

THE ROLE OF AGROCHEMICAL MONITORING IN ENSURING FOOD SAFETY OF WHEAT PRODUCTS

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Abstract. Wheat and other cereal crops are agricultural products of strategic importance for the food supply of the world's population. Against the background of population growth and increasing demand for food, it is important not only to increase the productivity of grain crops but also to ensure the safety of grain products. The aim of this structured literature review is to assess, on the basis of published scientific and regulatory sources, the impact of the main chemical contaminants found in wheat and grain products – pesticide residues, nitrates and nitrites, heavy metals, mycotoxins and other toxic substances – on food safety, and to determine the role of agrochemical monitoring. The reviewed evidence indicates that agrochemical control systems applied along the soil–plant–grain chain help to keep the content of hazardous substances in wheat products within regulatory limits and to minimize potential risks to human health. Maximum levels of contaminants, health-based guidance values (ADI, TDI, ARfD) and exposure-based risk indicators (EDI, HQ, HI, CR) are identified in the literature as the main criteria for assessing the food safety of wheat products.

Keywords: wheat, grain, pesticides, mycotoxins, metals, monitoring

Introduction

Wheat (*Triticum aestivum* L.) is one of the most strategic agricultural crops on a global scale and plays an important role in ensuring food security. According to FAO, approximately 20% of the daily energy needs of the world population and a significant part of its protein needs are met by wheat [22]. Sustainable development of wheat production while maintaining high product safety is therefore one of the priorities of modern agricultural science. In recent decades, rapid population growth, increasing demand for food and agricultural intensification have led to the widespread use of mineral fertilizers, pesticides and other agrochemicals to increase productivity [35, 39]. However, irrational use of these inputs, industrial and transport pollution, the use of poor-quality irrigation water and technological violations during storage and processing can lead to the accumulation of various toxic substances in cereal products [4, 33]. This poses serious risks to the hygienic quality and safety of food. The modern concept of food safety requires that a product not only has high nutritional value but is also free from chemical, biological and physical contaminants that may threaten human health [37]. Determining the content of pesticide residues, nitrates and nitrites, heavy metals, mycotoxins and other xenobiotics in cereal products is therefore of particular importance [7, 25], since exceeding regulatory limits can cause toxic, mutagenic, teratogenic and carcinogenic effects in the human body [20, 31].

Agrochemical research plays a key role in ensuring food safety. The study of the cycling of substances in the soil–plant–crop system, the assessment of the migration and accumulation of contaminants and the determination of their impact on product quality are the main directions of agrochemical monitoring [34, 36]. These studies serve to increase the safety of agricultural products, protect the environment and build sustainable food systems. The scientific literature contains numerous studies on the occurrence of contaminants of various origins in wheat and other cereals [28]; however, a comprehensive assessment of the interaction between soil properties, fertilization systems and the accumulation of contaminants in the crop from the standpoint of food safety remains relevant. The aim of this structured literature review is to characterize the main chemical and biological contaminants of wheat and other

cereal crops, to assess their potential risks to human health and to determine the role of agrochemical monitoring in ensuring food safety.

Material and Method.

This article is a structured literature review (narrative synthesis). It is theoretical in nature and is based on the results of fundamental and applied research in agrochemistry, soil science, agroecology, food safety, toxicology and sanitation, as well as on international regulatory documents; the authors did not generate new experimental or field data. Such a multidisciplinary approach allows a comprehensive assessment of the mechanisms by which contaminants form and accumulate in agricultural products [36].

The conceptual framework of the review is based on the theories of biogeochemical cycling of substances in the soil–plant–crop–human chain and of the migration and bioaccumulation of contaminants, in line with the systems approach widely used to assess the cycling of substances in agroecosystems [6, 34]. Internationally accepted methodological approaches to food safety risk assessment were used in interpreting the reviewed data [19, 20, 38].

The object of the review is the sources of chemical and biological contamination arising at the stages of cultivation, harvesting, processing, storage and consumption of wheat and other grain products. The subject of the review is the scientific assessment of the migration, transformation and bioaccumulation of contaminants of various origins (heavy metals, pesticides, nitrates/nitrites, mycotoxins and other xenobiotics) in the soil–plant–product system and of their impact on product quality and human health [25].

Articles, monographs, official reports and regulatory documents indexed in Scopus, Web of Science, ScienceDirect and other international scientific databases, as well as documents published by FAO, WHO, the Codex Alimentarius Commission, EFSA and the European Commission, were analyzed. Sources were selected according to their relevance to the topic, scientific reliability and methodological soundness. Priority was given to works published in the last 10 years; earlier fundamental studies and national (Azerbaijani) recommendations that form the theoretical basis of the topic were also taken into account. A full PRISMA procedure (a registered protocol, predefined search strings, the numbers of records identified, screened, excluded and finally included, and a flow diagram) was not applied. For this reason, the work is presented as a structured literature review rather than a systematic review; the PRISMA 2020 statement [30] was used only as a reference for transparent reporting of the source selection criteria.

The selected literature was analyzed in four thematic blocks: (1) the dynamics of nitrogen compounds in soil and plants under mineral fertilization and the potential accumulation of nitrates in the crop [29, 39]; (2) the application of pesticides, their degradation kinetics and the persistence of residues in the crop [8, 33]; (3) the conditions of mycotoxin formation in the field and during storage, including the effects of temperature, humidity and climate change [26, 27, 32]; and (4) the behavior of heavy metals in the soil–plant system depending on sorption–desorption processes, soil pH, humus content and irrigation-water quality [6, 9, 29].

To assess contaminants from the standpoint of food safety, internationally accepted toxicological parameters were considered: median lethal dose (LD_{50}), acceptable daily intake (ADI), tolerable daily intake (TDI), acute reference dose (ARfD), no-observed-adverse-effect level (NOAEL) and maximum residue limit (MRL), together with the exposure-based indicators EDI, HQ, HI and CR (Table 3). Possible synergistic or antagonistic effects of simultaneous exposure to several contaminants (mixture toxicity) were also taken into account [16]. Comparative analysis, analytical–synthetic evaluation and inductive and deductive reasoning were used to compare the results of different authors and to identify common patterns and differences. The regulatory basis of the review comprised the maximum levels set by the Codex Alimentarius Commission and the European Union, the recommendations of FAO and WHO, the risk assessment methodologies of EFSA and USEPA, and the carcinogenicity clas-

sification of IARC [10, 17, 19, 38].

Results and Discussion.

Main sources of contamination of wheat products. The safety of wheat and other grain products is formed by the interaction of physical, chemical and biological processes in the soil–plant–crop system. The reviewed literature shows that contamination of grain can occur at every stage of the production chain – from soil preparation to delivery of the product to the consumer [25, 28]. In intensive farming systems, the use of mineral fertilizers and pesticides at scientifically unfounded rates disturbs the balance of substances in soil, increases the concentration of toxic compounds in the soil solution and, consequently, their uptake by plants. Excessive nitrogen fertilization leads to the accumulation of nitrate nitrogen in soil and in the vegetative and generative organs of wheat [39], while long-term use of some phosphorus fertilizers adds cadmium and other heavy metals to the soil profile [4, 9]. Pesticide residues in grain increase when application rates and pre-harvest intervals are not observed, and persistent compounds can remain in soil for a long time and enter the soil–plant–human chain [8].

Contamination is not limited to agrochemical inputs. Irrigation with water polluted by industrial and domestic wastewater introduces heavy metals, nitrates and other toxic substances into soil, from which they pass to the plant through the root system [29]. Lead, cadmium, mercury and arsenic originating from industrial and vehicle emissions and atmospheric deposition are retained in soil for a long time and are absorbed by plants under favorable conditions [4, 31]. Violations of technological regimes during harvesting, transportation, processing and storage create conditions for fungal growth and mycotoxin formation [32]. The main contaminant groups, their sources, routes of transfer, health effects and reference values are summarized in Table 1. Contamination of wheat is thus a multifactorial process, and its control requires comprehensive agrochemical monitoring of the soil–plant–crop system rather than final-product testing alone.

Table 1.

Major Contaminants in Wheat Products: Sources, Routes of Transfer, Health Effects and Reference Values

Contaminant group	Main sources	Route of transfer to the product	Effects on human health	Reference values (examples)
Pesticide residues	Herbicides, insecticides, fungicides; non-observance of application rates and pre-harvest intervals	Through soil and plant surfaces	Neurotoxic effects; some active substances are mutagenic or carcinogenic	Substance-specific MRLs; ADI and ARfD for each active substance [8, 21]
Nitrates and nitrites	Nitrogen fertilizers, organic manures	Through the root system	Methemoglobinemia; formation of N-nitroso compounds	ADI: nitrate 3.7 mg/kg bw/day; nitrite 0.07 mg/kg bw/day [14, 15]
Mycotoxins	<i>Fusarium</i> , <i>Aspergillus</i> and <i>Penicillium</i> fungi	Field infection during the growing season; storage	Hepatotoxic, nephrotoxic, immunotoxic and carcinogenic effects	EU MLs, e.g. DON 1000 µg/kg in unprocessed common wheat (see Table 2) [18]
Heavy metals	Phosphorus fertilizers (Cd), industrial and vehicle emissions, contaminated irrigation water	Soil – root – grain	Chronic toxicity and bioaccumulation	Cd: 0.10 mg/kg (EU, cereal grains), 0.2 mg/kg (Codex, wheat); Pb: 0.2 mg/kg (Codex, cereal grains) [10, 17]
Radionuclides	Technogenic (anthropogenic) sources	Through soil and water	Genetic damage and mutagenic alterations	Codex guideline level for ¹³⁴ Cs + ¹³⁷ Cs: 1000 Bq/kg [10]

Source: compiled by the authors based on [4, 8–10, 14, 15, 17, 18, 21, 27, 31]. bw – body weight; ML – maximum level; MRL – maximum residue limit.

Influence of soil and climatic factors. The physicochemical properties of soil are among the main factors determining the mobility and bioavailability of contaminants. In acidic soils, the solubility and plant uptake of cadmium, zinc and lead increase significantly, whereas in alkaline soils these elements are more strongly bound to soil colloids and their bioavailability decreases. High contents of humus and organic matter increase the sorption capacity of soil for pesticides and heavy metals and limit their transfer to plants. These processes are closely related to the cation exchange capacity (CEC): high CEC values enhance the retention of contaminants in soil and reduce the risk of leaching [4, 6].

Climate change adds further dynamics to this system. Rising temperatures and uneven precipitation alter the rate of chemical reactions in soil and the kinetics of pesticide degradation and increase the risk of mycotoxin formation: warm and humid conditions favor the growth of *Fusarium* species, whereas drought causes physiological stress that disrupts nitrogen metabolism and promotes nitrate accumulation [26, 27]. A ten-year analysis of European wheat (2010–2019) showed persistent and high single- and multi-mycotoxin contamination with changing temporal and geographical patterns [24]. Integrated (mineral + organic) fertilization systems are generally considered more favorable for soil health and crop safety than the one-sided use of mineral fertilizers, although incorrectly applied organic fertilizers do not eliminate the risk of nitrate leaching.

Risk factors in the irrigated grain-growing areas of Azerbaijan.

Irrigated lands, including those of the Kur–Araz lowland and the Mugan Plain, are important for grain production in Azerbaijan [2, 23]. On the basis of the available national recommendations and published studies [1–3, 23], the following risk factors for the safety of wheat can be specified:

- *Soil salinization.* Under irrigation with insufficient drainage, salts accumulate in the upper soil layer; surface salt accumulation has been documented in the soils of the Mugan Plain [23]. Salinity causes physiological stress in wheat, disturbs the nutrient balance and nitrogen metabolism and can thus increase nitrate accumulation in plant tissues.
- *Fertilization.* Unbalanced or suboptimal application of nitrogen and phosphorus fertilizers on irrigated soils [2, 3] increases the risk of nitrate accumulation in the crop and of cadmium input with phosphorus fertilizers.
- *Irrigation water and anthropogenic emissions.* Surface soils of the Mugan Plain showed contamination with chromium, nickel and lead and a potential ecological risk from arsenic; fossil-fuel combustion associated with heating and vehicle traffic was identified as the main source [23]. The quality of irrigation water should therefore be monitored together with soil.
- *Grain storage.* Wheat can be stored safely for 2–3 months at a grain moisture content of 14%, whereas storage for 4–12 months requires moisture of 13% or below [5]. Where grain is stored on farms without drying, aeration and moisture control, these conditions are difficult to maintain, and storage becomes a significant factor of mycotoxin risk [5, 32]. Published data on mycotoxin occurrence in stored grain in Azerbaijan are scarce in the international literature, which in itself indicates the need for systematic national monitoring.

Mycotoxins in wheat.

Mycotoxin contamination of wheat in the field is mainly associated with *Fusarium* head blight (FHB). Infection occurs mainly at flowering and is accelerated by high humidity and temperature. Deoxynivalenol (DON), zearalenone (ZEA) and T-2 toxin produced by *Fusarium* species are the most common mycotoxins in wheat [24, 27]. The main mycotoxins, their producers and reference values are given in Table 2

Table 2.

Major Mycotoxins in Wheat and Cereal Products: Producers, Toxic Effects and Reference Values

Mycotoxin	Producing fungi	Commonly contaminated products	Primary toxic effects	Health-based guidance value	EU maximum level in unprocessed cereals
Aflatoxin B₁ (AFB₁)	<i>Aspergillus flavus</i> , <i>A. parasiticus</i>	Maize, rice, wheat	Potent carcinogenic and hepatotoxic effects	Not established (genotoxic carcinogen; MOE approach)	2.0 µg/kg (AFB ₁); 4.0 µg/kg (sum of aflatoxins)
Deoxynivalenol (DON)	<i>Fusarium graminearum</i> , <i>F. culmorum</i>	Wheat, barley, maize	Gastrointestinal disorders, immunotoxic effects	Group TDI 1 µg/kg bw/day [12]	1000 µg/kg (common wheat); 1500 µg/kg (durum wheat)
Zearalenone (ZEA)	<i>Fusarium</i> spp.	Cereal grains, maize	Estrogenic activity and reproductive disorders	TDI 0.25 µg/kg bw/day [11]	100 µg/kg (cereals other than maize)
Ochratoxin A (OTA)	<i>Aspergillus ochraceus</i> , <i>Penicillium verrucosum</i>	Wheat, cereals, feed grains	Nephrotoxic, immunotoxic and potentially carcinogenic effects	Not established (MOE approach) [13]	5.0 µg/kg
Fumonisin (FB₁, FB₂)	<i>Fusarium verticillioides</i>	Mainly maize and maize products	Hepatotoxic and nephrotoxic effects	–	4000 µg/kg (unprocessed maize only)

Source: compiled by the authors based on [11–13, 17, 18, 24, 27, 32]. MOE – margin of exposure, the approach applied to genotoxic and carcinogenic substances instead of a TDI; bw – body weight.

Contamination that begins in the field can persist and increase after harvest. Storage at 20–30 °C and relative humidity above 70% promotes the growth of *Aspergillus* and *Penicillium* species and additional mycotoxin contamination [27]; this is particularly relevant where storage infrastructure is poor. In the European Union, the maximum levels of DON in unprocessed common wheat and durum wheat are 1000 and 1500 µg/kg, respectively; the maximum level of ZEA in unprocessed cereals other than maize is 100 µg/kg, and that of ochratoxin A (OTA) in unprocessed cereal grains is 5 µg/kg [17, 18]. The Codex Alimentarius sets maximum levels for DON of 2000 µg/kg in cereal grains destined for further processing and 1000 µg/kg in wheat flour [10]. EFSA has established a group TDI of 1 µg/kg body weight (bw) per day for DON and its acetylated and modified forms [12] and a TDI of 0.25 µg/kg bw per day for ZEA [11].

Pesticide residues and their behavior in soil. The persistence of pesticides in soil is characterized by their half-life (DT₅₀), which varies widely with environmental conditions. Soil bacteria and fungi degrade pesticides through hydrolysis, oxidation and mineralization; higher temperature and microbiological activity shorten DT₅₀, whereas reduced microbial activity can lead to long-term persistence of residues. The movement of pesticides in soil is controlled mainly by sorption–desorption: in soils rich in organic matter sorption is high and bioavailability is reduced, whereas in soils with low humus content leaching and migration to groundwater increase. Soil reaction also matters: some herbicides are more stable in alkaline soils, while hydrolytic degradation may accelerate in acidic soils [8, 33]. Monitoring data confirm the value of residue control: in the 2022 EU monitoring program, 96.3% of 110,829 food samples were within legal limits, 3.7% exceeded the MRL and 2.2% were non-compliant after measurement uncertainty was taken into account [21]. Integrated pest management (IPM) is considered an effective approach to optimizing pesticide use and reducing residue risks [8].

Nitrate and nitrite formation and related risks. The nitrogen cycle is one of the main

biogeochemical processes in wheat agroecosystems. During nitrification ammonium is converted to nitrate, and during denitrification nitrate is reduced to gaseous nitrogen; both processes depend on soil moisture, temperature and aeration. Nitrate leaching increases under intensive fertilization and high precipitation, especially in sandy soils, and results in groundwater contamination [39]. In the human body nitrate can be converted to nitrite, which causes methemoglobinemia and can contribute to the formation of N-nitroso compounds. The ADI is 3.7 mg/kg bw per day for nitrate [15] and 0.07 mg nitrite ion/kg bw per day for nitrite [14].

Behavior and bioaccumulation of heavy metals in the wheat system. The behavior of heavy metals in the soil–plant system is determined by their bioavailability. The transfer factor (TF) and bioaccumulation factor (BAF) are used to quantify the transfer of elements from soil to plants, while the enrichment factor (EF) and pollution index (PI) characterize the degree of anthropogenic soil contamination. Cadmium enters soil mainly with phosphorus fertilizers, and lead accumulates through atmospheric deposition and industrial emissions; a decrease in soil pH increases the mobility of these elements and their accumulation in plants [9, 31]. In the EU, the maximum level of cadmium is 0.10 mg/kg for cereal grains, including common wheat, and 0.18 mg/kg for durum wheat [17]; the Codex Alimentarius sets 0.2 mg/kg for cadmium in wheat and 0.2 mg/kg for lead in cereal grains [10]. Phytoremediation and immobilization methods are considered promising approaches to reducing the mobility of heavy metals in contaminated soils [6].

Toxicological assessment and risk analysis. Health-based guidance values (ADI, TDI, ARfD) define the intake of a substance considered safe over a lifetime or within one day, while NOAEL and LOAEL characterize the thresholds of toxic effects in experimental studies from which these values are derived [38]. For quantitative risk assessment, the estimated daily intake ($EDI = C \times IR / BW$, where C is the contaminant concentration in grain, IR is the daily intake of the product and BW is body weight) is compared with the reference dose (RfD). A hazard quotient ($HQ = EDI / RfD$) greater than 1 indicates a potential non-carcinogenic risk, and the hazard index ($HI = \sum HQ$) characterizes the combined effect of several contaminants. For carcinogenic substances, cancer risk ($CR = EDI \times CSF$, where CSF is the cancer slope factor) is calculated; values between 10^{-6} and 10^{-4} are usually regarded as the acceptable range and values above 10^{-4} as high risk [23, 29, 31]. The LD_{50} provides information only on acute toxicity and is not sufficient for a comprehensive assessment of food safety risk. The definitions and fields of application of these indicators are given in Table 3.

Table 3.

Toxicological and Risk Indicators Used in Food Safety Assessment

Indicator	Full term	Definition	Application and interpretation
LD₅₀	Median lethal dose	Dose expected to cause death in 50% of the experimental population	Classification of acute toxicity; not sufficient for dietary risk assessment
NOAEL / LOAEL	No / lowest observed adverse effect level	Highest dose without, and lowest dose with, observed adverse effects in experimental studies	Point of departure for deriving ADI and TDI (divided by uncertainty factors, usually 100)
ADI	Acceptable daily intake	Amount of an intentionally used substance (pesticide, food additive) that can be ingested daily over a lifetime without appreciable health risk	Pesticide residues, nitrates and nitrites; expressed in mg/kg bw/day
TDI	Tolerable daily intake	Amount of a contaminant that can be ingested daily over a lifetime without appreciable health risk	Mycotoxins and heavy metals (for some metals expressed as weekly intake)
ARfD	Acute reference dose	Amount of a substance that can be ingested within 24 hours or less without appreciable health risk	Short-term (acute) exposure to pesticide residues

Indicator	Full term	Definition	Application and interpretation
MRL / ML	Maximum residue limit / maximum level	Highest legally permitted concentration of a pesticide residue (MRL) or contaminant (ML) in food	Regulatory control and compliance assessment of grain (Codex, EU)
EDI	Estimated daily intake	$EDI = C \times IR / BW$	Exposure estimate compared with ADI, TDI or RfD
HQ / HI	Hazard quotient / hazard index	$HQ = EDI / RfD$; $HI = \sum HQ$	HQ or HI > 1 indicates a potential non-carcinogenic risk
CR	Cancer risk	$CR = EDI \times CSF$	10^{-6} – 10^{-4} – acceptable range; > 10^{-4} – high risk

Source: compiled by the authors based on [16, 23, 29, 31, 38]. C – contaminant concentration; IR – daily intake of the product; BW – body weight; RfD – reference dose; CSF – cancer slope factor.

Role of agrochemical practices in ensuring the safety of wheat products. Ensuring the safety of wheat products is not limited to laboratory testing of the final product; it requires an agrochemical management system that starts with the soil and covers fertilization, plant protection, irrigation, storage and product quality control (Table 4). Agrochemical certification of soils is the initial stage: determining soil pH, humus reserves, nutrient supply and the concentration of potential contaminants makes it possible to assess the actual agroecological condition of a field and to develop optimal fertilization and land-reclamation strategies. Fertilization adapted to the biological needs of plants prevents excessive nitrogen accumulation and limits the transfer of nitrates into grain. Pesticide residue monitoring prevents MRL exceedances, and analysis of irrigation water identifies the sources of heavy metals and salts entering the agroecosystem. Laboratory control is the final stage that evaluates the effectiveness of all agrochemical measures and confirms compliance with national and international standards [10, 17, 38].

Table 4.
Role of Agrochemical Practices in Ensuring Food Safety of Wheat Products

Agrochemical practice	Objective	Expected outcome	Assessment criteria and references
Agrochemical soil assessment and certification	Evaluation of soil fertility and contamination status	Reduction of contamination risks and sustainable soil management	pH, humus, CEC, heavy metals (EF, PI) [4, 6]
Balanced and site-specific fertilizer application	Prevention of excessive nitrate accumulation and optimization of plant nutrition	Improved grain quality and safer wheat production	Nitrogen balance; nitrate ADI [15, 39]
Pesticide residue monitoring	Determination of pesticide residue levels and compliance with regulatory limits	Production of safe and high-quality wheat products	MRL, ADI, ARfD [21]
Irrigation water quality assessment	Identification of chemical contaminants and pollution sources	Reduced risk of heavy metal, salt and chemical contamination	Heavy metals, salinity [23, 29]
Grain storage control	Maintaining grain moisture at 13–14% or below and controlling temperature	Prevention of mycotoxin formation during storage	Grain moisture; EU MLs for mycotoxins [5, 18]
Laboratory quality control and monitoring	Evaluation of food safety indicators and contaminant levels	Compliance with national and international food safety standards	Codex and EU MLs; EDI, HQ [10, 17]

Source: compiled by the authors based on [4–6, 10, 15, 17, 18, 21, 23, 29, 39]. CEC – cation exchange capacity; EF – enrichment factor; PI – pollution index.

Conclusion. *Main scientific conclusion.* The reviewed literature shows that the safety

of wheat products is formed along the whole soil–plant–grain–storage chain. The accumulation of pesticide residues, nitrates, heavy metals and mycotoxins in grain is determined by soil properties (pH, humus content, CEC), fertilization and plant protection practices, irrigation-water quality, climatic conditions and storage regimes; therefore, final-product testing alone cannot guarantee the safety of wheat products.

Practical significance. An agrochemical monitoring system that combines soil certification, balanced fertilization, pesticide residue control, irrigation-water analysis, storage control and laboratory testing of grain, with results interpreted against Codex and EU maximum levels and health-based guidance values (ADI, TDI), makes it possible to identify risks at an early stage and to optimize decision-making in the agricultural sector. For Azerbaijan, soil salinization, fertilization practices, irrigation-water quality and farm-level storage conditions should be priority areas of such monitoring.

Future research directions. Further research is needed on the occurrence of mycotoxins, pesticide residues and heavy metals in wheat grown in the main grain-growing areas of Azerbaijan, on exposure-based risk assessment (EDI, HQ, HI, CR) for the national population, on the combined effects of multiple contaminants and on the impact of climate change on contamination risks.

References

1. Əliyev, C. Ə., Musayev, Ə. C., Qəmbərov, İ. C., & İbadov, V. F. (1986). *Azərbaycan SSR-də yüksək keyfiyyətli qüvvəli və bərk buğdaların yetişdirilməsinə dair tövsiyələr*. Bakı. 31 s.
2. Musayev, Ə. C., Təlai, C. M., Rzayev, M. Y., Cümşüdoğ, İ. M., Əzizova, M. N., Əbdürəhmanov, Ə. S., & Dünyamaliyev, S. Ə. (2012). *Suvarma şəraitində tarla bitkilərinin becərilməsinə dair tövsiyələr*. Müəllim nəşriyyatı. Bakı. 51 s.
3. Vəliyev, A., Əlibəyov, N., & Rəhmani, Ə. (2016). *Aqrar sahibkarlar üçün tövsiyələr: Fermerlərə kömək*. Bakı. 74 s.
4. Alloway, B. J. (Ed.). (2013). *Heavy metals in soils: Trace metals and metalloids in soils and their bioavailability* (3rd ed.). Springer. <https://doi.org/10.1007/978-94-007-4470-7>
5. Baloch, U. K. (1999). *Wheat: Post-harvest operations* (Post-harvest Compendium). Food and Agriculture Organization of the United Nations. https://www.fao.org/fileadmin/user_upload/inpho/docs/Post_Harvest_Compendium_-_WHEAT.pdf
6. Bolan, N., Kunhikrishnan, A., Thangarajan, R., Kumpiene, J., Park, J., Makino, T., Kirkham, M. B., & Scheckel, K. (2014). Remediation of heavy metal(loid)-contaminated soils – To mobilize or to immobilize? *Journal of Hazardous Materials*, 266, 141–166. <https://doi.org/10.1016/j.jhazmat.2013.12.018>
7. Bordin, A. B., Minetto, L., do Nascimento Filho, I., Beal, L. L., & Moura, S. (2017). Determination of pesticide residues in whole wheat flour using modified QuEChERS and LC–MS/MS. *Food Analytical Methods*, 10(1), 1–9. <https://doi.org/10.1007/s12161-016-0542-2>
8. Carvalho, F. P. (2017). Pesticides, environment, and food safety. *Food and Energy Security*, 6(2), 48–60. <https://doi.org/10.1002/fes3.108>
9. Clemens, S., & Ma, J. F. (2016). Toxic heavy metal and metalloid accumulation in crop plants and foods. *Annual Review of Plant Biology*, 67, 489–512. <https://doi.org/10.1146/annurev-arplant-043015-112301>
10. Codex Alimentarius Commission. (2019). *General standard for contaminants and toxins in food and feed* (CXS 193-1995, amended 2019). Food and Agriculture Organization of the United Nations & World Health Organization. <https://www.isdi.org/wp-content/uploads/2020/04/CXS-193-1995.pdf>
11. EFSA Panel on Contaminants in the Food Chain (CONTAM). (2011). Scientific opinion

- on the risks for public health related to the presence of zearalenone in food. *EFSA Journal*, 9(6), Article 2197. <https://doi.org/10.2903/j.efsa.2011.2197>
12. EFSA Panel on Contaminants in the Food Chain (CONTAM). (2017). Risks to human and animal health related to the presence of deoxynivalenol and its acetylated and modified forms in food and feed. *EFSA Journal*, 15(9), Article e04718. <https://doi.org/10.2903/j.efsa.2017.4718>
 13. EFSA Panel on Contaminants in the Food Chain (CONTAM). (2020). Risk assessment of ochratoxin A in food. *EFSA Journal*, 18(5), Article e06113. <https://doi.org/10.2903/j.efsa.2020.6113>
 14. EFSA Panel on Food Additives and Nutrient Sources added to Food (ANS). (2017a). Re-evaluation of potassium nitrite (E 249) and sodium nitrite (E 250) as food additives. *EFSA Journal*, 15(6), Article e04786. <https://doi.org/10.2903/j.efsa.2017.4786>
 15. EFSA Panel on Food Additives and Nutrient Sources added to Food (ANS). (2017b). Re-evaluation of sodium nitrate (E 251) and potassium nitrate (E 252) as food additives. *EFSA Journal*, 15(6), Article e04787. <https://doi.org/10.2903/j.efsa.2017.4787>
 16. EFSA Scientific Committee, More, S. J., Bampidis, V., Benford, D., Bennekou, S. H., Bragard, C., Halldorsson, T. I., Hernández-Jerez, A. F., Koutsoumanis, K., Naegeli, H., Schlatter, J. R., Silano, V., Nielsen, S. S., Schrenk, D., Turck, D., Younes, M., Benfenati, E., Castle, L., Cedergreen, N., ... Hogstrand, C. (2019). Guidance on harmonised methodologies for human health, animal health and ecological risk assessment of combined exposure to multiple chemicals. *EFSA Journal*, 17(3), Article 5634. <https://doi.org/10.2903/j.efsa.2019.5634>
 17. European Commission. (2023). Commission Regulation (EU) 2023/915 of 25 April 2023 on maximum levels for certain contaminants in food and repealing Regulation (EC) No 1881/2006. *Official Journal of the European Union*, L 119, 103–157. <https://eur-lex.europa.eu/eli/reg/2023/915/oj>
 18. European Commission. (2024). Commission Regulation (EU) 2024/1022 of 8 April 2024 amending Regulation (EU) 2023/915 as regards maximum levels of deoxynivalenol in food. *Official Journal of the European Union*, L series, 2024/1022. <https://eur-lex.europa.eu/eli/reg/2024/1022/oj>
 19. European Food Safety Authority. (2012). Risk assessment of contaminants in food and feed. *EFSA Journal*, 10(10), Article S1004. <https://doi.org/10.2903/j.efsa.2012.s1004>
 20. European Food Safety Authority, Carrasco Cabrera, L., & Medina Pastor, P. (2021). The 2019 European Union report on pesticide residues in food. *EFSA Journal*, 19(4), Article e06491. <https://doi.org/10.2903/j.efsa.2021.6491>
 21. European Food Safety Authority, Carrasco Cabrera, L., Di Piazza, G., Dujardin, B., Marchese, E., & Medina Pastor, P. (2024). The 2022 European Union report on pesticide residues in food. *EFSA Journal*, 22(4), Article e8753. <https://doi.org/10.2903/j.efsa.2024.8753>
 22. Food and Agriculture Organization of the United Nations. (2022). *World food and agriculture – Statistical yearbook 2022*. <https://doi.org/10.4060/cc2211en>
 23. Han, J., Lee, S., Mammadov, Z., Kim, M., Mammadov, G., & Ro, H.-M. (2021). Source apportionment and human health risk assessment of trace metals and metalloids in surface soils of the Mugan Plain, the Republic of Azerbaijan. *Environmental Pollution*, 290, Article 118058. <https://doi.org/10.1016/j.envpol.2021.118058>
 24. Johns, L. E., Bebbler, D. P., Gurr, S. J., & Brown, N. A. (2022). Emerging health threat and cost of Fusarium mycotoxins in European wheat. *Nature Food*, 3(12), 1014–1019. <https://doi.org/10.1038/s43016-022-00655-z>
 25. Kovač, M., Bulaić, M., Jakovljević, J., Nevistić, A., Rot, T., Kovač, T., Šarkanj, I. D., & Šarkanj, B. (2021). Mycotoxins, pesticide residues, and heavy metals analysis of Croatian cereals. *Microorganisms*, 9(2), Article 216.

- <https://doi.org/10.3390/microorganisms9020216>
26. Liu, C., & Van der Fels-Klerx, H. J. (2021). Quantitative modeling of climate change impacts on mycotoxins in cereals: A review. *Toxins*, 13(4), Article 276. <https://doi.org/10.3390/toxins13040276>
 27. Medina, A., Akbar, A., Baazeem, A., Rodríguez, A., & Magan, N. (2017). Climate change, food security and mycotoxins: Do we know enough? *Fungal Biology Reviews*, 31(3), 143–154. <https://doi.org/10.1016/j.fbr.2017.04.002>
 28. Mousavi Khaneghah, A., Fakhri, Y., Nematollahi, A., & Pirhadi, M. (2020). Potentially toxic elements in cereal-based foods: A systematic review. *Trends in Food Science & Technology*, 96, 30–44. <https://doi.org/10.1016/j.tifs.2019.12.007>
 29. Nawaz, H., Anwar-ul-Haq, M., Akhtar, J., & Arfan, M. (2021). Cadmium, chromium, nickel and nitrate accumulation in wheat (*Triticum aestivum* L.) using wastewater irrigation and health risks assessment. *Ecotoxicology and Environmental Safety*, 208, Article 111685. <https://doi.org/10.1016/j.ecoenv.2020.111685>
 30. Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372, Article n71. <https://doi.org/10.1136/bmj.n71>
 31. Rai, P. K., Lee, S. S., Zhang, M., Tsang, Y. F., & Kim, K. H. (2019). Heavy metals in food crops: Health risks, fate, mechanisms, and management. *Environment International*, 125, 365–385. <https://doi.org/10.1016/j.envint.2019.01.067>
 32. Schaarschmidt, S., & Fauhl-Hassek, C. (2018). The fate of mycotoxins during the processing of wheat for human consumption. *Comprehensive Reviews in Food Science and Food Safety*, 17(3), 556–593. <https://doi.org/10.1111/1541-4337.12338>
 33. Sharma, A., Kumar, V., Shahzad, B., Tanveer, M., Sidhu, G. P. S., Handa, N., Kohli, S. K., Yadav, P., Bali, A. S., Parihar, R. D., Dar, O. I., Singh, K., Jasrotia, S., Bakshi, P., Ramakrishnan, M., Kumar, S., Bhardwaj, R., & Thukral, A. K. (2019). Worldwide pesticide usage and its impacts on ecosystem. *SN Applied Sciences*, 1, Article 1446. <https://doi.org/10.1007/s42452-019-1485-1>
 34. Sparks, D. L. (2020). A golden period for environmental soil chemistry. *Geochemical Transactions*, 21, Article 5. <https://doi.org/10.1186/s12932-020-00071-0>
 35. Tilman, D., Balzer, C., Hill, J., & Befort, B. L. (2011). Global food demand and the sustainable intensification of agriculture. *Proceedings of the National Academy of Sciences of the United States of America*, 108(50), 20260–20264. <https://doi.org/10.1073/pnas.1116437108>
 36. White, P. J., & Brown, P. H. (2010). Plant nutrition for sustainable development and global health. *Annals of Botany*, 105(7), 1073–1080. <https://doi.org/10.1093/aob/mcq085>
 37. World Health Organization. (2026, June 4). *Food safety*. <https://www.who.int/news-room/fact-sheets/detail/food-safety>
 38. World Health Organization, & Food and Agriculture Organization of the United Nations. (2009). *Principles and methods for the risk assessment of chemicals in food* (Environmental Health Criteria 240). World Health Organization. <https://www.who.int/publications/i/item/9789241572408>
 39. Zhang, X., Davidson, E. A., Mauzerall, D. L., Searchinger, T. D., Dumas, P., & Shen, Y. (2015). Managing nitrogen for sustainable development. *Nature*, 528(7580), 51–59. <https://doi.org/10.1038/nature15743>

BUĞDA MƏHSULLARININ QIDA TƏHLÜKƏSİZLİYİNİN TƏMİN EDİLMƏSİNDƏ AQROKİMYƏVİ MONİTORİNQIN ROLU

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Xülasə. Buğda və digər taxıl bitkiləri dünya əhalisinin ərzaq təminatında strateji əhəmiyyət daşıyan kənd təsərrüfatı məhsullarıdır. Əhalinin artması və ərzağa olan tələbatın yüksəlməsi fonunda yalnız taxıl bitkilərinin məhsuldarlığının artırılması deyil, həm də taxıl məhsullarının təhlükəsizliyinin təmin edilməsi mühüm əhəmiyyət kəsb edir. Bu strukturlaşdırılmış ədəbiyyat icmalının məqsədi dərc olunmuş elmi və normativ mənbələr əsasında buğda və taxıl məhsullarında rast gəlinən əsas kimyəvi çirkləndiricilərin – pestisid qalıqlarının, nitrat və nitritlərin, ağır metalların, mikotoksinlərin və digər toksik maddələrin qida təhlükəsizliyinə təsirini qiymətləndirmək və aqrokimyəvi monitorinqin rolunu müəyyən etməkdir. Nəzərdən keçirilmiş elmi mənbələr göstərir ki, torpaq–bitki–dən zənciri boyunca tətbiq olunan aqrokimyəvi nəzarət sistemləri buğda məhsullarında təhlükəli maddələrin miqdarını normativ hədlər daxilində saxlamağa və insan sağlamlığı üçün potensial riskləri minimuma endirməyə imkan verir. Ədəbiyyatda çirkləndiricilərin yol verilən maksimum səviyyələri, sağlamlığa əsaslanan istinad göstəriciləri (ADI, TDI, ARfD) və məruzqalmaya əsaslanan risk göstəriciləri (EDI, HQ, HI, CR) buğda məhsullarının qida təhlükəsizliyinin qiymətləndirilməsində əsas meyarlar kimi göstərilir.

Açar sözlər: buğda, taxıl, pestisidlər, mikotoksinlər, metallar, monitorinq

РОЛЬ АГРОХИМИЧЕСКОГО МОНИТОРИНГА В ОБЕСПЕЧЕНИИ ПИЩЕВОЙ БЕЗОПАСНОСТИ ПРОДУКЦИИ ИЗ ПШЕНИЦЫ

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Аннотация. Пшеница и другие зерновые культуры являются сельскохозяйственной продукцией стратегического значения для продовольственного обеспечения населения мира. В условиях роста численности населения и увеличения потребности в продовольствии важно не только повышать урожайность зерновых культур, но и обеспечивать безопасность зерновой продукции. Цель настоящего структурированного обзора литературы – на основе опубликованных научных и нормативных источников оценить влияние основных химических загрязнителей пшеницы и зерновой продукции (остатков пестицидов, нитратов и нитритов, тяжёлых металлов, микотоксинов и других токсичных веществ) на пищевую безопасность и определить роль агрохимического мониторинга. Рассмотренные данные свидетельствуют о том, что системы агрохимического контроля, применяемые на всех звеньях цепи «почва – растение – зерно», позволяют поддерживать содержание опасных веществ в пшеничной продукции в пределах установленных нормативов и минимизировать потенциальные риски для здоровья человека. В литературе в качестве основных критериев оценки пищевой безопасности пшеничной продукции рассматриваются максимально допустимые уровни загрязнителей, ориентировочные показатели безопасности для здоровья (ADI, TDI, ARfD) и показатели риска, основанные на оценке экспозиции (EDI, HQ, HI, CR).

Ключевые слова: пшеница, зерно, пестициды, микотоксины, металлы, мониторинг

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