	Triazoles	Tetraconazole	[red]	[yellow]	[yellow]	?	A3; B3; C3; D0; E0	n.d.	?	-	-	-	n.d.	-	n.d.
Fungicides	Strobilurins	Azoxystrobin	[red]	[yellow]	[yellow]	-	A2; B0; C3; D0; E2	n.d.	?	-	n.d.	+	n.d.	+	n.d.
Fungicides	Strobilurins	Pyraclostrobin	[yellow]	[red]	[red]	-	A3; B0; C0; D0; E3	-	+	-	+	+	-	-	-
Fungicides	Strobilurins	Trifloxystrobin	[yellow]	[red]	[red]	-	A3; B0; C0; D0; E0	-	+	-	-	?	?	-	-
Fungicides	Strobilurins	Kresoxim methyl	[yellow]	[yellow]	[yellow]	?	A3; B3; C3; D0; E0	n.d.	-	-	+	+	n.d.	+	n.d.
Fungicides	Phenylpyrroles	Fludioxonil	[yellow]	[red]	[yellow]	-	A2; B2; C3; D0; E0	n.d.	?	-	-	+	-	+	n.d.
Fungicides	Anilines	Boscalid	[red]	[yellow]	[yellow]	-	A3; B0; C0; D0; E0	-	?	-	-	-	-	-	-
Fungicides	Phthalimides	Captan	[yellow]	[yellow]	[red]	?	A2; B1; C2; D0; E2	+	b	-	n.d.	+	?	+	n.d.
Fungicides	Amides	Mandipropamid	[yellow]	[yellow]	[yellow]	-	A3; B3; C3; D0; E3	-	-	-	-	-	+	-	n.d.
Fungicides	Pyrimidineamines	Ametoctradin	[yellow]	[red]	[yellow]	-	A3; B0; C0; D0; E3	-	?	-	n.d.	-	n.d.	-	n.d.
Fungicides	Carbamic acids	Propamocarb	[yellow]	[yellow]	[red]	-	A3; B0; C3; D0; E0	+	b	?	n.d.	+	+	-	n.d.

[green] *– Low risk* [yellow] *– Moderate risk* [red] *– High risk*

+ *– yes. it is known to cause problems;* **–** *– no. it is known that it does not cause problems;* **?** *– probably the status was not identified;* **n.d.** *– no scientific data*

A *– Chromosomal aberration (EFSA database);* **B** *– DNA damage/repair (EFSA database);* **C** *– Gene mutation (EFSA database);* **D** *– Genome mutation (EFSA database);* **E** *– Unspecified type of genotoxicity (different data source)*

0 *– No data;* **1** *– Positive;* **2** *– Mixed/ambiguous results;* **3** *– Negative*

Compounds in red font are withdrawn in the EU

Insecticides

The most frequently detected insecticides were neonicotinoids, the presence of which was confirmed in 131 product samples, which constitutes 27% of the tested products. Acetamiprid was recorded in 23 smoothie samples (0.001–0.01 mg/kg), 12 humus samples (0.001–0.004 mg/kg), 10 fruit samples (melons, oranges, grapefruits, pears, apples, blueberries, and grapes) in the concentration range of 0.001–0.209 mg/kg, 3 types of vegetables (cucumber, eggplant, lettuce) at the level of 0.034–0.109 mg/kg, 6 types of tea (black, red, white, fruit, mint, and lemon balm) at concentrations of 0.001–0.064 mg/kg, 12 honey samples (0.001–0.146 mg/kg), and 3 rice samples (0.001–0.003 mg/kg) (fig. 17). Thiacloprid was found in 12 honey samples (0.001–0.528 mg/kg) and 4 types of tea (black, white, green, fruit) at the level of 0.001–0.084 mg/kg. Imidacloprid was confirmed in 10 humus samples (0.001–0.007 mg/kg), 3 types of tea (fruit, white, mint) at concentrations of 0.002–0.013 mg/kg, 2 smoothie samples (0.001 mg/kg), groats buckwheat (0.017 mg/kg), rice (0.007 mg/kg), grapefruit (0.004 mg/kg), and potatoes (0.006 mg/kg). Another detected neonicotinoid was thiamethoxam, present in 6 tea samples (black, fruit, and green) at concentrations of 0.011–0.121 mg/kg, a melon sample (0.002 mg/kg), and a humus sample (0.001 mg/kg). Clothianidin was detected in 3 rice samples (0.001–0.003 mg/kg). Thiamethoxam, imidacloprid, and thiacloprid have been withdrawn in the EU. Acetamiprid irritates the skin through contact exposure. Some evidence suggests it is linked to infertility in humans. Thiacloprid causes negative reproductive and developmental effects in case of chronic exposure, shows neurotoxicity, and irritates the skin and eyes. According to the EPA, it is a probable carcinogen. Imidacloprid is moderately toxic and causes negative reproductive and developmental effects. Thiamethoxam has also been classified by the EPA as a probable carcinogen. Moreover, clothianidin has neurotoxic effects and may cause endocrine disorders in case of chronic exposure (table 31).

Ketoenols were the second most frequently detected insecticides, the only representative of which was spirotetramat found in 48 samples (5.4% of all tested products). It was present in 20 humus samples (0.002–0.351 mg/kg), 12 smoothie samples (0.001–0.048 mg/kg), 9 fruit samples (grapes, grapefruits, lemons, bananas, oranges) at the level of 0.003–0.076 mg/ kg, 5 types of vegetables (broccoli, celery, lettuce, onion, tomatoes) at concentrations of 0.002–0.044 mg/kg, and black fruit tea (0.081 mg/kg) (fig. 17). Spirotetramat is approved in the EU, and its concentrations did not exceed the MRL. Spirotetramat is a skin sensitizer and eye irritant through contact exposure. It may cause negative reproductive effects with chronic exposure. It has moderate acute and chronic toxicity to aquatic organisms and birds. Spirotetramat has a moderate tendency to migrate with drainage water into the soil (table 31).

Organophosphorus insecticides were present in 27 samples, constituting 5.6% of all products analyzed. Chlorpyrifos-methyl was found in 3 mint teas (0.013–0.028 mg/kg), lemon balm tea (0.029 mg/kg), 2 groups of vegetables (radish and cucumber) at the level of 0.003–0.008 mg/kg, 2 fruit samples (orange and grapefruit) in the concentration range of 0.008–0.052 mg/kg, millet (0.017 mg/kg), barley (0.003 mg/kg), and rice (0.008 mg/kg). Pirimiphos-methyl was recorded in 2 samples of buckwheat (0.001–0.002 mg/kg), 4 samples of barley (0.006–0.024 mg/kg), 5 samples of oat flakes (0.01–0.029 mg/kg), and millet (0.012 mg/kg). Malathion was detected in 4 fruit samples (grapefruits and lemons) in the concentration range of 0.011–0.044 mg/kg. Of the organophosphate insecticides detected, chlorpyrifos-methyl has been withdrawn in the EU. Chlorpyrifos-methyl disrupts hormonal balance, causes negative reproductive and developmental effects, and has neurotoxic effects in case of chronic exposure. Pirimiphos-methyl irritates the respiratory tract, eyes, and skin as a result of contact exposure. In turn, malathion causes endocrine problems and has neurotoxic effects. The EPA points to weak evidence suggesting its involvement in cancer development (table 31).

Macrocyclic lactones were present in 10 samples of the tested products, which constitute 2% of all analyzed products. The main representative of this group was spinosad, found in 3 grape samples (0.003–0.175 mg/kg), 2 smoothie samples (0.002–0.003 mg/kg), and tomatoes (0.036 mg/kg) (fig. 17). In turn, emamectin benzoate was recorded in 2 grape samples (0.001–0.009 mg/kg) and tomatoes (0.001 mg/kg). The presence of abamectin was detected in the eggplant sample (0.006 mg/kg). These macrocyclic lactones are approved in the EU, and their concentrations did not exceed the MRLs. Spinosad is suspected of causing negative reproductive and developmental effects under chronic exposure. Moreover, it is characterized by high acute contact and ingestion toxicity toward bees and high chronic toxicity toward *Daphnia. magna*. Spinosad has a moderate tendency to be transported on soil and sediment particles. Emamectin benzoate irritates the eyes and has high acute toxicity toward birds, *Daphnia magna,* and bees. Abamectin has a neurotoxic effect and a potential impact on reproduction in the case of chronic exposure. It is characterized by high acute toxicity toward fish, birds, *Daphnia magna,* bees, and earthworms (table 31).

Fig. 17. Concentrations of detected insecticides (mg/kg) in more than 5 samples of the tested products

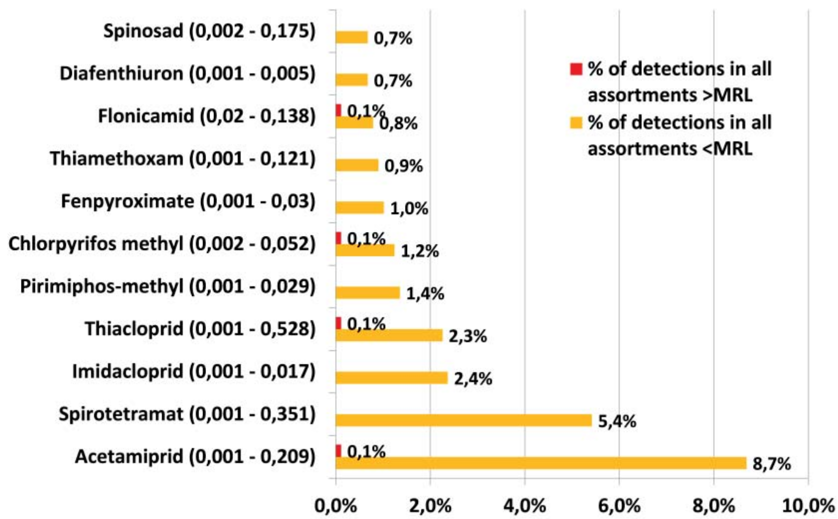


Table 31. Insecticides most frequently detected in tested foods of plant origin and their potential health and environmental effects

	Chemical group	Pesticide	Environmental fate	Ecotoxicity	Human health	Cancers	Mutagen	Hormonal system	Reproduction/development	Neurotoxicity	Respiratory system	Skin irritant	Skin sensitizer	Eye irritant	Phototoxicity
Insecticides	Neonicotinoids	Acetamiprid	yellow	red	yellow	-	A0; B0; C0; D0; E3	n.d.	?	-	-	+	n.d.	?	n.d.
		Thiacloprid	yellow	red	red	?	A3; B0; C0; D0; E3	+	+	+	-	+	-	+	-
		Imidacloprid	red	red	red	-	A3; B3; C3; D3; E2	n.d.	+	?	-	?	n.d.	?	n.d.
		Thiamethoxam	red	red	yellow	?	A3; B3; C3; D0; E0	-	-	-	-	?	n.d.	-	n.d.
		Clothianidin	red	red	red	-	A0; B0; C3; D0; E3	?	?	+	-	-	n.d.	-	n.d.
	Ketoenoles	Spirotetramat	yellow	yellow	yellow	-	A3; B3; C3; D0; E3	-	?	-	?	?	+	+	n.d.
	Organophosphates	Chlorpyrifos	yellow	red	red	-	A3; B3; C3; D0; E3	+	+	+	-	-	?	-	-
		Pirimiphos metyl	yellow	red	red	-	A3; B2; C3; D0; E3	n.d.	?	n.d.	+	+	?	+	-
		Malathion	yellow	red	red	?	A2; B3; C3; D0; E2	+	?	+	?	?	?	-	n.d.
	Macrocyclic lactones	Spinosad	yellow	red	yellow	-	A3; B0; C0; D0; E3	-	?	-	-	-	-	-	-

		Emamectin benzoate				-	A3; B0; C0; D0; E3	n.d.	?	?	n.d.	-	-	+	n.d.
		Abamectin				-	A3; B0; C3; D0; E3	-	?	+	-	-	-	-	n.d.

– Low risk – Moderate risk – High risk

+ *– yes. it is known to cause problems;* **–** *– no. it is known that it does not cause problems;* **?** *– probably the status was not identified;* **n.d.** *– no scientific data*

A *– Chromosomal aberration (EFSA database);* **B –** *DNA damage/repair (EFSA database);* **C** *– Gene mutation (EFSA database);* **D –** *Genome mutation (EFSA database);* **E** *– Unspecified type of genotoxicity (different data source)*

0 *– No data;* **1** *– Positive;* **2** *– Mixed/ambiguous results;* **3** *– Negative*

Compounds in red font are withdrawn in the EU

3.1.3. Toxic Elements

Fruit

It should be noted that some vegetables (e.g., root or leafy vegetables) and fruit show a great absorbability of toxic elements.

The fruit samples were not significantly contaminated with toxic elements, and organic production was not always more favorable than conventional. For example, organic plums, strawberries, and cherries contained higher **lead concentrations** (fig. 18).

In the case **of cadmium,** organic apples had the best results compared to apples from conventional crops, in which the content of this toxic element was the highest among all the tested fruits (fig. 19).

Mercury content was the highest in black currants (organic and conventional), but it did not constitute a health hazard (fig. 20).

Arsenic content in fruit samples was at the ICP–MS detection limit.

Fig. 18. Lead content in fruit samples

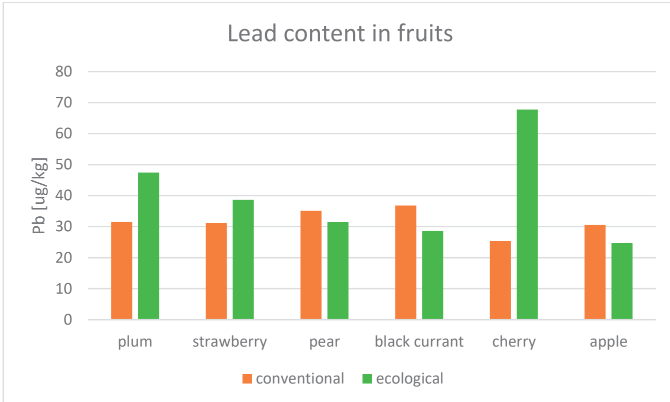


Fig. 19. Cadmium content in fruit samples

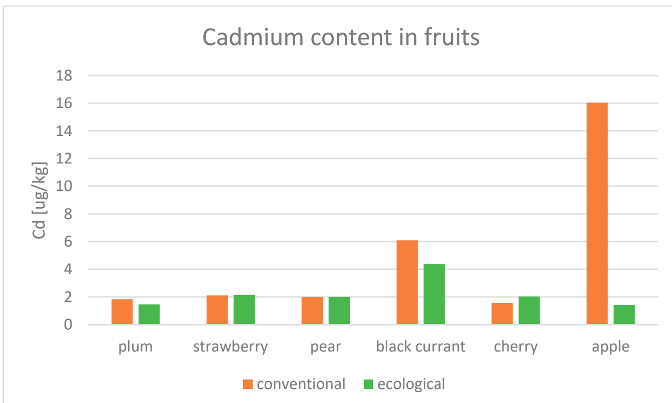
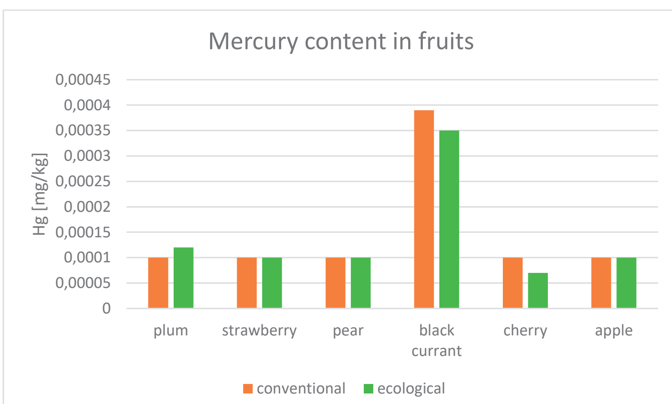


Fig. 20. Mercury content in fruit samples



Vegetables

In vegetable samples, the highest content **of lead** (Pb) (fig. 21) **and mercury** (Hg) (fig. 22) was found in spinach, and **cadmium** (Cd) levels were comparable in all samples (fig. 23), with most cadmium found in spinach, lettuce, and organic broccoli. A similarly unexpected trend was observed in the case of **lead content** in carrots, where it was significantly higher in organic carrots ($p<0.05$).

Arsenic (As) content was low in all samples at the ICP–MS detection limit.

No sample exceeded the permissible content of toxic elements. Most organic vegetables, except those mentioned above, contained lower or comparable levels of contaminants.

Fig. 21. Lead content in vegetable samples

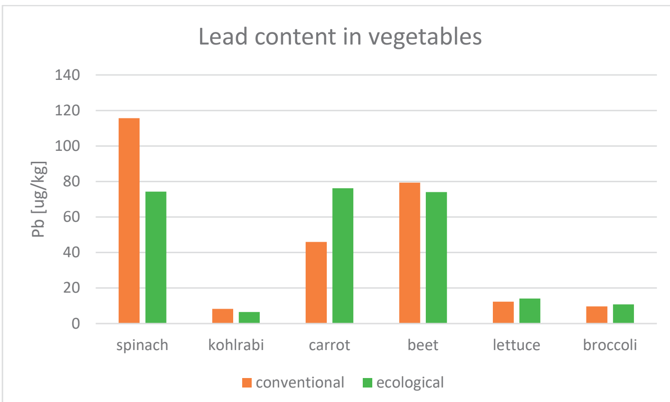


Fig. 22. Mercury content in vegetable samples

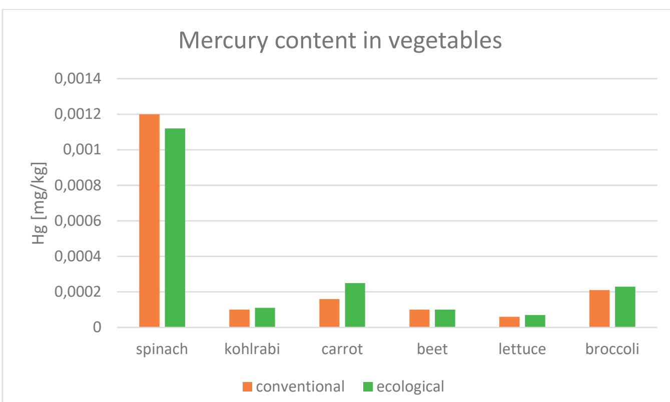
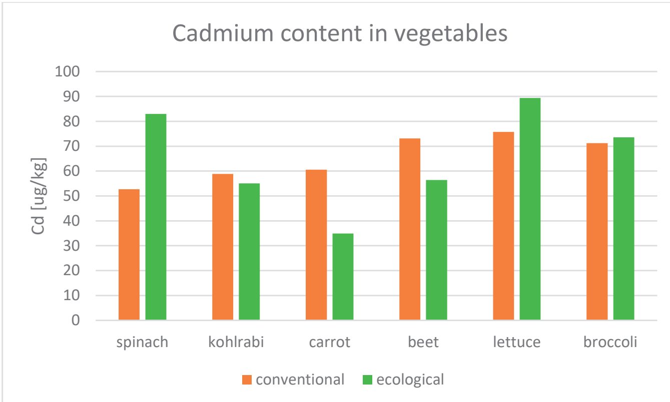


Fig. 23. Cadmium content in vegetable samples



Nuts

Taking into account toxic elements, the highest **cadmium** (Cd) content was found in pine nuts and the lowest in pistachios, Brazil nuts, macadamia nuts, and cashew nuts (fig. 24). The highest **lead** (Pb) was determined in Brazil nuts and peanuts, and the lowest in pistachios and walnuts from conventional crops (fig. 25). The highest concentration **of arsenic** (As) occurred in conventional pistachios and organic pecans, and the lowest in organic hazelnuts, almonds, and walnuts (fig. 26). **Mercury** (Hg) was present in low concentrations in all types of nuts, although the highest values were recorded in conventional pecans and cashew nuts (fig. 27). The average content of toxic elements in the tested nuts was not exceeded. A large proportion of pine nuts had a high **cadmium content** (up to 400 μg/kg), and only peanuts are legally monitored for cadmium content. Similarly, **the arsenic** content in nuts is not monitored, and higher values (above 150 μg/kg) were found in some pecans and pistachios compared to the maximum permissible content, for example, for rice, which is monitored for this toxic element.

Comparing the content of toxic elements **in organic nuts to conventional nuts,** the trend is consistent with expectations: Lower contents were recorded in organic peanuts ($p<0.05$), almonds, pecans, and pine nuts ($p<0.05$) in the case of cadmium; organic peanuts ($p<0.05$), Brazil nuts, hazelnuts ($p<0.05$), macadamia nuts, and almonds had lower lead contents; organic hazelnuts ($p<0.05$), macadamia nuts, almonds, pistachios, and walnuts had lower arsenic contents. However, organic walnuts had significantly higher contents of cadmium and lead ($p<0.05$). Organic pecans, pine nuts, and pistachios also contained a higher lead content, and a significantly higher ($p<0.05$) arsenic content was recorded in organic Brazil nuts. Organic cashew nuts, pecans, and pine nuts also had more arsenic. The mercury content was low in both organic and conventional nuts, but it should be noted that in most cases, samples from conventional cultivation contained a significantly higher content of this toxic element ($p<0.05$) compared to organic peanuts, hazelnuts, cashew nuts, pecans, pine nuts, pistachios, and walnuts.

Fig. 24. Cadmium content in nut samples

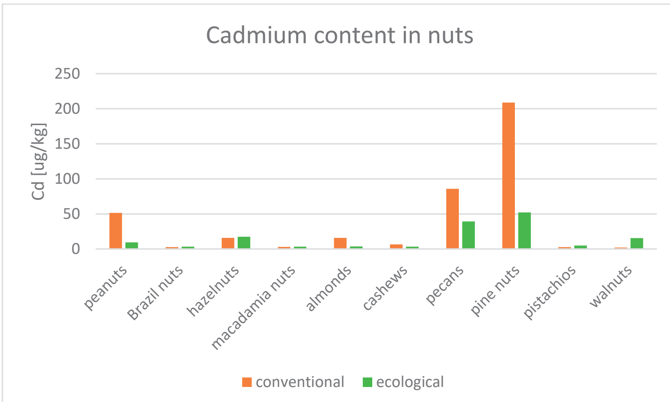


Fig. 25. Lead content in nut samples

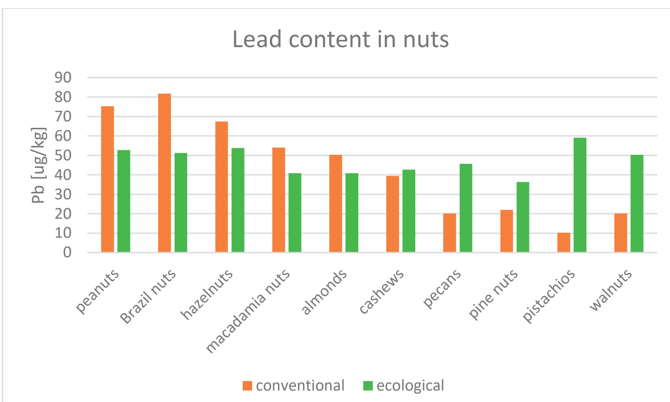


Fig. 26. Arsenic content in nut samples

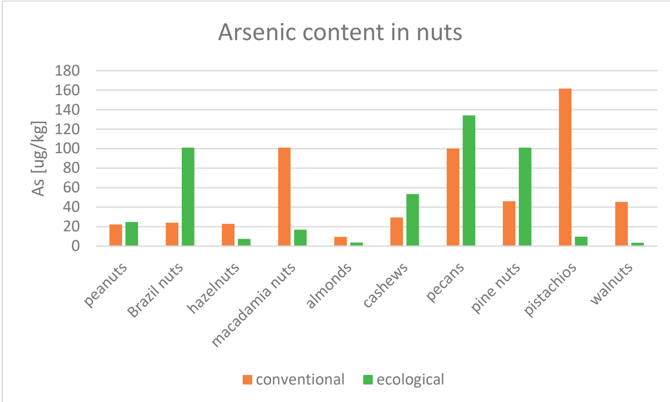
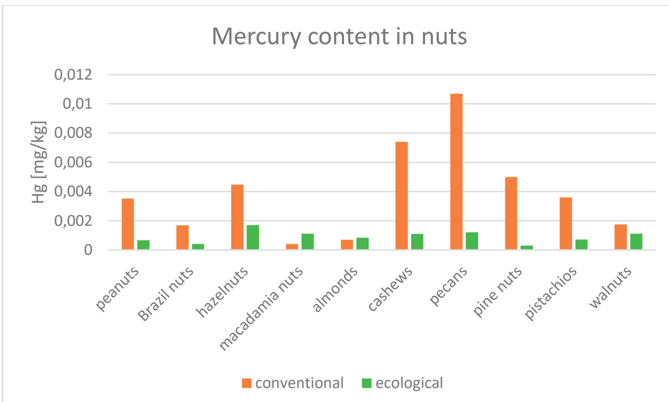


Fig. 27. Mercury content in nut samples



Tea

All types of tested tea contained relatively low concentrations **of cadmium** (Cd), **lead** (Pb), **arsenic** (As), and **mercury** (Hg). It should be noted that tea is consumed in the form of infusions, which contain only some of the tested toxic elements. The maximum permissible content of toxic elements in tea is not defined by law. Our results do not indicate the need for monitoring.

Comparing **toxic elements in organic and conventional tea samples, lead and arsenic** are significantly more often ($p<0.05$) found in conventional than organic production of lemon balm tea (fig. 29, 30). In the case of **mercury,** the tendency was opposite to expectation, with significantly more Hg ($p< 0.05$) in organic lemon balm tea (fig. 31). The **cadmi-**

um content did not differ significantly in organic and conventional teas, but higher concentrations were observed in organic white tea samples (fig. 28). Organic white and black tea also contained more **lead.**

Fig. 28. Cadmium content in tea samples

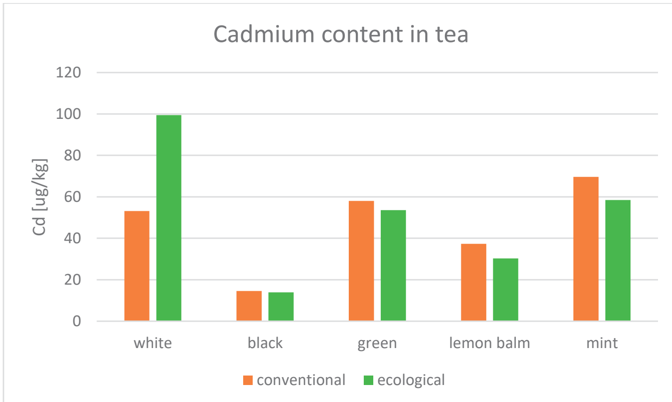


Fig. 29. Lead content in tea samples

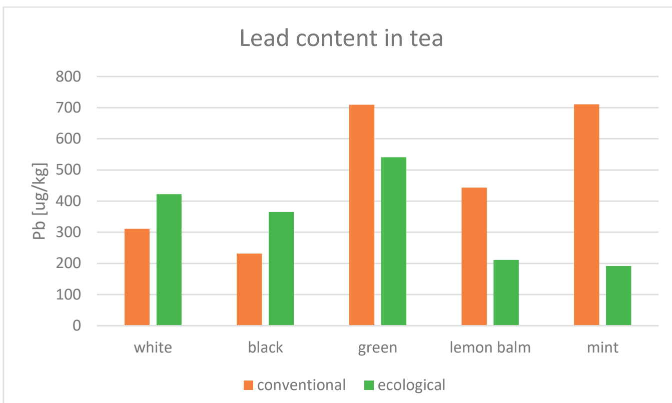


Fig. 30. Arsenic content in tea samples

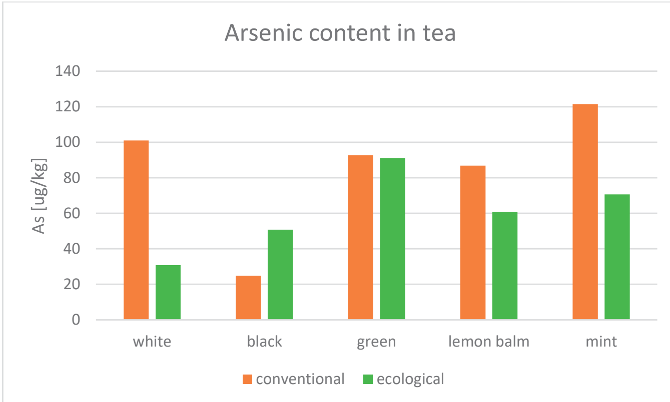
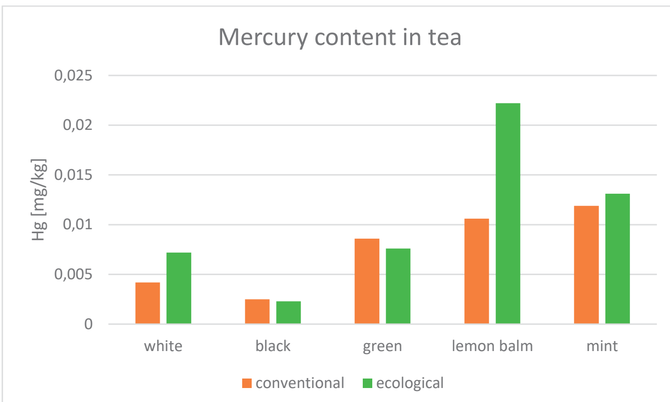


Fig. 31. Mercury content in tea samples



Coffee

In the case of **cadmium, lead,** and **arsenic,** the prediction that organic coffee was less contaminated was correct (fig. 32, 33, 35), while in the case of **mercury,** the opposite was true, with higher mercury content in organic coffee samples. However, these differences were not of statistical significance (fig. 34).

Toxic elements in coffee samples did not pose a health risk. Like in tea, the content of toxic elements in coffee is not officially monitored.

Fig. 32. Cadmium content in coffee samples

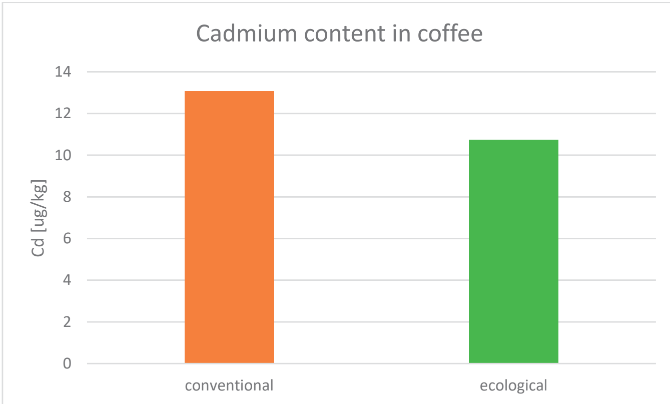


Fig. 33. Lead content in coffee samples

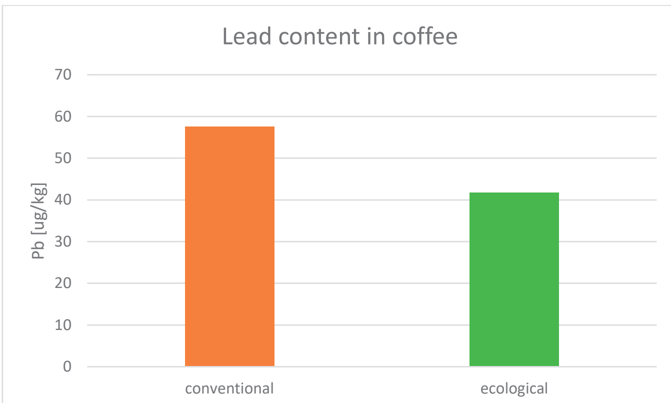


Fig. 34. Mercury content in coffee samples

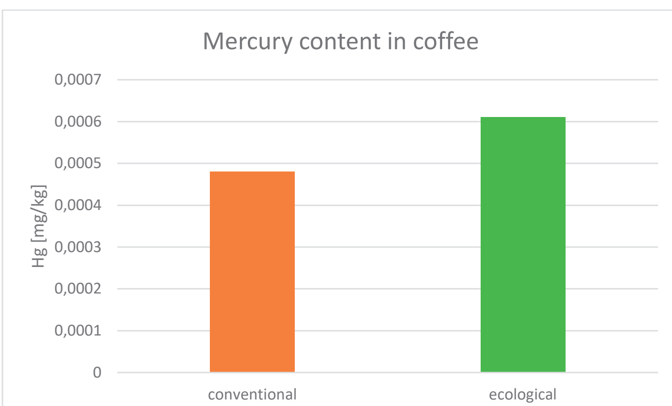
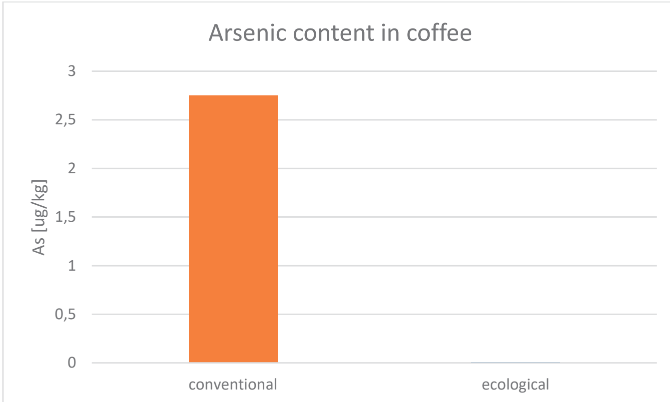


Fig. 35. Arsenic content in coffee samples

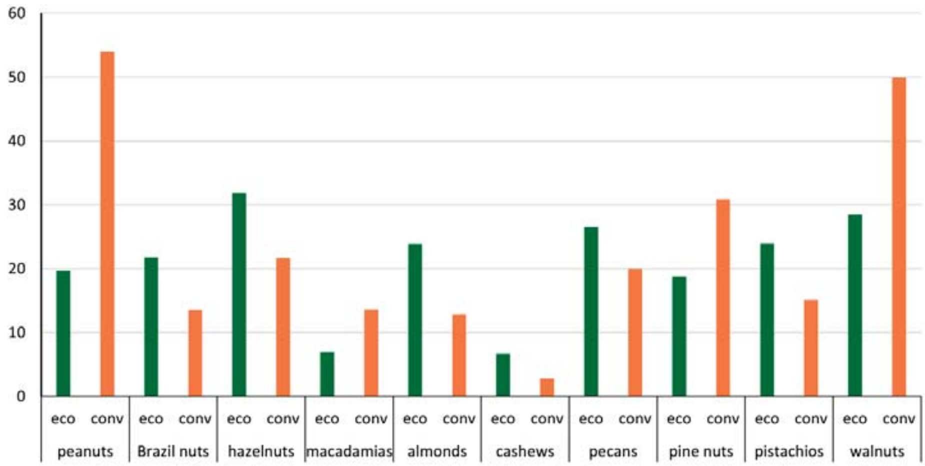


3.2. Biological Pollutants – Mycotoxins in Nuts and Coffee

Nuts

Research results indicate the presence of mycotoxins in all types of nuts. However, conventional peanuts and walnuts were the most contaminated (54 µg/kg and 49.9 µg/kg, respectively), while organic and conventional cashew nuts were the least contaminated (2.8–6.7 µg/kg). In general, organic nuts were more contaminated with mycotoxins, while peanuts, macadamia nuts, pine nuts, and walnuts from conventional production had higher mycotoxin concentrations, by 174%, 95%, 60%, and 80%, respectively (fig. 36).

Fig. 36. Concentration of mycotoxins
in nuts from organic and conventional farming

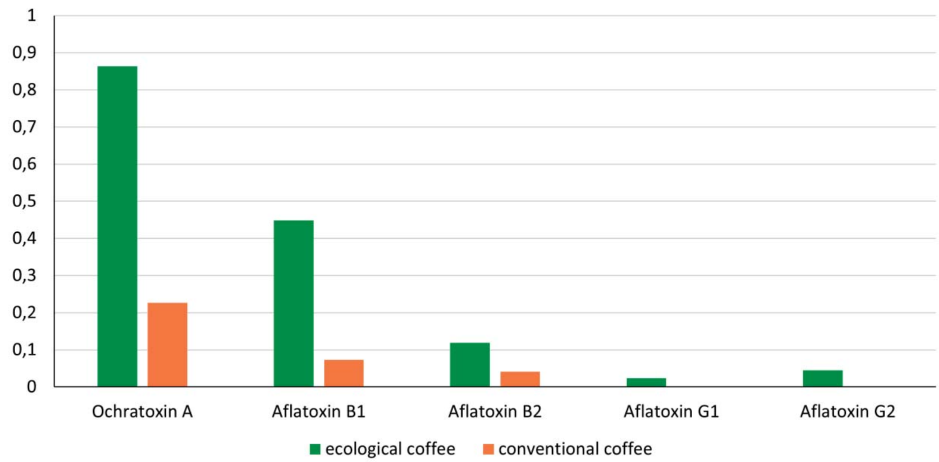


Of the 14 mycotoxins found, HT-2 toxin was commonly detected in all nuts, except almonds, and reached a concentration of 16.2 µg/kg in organic Brazil nuts. In addition, 3-acetyldeoxynivalenol (3-AcDON) and 15-acetyldeoxynivalenol (15-AcDON) were detected at the highest concentrations in conventional peanuts (27.7 µg/kg and 20.4 µg/kg, respectively). The presence of deoxynivalenol (DON) was confirmed in peanuts, pecans, pistachios, and walnuts in the range of 0.3–1.3 µg/kg. High concentrations of fumonisin B1 were found in organic hazelnuts (17.4 µg/kg) and conventional pine nuts (17.8 µg/kg). Relatively low concentrations of aflatoxins B1 and G1, DON, and T-2 toxin were found in all nut samples at 0.2–4.1 µg/kg. Zearalenone (ZEN) and ochratoxin A (OTA) were not detected in the tested nuts.

Coffee

The results indicate that among the 14 mycotoxins analyzed, coffee samples contained mainly aflatoxins and ochratoxin A. Organic coffee samples were the most contaminated with mycotoxins (1.5 µg/kg), and the least contaminated were samples from conventional production (0.34 µg/kg). Ochratoxin A was present at the highest concentration (0.86 µg/kg in the case of organic coffee and 0.23 µg/kg in the case of conventionally grown coffee) (fig. 19). Aflatoxins occurred in lower concentrations, and aflatoxin B1 was the most common (0.45 µg/kg and 0.07 µg/kg in the organic and conventional coffee samples, respectively). Aflatoxin B2 was present in lower concentrations (0.12 µg/kg and 0.04 µg/kg). Aflatoxins G1 and G2 were present only in samples from organic farming (0.02 μg/kg and 0.04 μg/kg, respectively) (fig. 37).

Fig. 37. Concentrations of mycotoxins
in coffee from organic and conventional farming



3.3. Beneficial Components in Food of Plant Origin

3.3.1. Mineral Content

Fruit

Blackcurrant samples had a significantly high calcium (Ca) content, regardless of the cultivation method, and its content in organic and conventional production was comparable (fig. 38). Blackcurrants, strawberries, and cherries had the highest magnesium (Mg) content (fig. 39). The method of cultivation (conventional vs. organic) did not significantly impact its content.

Fig. 38. Calcium content in fruit samples

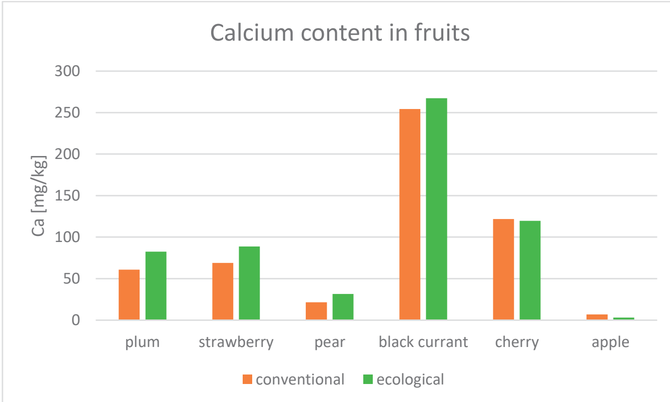
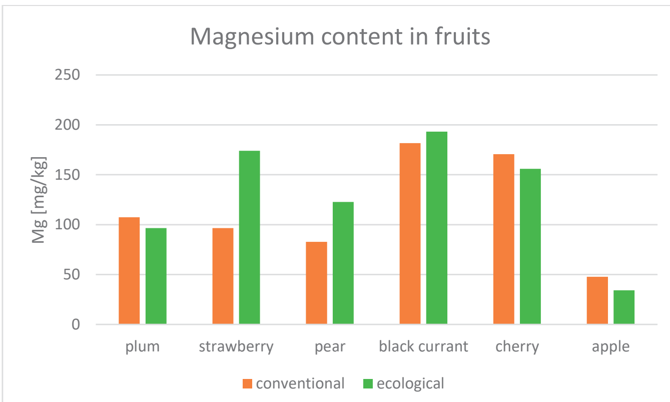


Fig. 39. Magnesium content in fruit samples



Blackcurrants also had the highest content of the tested micronutrients, i.e., **iron** (Fe), **zinc** (Zn), and **copper** (Cu), both in organic and conventionally grown fruit (fig. 40, 41, 42).

Fig. 40. Iron content in fruit samples

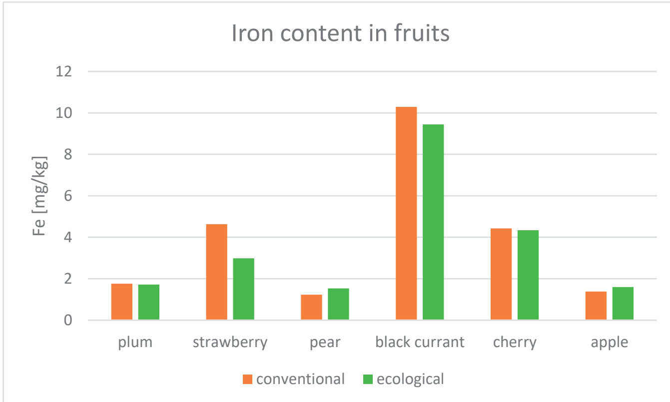


Fig. 41. Zinc content in fruit samples

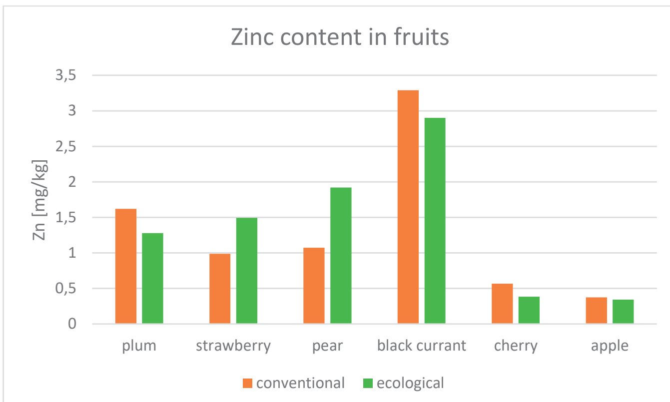
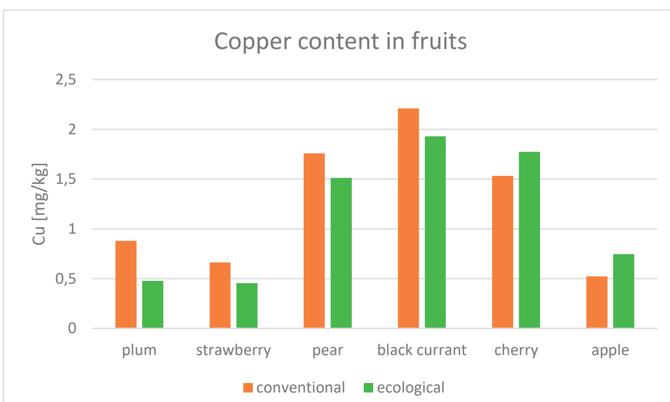


Fig. 42. Copper content in fruit samples



Vegetables

Spinach had the highest **calcium** (Ca) content, and no significant differences were noted for organic and conventional production (fig. 43).

Magnesium (Mg) content was also determined in spinach, with significantly higher results ($p<0.05$) for samples from conventional compared to organic farming (fig. 44).

Fig. 43. Calcium content in vegetable samples

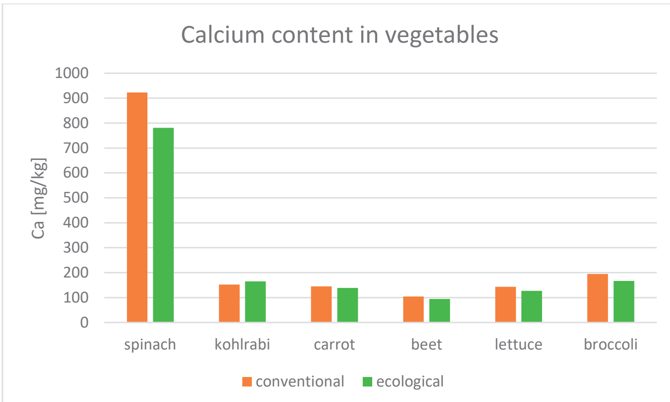
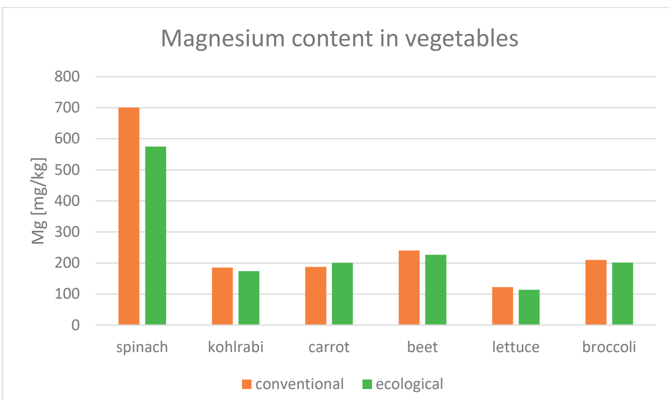


Fig. 44. Magnesium content in vegetable samples

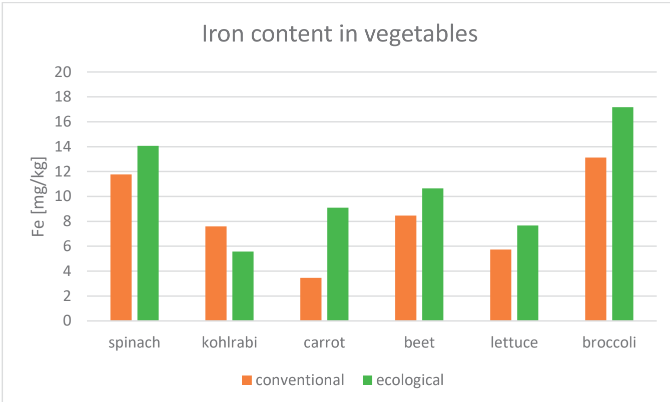


Iron (Fe) content was recorded in broccoli and spinach samples.

It is worth noting that the spinach samples did not differ significantly in Fe content from other vegetables, e.g., broccoli, beets, or carrots from organic farming, which refutes the long-standing myth about the extraordinarily high iron content in this vegetable.

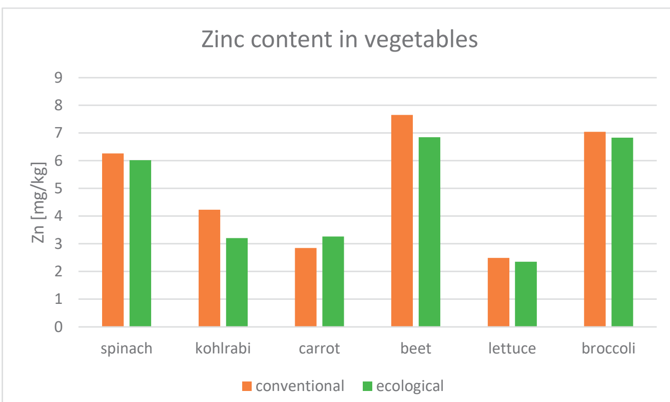
In terms of **Fe** content in samples from conventional and organic crops, a significantly ($p<0.05$) higher content of this micronutrient was recorded in organic carrots and kohlrabi from conventional crops (fig. 45).

Fig. 45. Iron content in vegetable samples



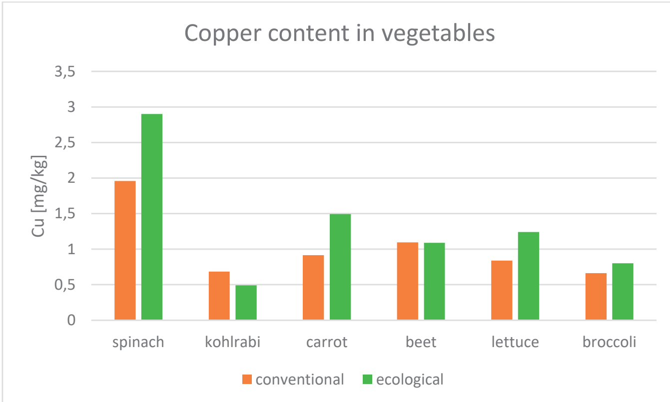
The highest content **of zinc** (Zn) was found in beetroot, broccoli, and spinach samples. Statistical significance ($p<0.05$) for this element was noted only in the case of kohlrabi, where samples from conventional farming had a higher content than organic kohlrabi (fig. 46).

Fig. 46. Zinc content in vegetable samples



In turn, the highest **copper** (Cu) content was recorded in spinach samples. Organic carrot samples contained a significantly higher ($p<0.05$) content of this micronutrient compared to carrots from conventional production (fig. 47).

Fig. 47. Copper content in vegetable samples



Nuts

The highest **magnesium** (Mg) content was found in pecan nuts, pine nuts, and pistachios (fig. 49), **calcium (Ca)** in organic peanuts (fig. 48), and **iron** (Fe) in Brazil nuts, pistachios, and walnuts, with walnuts from organic farming containing significantly less Fe ($p<0.05$) compared to nuts from conventional cultivation (fig. 50). The highest contents of **zinc** (Zn) were found in pistachios, cashew nuts, and peanuts (fig. 51), while **copper** (Cu) in peanuts, pine nuts, and pistachios (fig. 52). Organic pine nuts contained significantly more of this micronutrient ($p<0.05$), while a significantly higher Cu content ($p<0.05$) was recorded in conventionally grown pistachios.

When comparing **organic and conventional nuts,** in most cases, conventional nuts contained higher concentrations of the tested macro- and micronutrients, or their content was comparable. The exceptions were organic pine nuts, which had a higher content of all elements, as well as pistachios, where organic samples contained higher concentrations of magnesium, calcium, and zinc, and organic macadamia nuts, which had a higher content of magnesium, iron, and copper.

Fig. 48. Calcium content in nut samples

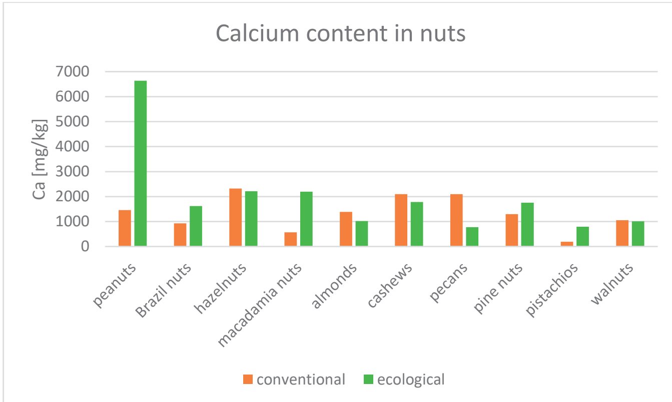


Fig. 49. Magnesium content in nut samples

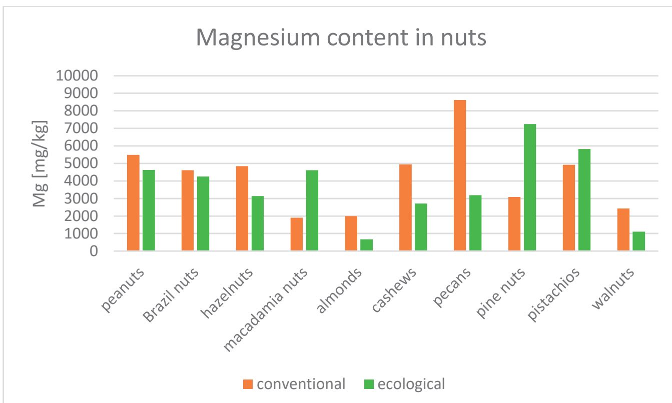


Fig. 50. Iron content in nut samples

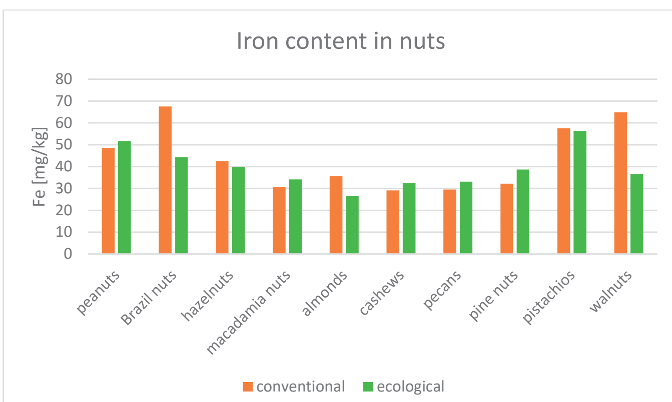


Fig. 51. Zinc content in nut samples

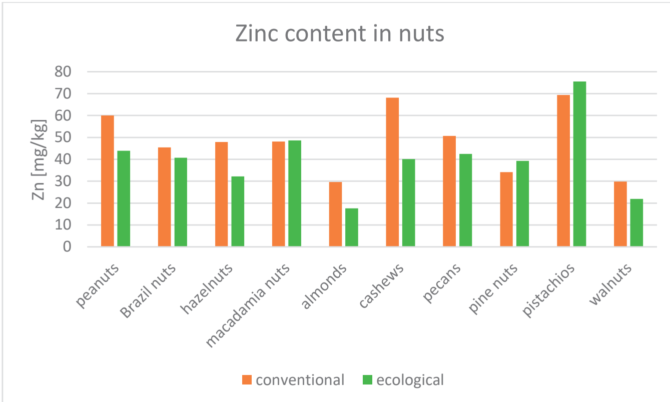
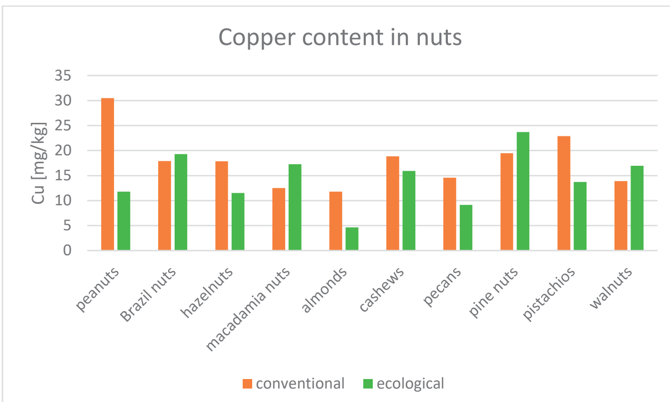


Fig. 52. Copper content in nut samples



Tea

As part of the project, various popular types of tea were tested for beneficial and toxic elements. Mint tea had the highest content of selected macronutrients: **calcium** (Ca), **magnesium** (Mg), and micronutrients: **iron** (Fe) **and zinc (Zn).** High Ca, Mg, and Zn levels were also recorded in lemon balm tea samples. Black tea samples had the highest content of **copper** (Cu).

Comparing **organic and conventional tea** samples in terms of beneficial minerals, conventional green tea had a significantly higher ($p<0.05$) **calcium content** (fig. 53), while organic green tea contained significantly more ($p<0.05$) **magnesium** (fig. 54). In the case of **iron,** no significant differences were found between organic and conventional samples (fig. 55). Organic lemon balm tea had a significantly higher ($p<0.05$) **zinc** content (fig. 56), and conventional lemon balm tea had a significantly higher ($p<0.05$) **copper** content (fig. 57). Taking into account the more favorable Cu/Zn ratio in certified organic lemon balm tea samples, it can be concluded that such tea offers better antioxidant protection compared to conventional lemon balm tea.

There were no significant differences in the content of macro– and micronutrients between organic and conventional black tea samples.

Fig. 53. Calcium content in tea samples

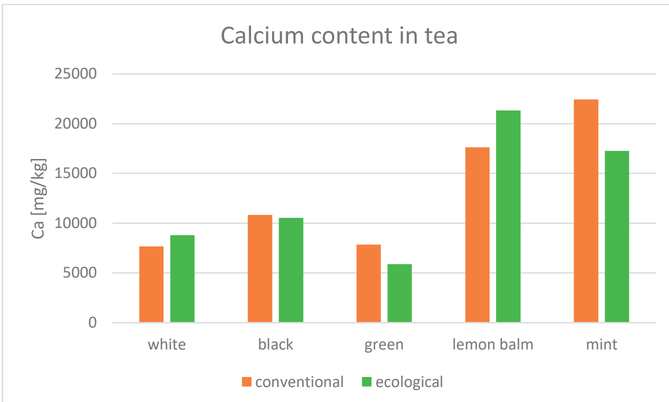


Fig. 54. Magnesium content in tea samples

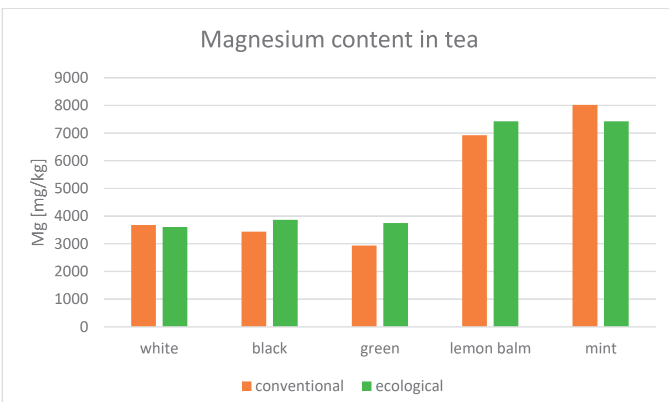


Fig. 55. Iron content in tea samples

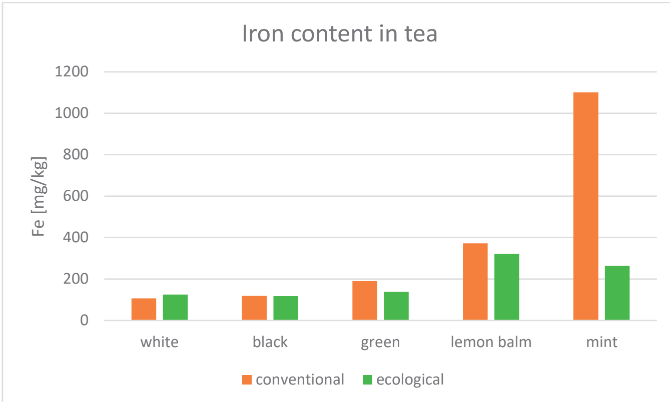


Fig. 56. Zinc content in tea samples

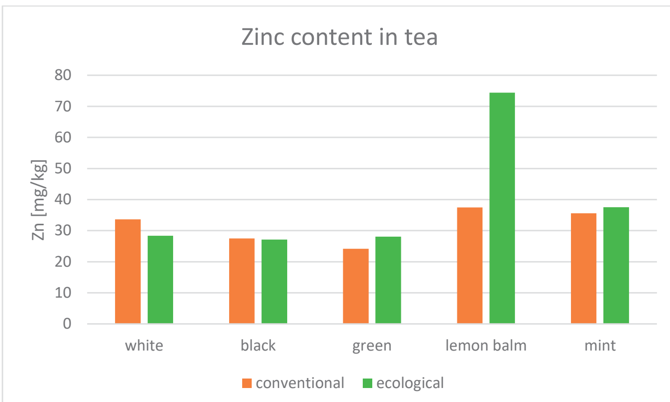
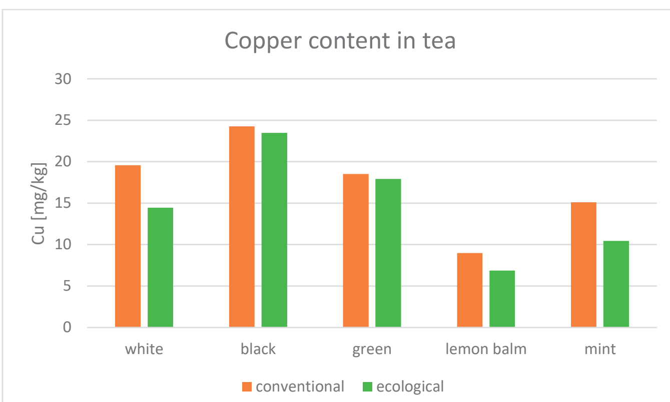


Fig. 57. Copper content in tea samples



Coffee

As part of the study to assess the content of macronutrients **(calcium, magnesium)** and micronutrients **(iron, zinc, copper)** in coffee, their higher contents were found in conventional compared to organic coffees (fig. 58, 59, 60, 61, 62), with statistical significance ($p<0.05$) noted only in the case of calcium.

Fig. 58. Calcium content in coffee samples

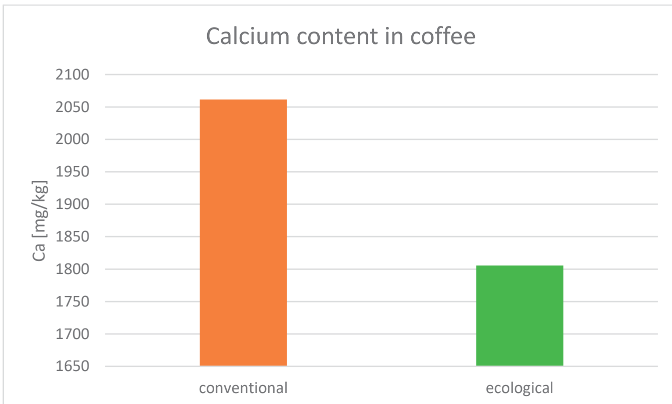


Fig. 59. Magnesium content in coffee samples

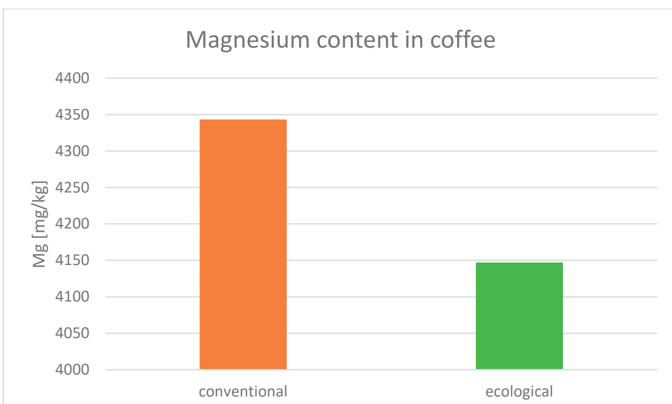


Fig. 60. Iron content in coffee samples

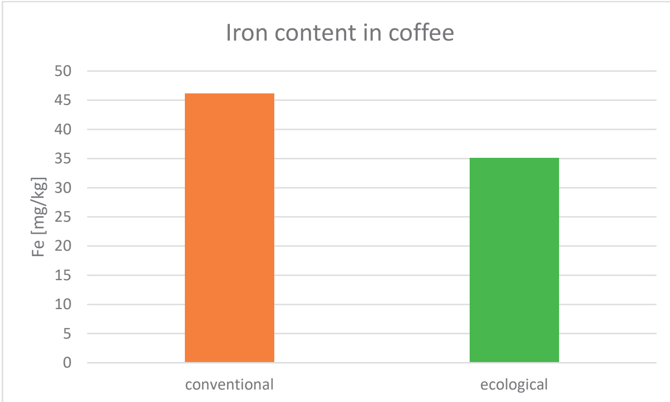


Fig. 61. Zinc content in coffee samples

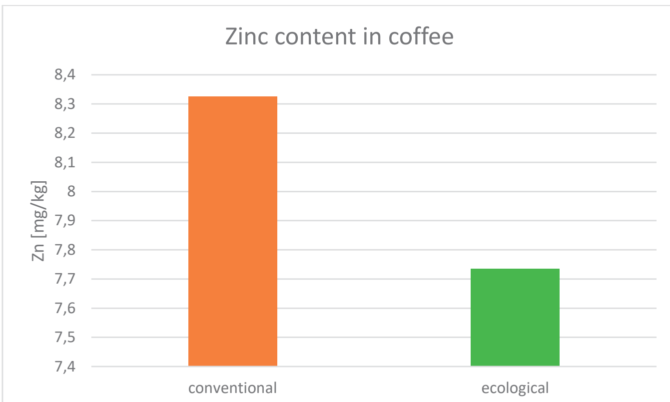
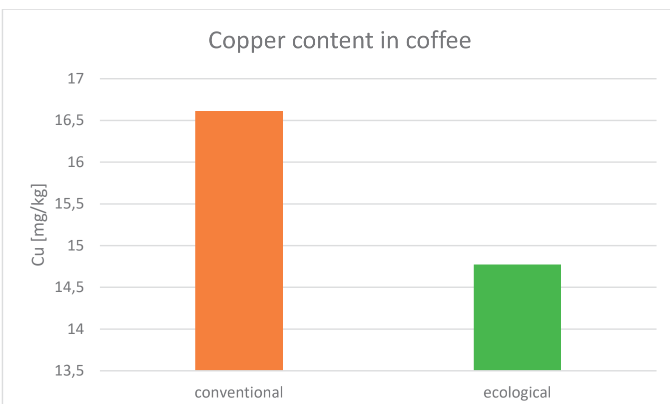


Fig. 62. Copper content in coffee samples

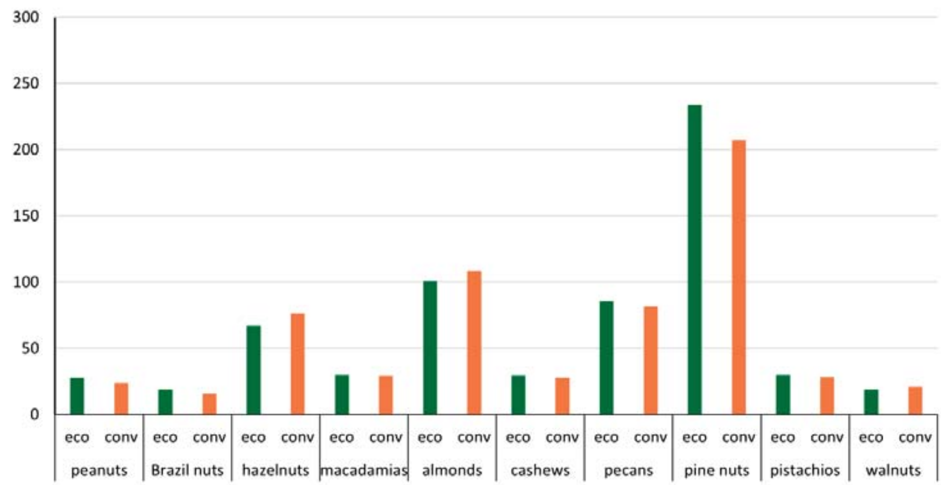


3.3.2. Selected Nutrients in Nuts

Amino Acids

The research results indicate different amino acid content in individual types of nuts. The highest concentration was found in pine nuts (233.87 g/kg), followed by almonds (108.43 g/kg), pecans (85.72 g/kg), and hazelnuts (76.29 g/kg) (fig. 63). The lowest amino acid content was determined in Brazil nuts (15.69 g/kg). In most organic samples, this farming system resulted in higher amino acid content, with the largest difference in pine nuts (12%). In the case of hazelnuts, walnuts, and almonds, the conventional cultivation system increased the amino acid content by 12%, 10%, and 7%, respectively.

Fig. 63. Concentrations of amino acids
in nuts from organic and conventional farming



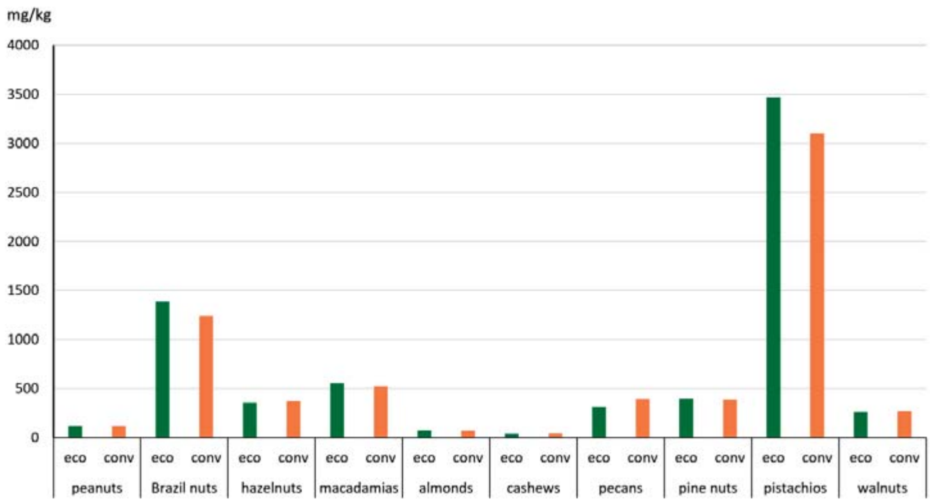
Among exogenous amino acids, the highest concentration was found for tryptophan (21.24 g/kg in pine nuts), 5.28 g/kg in pecans, and 2.90 g/kg in almonds. The next most common amino acid was phenylalanine, detected in the highest concentration in hazelnuts (5.38 g/kg) and almonds (4 g/kg). Among endogenous amino acids, aspartic acid (0.5 g/kg), glutamine (1.03 g/kg), and alanine (0.39 g/kg) had the highest concentrations in almonds.

Vitamins

The highest content of vitamins (A, E, B1, B2, B3, B5, B6, and B9) was confirmed in pistachios (3471.4 mg/kg) and Brazil nuts (1388.4 mg/kg). Cashew nuts (39.8 mg/kg), almonds (65.5 mg/kg), and peanuts (116.2 mg/

kg) had the lowest vitamin content. In the case of pistachios, Brazil nuts, macadamia nuts, and pine nuts, the organic cultivation system resulted in higher vitamin content, with the most significant difference recorded between organic and conventional pistachios (12%) (fig. 64).

Fig. 64. Vitamin concentrations
in nuts from organic and conventional farming



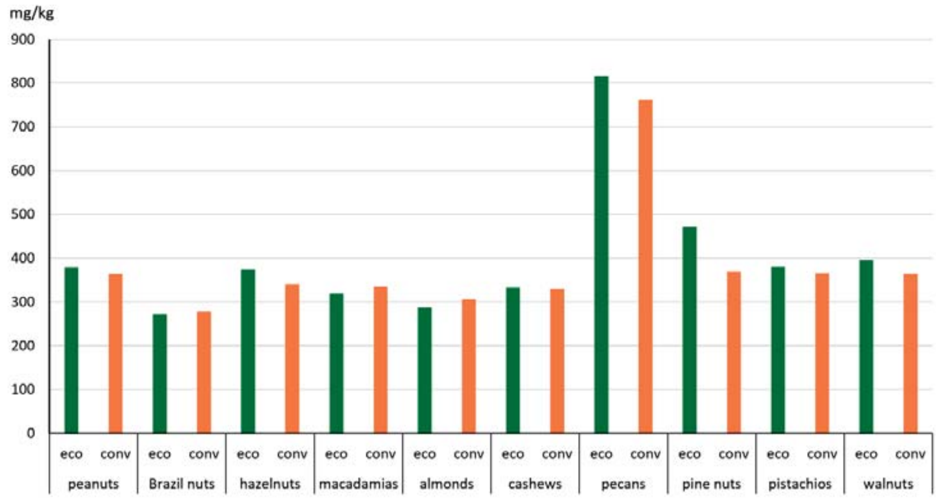
Vitamin A reached the highest content in pistachios (3054.8 mg/kg) and was absent in peanuts and cashew nuts. High levels of vitamin B9 were found in Brazil nuts (186.3 mg/kg) and pistachios (361.9 mg/kg), but the vitamin was not found in hazelnuts, macadamia nuts, and pine nuts. A high concentration of vitamin E was determined in hazelnuts (100.6 mg/kg), while the highest concentration of vitamin B3 was found in peanuts (95.5 mg/kg). Cashew nuts and almonds had a low content of all analyzed vitamins. Vitamin B1 was not found in pine nuts, and vitamin A was absent in peanuts and cashew nuts.

3.3.3. Selected Antioxidants in Nuts

Phenolic Acids

The concentration of phenolic acids was comparable in all nuts tested, with the highest levels found in pecan nuts (816.6 mg/kg), pine nuts (471.7 mg/kg), and walnuts (396 mg/kg). Most organic samples had a higher content of phenolic acids (28% more in the case of organic pine nuts compared to conventional ones). This content was higher in organic hazelnuts, walnuts, and pecans compared to conventional ones by 10%, 9%, and 7%, respectively (fig. 65).

Fig. 65. Concentrations of phenolic acids in nuts from organic and conventional farming



Cinnamic acid was found in the highest concentration in most nuts. Its content in walnuts was 267 mg/kg. Coumaric acid was found in the highest concentration in pine nuts (156.7 mg/kg). Pecans had the highest content of gallic acid (663 mg/kg), while almonds had the highest concentration of gentisic acid (154 mg/kg). Of the 11 phenolic acids, sinapic acid had the lowest concentration. The presence of caffeic acid was not confirmed in Brazil nuts, hazelnuts, and pine nuts, while caffeic acid reached a high level in pistachios (72.1 mg/kg). The presence of vanillic acid was not detected in any of the nuts sampled.

4. Research Conclusions

One of the pillars of the European Commission's activities is care for consumer health and the environment. Therefore, the EC systematically reviews agrochemicals and, as a result, withdraws many dangerous pesticides from the European market every year.

It is worth noting that pesticides are widely used in developing countries, and the demand is growing due to the current agricultural production system, which is focused on obtaining high yields. Pesticides in these countries may provide the only available form of crop protection, especially when changing weather conditions due to global warming increase uncertainty about crop yields. Developing countries, in particular, lack the resources and expertise to enforce pesticide residue regulations. This fact is vital for ensuring the safety of European consumers who eat products from all over the world, subject to various regulations in relation to chemical and biological contamination standards.

European chemical companies supply third countries with pesticides banned in the EU. These pesticides go mainly to South America, Asia, Africa, and European countries outside the EU, with their main recipients being Brazil, Ukraine, and South Africa. Pesticides banned in the EU that are exported include neonicotinoids, chlorpyrifos, atrazine, chlorothalonil, and paraquat.

Nevertheless, it should be noted that the production and export of EU-banned pesticides are fully consistent with EU law, and the residues of such substances are still detected in food imported from outside the EU. This research confirmed the presence of these banned pesticides in plant products.

Between 2020 and 2023, a total of 29 active substances found in pesticides were withdrawn. Thanks to the European Green Deal, which stipulates, among other things, that by 2030, the use of pesticides will be reduced by 50% (and in the case of more dangerous ones, by 65%), the synthetic pesticide market is undergoing profound changes. In 2020, the nine most dangerous substances were withdrawn (i.e., thiuram, chlorothalonil, propiconazole, pymetrozine, diquat, dimethoate, chlorpyrifos, desmedipham, and methoxyfenozide); another eight were banned in 2021 (i.e., bromoxynil, benalaxyl, thiophanate-methyl, mancozeb, beta-cyfluthrin, thiacloprid, chlorsulfuron, and fenpropimorph), and further nine in 2022 (i.e., epoxiconazole, phosmet, haloxyfop-P, imidacloprid, cyproconazole, alpha-cypermethrin, famoxate, and flutriafol, indoxacarb); another three in 2023 (oxamyl, sulfoxaflor, and prochloraz); followed by and benfluralin, S-metolachlor, triflusulfuron-methyl, ipconazole, dimoxystrobin, metiram, benthiavalicarb, abamectin, and clofentezine in 2024.

With growing global concerns about human, animal, and environmental health and sustainable food production, moving away from exclusive reliance on pesticides is becoming crucial. A leading example of this approach is integrated plant protection, which involves the use of natural predators and biopesticides in combination with mixed crops and crop rotation, which is recommended by the EU and the Food and Agriculture Organization of the United Nations. International agreements place responsibility on governments to ensure access to safe food, which means food that is safe at every stage, from initial production to final consumption, and to set maximum levels of pesticides.

According to EFSA data, 7.6% of food samples imported from third countries into the EU exceeded pesticide limits.[25] This rate was higher than for food produced in the EU, at 2.6%. The most effective way to ensure safer, residue-free imports is to implement better monitoring and control systems in countries of origin. EU regulatory practice requires that products from countries with previously high MRLs be subject to additional testing.

The widespread use of pesticides in agricultural production makes it difficult to assess the health effects of exposure to their residues in food. Food products contain not only single substances but also their mixtures. The detected levels of pesticide residues are usually so low that their harmful effects at these concentrations are excluded, but there are cases where otherwise is true. However, the likelihood of overlapping toxic effects of substances with a similar mechanism of action poses a health risk. Attempts are being made to create a model to estimate the cumulative risk for consumers resulting from a mixture of active substances in one product or the consumption of several products containing residues of various pesticides.

These studies confirmed the presence of samples containing pesticide cocktails, i.e., multiple pesticides per sample.

Fruit samples with one pesticide accounted for 5%, while the remaining contained 2 to 18 active substances (grapes from Portugal had a sum of concentrations of 1.7 mg/kg). Most samples (18%) contained 6 pesticides, while residues of three and five compounds were found in 11% of the samples, and 9% of samples contained nine to 15 pesticides. For example, in grapefruits (USA), beflubutamid was detected at twice the standard level, and 4 active substances banned in the EU were found (bromopropylate, chlorpyrifos, oxadixyl, and imidacloprid). Oranges (Italy) contained the EU-banned chlorpyrifos at a concentration five times higher than the MRL, as well as acetamiprid, imazalil, and pyrimethanil.

One pesticide was found in 8% of vegetable samples, while the rest contained two to nine active substances (leek from Belgium had a sum of concentrations of 0.19 mg/kg: ametoctradin, boscalid, propamocarb, dimethomorph, fludioxonil, fluopicolide, pyrimethanil, prothioconazole, and

25 EFSA et al., The 2022 European Union report on pesticide residues in food, „EFSA Journal” 2022, 22(4), e8753, https://doi.org/10.2903/j.efsa.2024.8753.

tebuconazole). Multiple pesticides per sample were common and included two and five pesticides (19%), three in 11% of the samples, four and six pesticides in 8% of the samples, seven in 6% of the samples, and nine in 5% of the vegetable samples.

For humus, only multi-residue samples were found, and five to nine pesticides were recorded. The smallest number of pesticides detected in the sample was five (23%), and six were present in 32%, seven in 14%, eight in 4%, nine in 23%, and 11 in one sample (4%).

In tea samples, 14% had one pesticide, while the rest contained two to eight active substances. Two pesticides were present in 11% of the samples, three were detected in 9%, four were found in 3%, five were present in 2%, and six and eight in 8%. Two samples of black fruit tea from China had eight pesticides, with total concentrations of 0.13 mg/kg and 0.16 mg/kg.

Smoothies contained the fewest samples (6%) with one pesticide, while the rest contained two to nine active substances. The highest number of nine pesticides was found in a smoothie sample from Spain (blackberry–apple–raspberry–blackcurrant), with a total concentration of 0.04 mg/kg, and a smoothie sample from Poland (banana–apple–strawberry), with a total concentration of 0.15 mg/kg. Most samples (23%) contained three pesticides, two and seven were found in 14% of the samples, five residues were recorded in 11%, while one, six, eight, and nine pesticides were detected in 6% of the smoothies.

The groats with one pesticide constituted 28%, while the remaining had two (12%), three (10%), and four pesticides (6%).

In addition, 37% of honey samples contained one pesticide, 17% contained two, and 5% three pesticides.

In accordance with EU legislation (Article 32 of Regulation 396/2005), the European Food Safety Authority presents an annual report assessing the levels of pesticide residues in food on the European market. As part of the monitoring coordinated by the EU in 2022, 11,727 samples were analyzed, of which 51.4% did not contain pesticides, 48.6% had pesticide residues, and 1.6% of samples exceeded the MRLs.[26] The presence of more than one pesticide was confirmed in 32.1% of samples. Multi-residue products of plant origin (above 10%) included apples (18.6%), strawberries (17.5%), peaches (16.9%), tomatoes (14.2%), and lettuce (12.4%). The most pesticides were detected in a sample of tomatoes, which con-

26 *Ibid.*

tained 16 different compounds, and in strawberries, which contained 15 different pesticides. The tomatoes were grown in the EU, while the origin of the strawberries is unknown.

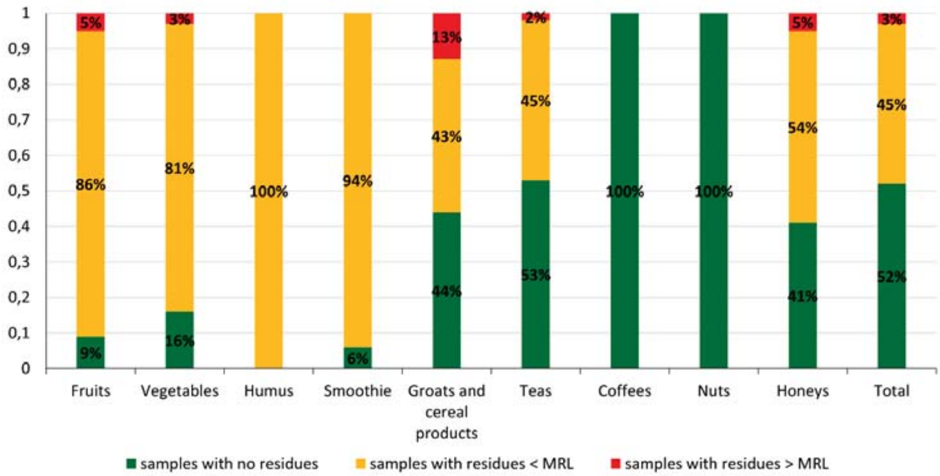
As part of the monitoring of EU countries, in 2022, 59% of the 110,829 samples analyzed were residue-free, 36.3% were below the MRLs, and 3.7% exceeded the MRLs.[27] The 2022 EFSA report indicates that in Poland, as part of official control, 4,706 samples of vegetables, fruits, and cereals were tested for pesticides. No pesticide residues were found in 42.7% of the samples, pesticides below the MRLs were detected in 50%, and the MRLs were exceeded in 7.3% of the samples. Moreover, the EFSA report shows that products originating from Poland had the highest percentage of pesticide-free samples compared to imported plant products.

This examination of 479 samples of food of plant origin and honey for 583 pesticides confirms the occurrence of chemical contamination, which may, in some cases, raise consumer concerns and affect food safety. No pesticides were found in 52% of the samples, 45% contained them within safe limits, and 3% exceeded safe limits (fig. 66).

Among the analyzed ten commonly consumed products, such as fruits, vegetables, herbs, tea, coffee, humus, smoothies, honey, groats and cereal products, and nuts, only coffee and nuts did not contain pesticides. The survey indicates that respondents do not know the characteristics of safe food, and most classify it as pesticide-free. Meanwhile, safe foods may contain pesticide residues below the MRLs, which is confirmed by this design study. Most of the tested products contained pesticides below safe limits and did not pose a threat to human health.

27 *Ibid.*

Fig. 66. List of food pesticide residues and compliance with the MLRs



Disturbingly, pesticides were found in over 91% of fruit samples, exceeding safe limits in 5% of samples. Of the 70 pesticides found (with the highest concentration at 2.43 mg/kg) in fruit originating from third countries: Peru, Costa Rica, Ecuador, Colombia, and the USA and the EU: Portugal, Greece, Italy, and Spain, 16 (23%) are not approved for use in the EU. i.e., trifruralin, thiamethoxam, flutriafol, epoxiconazole, triflumuron, carbendazim spiromesifen, imidacloprid, bromopropylate, oxadixyl, chlorpyrifos, bifenthrin, diafenthiuron, fenpropimorph, myclobutanil, and fenbutatin oxide. Due to the common occurrence of fungal diseases in fruit cultivation and the protection of fruit against them during transportation, fungicides were the most common (45 found). Pests are less of a problem, and three times fewer insecticides were used for protection (21 found), while herbicides were detected sporadically (four found). Of the 14 species of fruit tested, only a sample of blueberry and avocado each were free from contaminants (32% and 72%). Oranges and grapefruits contained pesticides exceeding the MRLs in 32% and 20% of the samples, and pesticides below the MRLs were detected in 68% and 80% of the samples. All tested pineapples, bananas, lemons, pears, apples, kiwifruit, mangoes, melons, strawberries, and grapes contained pesticides below the MRLs. Such a common occurrence of pesticides in fruit should encourage consumers to wash them very carefully, if possible, remove the skin before consumption, and limit their consumption by small children who do not have a well-developed immune system.

There is also great concern about the presence of pesticides in over 84% of vegetable samples, including above the MRL for flonicamid in a sample of Chinese cabbage from Poland (3%). Of the 40 pesticides detected (with the highest concentration at 7.89 mg/kg) in vegetables from Poland and imported from the EU: Italy, Cyprus, Spain, Germany, and from outside the EU: USA, seven are prohibited for use in the EU, i.e., benthiavalicarb isopropyl, flutriafol, prochloraz, dichlorate, diafenthiuron, fenbutatin oxide, and imidacloprid. Due to the common occurrence of fungal diseases in vegetable cultivation, fungicides were the most common (29 pesticides). Pests are less of a problem, and three times fewer insecticides were used for protection (11 found), and no herbicides were detected. Of the 15 vegetables tested, pesticides were found in all (100%) samples of Chinese cabbage, eggplants, garlic, parsley, cucumbers, peppers, tomatoes, leeks, radishes, lettuce, and celery contained pesticides, in 70% of potatoes and broccoli, and 40% of onions. The most pesticide residues were detected in leeks, tomatoes, and potatoes.

All humus samples (100%) contained pesticides, including those banned in the EU, mainly the imidacloprid/carbendazim combination. Thirteen compounds were found (with the highest concentration of 0.352 mg/kg), including four not approved for use in the EU, i.e., imidacloprid, thiamethoxam, carbendazim, and thiophanate-methyl. Due to the common occurrence of fungal diseases in the cultivation of vegetables intended for humus, fungicides were most frequently reported (nine pesticides). Pests are less of a problem, and twice as many insecticides were used for protection (four pesticides), and no herbicides were detected.

Smoothies were the second group of products with the highest percentage of samples (94%) containing residues only below the MRLs. Eighteen pesticides were determined, including 4 (22%) not approved for use in the EU in samples from Germany, Spain, and Poland, i.e., haloxifop, fluazifop, carbendazim, and imidacloprid. Due to the fruit and vegetable composition and the prevalence of fungal diseases, fungicides were the most common (12 found, 50%). Pests are less of a problem, and three times fewer insecticides (three compounds, 25%) and herbicides (three found, 25%) were used for their protection.

Of less concern, compared to fruits and vegetables, is the presence of pesticides in 47% of tea samples, including unacceptable exceedances of the MRL for linuron in a sample of mint tea from Poland at a concentration of 0.34 mg/kg. Of the seven tea types, only black tea mixed with fruit contained pesticides, and the lowest number was recorded in green tea. Of the

24 pesticides determined in tea samples, eight (47%) are not approved for use and were reported in samples from the EU, Poland, and outside the EU (China and India), i.e., carbendazim, linuron, thiacloprid, thiamethoxam, imidacloprid, flufenoxuron, lufenuron, and chlorpyrifos. In the case of growing tea bushes, pests are a significant problem, which is why insecticides were most frequently recorded (11, 65%, 58 detections), and weeds are regulated by herbicides, which accounted for 20% of pesticides (eight found), and fungicides accounted for 15% (five found).

Moreover, 70% of groats and cereal products contained pesticides, including 7% inconsistent with safety standards. Pesticides were detected in barley (85% of samples), oatmeal (65%), buckwheat (76%), while rice (38%), and millet (22%). The greatest concern is buckwheat groats, with the highest percentage of samples not meeting the standards (33%). Twenty-one pesticides were detected in groats, including 8 (38%) withdrawn in the EU, i.e., chlorpyrifos, imidacloprid, fluazifop, haloxyfop, diafenthiuron, clothianidin, isoprothiolate, and tricyclazole, in buckwheat from Poland and Lithuania, barley (Poland), oat flakes (Poland), rice (Pakistan, Vietnam, Myanmar, Guyana). The maximum levels for chlormequat in Vietnamese rice were exceeded. In the case of buckwheat and cereal cultivation, lodging in cereals is a significant problem, hence growth regulators, i.e., chlormequat (38%), as well as the activity of pests, hence insecticides (six found, 30%). The fight against fungal diseases and **weeds** was carried out using fungicides (eight found, 16%) and herbicides (six found, 16%).

In total, 108 pesticides were detected, including 32 withdrawn in the EU. The vast majority of pesticides detected, especially those withdrawn, pose a high health risk and moderate ecotoxicological and environmental risk. Fungicides were the most common (61%), followed by insecticides (30%) and herbicides (9%). The most frequently detected herbicides in food of plant origin included 2,4-D (1.9%), haloxyfop (1.5%), and glyphosate (1.5%); the most common fungicides were fluopyram (4.6%), fluxapyroxad (4.3%), fludioxonil (3.7%), and carbendazim (3.6%), and insecticides–acetamiprid (8.8%) and spirotetramat (5.4%).

Of the groats, cereal products, and tea declared organic by producers, 31% contained pesticides or growth regulators.

Extensive research into pesticides in various products confirms their presence. Disturbingly, some pesticides exceeded the permissible limits, and many pesticides were found in one sample, including those banned in the EU. On the other hand, the determined concentrations were, in most cases, at very low levels (smoothies). Most tested products did not pose a significant health risk, but their consumption by young children should be limited. These studies have confirmed the presence of pesticides in most products. This is consistent with the survey results, in which respondents indicated that pesticides in food were a cause for concern. However, many consumers did not know which crops use the most pesticides. The second largest group of respondents indicated that fruit (apples, pears, cherries) might contain a lot of pesticides, which was confirmed by the research. Moreover, only a few respondents indicated the need to use pesticides and that they are necessary to provide an adequate amount of food. The respondents' expectations in this respect were different from the reality. This research confirmed the widespread use of pesticides in products from the EU and third countries in order to ensure the production of sufficient food.

Biological contaminants, including mycotoxins, are also a significant problem in ensuring safe food. Mycotoxins cause adverse health effects, and this study confirmed their presence in tested products. Mycotoxins were found in coffee and nuts, and products from organic farming had higher concentrations compared to conventional ones. To avoid consuming products with these secondary metabolites of mold fungi, it is necessary to purchase food from trusted suppliers who use appropriate storage and quality control practices. It is also important to store food in dry, cool places to prevent mold. Consumers should regularly check the condition of the stored food, remove any products showing signs of spoilage, and avoid eating nuts, grains, and dried fruit that appear damaged or have an unpleasant odor. Additionally, cooking and baking foods at appropriate temperatures can help reduce the presence of some mycotoxins. The survey indicates that the presence of mycotoxins in food causes concern among respondents, but they could not estimate which food groups are at risk. Respondents indicated the presence of mycotoxins in nuts, which is confirmed by this research and literature data. The second group of products indicated by respondents was cereals.

As mentioned, plant foods play a key role in a healthy diet, offering many health benefits. Macro- and micronutrients are necessary for the proper functioning of the body. They are crucial for maintaining health and well-being, and their deficiency may lead to various diseases and disorders. These studies indicate different contents of beneficial and unfavorable components in individual food groups tested, depending on the type of vegetable, fruit, nut, tea, or coffee and the method of cultivation.

For example, the highest content of beneficial minerals was found in blackcurrants, regardless of the cultivation method, and in the case of magnesium, high concentrations were also found in strawberries and cherries. At the same time, a significant amount of iron was confirmed in blackcurrants rich in vitamin C, which improves the bioavailability of heme iron and allows us to recommend this fruit to counteract the deficiencies of this important micronutrient.

Among the examined vegetables, spinach had the highest total content of macro- and micronutrients. Analyzing the content of individual elements, broccoli had the highest concentration of iron, and a comparable content of this element was recorded in organic carrots and spinach, while beets and broccoli contained a high amount of zinc. The research has verified, in terms of scientific certainty, that spinach does not have the highest iron content popularly attributed to it.

Most organic fruits and vegetables contained comparable amounts or slightly lower concentrations of toxic elements compared to products from conventional farming. Nevertheless, there were few cases where the content of chemical contaminants in organic products was higher than in conventional ones. For example, a higher concentration of cadmium was determined in organic spinach, a higher concentration of lead in organic carrots, more cadmium and lead were found in organic strawberries, and a higher lead content was recorded in organic cherries and plums. Despite differences in the concentrations of individual elements, the maximum permissible contents of toxic elements were not exceeded in any of the fruit and vegetable samples. This research found toxic elements in many products, which coincides with the survey in which respondents indicated that heavy metals in food are of concern.

Of the tested types of tea, mint and lemon balm teas had the highest content of beneficial minerals, with the exception of copper, where the highest concentration was determined in black teas. Organic lemon balm teas showed the most favorable Cu/Zn ratio, which may give them antioxidant properties.

When comparing the content of toxic elements in organic and conventional tea samples, no differences were found in the cadmium content. However, mercury concentration was higher in organic teas. In all tea samples tested, these amounts did not pose a health risk.

Organic coffee samples contained fewer beneficial minerals compared to conventional coffee. Organic coffee contained more mercury; in turn, no significant differences were recorded in the arsenic content, while in the case of cadmium and lead, lower contents of these toxic elements were found in certified organic coffees.

Individual types of nuts had different contents of the examined macro- and micronutrients. Organic peanuts, as well as hazelnuts, cashew nuts, and organic macadamia nuts, contained the most calcium. Pecans, pine nuts, and pistachios had the highest magnesium content, while Brazil nuts, pistachios, and walnuts had the highest iron content, with organic walnuts containing lower concentrations of this element. Pistachios and cashew nuts had a high zinc content, while peanuts, pine nuts, and pistachios had a high copper content. In most cases, organic nuts contained fewer beneficial minerals, with the exception of pine nuts, pistachios, and macadamia nuts, where the opposite was true. In most cases, organic nuts contained less toxic elements, but organic pistachios and walnuts contained more lead, and organic Brazil nuts contained more arsenic. High cadmium content was recorded in pine nuts, and it should be noted that under current legislation, only peanuts are monitored for cadmium content. Moreover, organic nuts, in most cases, had a higher content of nutrients, such as amino acids and phenolic acids. Compared to other types of nuts, the significantly highest content of amino acids was found in pine nuts, phenolic acids in pecan nuts, and vitamins in pistachios.

Research indicates that organic products are not completely free from chemical contaminants, pesticide residues, and toxic elements. They contain different contents of beneficial and unfavorable components, and their presence depends on many factors, including environmental factors, production methods, and transportation conditions. Organic products, in principle, should be much more beneficial from the consumer's point of view than conventional ones. These multi-faceted studies, in the light of scientific certainty, do not always confirm this expectation. Spending two or three times as much money on such products, the consumer expects quality and complete safety of the products. Survey respondents correctly recognized organic food, but this research shows that they may be misled by producers because, despite the organic food certificate, it may be contaminated with pesticide residues, toxic elements, and mycotoxins.

The scientific certainty resulting from this research has the potential to change the public perception of healthy and safe food. The knowledge provided will allow the consumers to more thoroughly evaluate the food consumed and give them the opportunity to estimate certain risks associated with its consumption and become familiar with the potential threats and health-promoting properties.

Moving on to more general conclusions, the following should be stated.

According to the current state of knowledge, consuming vegetables and fruits, or other products of plant origin in the amounts recommended by healthy eating experts, seems to have higher health benefits than the risks associated with the presence of pesticide residues, toxic elements, and mycotoxins.

The research confirmed the presence of nutrients in plant products and verified the characteristics attributed to the content of certain elements in leafy vegetables.

In order to ensure consumers have access to healthy and safe food, the research indicates the need to increase the scope of official control, especially in the case of products originating from outside the EU, in order to minimize the inflow of fruit and vegetables containing pesticides banned in the EU.

In order to minimize the risk of pesticides in food, it is advisable to conduct educational activities addressed to agricultural producers, including effective information on the withdrawal of pesticides from the market, changes in regulations, and sales conditions, which are currently based on strict free market principles.

The fact that there is a high percentage of samples containing pesticide residues in fruits and vegetables is disturbing. Consumers can minimize the presence of some pesticides through thorough washing, cooking, and peeling of fruits and vegetables.

Organic food is not always free from contaminants. It may contain pesticide residues and toxic elements. This may be due to environmental conditions and, in a few cases, the dishonesty of producers.

The content of harmful mycotoxins is, in some cases, higher in organic food compared to conventional food. This may be due to ineffective protection against fungal pathogens or improper transportation conditions.

Research confirms the different levels of consumer awareness. The respondents are aware of the threats linked to food, but, in some cases, their knowledge does not correspond to scientific certainty, which indicates the need for public education on food safety.

SYNTHESIS OF RESEARCH RESULTS – CONCLUSION

This monograph attempts to provide an interdisciplinary analysis of the social perception of healthy food, revealing the complexity and ambiguity of the very concept of „healthy food". Despite the widespread use of the term healthy food in everyday contexts (newspaper articles, store signs, or conversations), its precise boundaries remain blurred. There is a concept of safe food in food law, which strictly refers to contaminants; however, awareness of it is low. Respondents largely identify it with healthy food and classify food as healthy, for example, in terms of nutritional value or due to its specific physiological effect (functional food). However, these issues go beyond legally understood food safety. In turn, in the chemical or health sciences, the concept of healthy food is not used. It emerges from the available literature discussed in section 1.2 and the survey conducted, the content of which is determined through the prism of certain features that food should contain in order to constitute a designator of this concept. The hypothesis was confirmed that consumers' perception of food, including the classification of specific foodstuffs as healthy or unhealthy, is strongly influenced by factors irrelevant from the perspective of health sciences, such as attractive packaging.

There are a number of implications associated with the above. It is worth considering the example of a food store shelf marked with the quite common term „healthy food" with a bar of chocolate containing large amounts of simple sugars, comparable in terms of nutrients to its conventional counterparts, but whose ingredients were produced organically. This bar is not marked with any health or nutritional claims apart from the organic production certificate. This would likely confuse the consumer. Although the law affects the entire spectrum of issues related to the perception of food, it does not always effectively contribute to making it easier for consumers to make choices regarding healthy food.

It is possible that the lack of recognition of such problems by the bodies responsible for official food control may result from the dispersion of competences in this area between different entities. In Poland, the State Sanitary Inspection, Veterinary Inspection, Inspectorate of Agricultural and Food Quality Inspection and Trade Inspection are responsible for food control. Each of these institutions supervises a different aspect of the food market. Additionally, in the case of organic products, an important role is played by organic food certification bodies, which also have their own control procedures. Such dispersion may lead to some less obvious aspects of food control escaping the attention of the authorities. Moreover, it promotes the „blurring of responsibility", i.e. a situation in which none of the bodies feels fully responsible for a given problem, which may lead to gaps in supervision.[1]

The survey results support the adoption of considerations such as those mentioned above. In social perception, the concept of healthy food is associated with various characteristics. In the authors' opinion, only one characteristic (e.g., organic production) is insufficient to classify a product as healthy, taking an interdisciplinary perspective and consumers' assumptions as a starting point. Combining characteristics, e.g., not using GMOs or plant protection products while meeting certain nutritional standards (not exceeding certain limits of salt or sugar, for instance), would be closer to the truth (and therefore certainty) of the scientific and multi-faceted public perception of food. In order for the public perception of healthy food to be closer to scientific certainty as to which food (and the way of eating this food) actually has a beneficial effect on health, it would be useful to define some „boundary conditions".

Defining the category of healthy food in the law, based on specific and scientifically proven criteria, is a key step towards effective management of the food market and promotion of healthy eating habits. Such action would not only organize the concepts related to healthy food, but would also enable more effective implementation of legal regulations in this area. The introduction of clearly defined categories of healthy food will eliminate abuses related to health and nutrition claims, as well as the possible introduction

1 See e.g. P. Wojciechowski, Organy urzędowej kontroli żywności w Polsce, „Kontrola Państwowa" 2014, vol. 59, no. 1(354), pp. 49–65; A. Serlikowska, Wdrażanie unijnej reformy urzędowej kontroli żywności – rozproszenie kompetencji krajowych organów, „Kontrola Państwowa" 2019, vol. 64, no. 6(389), pp. 29–44; I. Lipińska, J. Dobkowski, Urzędowy model kontroli żywności, „Studia Iuridica" 2022, vol. 91, pp. 206–226. Moreover, in 2022, NIK prepared a systemic analysis based on the results of nine NIK audits conducted in 2016–2021 and five European Commission audits from 2018–2019, which also recommended the consolidation of official food control bodies – see System kontroli bezpieczeństwa żywności w Polsce – stan obecny i pożądane kierunki zmian, Najwyższa Izba Kontroli, LLO.034.001.2020, Nr ewid. 198/2020/megainfo/LLO, Warszawa 2020, https://www.nik.gov.pl/plik/id, 25232,vp,27982.pdf.

of mandatory warning signs on products that do not meet the standards of healthy food (e.g. with excessive sugar or saturated fat content). Systemic differentiation of products on the market based on their health values will also enable the introduction of specific financial incentives for producers who meet the designated criteria of healthy food. Reducing taxes on such products, combined with higher taxation of products harmful to health (e.g. sweetened beverages), would effectively influence consumer preferences and increase the availability of healthy products.

It seems that classifying food as healthy had a reverse trajectory–marketing activities and, among other things, placing certain categories of food on „healthy food" shelves, such as organic food, influenced the public perception of what is considered healthy. It should be emphasized that this research does not show that organic food contains all the positive qualities that consumers attribute to it. Organic products did not always perform better in analytical tests in terms of essential and toxic elements and mycotoxin content. Often, no significant differences were observed, or the opposite was true, and organic products had more contaminants. However, legal regulations focus primarily on the method of production, not on the final product. Because organic products are more expensive, the consumer expects better quality. Additionally, it is worth noting that international organizations such as the EU, WHO, or FAO have not issued any recommendations or guidelines suggesting that organic food is clearly associated with health benefits.

The above observations should be treated as confirmation of the halo effect in relation to food, already described in research. The halo effect itself was introduced at the beginning of the last century by Thorndike and refers to the perceptual bias in which one distinctive characteristic determines the overall impression of a person or object, influencing the perception of other, conceptually different, and independent characteristics. In food, the halo effect occurs when the evaluation of one specific product characteristic strongly influences the perception of other characteristics of the same product.[2] Our research adds to the literature confirming the existence of this effect in the case of organic food, to which respondents attributed virtually all the characteristics they were asked about and which they considered positive, associated with the content of vitamins, micro and macro elements, and to a lesser degree with heavy metals or pesticides. One might

2 V. Apaolaza, P. Hartmann, C. Echebarria, J.M. Barrutia, Organic label's halo effect on sensory and hedonic experience of wine: A pilot study, „Journal of Sensory Studies" 2017, vol. 32, no. 1, e12243. doi:10.1111/joss.12243.

ask whether this perception results from many years of „programming" consumers by placing organic products on „healthy food" shelves.

In some cases, succumbing to the halo effect could lead consumers to make dietary choices that are not at all best for their health. It is worth mentioning here the study Impact of warning labels on reducing halo effect of nutrient content claims on breakfast cereal packages: A mixed-measures experiment (2021). Chile has introduced a food labeling law that requires warning labels on food packaging that exceed government-defined thresholds for sugar, saturated fat, sodium, and/or calories. This law does not prohibit the use of health-related marketing claims regarding nutrient content. The results of this study suggest that warnings may reduce the halo effect caused by marketing labels. Considering similar solutions in Europe would be consistent with the increasingly popular approach based on nudging, which is a manifestation of, as the authors of this concept themselves call it, libertarian paternalism, influencing the behavior of individuals in such a way that they make choices consistent with their interests, while not limiting in any way their freedoms or available behavioral options.[3]

In the spirit of this approach, it would also be worth considering the implications of three issues that emerged in the survey: The Internet is the main source of information about food products for the majority of respondents (77%), 68% of respondents believe that locally produced food is healthier than mass-produced food, and one of the key determinants of consumers' purchasing choices is price. These results indicate the need to integrate new technologies with the policy of supporting local food producers and educating consumers about the benefits of choosing local products.

Since the Internet is the main source of information, digital platforms can be an effective tool for promoting local products and educating consumers. Creating websites, mobile applications, and social media campaigns can strengthen existing trends toward a favorable perception of local food products. These activities can also help local farmers reach a wider audience, which in turn supports the local economy. At the same time, it is important to try to reduce the costs of producing and distributing local food. Potential actions to strengthen short supply chains include supporting consumers in sourcing from local suppliers, fostering the creation of local partnerships, and organizing producer groups and activities supporting direct sales as part of agricultural activities. In particular, it is worth considering facilitating online contacts between consumers and farmers, which may include pur-

3 See R.H. Thaler, C.R. Sunstein, Nudge: The Final Edition, „Penguin Boks" 2021.

chasing platforms, mobile applications, and websites enabling easy ordering and delivery of products directly from producers. Facilitating such interactions not only supports local farmers but also increases the transparency of the supply chain, which helps build consumer trust in the products. It is also worth promoting educational initiatives that will increase awareness of the possibility of buying local products, both for health and ecological reasons and to support the local economy. Thanks to these activities, it will be possible not only to support local producers but also to promote sustainable development and a healthy lifestyle among consumers.

Based on the above considerations and due to the key role of price as a determinant of consumer purchasing decisions, it may also be suggested to develop food indicators/markings or promotional campaigns encouraging consumers to make decisions beneficial for their health, which would emphasize the economic dimension of the decisions made. The idea is for consumers to be aware that the dietary decisions they make may have hidden costs, for example, visits to doctors, tests and treatments, and dietary supplements. At this stage, this is, of course, a vague postulate, but it is directionally justified and worth in-depth analysis.

Implementing nudging-based solutions at the EU level would require changes in the institutional structure and legislative process, carried out in such a way that the proposed regulations would also be analysed in terms of how they would affect people's decisions and behaviours. In other words, establishing scientific facts about the subject of the regulation alone is not enough. Applying an approach based on nudging requires a thorough analysis of how individual intervention tools may affect consumer behaviour. For example, research on warning labels on food products, similar to the one conducted in Chile, mentioned above, can provide valuable information on how different forms of labelling affect purchasing decisions. Incorporating such targeted analyses into EU legislative processes could significantly increase the effectiveness of promoting pro-health behaviours. Effective application of such an approach at the EU level would require establishing or designating a research unit within the existing organisational structure to analyse the impact of behavioural factors on consumer choices. At the national level, such units have been established, among others, in the United Kingdom[4]. Such a unit should cooperate with an interdisciplinary team of experts, including specialists in fields such as psychology, sociology, behavioral economics and health sciences. Such cooperation

4 The Behavioral Insights Team, „About us", accessed September 15, 2024, https://www.bi.team/about-us.

would make it possible to predict the effects of regulations on consumer choices and create more effective public policies.

However, in order to fully adapt the so-called behavioral risk factors to EU food law, it would be necessary to make changes to Regulation 178/2002[5]. Currently, the risk analysis on which food law regulations are based does not take them into account to a sufficient degree. The regulations are designed primarily to ensure food safety, without taking into account how they affect consumer choices and habits.

Extending the definition of „hazard” referred to in Article 3, paragraph 14 of Regulation 178/2002 could enable the formal inclusion of behavioral analysis in the legislative process. Thanks to this, similarly to the existing regulatory impact assessments (RIAs), draft legal acts would be assessed in terms of how they affect pro-health consumer behavior. Before the new food law regulation comes into force, it would be analysed in terms of its potential impact on consumers' dietary choices – whether it would lead to an increase in the consumption of products that are not conducive to maintaining health, or whether it would support more health-promoting choices.

Referring to the analytical analyses, it should be emphasized that, in general, the tested food is safe and does not pose a health risk, and some products may be a source of beneficial minerals. Vegetables and fruits are rich in some macro- and micronutrients. Importantly, some plants have the ability to absorb unfavorable components, including toxic elements, constituting a contaminant in the food consumed. However, our tests did not indicate that the permissible contents of toxic elements in the analyzed products were exceeded. Most organic vegetables contained lower or comparable pollutant levels. Organic fruits also had a lower content of toxic elements than conventional ones. In turn, in most cases, conventional nuts contained higher amounts of macro- and micronutrients, or their contents were comparable. It is worth emphasizing that some of the nuts showed high concentrations of toxic elements, which indicates the need to monitor their content. The content of toxic elements in organic and conventional nuts varied: Sometimes organic nuts had better results, and sometimes conventional nuts. Similar results were obtained in the case of tea, where the advantage of organic products cannot be clearly stated, both in terms of the content of toxic and health-beneficial elements. The maximum allow-

5 See WHO Western Mediterranean Region, „Health education and promotion Behavioral risk factors", accessed September 16, 2024, https://www.emro.who.int/health-education/health-risk-factors/behavior-risk-factors.html.

able content of toxic elements in tea is not specified in the legislation, and the results do not indicate the need to monitor them. Interestingly, the content of macro- and micronutrients in coffee samples was significantly higher in conventional coffee compared to certified organic coffee. On the other hand, taking into account the content of toxic elements, organic coffee samples were less contaminated. Organic products, as shown by the survey, have more favorable characteristics in terms of health benefits and food safety, but the research results show that some organic products are not completely free from contamination with pesticides, toxic elements, and mycotoxins. This is not always due to the intentional actions of producers but may result from unfavorable environmental conditions, lack of knowledge, and protection of plant products during transportation. Moreover, organic food does not always have a higher content of health-promoting ingredients compared to conventional products. To sum up, the research results will allow the consumer to have a more critical approach to organic food and additionally indicate the safety and not always inferior quality of conventional products. However, based on the research results, it is not possible to clearly state whether food perceived by society as healthy has specific health qualities. Due to the above, the research hypothesis can be seen as partially true in accordance with the research results.

The social perception of healthy food, studied from an interdisciplinary perspective and focused on the search for scientific certainty, requires continued research and careful monitoring. Only in this way will it be possible to ensure that both the state and the European Union will be able to adequately respond to any gaps in this perception and to the potential threats that may result from it. Continuation is also necessary for the effective shaping of food policy that will be able to meet contemporary health and social challenges.

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SPOŁECZEŃSTWA

ABOUT THE „SCIENCE FOR SOCIETY" PROGRAM

The „Science for Society" program was established through the Announcement of the Minister of Education and Science dated July 1, 2021. The program's objective was to support entities within the higher education and science system, as well as other organizational units working to promote science, in implementing projects aimed at fostering collaboration between those operating in the field of science and those engaged in the socio-economic sphere.

The program encompassed funding for projects in three areas:

1) Scientific Excellence,

2) Science for Innovation,

3) Humanities – Society – Identity.

The program currently operates under the title „Science for Society II." Compared to the previous program, the above priorities have been slightly modified, and a new priority has been added: „Physical Culture for an Active and Healthy Society."

For more information: Science for Society II, Ministry of Science and Higher Education. https://www.gov.pl/web/nauka/nauka-dla-spoleczenstwa-ii

ABOUT THE AUTHORS

mgr Jakub Ali Farhan

Lawyer, PhD student at the Doctoral School of Social Sciences of the University of Białystok, and since 2020, collaborator of the Law and Partnership Foundation.

For his scientific achievements as part of his master's studies, he received a scholarship from the Minister of Science and Higher Education for outstanding scientific achievements in 2018. In 2020, he began his education at the doctoral school, and since 2021 he has been the head of the scientific project „Counteracting non-communicable diseases in EU food law" financed by the National Science Center.

In addition to his rich academic achievements, considering his relatively short tenure, he is active in the area of law practice. He has worked in legal and advocate firms and in one of the largest international law firms in Poland. In recent years, he has gained experience as a legislator in the Government Legislation Centre, and currently holds the position of senior specialist in the Legal Department of the Ministry of Agriculture and Rural Development.

dr Piotr Iwaniuk

Assistant professor, researcher at the Institute of Plant Protection – National Research Institute.

Co-author of over 20 scientific publications, including 17 with an Impact factor Factor. Total IF 82,471, number of Web of Science citations 218; Hirsch index 11, MNiSW points 2190.

His scientific interests include primarily research on plant responses at the genetic, biochemical and physiological levels in the pesticide-biostimulant-pathogen system, as well as molecular bases of biostimulator action in mitigating abiotic plant stresses, modern plant protection methods, food safety and quality, and the impact of technological processes on changes in the concentration of plant protection product residues and mycotoxins in food.

Author of a distinguished doctoral dissertation. Winner of the prestigious „START" competition organized by the Foundation for Polish Science. Executor of the NCN project, four projects for organic farming, financed by the Minister of Agriculture and Rural Development and four statutory projects, financed by the Minister of Science and Higher Education. Manager of the statutory project and the Young Scientists' Research project. Member of the Expert Council of the International Academy of Applied Sciences in Łomża. Scientific supervisor of students and PhD students. Speaker at national and international conferences. Reviewer in international scientific journals and section editor in the scientific journal „Journal of Plant Protection Research". Member of the Polish Agronomic Society and the Association of Agricultural Engineers and Technicians.

dr hab. Piotr Kaczyński, prof. IOR-PIB

Professor at IOR-PIB, researcher at the Institute of Plant Protection – National Research Institute, head of the Food and Feed Safety Research Laboratory in Białystok.

Author and co-author of over 120 scientific publications, including 87 with an Impact factor Factor (IF). Total IF 204.55, number of citations Web of Science 1956; Hirsch index 26, MNiE points 4862.

His scientific work focuses primarily on the development of modern analytical methods for testing the safety and quality of food and the agricultural environment, assessing the quality of agricultural crops in terms of their contamination with residues of plant protection products, mycotoxins and alkaloids and estimating the associated risk of consumer exposure, as well as the impact of technological processes on changes in the content of health-promoting and anti--nutritional substances.

Expert of the European Food Safety Authority (EFSA) and the National Science Centre (NCN) in project evaluation. Author of expert opinions for government administration bodies. Manager and executor of eight NCN and NCBiR projects. Manager and executor of statutory projects financed by the Minister of Science and Higher Education and projects for organic farming financed by the Minister of Agriculture and Rural Development. Chairman and member of the Mid-Term Evaluation Committee of PhD Students of Doctoral Schools. Lecturer at Polish universities. Supervisor, assistant supervisor and co-supervisor of doctoral dissertations in Poland and abroad. Member of the organizing committees of Polish and international scientific conferences. Speaker at many national and international scientific conferences. Reviewer in international scientific journals. Long-term deputy editor-in-chief of the scientific journal „Journal of Plant Protection Research", section editor of the scientific journal „Postępy w Ochronie Roślin/Progress in Plant Protection". Member of the Polish Agronomic Society, the Association of Agricultural Engineers and Technicians and the Polish Society for Plant Protection. Awarded with the Bronze Cross of Merit and the Medal of Merit for Agriculture.

prof. dr hab. Bożena Łozowicka

Full professor, researcher at the Institute of Plant Protection – National Research Institute, head of the Field Experimental Station in Białystok.

Author and co-author of over 350 scientific publications, including 111 with an Impact Factor (IF). Total IF 232,776; number of Web of Science citations 2570; Hirsch Index 28.

Her research interests include food and feed safety, analytical chemistry, ecotoxicology, plant protection, agriculture, pesticide chemistry, risk assessment and toxicology.

Member of the Scientific Council of the Institute of Plant Protection – National Research Institute and the Institute of Technology and Life Sciences – National Research Institute and the FoodRentgen Program. Chairwoman of the Consultative Council of GIORIN and Vice-Chairwoman of the Consultative Council of the Podlasie Post-Registration Variety Experimentation Team. Member of the Faculty Consultative Council at the Faculty of Chemistry of the University of Białystok and the Council of Women Acting for Polish Agriculture at the Ministry of Agriculture and Rural Development. Chairwoman of the Commission for Plant Protection Products at the Ministry of Agriculture and Rural Development. Member of the thematic group for food quality at the Marshal's Office of the Podlasie Voivodeship and the advisory team for solving rural problems at the Podlasie Voivode. Expert of the European Food Safety Authority (EFSA) and the International Academy of Applied Sciences in Łomża. Author of expert opinions for government administration bodies. Lecturer at Kazakh and Polish universities. Supervisor and co-supervisor of doctoral dissertations in Poland and abroad. Reviewer in international scientific journals. Deputy editor-in-chief of the scientific journal „Postępy w Ochronie Roślin/Progress in Plant Protection". Member of the Polish Agronomic Society, the Association of Agricultural Engineers and Technicians and the Polish Society for Plant Protection. Personality of the Year 2019 of the Podlaskie Voivodeship in the science category. Awarded with the Golden Cross of Merit, Silver Cross of Merit, Cross of Merit of the Rector of the Kazakh State Agricultural University and the Medal „Meritorious for Agriculture".

prof. dr hab. n. med. Barbara Mroczko

Graduate of the Faculty of Medicine at the Medical University of Białystok, which she graduated with distinction. Director of the Doctoral School of the Medical University of Białystok (UMB). Rector's Representative for Ensuring and Improving the Quality of Education at UMB. Member of the Scientific Council of the M. Mossakowski Institute of Experimental and Clinical Medicine of the Polish Academy of Sciences (PAN). Winner of the Minister of Health Award for scientific achievements. Winner of the „Pomosty Przyszłości" Competition in the category „Bridge from science to business for a person". Representative of the Supreme Medical Council in the State Examination Board. Expert in the Assessment Team for Internationalization within the National Agency for Academic Exchange (NAWA). Head of the Head of the Department of Neurodegeneration Diagnostics and the Department of Biochemical Diagnostics at UMB.

Author and co-author of over 500 works, including 305 scientific publications with a total IF of 914, MNiSW score of 18596, Hirsch Index of 40, number of citations 6805. Scientific achievements include, among others, assessment of the usefulness of specific protein assays, as well as inflammatory response mediators as biomarkers in early diagnosis of neurodegenerative diseases and neoplastic diseases, including the impact of food components on health.

Classified among the top 2% of scientists in the world – winner of the World's TOP 2% Scientists ranking.

Manager or executor of projects financed from external sources, including the Joint Programme for Neurodegenerative Disease Research (JPND Research BiomarkAPD). Research area coordinator within the National Leading Scientific Center (KNOW). Winner of the Competition of the Ministry of Education and Science for the acquisition of the first automated platform in Poland for the analysis of proteomic profiles using the ultrasensitive method (SIMOA).

Research internships in Poland and abroad: Université Libre de Bruxelles (2024); Weill Cornell Medicine, USA (2022); New York University, Center for Brain Health (2015); Fatebenefratelli Hospital, Isola Tiberina, Roma, Italy (2012); Universitätsklinikum Erlangen, Germany (2009, 2011, 2014). Member of many Scientific Societies, including Alzheimer's Association International Society to Advance Alzheimer's Research and Treatment (ISTAART).

Awarded with the Medal of the National Education Commission.

dr hab. n. med. Karolina Orywal

Research and teaching assistant at the Department of Biochemical Diagnostics of the Medical University of Bialystok, specialist in laboratory medical diagnostics. Co-author of two monographs „Laboratory diagnostics in dietetics" (2018, 2023), containing issues related to food, its nutritional value and nutritional recommendations for people with health problems and interested in health prevention. Lecturer in medicine, laboratory diagnostics and psychodietetician. Author of publications on enzymatic disorders in cancer and non-cancer diseases, the content of toxic and antioxidant trace elements in various biological materials and food, as well as the impact of the use of probiotics on body composition parameters, cardiorespiratory efficiency and inflammation in runners. Her scientific achievements include 80 publications with a total IF score = 124.485, MEiN score = 2703, h-index = 13.

prof. dr hab. Maciej Perkowski

Lawyer, professor of law, research and teaching employee at the Faculty of Law of the University of Białystok, president of the Law and Partnership Foundation. He heads the Department of Public International Law at the Faculty of Law of the University of Białystok, as well as Europe Direct Podlaskie, operating within the European Commission network. He is a member of the Interdisciplinary Advisory Team of the Institute of Functional Food (as part of the Agricultural Valley 4.0 project).

Professor Perkowski is an experienced scientist – author or co-author of over 200 publications, participant of over a hundred national and international conferences, experienced manager or contractor in many projects, including those financed by the National Science Centre, the European Commission or European funds. He has visited, among others, the University of Vienna (Austria), the Humboldt University (Berlin/Germany), Yale University (USA), the Hague Academy of International Law (Netherlands), the European University Institute in Florence (Italy), EU institutions (Brussels/Belgium, Luxembourg). He is a member of scientific societies, editor-in-chief of the Eastern European Journal of Transnational Relations, advisor to public institutions and private entities. For years he has been involved in corporate governance of companies in the agricultural sector. His main research areas include public international law, European

Union law and the law of international relations, including in relation to environmental protection and food safety.

Recently, he has become a co-author (together with Wojciech Zoń from the Faculty of Law, University of Białystok, and prof. Przemysław Saganek from the Institute of Legal Sciences of the Polish Academy of Sciences) of the monograph „The Disputed Białowieża Forest. Legal Remedies for the Protection of Cross-border Properties", which was published in one of the largest and most prestigious scientific publishing houses in the world (BRILL / Nijhoff) and a number of interdisciplinary works relating to food safety. He participates in the work on the management plan for the Białowieża Forest World Heritage Site.

He has received numerous awards and distinctions.

prof. dr hab. Katarzyna Socha

Head of the Department of Bromatology at the Medical University of Białystok. Vice-Rector for Development and Cooperation with the Economic Environment of the Medical University of Białystok. Chairwoman of the Food Safety and Nutrition Committee of the Human Nutrition Science Committee of the Polish Academy of Sciences. Member of the Food, Raw Materials and Food Products Analytics Team of the Analytical Chemistry Committee of the Polish Academy of Sciences. Member of the Nutrition and Food Science Section of the Polish Academy of Sciences Branch in Olsztyn and Białystok. Member of the Main Board of the Polish Society of Nutritional Sciences (Chairwoman of the Białystok Branch). Member of the Polish Pharmaceutical Society (Chairwoman of the Audit Committee of the Białystok Branch).

Scientific achievements include over 200 publications in the field of assessment of quality and safety of food and dietary supplements, the influence of dietary habits on the concentration of selected elements and antioxidant status in biological material in the course of various diseases, assessment of the way of nutrition of the population in different age groups. Total publication IF: 477.875; Hirsch index 22 (according to WoS), 26 (according to Scopus).

Co-author of 2 patents. Documented cooperation with industry in the field of R&D: development or improvement of recipes for health-promoting products dedicated to children and adults and assessment of the health quality of food: sale of rights to know-how, license agreements, research and commercialization services for companies in the food industry.

Manager or contractor of 3 projects, financed from external sources (MNiSW, KBN, NCN), on topics related to food quality, the impact of food components on health, as well as two projects in the field of pre-implementation research on the design of functional food, as part of the „Innovation Incubator 4.0".

Internships scientific at: Firat University in Elazig, Department of Animal Nutrition, Turkey (2007), University of Natural Resources and Life Sciences, Department of Chemistry; Austrian Center of Industrial Biotechnology, Austria (2012), Nofer Institute of Occupational Medicine, Department of Biological and Environmental Monitoring (2013, 2015).

mgr Wojciech Zoń

Lawyer, research and teaching employee at the Faculty of Law of the University of Białystok, vice-president of the Law and Partnership Foundation.

On a daily basis, he works at the Department of Public International Law at the Faculty of Law, University of Bialystok and as the Organizational Director at Europe Direct Podlaskie.

He is also an expert at the Legal Education Research Center at the University of Bialystok and the editorial secretary of the Eastern European Journal of Transnational Relations. He is the author or co-author of several scientific publications in various areas of international and EU law. He has participated in dozens of conferences, seminars and scientific meetings, as well as several national and international projects, including in the area of education and the rights of people with disabilities. As a specialist at the Institute of Environmental Protection – National Research Institute, he participated in the work on the management plan for the Białowieża Forest World Heritage Site.

Winner of the Active Student 2014/2015 award of the Faculty of Law of the University of Białystok for outstanding achievements in scientific and organizational activities, winner of the Santander Universidades 2015 award of Bank Zachodni WBK for achievements in science and for social involvement, winner of the scholarship of the Minister of Science and Higher Education of the Republic of Poland for the academic year 2015/2016 for outstanding scientific achievements. As a research and teaching employee: Winner of the scholarship of the Minister of Education and Science for outstanding young scientists in 2022.

NAUKA DLA SPOŁECZEŃSTWA

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dr hab. Tomasz Srogosz prof. UAFM, Andrzej Frycz Modrzewski Krakow University

- 'Scientific monographs are usually read (or not) by a narrow circle of interested researchers. In this case, despite the rather complicated and scientific title, there is no doubt that the book should be disseminated. Certainly, its main assumptions, theorems and research results should reach readers outside the scientific community - consumers, producers, including farmers. [...] The substantive and formal level makes it a work that undoubtedly shapes in a responsible and scientifically competent way the desirable attitudes and eating habits of consumers and the approach of producers, intermediaries and shops, as well as state authorities to food safety.'

dr hab. Sławomira Drzymała-Czyż prof. UMP, Karol Marcinkowski University of Medical Sciences in Poznań

- '[...] the monograph is a valuable and useful study of the issue of healthy food. Thanks to the holistic approach to the research topic, it has a universal character and will certainly find a wide audience among dieticians, bromatologists, food technologists, food producers, lawyers and everyone interested in healthy nutrition. Especially as there is a lack of such comprehensive publications on the publishing market dealing with this topic.'

Temida 2

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