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# Assessment of health risks posed by heavy metal contamination of wild mushrooms and berries

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ABSTRACT

***BACKGROUND:*** One of the primary objectives in ensuring food security for the population is to reduce the mitigate the risk of chemical contamination in food. Wild mushrooms and berries have the potential to accumulate heavy metals from the environment, posing a threat to human health if consumed.

***AIM:*** To assess the risk of developing general toxic effects associated with the consumption of wild mushrooms and berries on health of the adults living in the Arkhangelsk region.

***MATERIAL AND METHODS:*** The amount and frequency of mushroom and berry consumption by the adult population of the Arkhangelsk region was assessed by a survey (n=445). Intake of heavy metals contaminating mushrooms and berries was calculated using four scenarios. Hazard Quotients (HQ) were used to characterize the risk of developing overall toxic effects due to exposure to mercury, arsenic, lead, and cadmium. Hazard Indexes (HI) for substances with unidirectional effects were employed to assess the risk of non-cancerous effects on critical organs and systems. Quantitative data were presented as medians (Me) with 95% confidence intervals (95% CI), and the 90th percentile ($P_{90}$).

***RESULTS:*** In total, 82% and 70% of respondents were engaged in collection of mushrooms and wild berries, respectively. On average, they reported consuming 180 grams of fresh or frozen berries, 133 grams of berries with juice, and 50 grams of mushrooms in soup or boiled/fried form per week. The Hazard Quotients (HQ) for all heavy metals did not exceed 1.0. The Hazard Index (HI) calculated for the average consumption of mushrooms and berries, as well as the average heavy metal contamination of wild plants was below 1.0.

However, at high levels of mushroom ($P_{90}$ — 417 g/week) and berry (P90 — 900 g/week) consumption, along with high levels of heavy metal contamination, elevated risk of developing general toxic effects on the endocrine- (HI=2.27), cardiovascular- (HI=2.0), digestive- (HI=2.0), nervous- and immune systems (HI =1.81 for both) and kidneys (HI=1.25) were detected. Forest mushrooms and wild berries can be consumed without restriction at an average level of their contamination. However, in cases of heavy metal contamination of mushrooms and berries at the $P_{90}$ level or above, it is not recommended to exceed daily consumption of 400 grams of forest mushrooms and 650 grams of wild berries.

***CONCLUSION:*** Consuming high amounts of wild mushrooms and berries at the upper limit of exposure to heavy metals, may lead to an elevated risk of developing toxic effects on endocrine, nervous, immune, cardiovascular, and digestive systems.

**Keywords**: mushrooms; berries; heavy metals; risk assessment; Arkhangelsk region.

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# Оценка риска развития общетоксических эффектов для здоровья населения, связанного с загрязнением дикорастущих грибов и ягод тяжёлыми металлами

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АННОТАЦИЯ

**Обоснование**. Снижение угрозы формирования недопустимых рисков, обусловленных химической контаминацией пищевой продукции, является одной из главных задач обеспечения продовольственной безопасности населения. Дикорастущие грибы и ягоды накапливают тяжёлые металлы из окружающей среды, что может повлиять на здоровье человека при их употреблении.

**Цель**. Оценить риск развития общетоксических эффектов для здоровья взрослого населения Архангельской области, связанный с употреблением дикорастущих грибов и ягод.

**Материал и методы**. Количество и частота употребления грибов и ягод взрослым населением Архангельской области изучены с помощью анкетирования (n=445). Дозы поступления тяжёлых металлов, загрязняющих грибы и ягоды, рассчитаны для четырёх сценариев. Характеристика риска развития общетоксических эффектов при воздействии ртути, мышьяка, свинца и кадмия выполнена с помощью коэффициентов опасности (HQ). Для оценки риска развития неканцерогенных эффектов со стороны критических органов и систем использованы индексы опасности для веществ однонаправленного действия (HI). Количественные данные представлены в виде медианы (Me), 95% доверительного интервала для медианы (95% ДИ), 90-го процентиля ($P_{90}$).

**Результаты**. Большинство респондентов собирают грибы (82%) и ягоды (70%) на территории Архангельской области самостоятельно. В среднем за неделю они употребляют 180 г свежих или замороженных ягод, 133 г ягод с морсом (соком, компотом), по 50 г грибов с супом или отварных/жареных грибов. Значения HQ для всех тяжёлых металлов не превышали 1,0; HI, рассчитанные для среднего уровня потребления грибов и ягод и среднего уровня загрязнения дикоросов тяжёлыми металлами, не превышали 1,0. При высоком уровне употребления грибов ($P_{90}$ — 417 г/нед.) и ягод ($P_{90}$ — 900 г/нед.) и высоком уровне их загрязнения тяжёлыми металлами формируется повышенный риск развития общетоксических эффектов со стороны эндокринной системы (HI=2,27), органов кровообращения (HI=2,0) и пищеварения (HI=2,0), нервной и иммунной систем (HI по 1,81), а также почек (HI=1,25). Установлено, что при среднем уровне загрязнения лесные грибы и ягоды можно употреблять без ограничений. При высоком уровне загрязнения грибов и ягод тяжёлыми металлами на уровне $P_{90}$ не рекомендуется употреблять более чем 400 г лесных грибов и 650 г лесных ягод в день.

**Заключение**. Установлен повышенный риск развития общетоксических эффектов для эндокринной, нервной, иммунной систем, органов кровообращения и пищеварения при высоком употреблении дикорастущих грибов и ягод и верхней границе экспозиции тяжёлыми металлами.

**Ключевые слова**: грибы; ягоды; тяжёлые металлы; оценка риска; Архангельская область.

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# 重金属污染野生蘑菇和浆果对公众健康造成一般毒性影响的风险评估

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简评

**论证。**减少食品化学污染造成的不可接受的风险威胁是确保居民食品安全的主要目标之一。野生蘑菇和浆果会从环境中积累重金属，食用后会影响人体健康。

**目的。**评估食用野生蘑菇和浆果对阿尔汉格尔斯克州成年人健康造成一般毒性影响的风险。

**材料与方法。**通过问卷调查（n=445）研究了阿尔汉格尔斯克州成年人食用蘑菇和浆果的数量和频率。污染蘑菇和浆果的重金属摄入量是按照四种情况进行计算。使用危险商数 (HQ) 对暴露于汞、砷、铅和镉的情况下产生一般毒性效应的风险进行了定性。为评估对关键器官和系统的非致癌影响风险，采用了单向物质危害指数（HI）。定量数据以中位数（Me）、中位数的 95% 置信区间（95% CI）、第 90 百分位数（P90）表示。

**结果。**大多数受访者自己在阿尔汉格尔斯克州境内采集蘑菇（82%）和浆果（70%）。他们平均每周食用 180 克新鲜或冷冻浆果、133 克浆果果酱（果汁、果酱）、50 克蘑菇汤或煮蘑菇/炒蘑菇。所有重金属的 HQ 值均不超过 1.0。根据蘑菇和浆果的平均食用量以及野生植物重金属污染的平均水平计算出的 HI 值不超过 1.0。如果食用大量蘑菇（P90 – 417 克/周）和浆果（P90 – 900 克/周），且其重金属污染水平较高，则会增加内分泌系统（HI=2.27）、循环系统（HI=2.0）和消化系统（HI=2.0）、神经和免疫系统（HI 为 1.81）以及肾脏（HI=1.25）产生一般毒性影响的风险。研究发现，在平均污染水平下，可以不受限制地食用森林蘑菇和浆果。如果蘑菇和浆果的重金属污染程度较高（P90），则不建议每天食用超过 400 克的森林蘑菇和 650 克的森林浆果。

**结论。**大量食用野生蘑菇和浆果以及重金属暴露上限会增加对内分泌、神经、免疫系统、循环和消化器官产生一般毒性影响的风险。

**关键词：**蘑菇；浆果；重金属；风险评估；阿尔汉格尔斯克州。

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## BACKGROUND

One of the main tasks in ensuring the safety of public nutrition is to reduce the threat of unacceptable risks caused by chemical contamination of food products [1]. The Arctic Monitoring and Assessment Program [2] reported that there is insufficient information on the safety levels of traditional local food products, such as wild mushrooms and berries, in the Arctic zone of the Russian Federation. Wild plants can accumulate heavy metals from the air, groundwater, and soil in areas exposed to pollution by industries [3–5]. The level of heavy metals in food products is influenced by their species specificity, concentrations of toxicants in the soil and groundwater, and the proximity of wild plants to the source of pollution. When ingested, heavy metals have a toxic effect on the human body, which depends on many factors, namely, dose, frequency and duration of exposure, age, gender, individual susceptibility, and genetic characteristics [6]. Heavy metals, such as lead (Pb), arsenic (As), cadmium (Cd), and mercury (Hg), are systemic toxicants and can have negative effects on various organs and systems, including the reproductive, nervous, and excretory systems [7–11]. Chronic intake of heavy metals into the body can cause damage to the nervous system, which manifests as an asthenovegetative syndrome [8]. Heavy metals can accumulate in the kidneys, causing histological and functional damage to the renal tubules, leading to the development of renal failure [11].

A risk assessment method is used to establish negative health effects when exposed to chemicals that pollute the environment [12, 13]. The characterization of general toxic (non-carcinogenic) effects during exposure to heavy metals allows consideration of their additive effects on critical organs and systems.

Wild plants growing in the Arkhangelsk region contain heavy metals in low concentrations [14, 15]. The sources of heavy metals entering the environment in the territory of the region are industries, including shipbuilding and mechanical engineering, pulp and paper industry, thermal power engineering, and transport. Another way by which heavy metals enter the atmosphere of the region is the transboundary transfer of polluted air masses from the central industrial regions of Russia and Europe, which leads to an increase in the content of heavy metals in all environmental components [16]. Considering the widespread consumption of wild mushrooms and berries in the region, it is necessary to assess the risk to public health of exposure to heavy metal pollution of wild plants.

**The aim of the study** was to assess the risk of general toxic effects associated with the consumption of wild mushrooms and berries on the health of the adult population of the Arkhangelsk region.

## MATERIAL AND METHODS

Data on the content of heavy metals in wild plants for the period 2015–2021 were obtained from the testing laboratory of the agrochemical service station "Arkhangelskaya." A total of 132 samples of berries and 94 samples of mushrooms were collected from the forest area near Arkhangelsk and Severodvinsk, in the Pinezhsky, Primorsky, Onega, Krasnoborsky, and Ustyansky districts. Quantitative determination of Hg in samples ($n = 88$) was performed using the colorimetric method according to GOST 26927-86 "Raw materials and food products. Methods for the determination of mercury." The content of As ($n = 129$) was determined on the analyzer "PAN-As" using the inversion voltammetry method according to GOST 31628–2012 "Food products and food raw materials. An inversion-voltammetric method for determining the mass concentration of arsenic." The contents of Pb ($n = 102$) and Cd ($n = 119$) were determined on an atomic absorption analyzer "Spektr-5" using the method of atomic absorption spectroscopy according to GOST 30178-96 "Raw materials and food products. Atomic absorption method for the determination of toxic elements."

The quantity and frequency of consumption of mushrooms and berries by the population of the Arkhangelsk region were evaluated using a questionnaire. We used a modified questionnaire from the Federal Research Center for Nutrition, Biotechnology and Food Safety, which allows determination of the frequency of food consumption over the previous month, indicating the portion size.

A total of 445 people aged 18 and above who permanently reside in Arkhangelsk, Novodvinsk, Severodvinsk, and districts of the Arkhangelsk region (Primorsky, Pinezhsky, Kholmogorsky) were surveyed.

Non-carcinogenic risk was calculated based on the concentrations of heavy metals in wild mushrooms and berries growing in the Arkhangelsk region (Table 1) [14]. Doses of heavy metals polluting mushrooms and berries were calculated taking into account the amount consumed and body weight of the respondents according to four scenarios:

**Table 1.** Concentration of heavy metals in wild mushrooms and berries in the Arkhangelsk region

| Metals | Measures | All types of mushrooms | All types of berries | Detection limits |
|---|---|---|---|---|
| Hg (mg/kg) | Me (95% CI) | 0.013 (0.011–0.022) | 0.006 (0.004–0.011) | 0.003–0.6 |
| As (mg/kg) | Me (95% CI) | 0.034 (0.027–0.082) | 0.031 (0.021–0.054) | 0.02–2.0 |
| Pb (mg/kg) | Me (95% CI) | 0.083 (0.039–0.134) | 0.065 (0.036–0.099) | 0.01–1.0 |
| Cd (mg/kg) | Me (95% CI) | 0.040 (0.030–0.062) | 0.022 (0.015–0.033) | 0.01–1.0 |

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- the first scenario (standard) is the consumption of wild plants and the content of heavy metals in them at the median level (Me);
- the second scenario is the consumption of wild plants at the level of the upper limit of exposure ($P_{90}$) and the content of heavy metals in them at the level of Me;
- the third scenario is the consumption of mushrooms and berries at the Me level and a high level of contamination of wild plants ($P_{90}$);
- the fourth scenario (the worst) is a high consumption of mushrooms and berries ($P_{90}$) and a metal content at the level of $P_{90}$.

The levels of public health risk associated with contamination of wild mushrooms and berries were calculated according to the "Guidelines for assessing public health risk from exposure to chemicals polluting the environment" [12] and the methodological guidelines "Determining exposure and assessing the risk of exposure to chemical contaminants of food products on the population" [13]. As the studied heavy metals (Hg, Pb, Cd, and As) have cumulative properties, the dose load was calculated incorporating the weekly consumption of berries and mushrooms according to formula 1:

$$E_{xp}=\frac{\sum_{i=1}^{N}\times(C_i\times M_i)}{BW}, \qquad (1)$$

where $E_{xp}$ is the value of exposure to a contaminant, mg/kg of body weight per week;
$C_i$ is the concentration of the substance in specific foods, mg/kg;
$M_i$ is the mass of the product consumed, kg/week;
BW is the calculated average body weight of the respondents (68 kg), and
N is the total number of products included in the study.

The risk of developing general toxic effects for individual substances was characterized by calculating hazard coefficients (HQ) — the ratio of the exposure dose of a chemical to its safe (reference) exposure level (formula 2):

$$HQi=\frac{E_{xp}}{RfDo}, \qquad (2)$$

where $HQ_i$ is the hazard coefficient of exposure to substance *i*;
$E_{xp}$ is the dose, mg/kg of body weight per week, and
RfDo is the reference dose for oral administration, mg/kg/week.

The values of the conditional tolerated weekly intake were used as reference doses for the studied metals [12].

The risk of non-carcinogenic effects on critical organs and systems was assessed by calculating hazard indices (HI) the sum of hazard coefficients for substances with a unidirectional mechanism of action (formula 3).

$$HI=\Sigma HQ_i, \qquad (3)$$

where HI is the hazard index;
$HQ_i$ is the hazard coefficients for chemicals that have an effect on the same critical organs and systems.

If HQ and HI did not exceed 1.0, the risk level was considered acceptable.

The recommended daily safe intake (Recommended food daily intake limit, RFDIL) of wild berries and mushrooms, considering the content of heavy metals in them, was calculated according to the method presented by Dudarev et al. [17], according to formula 4:

$$RFDIL=\frac{TDI\times BW}{C}, \qquad (4)$$

where RFDIL is the recommended daily safe intake (kg/day per person);
TDI is the permissible daily dose, mg/kg, developed by the joint FAO/WHO Expert Committee on Food Additives [18, 19];
BW is the average body weight of the respondents (68 kg), and
C is the concentration of the contaminant (mg/kg).

Quantitative data were tested for normality using the Kolmogorov–Smirnov test. As the distribution of data significantly deviated from normality, the median (Me), 95% confidence interval for the median (95% CI), and the 90th percentile ($P_{90}$) were used to characterize them. Categorical variables were expressed as percentages. The critical level of statistical significance was 0.05. The STATA software, version 17, was used for statistical data analysis.

## RESULTS

The average age of the respondents was 37 years ($P_{25-75}$: 24–50 years). Most of the respondents were women who constituted 77% of the respondents. By occupation, most of respondents were specialists (40%), university and college students (20%) and pensioners (12%). The average body weight of the adults surveyed was 68 kg ($P_{25-75}$: 58–80 kg).

The survey revealed that 96% of respondents consume wild berries and 83% consume wild mushrooms. Most of the respondents pick berries and mushrooms on their own in the Arkhangelsk region (82% and 70%, respectively).

One third of the respondents consume from one to five types of berries and mushrooms, about 45% consume from six to ten types of berries and mushrooms. Among berries, respondents preferred lingonberries, cranberries, and blueberries, and among mushrooms, they preferred edible boletus, rough boletus, and aspen mushrooms.

The frequency of consumption of mushrooms and berries is influenced by the season of the year. As in other Arctic territories, the population in the Arkhangelsk region consumes mushrooms and berries more in the warm season of the year, because of the seasonality of wild plants.

In the warm period of the year, 8.8% of respondents consume berries daily, and in the cold period, only 2.7% of respondents consume berries daily. In the summer and autumn seasons, most respondents consume berries 2–3 times a week (27.6%), and the frequency of mushroom consumption by most respondents (27.6%) ranges from

1 time a week to 1 time a month (32.4%). In the winter and spring seasons, most of the respondents consume berries and mushrooms once a month (35.3 and 55.3%, respectively).

Respondents who consume wild berries consume an average of 180 g of fresh or frozen berries per week, 133 g of berries with fruit juice (juice, compote), 38 g of soaked berries, 33 g of berry jam, and 13 g of berries in pie filling. Respondents who consume wild mushrooms consume an average of 50 g of mushrooms with soup or boiled/fried mushrooms, 25 g of salted mushrooms, 15 g of pickled mushrooms, and 20 g of mushroom caviar per week. At the $P_{90}$ level, the consumption of berries is 2–8 times higher, and that of mushrooms is 6–12 times higher than that of the average consumption at the Me level (Table 2).

A comparative characterization of the calculated doses for the four scenarios revealed that the quantity of mushrooms and berries consumed is essential in the dose load of contaminants. However, the contribution of berries to the total dose load of all metals for the first scenario is higher than for mushrooms, and amounted to 53%–70%. For the second and third scenarios, the largest contribution of berries to the dose load was As (60%–63%), Pb (60%), and Cd (51%–56%). For the fourth scenario, only As (53%) was contributed. The contribution of mushrooms to the total dose of Hg is higher than that of berries for the second, third, and fourth scenarios (53%–65%). The contribution of mushrooms to Pb for the second and fourth scenarios was 51 and 58%, respectively, and to Cd for the fourth scenario was 51%.

The HQ values for all heavy metals and for all exposure scenarios did not exceed 1.0, indicating an acceptable risk level. For the first and third exposure scenarios, the HQ values occur in the following descending order: Cd → Pb → As → Hg. For the second and fourth impact scenarios, the order of the HQ levels is as follows: As → Pb → Cd → Hg. This indicates that at an average level of contamination of mushrooms and berries with heavy metals, Cd is the greatest risk to health, and at the upper limit of exposure at the level of $P_{90}$, As is the greatest risk to health (Table 3).

Analysis of the contribution of individual dishes of berries and mushrooms to the total dose (Fig. 1) of all heavy metals, regardless of the exposure scenario, showed that the consumption of fresh berries and berry morses contributes 26.1 and 19.4%, respectively. Mushroom soup and fried mushrooms contributed 13.2% each to the dose load of heavy metals. The contributions of salted and pickled mushrooms and mushroom caviar were 6.6, 4.8, and 5.3%, respectively. The contributions of berry filling, jam, and soaked berries were insignificant amounting to 1.9, 4.8, and 5.5%, respectively.

The HI values for critical organs and systems under the influence of heavy metals with unidirectional action for the first, second and third exposure scenarios did not exceed 1.0, indicating an acceptable risk level (Table 4). For the fourth scenario, HI values exceeding 1.0 were recorded for the endocrine system (2.27), circulatory organs (2.00), digestive system (2.00), kidneys (1.25), and nervous and immune systems (1.81 each). The main contribution to HI for the first, second, and third impact scenarios was made by berries (50%–64%), but for the fourth scenario by mushrooms (51%–57%). Because of the high consumption of mushrooms and their high level of contamination with heavy metals, they constitute a high risk of general toxic effects on the endocrine system, circulatory and digestive organs, kidneys, and the immune system.

Considering the actual levels of contamination of mushrooms and berries growing in the Arkhangelsk region, the permissible safe consumption for public health was calculated and is shown in Table 5. At an average level of pollution, forest mushrooms and berries can be consumed without restrictions. Because of a high level of contamination

**Table 2.** Amount of berries, mushrooms, and dishes made from them consumed by the adult population of the Arkhangelsk region per week, grams per person

| Product | Median | 90th percentile | 95% CI for the median |
|---|---|---|---|
| Fresh berries | 180 | 900 | 60–180 |
| Frozen berries | 180 | 440 | 60–180 |
| Berry jam/berries crushed with sugar | 33 | 100 | 17–33 |
| Pickled berries | 38 | 300 | 25–97 |
| Berry filling in pies | 13 | 100 | 13–17 |
| Berry juice, mors, compote | 133 | 667 | 133–200 |
| Mushroom soup | 50 | 417 | 41–83 |
| Boiled/fried mushrooms | 50 | 300 | 25–90 |
| Salted mushrooms | 25 | 300 | 25–75 |
| Pickled mushrooms | 15 | 180 | 15–25 |
| Mushroom caviar | 20 | 148 | 10–25 |

**Table 3.** Doses (μg/kg/week) and hazard coefficients (units) of heavy metals entering the body through the consumption of mushrooms and berries

| Metals | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|
| **Doses, μg/kg/week** | | | | |
| Mercury | 0.07 | 0.18 | 0.48 | 1.34 |
| Arsenic | 0.26 | 2.13 | 1.82 | 15.23 |
| Lead | 0.58 | 1.79 | 4.04 | 13.24 |
| Cadmium | 0.22 | 0.44 | 1.60 | 3.19 |
| **Hazard Quotient (HQ), units** | | | | |
| Mercury | 0.01 | 0.04 | 0.10 | 0.27 |
| Arsenic | 0.02 | 0.14 | 0.12 | 1.02 |
| Lead | 0.02 | 0.07 | 0.16 | 0.53 |
| Cadmium | 0.03 | 0.06 | 0.23 | 0.46 |

*Note.* HQ ≤1.0 corresponds to the acceptable risk, when HQ >1, the the probability of occurrence of harmful effects in humans increases proportionally to the increase in HQ.

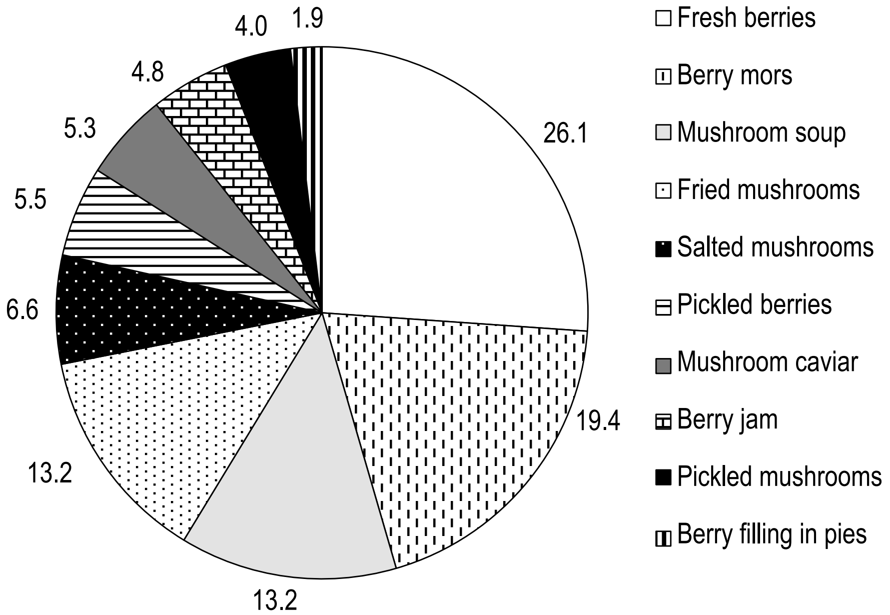


**Fig. 1.** Contribution of wild mushrooms, berries, and dishes made from them to the total intake of heavy metals, %.

**Table 4.** Hazard index for critical organs and systems associated with the consumption of mushrooms and berries contaminated with heavy metals

| Organs and systems | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|---|---|---|---|---|
| Endocrine system | 0.09 | 0.31 | 0.61 | 2.27 |
| Circulatory organs | 0.07 | 0.28 | 0.51 | 2.00 |
| Digestive organs | 0.07 | 0.28 | 0.51 | 2.00 |
| Kidneys | 0.07 | 0.17 | 0.49 | 1.25 |
| Blood system | 0.05 | 0.13 | 0.39 | 0.99 |
| Nervous system | 0.05 | 0.25 | 0.38 | 1.81 |
| Immune system | 0.05 | 0.25 | 0.38 | 1.81 |

*Note.* HI ≤1.0 corresponds to minimal risk; HI=1.1–3.0 corresponds to permissible (acceptable) risk.

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**Table 5.** Upper limits of recommended daily intake of mushrooms and berries (grams per day) by concentration of heavy metals

| Metals | Forest mushrooms | | Forest berries | |
|---|---|---|---|---|
| | Median | 90th percentile | Median | 90th percentile |
| Mercury | No limits | 880 | No limits | No limits |
| Arsenic | No limits | 400 | No limits | 650 |
| Lead | No limits | 630 | No limits | No limits |
| Cadmium | No limits | 820 | No limits | No limits |
| All metals | No limits | 400 | No limits | 650 |

of mushrooms and berries with heavy metals ($P_{90}$), it is not recommended to consume more than 400 g of wild mushrooms and 650 g of wild berries per day.

## DISCUSSION

In this study, an assessment was made of the risk of developing general toxic effects on the health of the population of the Arkhangelsk region due to exposure to heavy metals contained in wild mushrooms and berries. The HQ values for all heavy metals and for all exposure scenarios did not exceed 1.0, suggesting an acceptable risk level. A high risk of general toxic effects on critical organs and systems occurs only at a high consumption of wild mushrooms and berries and the upper limit of exposure to heavy metals. Mushrooms are the main contribution to HI for this exposure scenario.

The risk levels depend on the amount of wild plant material consumed and their heavy metal content. Our findings indicate that the consumption of fresh berries by the population of the Arkhangelsk region is 180 g per week, which is comparable to the consumption of wild berries by the population in Finland (158 g per week) [20]. The consumption of wild (boiled/fried) mushrooms in the Arkhangelsk region is 50 g per week, which is two times less than the quantity of wild mushrooms consumed by the population in the Murmansk region (96 g per week) [21].

The content of Hg, Cd, and Pb in wild mushrooms of the southern countries is 20%–40% lower than those recorded for the Arkhangelsk region in this study. The average concentrations of As in wild plants of the Arkhangelsk region are 16 and 38% lower than those in wild mushrooms in China (0.040 mg/kg) and Bangladesh (0.047 mg/kg) [22, 23].

Analysis of the contribution of heavy metals to the dose load in the consumption of wild plants of the Arkhangelsk region revealed that in the standard scenario, the main contribution to the dose is by Pb (51%), and in the worst-case scenario As (46%) is the main contributor. In the Pechengsky District of the Murmansk region, fungi are the main contributor to the intake of Pb (35%) and Cd (91%) from the diet [21]. In Poland, mushrooms are a significant source of Hg and Cd, with contributions to the dose load of 43 and 28%, respectively [24].

In line with findings of previous studies [22, 23, 25, 26], the calculated HI for the adult population at the level of average consumption of wild foods did not exceed 1.0. A study in Poland [24] recorded a high risk of cardiovascular and nervous system diseases due to regular consumption of wild mushrooms by adults. In Romania, the HI values for the child population when consuming wild plants contaminated with heavy metals were 3.3–6.5 in the age groups 1–3 years and 6–10 years, which corresponds to a high-risk level [27].

In the Chukotka Autonomous Okrug, mushrooms growing in the region have a low content of heavy metals, but wild berries contained Cd in concentrations exceeding the hygienic threshold [28]. It has been established that mushrooms collected in the coastal zone of the Bering Strait can be consumed without restrictions, and berry consumption should not exceed 300 g/day [17]. In this study, the permissible safe consumption of wild plants containing heavy metals at the upper limit of exposure ($P_{90}$) is high, being 400 g/day for mushrooms and 650 g/day for berries.

One of the limitations of this study is the predominance of women among the respondents (77%), which may affect the extrapolation of the study results to the whole population as the difference in the frequency and quantity of consumption of wild mushrooms and berries between men and women may be significant. Additionally, the duration of the study was short— from May to October 2021. Respondents might have found it difficult to specify the frequency of consumption of wild plants in the winter-spring season of the year, which could compromise the consumption data for this season.

## CONCLUSION

Average consumption of wild mushrooms and berries growing in the Arkhangelsk region, with an average level of heavy metal pollution, is safe for public health. A high level of consumption of mushrooms and berries and high level of contamination of wild plants with heavy metals pose a high risk of development of general toxic effects on the endocrine system, circulatory and digestive systems, kidneys, and the immune system. Because of the high level of contamination of mushrooms and berries with heavy metals ($P_{90}$), it is not recommended to consume more than 400 g of wild mushrooms and 650 g of wild berries per day. In light of these findings, we recommend monitoring of the levels of contaminants, including heavy metals, in wild-growing mushrooms and berries.

## ADDITIONAL INFORMATION

**Authors contribution**. D.A. Stepovaia obtained, analyzed, interpreted the data and wrote the first draft of the article; T.N. Unguryany made a significant contribution to the concept and design of the study, obtained, analyzed, interpreted the data, wrote, and edited the text. All authors confirm that their authorship complies with the international ICMJE criteria. Both authors made a significant contribution to the development of the concept, research and preparation of the article, read and approved the final version before publication.
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