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Research article

PUBLIC HEALTH RISKS CAUSED BY CONTAMINATION OF LOCAL FOOD PRODUCTS

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Food safety is a major concern around the world due to toxic metal contamination in food and associated health risks. Vegetables, cereals and baked goods make up a large part of a healthy human diet as vital sources of nutrients, minerals and fiber. Long-term intake of metals with food facilitates their accumulation in the human body.

The study aimed to assess health risks for adults and children caused by alimentary intake of chemical elements with local food products.

The study was conducted in the Republic of Bashkortostan, which is a territory with a developed agricultural and industrial complex. A total of 524 plant samples were selected and analyzed to identify levels of lead, cadmium, copper, zinc, iron, nickel and aluminum in them by using atomic absorption analysis. Samples included bakery and cereal products sold in the republic and vegetable products from private farms.

The article describes the results of hygienic assessment with its focus on contents of essential and toxic elements in locally produced foods. Intake of contaminants with local food products was established based on the data on average food consumption per capita. We determined contributions made by two groups of traditional mass-consumption products to the total exposure that influences health of people living in different districts across the republic. The study established the total hazard quotient of non-carcinogenic effects to be higher than its threshold vale and to equal 3.43 for children and 1.54 for adults. The greatest contributions to the total hazard quotients were made by copper (45 %) and cadmium (30 %). Our assessment of carcinogenic risks caused by intake of contaminants with foods revealed that the total health risk as per the median value corresponded to its permissible level.

Keywords: *risk assessment, metals, safety, quality, diet, vegetables, cereals, bakery products.*

Research on healthy diets clearly shows that they have considerable influence on people's health and quality of their life by providing the body with all the necessary nutrients. It is our diet that provides our bodies with enough energy to synthesize hormones, enzymes and vitamins and to recover cells and tissues properly [1]. Health of each individual as well as a nation as a whole depends on food quality and quantity. Food safety is a major issue in health protection [2–4].

Heavy metals are commonly recognized as food contaminants both on the global and regional scale [5]. Chemicals from this group are characterized with high prevalence and great ability to migrate in environmental objects. Some of them (cadmium, lead) are hazardous due to their high biological activity and

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toxic properties. Long-term intake of these elements even in low doses can result in impaired functioning of the cardiovascular, nervous and immune systems; it can cause factional disorders of the kidneys and liver and developing oncologic diseases. Some specific elements such as iron, copper, chromium, and zinc have a key role in maintaining proper functioning of the body and act as micronutrients whereas their excessive intake can affect metabolism [6].

Some studies have shown that traditional mass consumption products (cereals, bakery, milk products, vegetables, and potatoes) make the most considerable contributions to health risks caused by toxic elements in them [7–9]. Chemicals are usually contained in plant products in their ion form or are bound to a plant protein and pectin. Their levels are influenced by soil-related or geological natural factors as well as anthropogenic ones such as usage of fertilizers, industrial pollution and motor transport. It is rather difficult to reduce levels of toxic microelements in food products without changing their nutritional value since metal protein complexes are stable compounds; given that, it is especially vital to prevent food contamination [10, 11].

Researchers primarily pay attention to issues related to chemicals being dispersed at mining operation sites or contamination with heavy metals identified in agricultural soils [12, 13]. Much less attention has been given to burdens on public health created by contamination in locally produced agricultural foods, especially those produced on private farms; such products are often neglected in studies with their focus on food safety indicators. This aspect of the outlined problem is important due to growing consumption of vegetables and melons by the population in the Russian Federation [14], absence of standards on permissible levels of chemicals in foods that are priority contaminants in some regions and the system for monitoring of food quality and safety still being underdeveloped at the moment.

All the aforementioned gave grounds for conducting a study in the Republic of Bashkortostan, a leading industrial and agricultural region in Russia. A peculiar feature of the republican economy is that some oil-processing, chemical, mining and metallurgical enterprises are located in zones with developed agriculture; chemization of agriculture makes an additional contribution to technogenic dispersion of contaminants.

In this study, our aim was to assess health risks for adults and children caused by alimentary intake of chemical elements with food products produced locally in the Republic of Bashkortostan.

Materials and methods. To estimate levels of micronutrients in foods, we identified seven chemicals in bakery products and cereals (N = 228) sold in Bashkortostan and in plant products (N = 296) grown by locals on private farms. Levels of elements were identified by using the atomic absorption procedure with plasma and electrothermal atomization on Varian SpectrAA, models 240FS and 240Z (Australia).

Plant samples included open field potatoes, carrots and table beet; these vegetables were more eligible to examine contamination in them than, for example, greenhouse ones. Root vegetables were sampled directly at places where they were grown. To obtain one combined sample, not less than 8 to 10 spot samples of plant products were taken at different places within one selected land spot. Territories were selected for analysis considering specific economic activities performed there: the western part had oil and gas fields (5 districts); the south-eastern part, ore mines and ferrous and non-ferrous metallurgy (4 districts); the central part had both industry and agriculture (5 districts); and the northern part was the least industrialized (4 districts).

Daily alimentary intakes were calculated using data on average per capita consumption of basic food products in 2021 provided by the Federal State Statistics Service as well as data obtained by a survey that focused on actual diets consumed by children aged 7–11 years; the survey was conducted by round-the-clock diet tracking.

We assessed health risks caused by alimentary intake of contaminants and influence exerted on public health by the calculated exposure to chemical contaminants in food products in accordance with the Guide R 2.1.10.1920-04. Human Health Risk Assessment from Environmental Chemicals[1]. Risks of developing non-carcinogenic effects were estimated by calculating hazard quotients (HQ) and hazard indexes (HI). Risks of carcinogenic effects involved calculating individual carcinogenic risks (CR). HQs were calculated allowing for a median dose.

All the results were statistically analyzed with SPSS Statistics 21.0. The Kolmogorov – Smirnov test was applied to check normalcy of distribution in the analyzed groups. To estimate whether intergroup differences were significant, we took the non-parametric Kruskal – Wallis test for three or more groups and the non-parametric Mann – Whitney test for two groups. The data were given as the median with the 25th and 75th percentiles. Differences were considered significant at $p < 0.05$.

Results and discussion. Lead, mercury, cadmium and arsenic are considered toxic elements that are subject to hygienic control in food raw materials and food products. These aforementioned heavy metals are widely spread contaminants that occur in food raw materials and food products and affect human health [15]. Nutritional value of food products is no less important than their safety, in particular, levels of other microelements in them. Essential and conditionally essential elements, if taken in excessive quantities, may also induce substantial changes in health and adaptive capabilities of the body [16, 17].

Levels of chemicals in vegetables, cereals and bakery products are given in Figure 1.

Comparative analysis with the Kruskal – Wallis test revealed statistically significant differences between various vegetables as per levels of cadmium (H = 12.1; $p = 0.002$), iron (H = 16.8; $p = 0.0001$), zinc (H = 61.1; $p = 0.0001$), copper (H = 86.9; $p = 0.0001$) and aluminum (H = 16.8; $p = 0.0001$).

The highest levels of copper (Me = 0.84 mg/kg (0.64; 1.1)), zinc (Me = 3.3 mg/kg (2.6; 4.5)), cadmium (Me = 0.016 mg/kg (0.008; 0.028)) were identified in table beetroot; iron, in potatoes (Me = 4.3 mg/kg (3.2; 5.0)); aluminum, in carrots (Me = 0.51 mg/kg (0.28; 0.97)). We did not detect any statistically significant differences between lead and nickel levels in various root vegetables ($p > 0.05$). Median contents of lead and cadmium in vegetables did not exceed maximum permissible levels. Still, single samples contained cadmium in levels higher than the existing hygienic standards. The highest lead contamination was identified in table beet (0.16 mg/kg, the permissible level being 0.03 mg/kg).

Statistical analysis of two independent product groups (cereals and bakery products) with the Mann – Whitney test established significant differences as per levels of copper (U = 179; $p = 0.0001$), zinc (U = 271; $p = 0.002$), nickel (U = 247; $p = 0.002$), cadmium (U = 4361; $p = 0.018$) and lead (U = 7074; $p = 0.0001$). We did not detect any statistically significant differences in aluminum and iron levels ($p > 0.05$). The highest levels of zinc were identified in whole grain oat flakes (34 mg/kg); copper, in buckwheat cereal (5.7 mg/kg). The median levels of lead and cadmium did not exceed their maximum permissible levels. The highest lead contents were identified in bakery products (Me = 0.015 mg/kg (0.006; 0.029)); cadmium, in cereals (Me = 0.009 mg/kg (0.005; 0.013)).

We analyzed chemical contamination comparatively in different districts in the republic and established certain peculiarities typical for each of them. The established differences were statistically significant and were identified as per levels of iron (H = 24.0; $p = 0.0001$), copper (H = 15.7; $p = 0.001$), zinc (H = 12.8; $p = 0.005$), aluminum (H = 26.7; $p = 0.0001$), cadmium (H = 31.2; $p = 0.0001$) and lead (H = 99.9; $p = 0.0001$). Figure 2 provides the results.

[1] R 2.1.10.1920-04. Human Health Risk Assessment from Environmental Chemicals (approved and validated by G.G. Onishchenko, the RF Chief Sanitary Inspector, the First Deputy to the RF Public Healthcare Minister on March 5, 2004). *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200037399 (June 12, 2022) (in Russian).

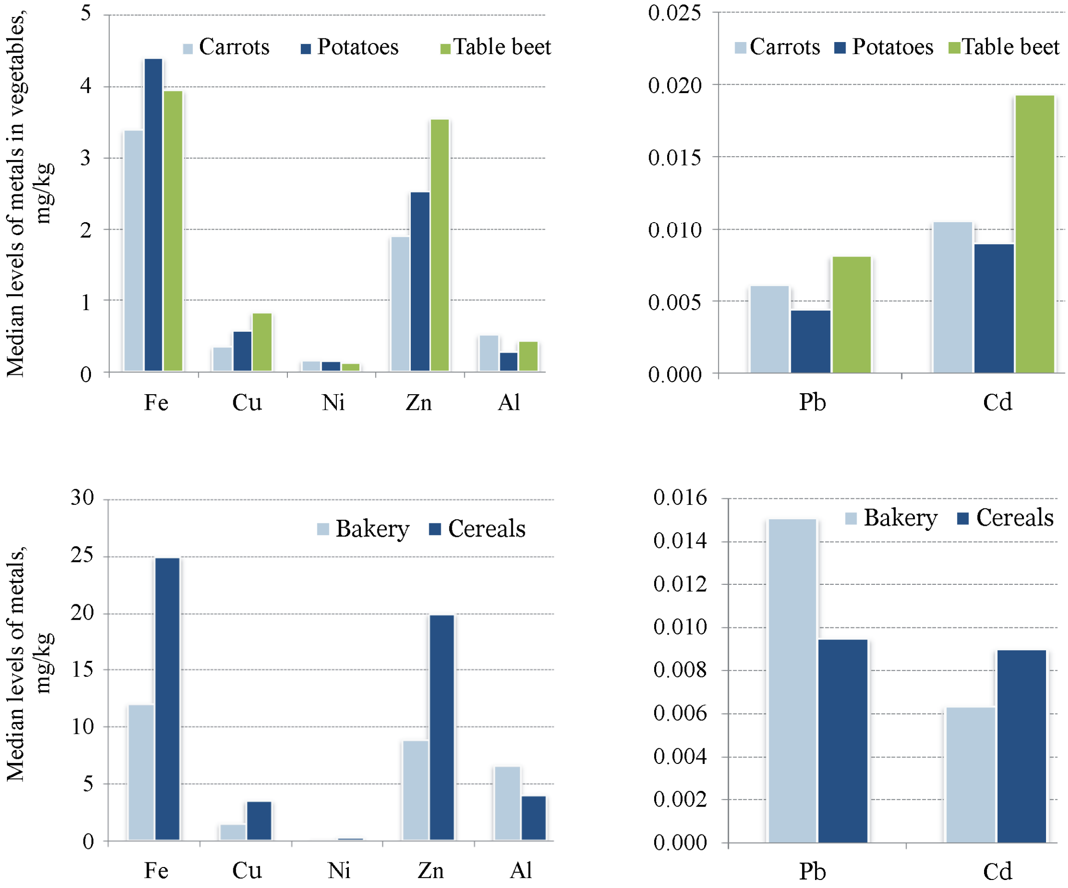

Figure 1. Microelements in food products

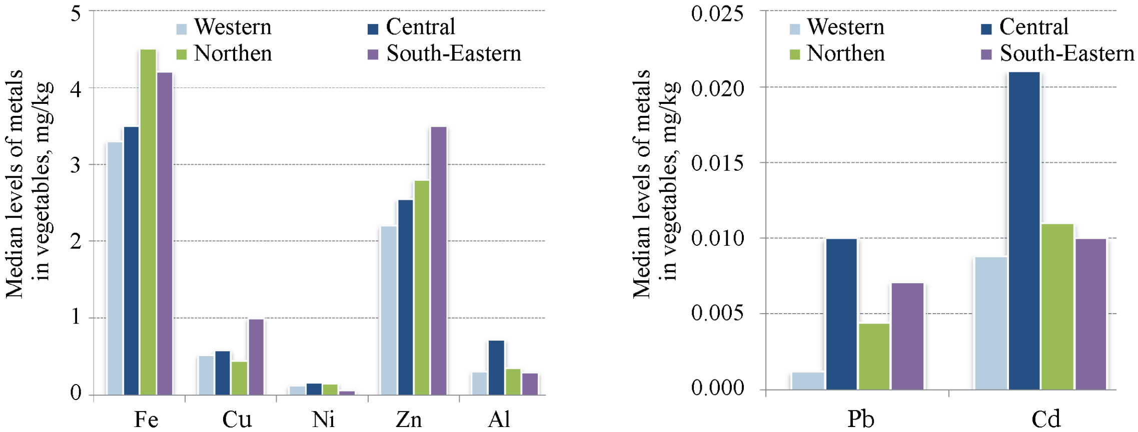

Figure. 2. Microelements in vegetables grown in Bashkortostan districts with different economic specialization

The highest levels of copper (Me = 1.00 mg/kg (0.47; 1.3)) and zinc (Me = 3.5 mg/kg (2.3; 4.2)) were identified in vegetables from the south-eastern part of the republic. They occurred due to ore mining enterprises located on this territory. The lowest levels of lead contamination were detected in vegetables from the western part. The higher median cadmium levels (up to 4 MPC) were identified in vegetables from the central part of the republic. A share of samples with cadmium levels being higher than MPC was also higher in the central part where it equaled 29 % whereas such shares did not exceed 10 % in other districts and the median levels to MPC ratios varies from 1.1 to 3.

Therefore, metal levels varied depending on a kind of a vegetable due to their different absorbability as well as due to regional peculiarities of soil and ambient air contamination.

The research data on levels of elements in bakery products, cereals and vegetables were used to calculate exposures to contaminants for children and adults (Table 1).

Daily intake of a specific metal depends on both its contents in food products and their consumed quantities. In Bashkortostan, average daily consumption of vegetables, potatoes included, amounts to 400 grams per person; cereals and bakery products, about 300 grams per person[2]. The RF Public Healthcare Ministry recommends daily consumption of vegetables to be about 340 grams per person; bakery products and cereals, 260 grams per person. The questioning [18] established that children aged 7–11 years consumed approximately 150 grams of vegetables and about 380 grams of cereals and bakery goods a day. Obviously, daily intake of vegetables was lower that recommended whereas cereals and bakery products were consumed in quantities that were by 1.5 times higher than the recommended norms.

The median exposure of adults to copper and zinc was considerably lower that their tolerable daily intake (500 and 1000 μg/kg of body weight a day for copper and zinc accordingly). Daily intake of these metals was higher for children and amounted to 6 % of tolerable daily intake of copper and 18.2 % of tolerable daily intake of zinc.

Calculated daily intake of iron amounted to 12.4 % of its tolerable daily intake for adults and 30 % for children (0.8 mg/kg of body weight per day). Iron was introduced with bakery products and cereals in higher quantities than with vegetables.

The median nickel intake with the analyzed food products amounted to 8.5 % and 16 % of its tolerable daily intake (0.02 mg/kg of body weight per day) for adults and children accordingly. Nickel contained in bakery products and cereals was established to make greater contribution to the total daily intake by children than nickel in vegetables. As for adults, differences in nickel intakes with these product groups were minimal for adults.

Daily intake of aluminum amounted to 1.6 mg for adults and 1.8 mg for children and was substantially lower than tolerable weekly intake. Its value equals 7 mg/kg of body weight per day, that is, 70 mg a day for adults and 30 mg a day for children. Bakery products made the greatest contribution to aluminum intake.

Tolerable weekly intake of lead recommended for adults by the FAO/WHO amounts to 3.6 μg/kg a day. If we take an average body weight to be 70 kg for an adult and 30 kg for a child, we will get tolerable daily intake of lead to be equal to 250 and 107 μg accordingly. According to our calculations, the median lead intake by children is the highest when they consume bakery products; it equals 0.18 μg and is considerably lower that the permissible level.

Table 1

Median levels of microelement intake with food products, μg/kg of body weight a day

Microelement	Adults			Children		
	vegetables	bakery products and cereals	Σ	vegetables	bakery products and cereals	Σ
Lead	0.032	0.053	0.085	0.029	0.15	0.18
Cadmium	0.072	0.033	0.11	0.065	0.093	0.16
Iron	22	77	99	20	219	239
Copper	3.6	9.5	6.9	3.3	27	30
Nickel	0.70	0.99	1.7	0.63	2.6	3.2
Zinc	16	59	75	14	168	182
Aluminum	2.4	21	23	2.2	57	59

[2] Potreblenie produktov pitaniya v domashnikh khozyaistvakh v 2020 godu po itogam vyborochnogo obsledovaniya byudzhetov domashnikh khozyaistv [Food consumption in households in 2020 as per the results of the sample survey with its focus on household budgets]. Moscow, The Federal State Statistics Service, 2021, 83 p. (in Russian).

Table 2

Hazard quotients (HQ) for microelements in food products

Microelement	Adults			Children		
	vegetables	bakery products and cereals	∑ HQ	vegetables	bakery products and cereals	∑ HQ
Lead	0.01	0.02	0.02	0.008	0.04	0.05
Cadmium	0.14	0.07	0.21	0.1	0.2	0.32
Iron	0.07	0.3	0.33	0.07	0.7	0.80
Copper	0.2	0.5	0.69	0.2	1.42	1.60
Nickel	0.002	0.002	0.00	0.001	0.005	0.01
Zinc	0.05	0.2	0.25	0.05	0.6	0.61
Aluminum	0.002	0.02	0.02	0.002	0.06	0.06

The total daily intake of cadmium is equal to 11 and 16 % of its tolerable daily intake (1 µg/kg of body weight a day) for adults and children accordingly. Bearing in mind, that cadmium is a toxic metal with long half-life, it is advisable to closely monitor its intake with other food products and drinking water.

We calculated hazard quotients (HQ) for each element allowing for intake with different food products. It was done to determine potential risks of developing non-carcinogenic health effects caused by exposure to metals. The results are given in Table 2.

The total non-carcinogenic risk caused by exposure to metals in vegetables turned out to be lower that the relevant permissible level (HQ < 1) as it equaled 0.47 for adults and 0.43 for children. The hazard quotient of each metal calculated for cereals and bakery products did not exceed its permissible levels for adults.

However, a health risk associated with copper intake equaled 1.42 for children and this was by three times higher than for adults. In general, children are more susceptible to contaminants in the environment due to their physiological peculiarities (elevated absorption of some chemicals in the gastrointestinal tract, lower body weight). Having ranked contributions made by the analyzed food products to exposures to chemicals, we established that the highest contribution to exposure to cadmium was made by vegetables (30 %); exposure to copper (45 %) and iron (22 %), by bakery products and vegetables.

We also calculated hazard quotients for non-carcinogenic effects caused by intake of metals with vegetables for people living in different districts in Bashkortostan (Figure 3).

According to the research results, a risk of harmful health effects caused by daily intake of lead, iron, nickel, zinc and aluminum with vegetables was permissible in the analyzed districts. The total hazard quotient varied between 0.36 in the western part of the republic and 0.57 in the central one. The highest contribution to the total hazard index was made by cadmium in all the districts in the republic. The calculated hazard quotient for cadmium was usually below 1 but approximately 25 % of all the analyzed samples had HQ between 1 and 2 for this metal.

Several organs and systems were established to be critical under simultaneous exposure to the analyzed chemicals in food products. They included the gastrointestinal tract and liver (the hazard index, or HI, equals 0.69 for adults and 1.60 for children), blood (HI = 0.59 for adults, HI = 1.41 for children), the immune system (HI = 0.33 for adults, HI = 0.80 for children), the hormonal system (HI = 0.23 for adults, HI = 0.37 for children), and the kidneys (HI = 0.21 for adults, HI = 0.32 for children).

A probability that malignant neoplasms would develop due to cadmium and lead intake with food products varied within 10^{-6}–10^{-4} thus corresponding to a conditionally acceptable (permissible) risk level (Table 3). However, as cadmium contents were by 4 times higher than MPC in some samples, in this case an average daily intake of the metal was beyond safe levels. As a result, an individual carcinogenic risk also grew and moved closer to its permissible limits. Our study highlights the necessity to conduct relevant monitoring of agricultural products as per safety indicators

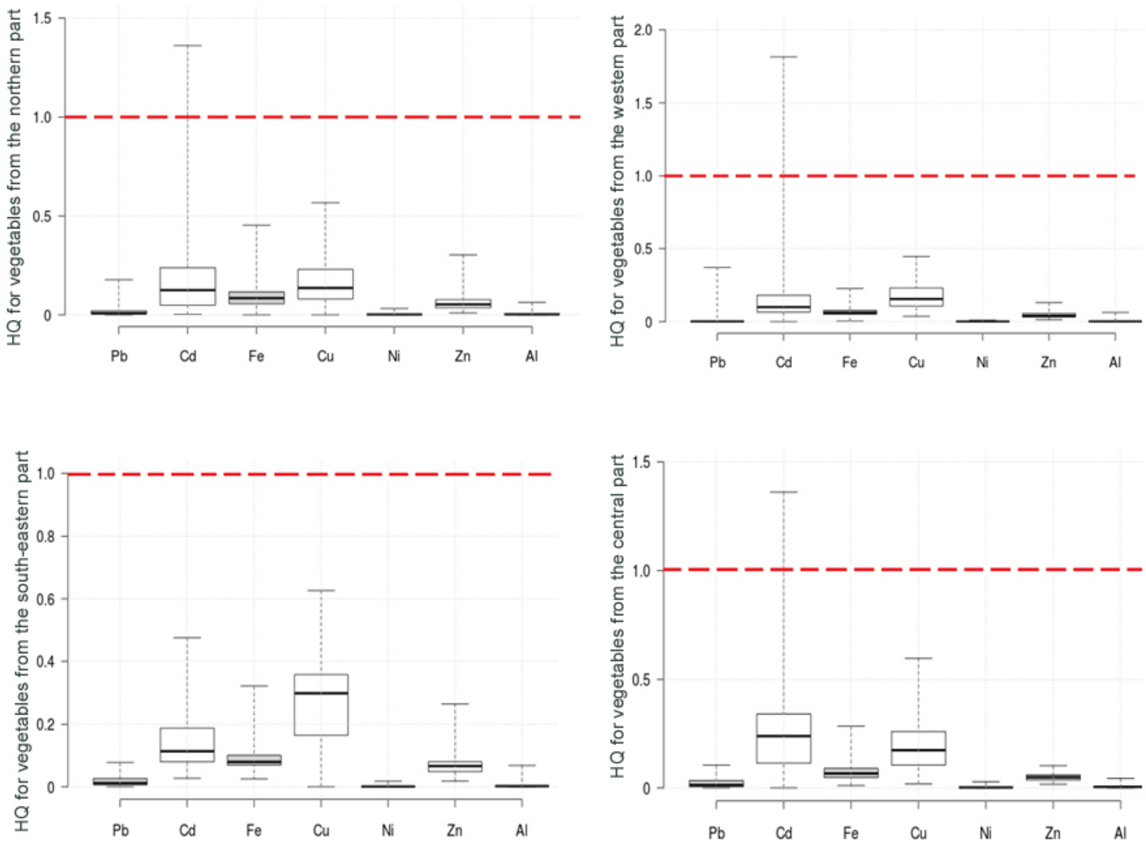

Figure 3. Hazard quotients for non-carcinogenic effects caused by intake of metals with vegetables for people living in Bashkortostan

Table 3

Assessment of carcinogenic risks for people of Bashkortostan caused by exposure to chemicals in food products

Microelement	adults		children	
	vegetables	bakery products and cereals	vegetables	bakery products and cereals
Lead	$1.5 \cdot 10^{-6}$	$2.5 \cdot 10^{-6}$	$1.4 \cdot 10^{-6}$	$7.0 \cdot 10^{-6}$
Cadmium	$2.7 \cdot 10^{-5}$	$1.2 \cdot 10^{-5}$	$2.5 \cdot 10^{-5}$	$3.5 \cdot 10^{-5}$
Total risk	$4.4 \cdot 10^{-5}$		$6.9 \cdot 10^{-5}$	

and to assess harmful effects produced on children since their bodies have much weaker abilities to metabolize, detoxify and excrete toxins [19–21].

Conclusion. This study established that in general agricultural products grown on private farms and cereals / bakery products sold in the Republic of Bashkortostan were not contaminated with extreme levels of toxic elements. Among all the analyzed product groups, vegetables contaminated with cadmium pose a relatively higher health risk, especially for people living in the central part of the republic (HQ = 0.57).

Critical organs and systems under simultaneous exposure to the analyzed contaminants in foods include the gastrointestinal tract and liver (the hazard index, or HI, equals 0.69 for adults and 1.60 for children), blood (HI = 0.59 for adults, HI = 1.41 for children). Non-carcinogenic risks for other organs and systems do not exceed their permissible levels.

The greatest contributions into non-carcinogenic health risks are made by copper (45 %) and cadmium (30 %) whereas those made by other elements account for less than 20 %. We have established that a potential health risk for children is associated with consumption of cereals and bakery products (3.01) whereas consumption of vegetables accounts for an insignificant share in this risk (0.43). The highest total hazard index has been established for chemicals that affect the gastrointestinal tract, liver and blood. The median value of the total carcinogenic risks associated with contaminants in food amounts to $4.4 \cdot 10^{-5}$ for adults and $6.9 \cdot 10^{-5}$ for children and was within its permissible levels. Therefore, potential health risks occur even under exposure to chemicals in concentrations lower than MPC.

Limitations of the study: the established risks occur only when locally produced foods are consumed; the research results should not be extrapolated to other territories.

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