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Increased Human Body Contamination With Cadmium Following Inclusion of Sunflower Seeds in Diet

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ABSTRACT

BACKGROUND: Sunflower seeds are characterized by their year-round availability, high nutritional value, and relatively low cost. Medical professionals and applied science experts emphasize the importance of incorporating whole sunflower seeds into the general population's diet. However, concerns about consumer safety—particularly the elevated cadmium content in sunflower seeds—are periodically raised in mass media. The Oil and Fat Union of Russia acknowledges the existence of this issue. At the same time, there is no consensus among scientists regarding the permissible levels of heavy metals in food and their overall impact on human health and the food chain.

AIM: The study aimed to assess the contribution of cadmium to the total toxic load from heavy metals present in sunflower seeds and to determine potential health risks associated with their regular consumption using dietary simulation modeling.

MATERIALS AND METHODS: The study included food products of regional origin and water samples from 27 centralized water supply sources located in the areas where study participants resided. Seven-day dietary and water intake recall questionnaires were collected and processed from 160 physically healthy respondents of reproductive age. In addition, cadmium and other toxic elements were measured in 26 samples of snack-type sunflower seeds using chemical analysis.

RESULTS: The permissible concentration of toxic elements in sunflower seeds was exceeded only for cadmium, with an average content of 0.23 ± 0.06 mg/kg. Daily consumption of the seeds in the amount recommended by nutritionists (50 g per day), cadmium intake ranges from 0.007 to 0.009 mg, which is twice as high as the intake from food and water—0.0033 ± 0.0012 mg and 0.0007 ± 0.0003 mg, respectively.

CONCLUSION: Simulation modeling of dietary inclusion of 50 g of snack-type sunflower seeds predicts an oral cadmium intake corresponding to an average of 31.4% of the tolerable daily intake established in the Russian Federation.

Keywords: cadmium; diet; sunflower seeds; bioaccumulation in plants, animals, and humans; safety thresholds.

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Повышение уровня контаминации организма человека кадмием при дополнении его рациона семенами подсолнечника

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АННОТАЦИЯ

Обоснование. Семена подсолнечника отличаются доступностью, высокой питательной ценностью и относительно низкой стоимостью в течение всего года. Медицинские специалисты и эксперты в области прикладных наук подчёркивают целесообразность включения цельнозернового подсолнечника в рацион питания населения. Вопрос безопасности продукции для потребителя, в частности повышенного содержания кадмия в семенах подсолнечника, периодически рассматривают в средствах массовой информации. Масложировой Союз России не отрицает наличие данной проблемы. При этом отсутствует единая точка зрения среди учёных относительно допустимого содержания тяжёлых металлов в продуктах питания и их влияния на человека и пищевую цепь в целом.

Цель. Оценить вклад кадмия в общую токсическую нагрузку от тяжёлых металлов, содержащихся в семенах подсолнечника, а также определить потенциальные риски для здоровья при их регулярном потреблении с использованием метода имитационного моделирования рациона.

Материалы и методы. Проведено исследование продуктов питания регионального происхождения и проб воды из 27 источников централизованного водоснабжения с территорий проживания участников эксперимента. Собраны и обработаны анкеты воспроизведения семидневного рациона питания и потребления воды 160 физически здоровых респондентов фертильного возраста. Кроме того, выполнен химический анализ 26 образцов грызовых семян подсолнечника на содержание кадмия и других токсичных элементов.

Результаты. Допустимая концентрация токсичных элементов в семенах подсолнечника превышена только по кадмию и составляет 0,23±0,06 мг/кг. При потреблении семян в количестве, рекомендуемом нутрициологами (50 г в день), в организм поступает от 0,007 до 0,009 мг кадмия, что в два раза превышает поступление с пищей и водой 0,0033±0,0012 и 0,0007±0,0003 мг соответственно.

Заключение. Имитационное моделирование включения в рацион питания 50 г семян подсолнечника грызовых сортов позволяет спрогнозировать уровень перорального поступления кадмия, который в среднем составляет 31,4% предельно допустимого суточного поступления, принятого в Российской Федерации.

Ключевые слова: кадмий; рацион питания; семена подсолнечника; накопление в растениях, животных и человеке; границы безопасности.

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食用向日葵种子导致人体镉污染水平升高

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摘要

论证。向日葵种子全年均具有可得性、高营养价值和相对低廉的价格。医学专家与应用科学领域的研究人员普遍建议在人群膳食中加入整粒向日葵籽。关于面向消费者的产品安全问题，尤其是向日葵种子中镉含量偏高的情况，媒体时常予以关注。Oil and Fat Union of Russia亦未否认该问题的存在。同时，科学界尚无关于食品中重金属允许含量及其对人体和整个食物链影响的统一观点。

目的。评估向日葵种子中镉在食物中所含重金属总体毒性负担中的贡献，并通过模拟膳食结构，评估其经常性摄入对健康的潜在风险。

材料与方法。研究包括对参与者居住区域的地方食品样本及27处集中供水水源水样的检测分析。收集并处理了160名身体健康、处于育龄阶段的受试者关于7天食物摄入与饮水情况的回顾性问卷。另对26份咀嚼类向日葵种子样本进行了镉及其他有毒元素的化学分析。

结果。在向日葵种子中，所有检测的有毒元素中，只有镉的含量超过了允许浓度，达到0.23±0.06 mg/kg。在按营养学家推荐的每日摄入量（50克）食用向日葵种子的情况下，人体可摄入0.007–0.009毫克镉，这一数值约为通过食物和饮水摄入量（分别为0.0033±0.0012毫克和0.0007±0.0003毫克）的两倍。

结论。膳食模拟显示，将50克咀嚼类向日葵种子纳入膳食结构，可预测其所致的镉经口摄入量，平均相当于俄罗斯联邦规定的每日允许摄入上限的31.4%。

关键词：镉；膳食结构；向日葵种子；植物、动物与人体的积累；安全限值。

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BACKGROUND

In the human trophic niche, sunflower is inferior to cereal crops. However, it is an important source of nutrients. Sunflower seeds contain a wide range of phytochemicals and minerals; their content and bioavailability for the human body is higher as compared to nuts [1, 2]. Their regular consumption helps protect the skin from the effects of free radicals [3, 4], reduce the cardiovascular risk, normalize cholesterol and blood pressure, and manage type 2 diabetes mellitus [5–7]. Thirty grams of sunflower seeds in the daily diet reduces blood glucose associated with the chlorogenic acid level [7]. This amount of unroasted peeled seeds is more than 40% of the recommended daily intake of phosphorus, copper, selenium, vitamins E and B5; 30% manganese, 17%–18% vitamins B9 and PP, and approx. 10% potassium and magnesium in adults.[1]

In addition to nutritional value of a product, it is also required to consider the product's food safety for humans—primarily the level of cadmium, lead, mercury, and arsenic because their toxicity is associated with their ability to form complexes with protein SH-groups. The accumulation of these elements is associated with the risk of bioaccumulation and biomagnification in organs and tissues, if they are consumed in excess, as this may lead to disruption of physiological and biochemical toxicity protection mechanisms [8].

Russia is a leader in the global sunflower seed and sunflower oil sector, providing a gross harvest of 5.65 million tons in a territory that accounts for 22.9% of the global cultivated area [9]. However, concerns about the high heavy metal content in sunflower seeds sold in retail chains are periodically raised in mass media—mainly the level of cadmium that can be as high as 0.2 mg/kg.

Sunflower seeds contaminated with 0.2 maximum allowable concentration (MAC) of cadmium inhibit lipase activity [10]. 0.25 MAC of mercury ions inhibit acidic and alkaline lipase activity by 42.4%–45.8% and 1.0 MAC of mercury almost completely inhibit the enzymatic activity. Lead ions have a lower inhibitory capacity as compared to cadmium and mercury; 1.0 MAC of lead decreases lipase activity by 1.7 times [11].

In equal agricultural conditions, sunflower seeds accumulate more cadmium as compared to most other cereal and oilseed crops. At a daily intake of 28.35 g (one ounce) for 48 weeks, cadmium intake does not exceed the World Health Organization (WHO) tolerable weekly intake of 490 μg and does not affect the health of volunteers [12].

If the staple food of the population is rice, it is highly susceptible to cadmium toxicity. An experiment on laboratory rats showed that the introduction of sunflower seeds in the diet reduces the absorption of cadmium due to the high content of calcium, iron, and zinc [13]. In addition, studies involving Japanese quail showed that moderate excess of some micronutrients had a positive effect by reducing the absorption and accumulation of cadmium [14].

Of all heavy metals, cadmium is one of the most common environmental pollutants in cities. Moreover, it is a cumulative toxin with the elimination period of 25–30 years [15].

From a food safety perspective, cadmium level is an important monitoring parameter as food is the main source of cadmium intake in humans.[2] The tolerable monthly intake of cadmium determined by WHO experts is 25 μg per 1 kg of human body weight.

5%–10% of cadmium is absorbed in the gastrointestinal tract. However, when it enters the systemic blood and reaches the liver, cadmium is absorbed by hepatocytes and activates the metallothionein synthesis. As a result, a complex (cadmium-metallothionein, Cd-MT) is formed, which enters the kidneys with the blood. In kidneys, due to the high reabsorption capacity of the proximal tubules, it accumulates in their cells and causes tissue damage over time [16, 17].

Toxicologists from the Ufa Research Institute of Occupational Medicine and Human Ecology modeled the cadmium salt intoxication on rats and found that when the safe dose is exceeded 10-fold, the greatest amount of the metal is accumulated in the liver rather than kidneys [18].

The main toxicity mechanism of cadmium is the substitution of other divalent cations, mainly in protein molecules. Throughout evolution's history, plants have developed defense mechanisms aimed at maintaining the vital metabolic pathways. However, in sunflowers, cadmium overcomes these barriers, penetrating into cells through the same transport routes as micronutrients. This leads to disruption of nutrient transport and distribution mechanisms. One of the plant's defense mechanisms is the deposition of the toxicant in the seeds to reduce the load on the root system and to minimize cell damage. Experiments showed that the concentration of cadmium in cotyledons may be as high as 10–20 μg/g. Thus, as little as 7 g of seeds can be equal to the maximum permissible intake of cadmium (70 μg) for a body weight of 70 kg. In addition, a high metal imbalance is observed in sunflower seeds; it is manifested both by changes in the copper, manganese, and iron levels and their distribution disruption in the seeds. As cotyledons is the most common part consumed as food, sunflowers grown in soils with contamination levels similar to those used in the experiment is a potential threat to human health [19].

In terms of bioavailability of essential and toxic metals contained in the edible parts of nuts and sunflower seeds, mercury has the lowest dialyzability not exceeding 3.8%. Cadmium, like most micronutrients, has moderate availability;

[1] Sunflower seed nutrition: calories, carbs, GI, protein, fiber, fats; [about 14 pages]. B: Food Struct [Internet]. Boston: FoodStruct, 2016–2024. URL: https://foodstruct.com/food/sunflower-seed. Accessed on August 16, 2024.

[2] Commission Regulation (EC) No. 1881/2006. Commission Directive of December 19, 2006, setting maximum levels for certain contaminants in foodstuffs. Official Journal of the European Communities. L364:5–24. URL: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:364:0005:0024:EN:PDF. Accessed on August 16, 2022.

whereas arsenic translocation varies widely, from 28 to 75%. It has been found that the degree of bioavailability correlates with the composition of micronutrients: fat reduces the dialyzability of metals; and carbohydrates, on the contrary, increase it. Protein and dietary fiber do not affect the bioavailability of metals [1, 20].

With increasing knowledge about the bioavailability of sunflower, its seeds are becoming more important in the human diet. However, in publications, sunflower is increasingly considered as a cadmium accumulator plant, capable of depositing this xenobiotic in seeds. Findings made by non-governmental organizations were verified by the analysis conducted by the testing laboratory of the Omsk Branch of the Federal State Budgetary Institution Grain Quality Assessment Center. According to its data, the average cadmium content in sunflower seeds sold in retail chains with certifications or declarations exceeded 0.1 mg/kg in 24% of samples.[3] The Independent Center at Autonomous Non-Commercial Organization Soyuzexpertiza of the Chamber of Commerce and Industry of the Russian Federation and Consumer Protection Society Public Control have similar approaches to product safety assessment.[4] In addition, there are applicable Unified Sanitary, Epidemiological, and Hygienic Requirements to Goods Subject to Sanitary and Epidemiological Supervision,[5] where the MAC of cadmium in sunflower seeds is 0.2 mg/kg. This threshold increase is explained by the All-Russia Union of Oils and Fats of Russia as "...the real-life situation with this raw material in the Russian market."[4] However, the underlying document, Technical Regulations of the Customs Union On the Safety of Food Products (TR CU 021/2011), does not provide for the MAC of cadmium in oilseeds.

According to the Federal State Budgetary Scientific Institution All-Russian Research Institute of Fats, an analysis of 92 samples of sunflower seeds obtained in various regions of Russia showed a significant range of cadmium content, depending on the geographical origin of the raw materials.[4]

Voronezh State Agrarian University conducted a behavioral analysis of heavy metals in the soils of roadside farmed sunflower ecosystems as part of its research. It showed that the degree of lead and cadmium translocation in sunflower correlates with the content of their active forms in the soil. Metal accumulation is influenced by several factors, such as distance from roads, ingredients and doses of agrochemicals, weather conditions, and cultivation techniques. Lead content in plants exceeded 2.9–5.3 times and cadmium content exceeded 1.4–3.2 times at different combinations of these conditions [21]. It was found that the transfer of cadmium from the soil to sunflower inflorescences does not depend on its subtype [22].

AIM

To assess the contribution of cadmium to the total toxic load from heavy metals in sunflower seeds and to determine potential health risks associated with their regular consumption using dietary simulation modeling.

MATERIALS AND METHODS

For the study, sunflower seeds of 10 brands were purchased and 16 samples of economically mature seeds were obtained in suburban areas of the industrialized city of Ufa (500 g at each point). The husk-free crushed seeds weighing approximately 0.5 g were placed in Teflon beakers containing 8 ml of concentrated nitric acid [65%, for analysis, Merck KGaA (Germany) and EMD Millipore Corporation (Canada)] and subjected to microwave-assisted digestion in Speedwave Xpert® microwave system (Berghof, Germany) according to the manufacturer's instructions. Cadmium and lead content in samples was quantified by graphite furnace atomic absorption spectrometry with electrothermal atomization; arsenic was quantified by flame atomization absorption spectrometry [AA240Z, AA240FS (Varian, Australia)]. Total mercury content was determined by the atomic absorption in a RA-915M mercury analyzer with a PYRO-915+ attachment (Lumex, Russia).

Oral cadmium intake was based on the average regional values of its content in foods and drinking water, typical for the respondents' area of residence. The data were obtained by long-term observation by the testing center at the Federal Budgetary Scientific Institution (FBSI) Ufa Research Institute for Industrial Medicine and Human Ecology.

Additional contamination with cadmium when introducing sunflower seeds in the diet was modeled based on the average results of our own studies equivalent to 50 g of the product, i.e. the amount recommended for consumption by the Department of Food Science and Technology at Kasetsart University (Thailand) [23].

Eligibility Criteria

Oral weekly intake of cadmium was calculated with the written consent of 160 eligible participants. The eligibility criteria are:

- Health status (group I);
- Gender-appropriate fertile age (15–65 years);
- Normal body mass index (Quetelet index) in the range of 20.0–25.9;

[3] Cadmium Content as an Indicator of Oilseed Safety; [about 2 pages]. In Federal State Budgetary Institution Federal Center for Assessment of Safety and Quality of Agricultural Products [Internet]. Moscow, Federal State Budgetary Institution Federal Center for Assessment of Safety and Quality of Agricultural Products, 2017–2024. URL: https://agbz.ru/articles/soderjanie-kadmiya-kak-pokazatel-bezopasnosti-maslichnyih-kultur/. Accessed on August 16, 2024.

[4] How Much Cadmium Can A Seed Contain? [about 2 pages]. In RosInvest.Com; 2012–2024. URL: https://rosinvest.com/novosti/940572. Accessed on August 16, 2024.

[5] Resolution No. 299 of the Customs Union Commission dated May 28, 2010 (On Sanitary Actions in the Eurasian Economic Union). URL: https://www.alta.ru/tamdoc/10sr0299/. Accessed on November 12, 2024.

- Body weight close to the estimated value based on WHO requirements (70 kg);
- No sunflower seeds in the diet during the study week.

Study Setting

The analysis was conducted in the accredited laboratory of the testing center at Ufa Research Institute for Industrial Medicine and Human Ecology and registered in the Database Registry No. 2024624090 of the Federal Service for Intellectual Property.[6,7]

Statistical Analysis

Statistical analysis of the data (calculation of average values, standard deviation of the variation coefficient) used Microsoft Excel® software (Microsoft, USA).

RESULTS

The test analysis of sunflower seeds was conducted in response to the issue of high levels of cadmium contamination periodically raised in the media.

The first stage of the study involved a quantitative analysis of toxic element levels in sunflower seeds in industrial packaging intended for direct consumption. For the analysis, the entire range of seeds was purchased in a major supermarket (see Table 1).

Table 1. Quantitative Content of Toxic Elements in Sunflower Seeds Supplied by Producers to Retail Chains

Sample	Concentration, mg/kg			
	Pb	Cd	As	Hg
№ 1	0.23±0.08	0.013±0.004	<0.01	<0.0025
№ 8	0.28±0.10	0.027±0.008	<0.01	<0.0025
№ 7	0.25±0.09	0.034±0.010	<0.01	<0.0025
№ 4	0.33±0.12	0.091±0.027	<0.01	<0.0025
№ 5	0.03±0.01	0.184±0.055	<0.01	<0.0025
№ 10	<0.02	0.193±0.058	<0.01	<0.0025
№ 2	<0.02	0.203±0.061	<0.01	<0.0025
№ 3	<0.02	0.250±0.075	<0.01	<0.0025
№ 9	<0.02	0.253±0.076	<0.01	<0.0025
№ 6	<0.02	0.295±0.089	<0.01	<0.0025

In all sunflower seed kernel samples obtained from different producers, the arsenic and mercury level was below the detection limit of the analytical methods used. The quantity of lead does not exceed 0.3 MAC. Cadmium content in the seeds was max 0.1 mg/kg in three samples, max 0.2 mg/kg in one sample, and max 0.3 mg/kg in five samples. The findings indicate that even with a limited sample, there is a high probability of exceeding cadmium standards with regular consumption of seeds, leading to a potential health risk.

In addition, we tested sunflower seeds from agricultural fields and private farms near a city with a population of one million in the Republic of Bashkortostan.

The atomic absorption spectrometry analysis of 16 samples of sunflower seeds grown in the Central Industrial Region of Bashkortostan is shown in Table 2.

Arsenic content in these samples did not exceed 0.2 MAC. A single case of mercury exceeding the MAC was recorded in seeds collected near a railway.

High lead levels were found in seeds sampled in areas with heavy traffic; MAC levels were exceeded in samples obtained along a highway. The same samples showed the highest values of cadmium.

DISCUSSION

In the premises, sunflower should definitely be classified as a cadmium accumulating plant. In the context of anthropogenic environmental pollution, cadmium levels, previously considered as maximum allowable concentrations, are now considered by agroindustrial entities as background concentrations. There is a need to assess the potential contribution of oral intake of this toxicant to the overall human exposure as there is no uniform approaches to determining the safe level of cadmium in sunflower seeds.

For this, an analysis of a 7-day diet and fluid consumption of 160 respondents was conducted, including health group I athletes, trainers, and physical education teachers of reproductive age (35±14 years), with a normal body mass index (24.7±3.7) and average body weight (69.4±12.1 kg).

An assessment of 1,120 diets of respondents from the selected group showed that with an average consumption of 1,611±638 of food and 986±237 g of tap water, soups, and drinks, healthy residents of the Republic of Bashkortostan consume 0.004 mg of cadmium (including food and water; 0.0033±0.0012 and 0.0007±0.0003 mg, respectively). According to estimates of the Federal Scientific Center for Medical and Preventive Health Risk Management Technologies, this value does not exceed the reference dose of cadmium of 0.00055 mg/kg per day [24].

This shows the obvious importance of the increasing cadmium intake by humans through the consumption of sunflower seeds. For example, as little as 50 g of seeds contain on average 2 times more cadmium ($\overline{X}$ of $_{\text{edible varieties}}$=0.007 mg; $\overline{X}$ of $_{\text{analyzed samples}}$=0.009 mg)

[6] Certificate of State Registration of Database No. 2024624090 dated September 12, 2024. Report No. 9. M.R. Yakhina, T.K. Valeev, E.E. Zelenkovskaya, et al. Actual weekly diet structure as illustrated by the population of the Republic of Bashkortostan with different economic specializations. URL: https://elibrary.ru/download/elibrary_69586451_36328408.PDF. Accessed on September 12, 2024.

[7] Certificate of State Registration of Database No. 2024624203 dated September 26, 2024. Report No. 10. M.R. Yakhina, T.K. Valeev, E.E. Zelenkovskaya, et al. Quantification of nutrients and toxic elements in the diet of non-production employees. URL: https://elibrary.ru/download/elibrary_73233368_16143777.PDF. Accessed on September 12, 2024.

Table 2. Statistical Frequencies of Toxic Substance Content in Sunflower Seeds

Sample	Concentration, mg/kg			
	Pb	Cd	As	Hg
Field located along the M-7 highway				
15 m from the highway	1.52±0.53	0.24±0.07	<0.01	<0.0025
25 m from the highway	1.09±0.38	0.28±0.09	<0.01	0.017±0.007
50 m from the highway	1.11±0.39	0.25±0.08	<0.01	<0.0025
Cottage settlements near the M-5 federal highway				
Residential areas	0.31±0.11	0.40±0.12	<0.01	<0.0025
Newly developed settlements	0.71±0.25	1.16±0.35	<0.01	<0.0025
Along the railway	0.62±0.22	1.38±0.41	<0.01	0.088±0.025
Agricultural area				
For dietary intake (seed)	0.12±0.04	0.073±0.022	0.035±0.012	0.006±0.002
For compound feed stuff	0.45±0.16	0.095±0.029	<0.001	<0.0025
Field 1	0.55±0.19	0.049±0.015	<0.001	<0.0025
Field 2	0.38±0.13	0.093±0.028	<0.01	<0.0025
Field 3	0.31±0.11	0.091±0.027	<0.01	<0.0025
Field 4	0.33±0.12	0.14±0.04	<0.001	<0.0025
Seeds produced at the development farm				
High-quality	0.18±0.06	0.016±0.005	0.05±0.02	<0.0025
Environmental	<0.02	0.016±0.005	0.05±0.02	<0.0025
Coarse grains	0.17±0.06			<0.0025
Nongrade	0.21±0.07	0.067±0.020	0.05±0.02	<0.0025

than is consumed daily with food and water (0.004 mg) by participants in the experimental survey part of the study, who consumed on average 1,611 and 986 g of food and water per day, respectively.

The reference dose of super toxic substances (including cadmium) is determined by their reproductive, neurotoxic, hematological, cytotoxic, cytogenetic, and immunotoxic effects. For cadmium, it has been found that it accumulates in various tissues and organs with low metabolic and detoxification capacity [25].

Foods are the main source of cadmium intake, up to 90%. Its elimination rate is low (about 0.001%, mainly in urine), requiring strict regulation of intake. However, the issue of the MAC of cadmium is still controversial and there are major controversies in the scientific community (see Table 3).

Study Limitations

The simulation model is based on the diet of healthy respondents with adequate eating behavior; cadmium content in foods is calculated based on average regional values. This indicates that in real life, the actual exposure may be significantly higher due to additional sources of contamination.

CONCLUSION

Sunflower has high bioavailability and nutritional value and improves the quality of nutrition for farm animals and humans without synthetic supplements. However, the plant is obviously able to accumulate cadmium, mainly in its reproductive part, creating a risk, if it is grown in conditions of anthropogenic pollution.

The analytical stage of the study showed that sunflower seeds that do not meet health standards for cadmium content are sold in 40% of cases. The highest level of contamination with heavy metals was recorded in oilseed varieties grown near transport infrastructure.

We simulated a case of increased cadmium content in the diet of respondents by adding a biologically reasonable amount of sunflower seeds from the studied samples. It should be noted that the possible daily intake of cadmium is 0.0001 mg and higher (which in itself does not exceed the MAC) with the consumption of as little as 50 g of whole sunflower seeds.

The simulation modeling showed that when sunflower seeds are included in the diet, the daily intake of cadmium can be as high as 0.011±0.005 mg, i.e. approximately 15.7% of the MAC (according to WHO) and an average of 31.4% of the value applicable in the Russian Federation.

Table 3. Tolerable Daily Intake of Cadmium for Regular Oral Intake

Regulation	Reference dose of Cd	Country / Regulator
Agency for Toxic Substances and Disease Registry	0.0001 mg/kg per day	United States of America (federal agency)
R 2.1.10.3968-23. 2.1.10. Health of the population in relation to the environment and living conditions of the population. Assessing public health risks from exposure to environmental chemicals: Guidelines (approved by Rospotrebnadzor on September 6, 2023)	0.0005 mg/kg per day	Russia
Office of Environmental Health Hazard Assessment		United States of America (California)
World Health Organization	0.025 mg/kg per month	World Health Organization
Integrated Risk Information System of the U.S. Environmental Protection Agency	0.001 mg/kg per day	United States of America (federal agency)

ADDITIONAL INFORMATION

Author contribution: S.R. Afonkina: concept and design of the stydy, data collection; M.R. Yakhina: concept and design of the study, data processing, writing—original draft; E.N. Usmanova, G.R. Allayarova, M.I. Astakhova: data processing; T.K. Larionova writing—original draft; R.A. Dukaev writing—review & editing; A.S. Fazlyeva: data collection. All authors approved the version of the manuscript to be published and agree to be accountable for all aspects of the work, ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.
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ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Вклад авторов. С.Р. Афонькина — концепция и дизайн исследования, сбор данных; М.Р. Яхина — концепция и дизайн исследования, анализ данных, написание текста рукописи; Э.Н. Усманова, Г.Р. Аллаярова, М.И. Астахова — анализ данных; Т.К. Ларионова — написание текста рукописи; Р.А. Даукаев — редактирование текста рукописи; А.С. Фазлыева — сбор данных. Все авторы одобрили рукопись (версию для публикации), а также согласились нести ответственность за все аспекты работы, гарантируя надлежащее рассмотрение и решение вопросов, связанных с точностью и добросовестностью любой её части.
Этическая экспертиза. Исследование одобрено на заседании биоэтической комиссии ФБУН «Уфимский НИИ медицины труда и экологии человека» (протокол № 01-12 от 23.12.2024).
Источник финансирования. Отсутствуют.
Раскрытие интересов. Авторы заявляют об отсутствии отношений, деятельности и интересов за последние три года, связанных с третьими лицами (коммерческими и некоммерческими), интересы которых могут быть затронуты содержанием статьи.
Оригинальность. При создании настоящей работы авторы не использовали ранее опубликованные сведения (текст, иллюстрации, данные).
Доступ к данным. Все данные, полученные в настоящем исследовании, доступны в статье.
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Рассмотрение и рецензирование. Настоящая работа подана в журнал в инициативном порядке и рассмотрена по обычной процедуре. В рецензировании участвовали два внешних рецензента, член редакционной коллегии и научный редактор издания.

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