environments

MDPI

Article

Site-Specific Assessment of Potentially Toxic Element Accumulation and Pretreatment Response in Urban Wild *Agaricus* spp.

Nurgul Nursapina [1], Ilona Matveyeva [1,2,*], Tomiris Mazhit [1], Anar Seisembekova [3] and Daniil Shepilov [1,3]

[1] Faculty of Chemistry and Chemical Technology, Al-Farabi Kazakh National University, Almaty 050040/A15E3B4, Kazakhstan; nurgul.nursapina@kaznu.edu.kz (N.N.); tomirismazhit@gmail.com (T.M.); shepilov2002@gmail.com (D.S.)
[2] School of Chemical Engineering, Kazakh-British Technical University, Almaty 050005/A05H1T2, Kazakhstan
[3] JSC Scientific Center for Anti-Infectious Drugs, Almaty 050057/A15G7D2, Kazakhstan; seysembekovaanar@gmail.com
* Correspondence: i.matveyeva@kbtu.kz

Abstract

Urban mushrooms can reflect contaminant inputs from soil and atmospheric deposition, linking ecosystem quality with potential human exposure. This study compared potentially toxic element (PTE) accumulation in wild *Agaricus* spp. collected from an urban park in Almaty, Kazakhstan, with that in retail-purchased *Agaricus* spp. and evaluated pretreatment response. Aluminium (Al), chromium (Cr), nickel (Ni), copper (Cu), arsenic (As), and cadmium (Cd) were quantified by inductively coupled plasma mass spectrometry (ICP-MS) before and after 1 h ultrasound-assisted treatment with citric acid or ethylenediaminetetraacetic acid (EDTA) (0.5 and 8 g/L). Wild samples contained higher concentrations of all investigated elements, including approximately 60-fold higher Cd and 40-fold higher Al concentrations. After conversion to fresh weight using a dry-matter fraction of 0.07, Cd and total As in untreated wild samples exceeded the corresponding Technical Regulation of the Customs Union (TR CU) 021/2011 screening benchmarks. Citric acid at 8 g/L produced the largest decreases in wild mushrooms: Cd decreased from 6.64 ± 0.09 to 2.46 ± 0.02 mg/kg, Al from 421 ± 15 to 70 ± 2 mg/kg, and Ni from 1.5 ± 0.3 to 0.61 ± 0.07 mg/kg dry weight. Target hazard quotient (THQ) and hazard index (HI) values remained below 1 under the defined consumption scenario. The marked concentration differences and differential pretreatment responses show different elemental profiles between the examined wild and retail samples and may indicate potential differences in dietary exposure under the defined consumption scenario.

Keywords: potentially toxic elements; mushrooms; pretreatment response; citric acid pretreatment; non-carcinogenic risk

Check for updates

Received: 16 September 2026
Revised: 19 October 2026
Accepted: 23 October 2026
Published: 30 October 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

1. Introduction

Edible mushrooms are widely consumed because of their nutritional value and content of proteins, dietary fiber, minerals, and biologically active compounds. Wild mushrooms collected in urban and peri-urban environments may also enter the human diet. In such environments, fungal fruiting bodies develop under the combined influence of soil properties, atmospheric deposition, resuspended dust, traffic-related emissions, and other anthropogenic inputs. Through their extensive mycelial systems and close interaction with the

substrate, mushrooms can accumulate potentially toxic elements (PTEs) and other contaminants [1–7].

Their elemental composition may therefore provide site-specific information on environmental exposure while also representing a potential pathway of human exposure when wild mushrooms are collected for consumption [8]. Previous studies have demonstrated substantial variation in metal accumulation in urban and wild mushrooms. Reported concentrations depend on mushroom species, substrate characteristics, soil contamination, atmospheric deposition, and the bioavailability of elements in the local environment [9–15]. Kokkoris et al. [11], for example, reported that metal concentrations in wild mushrooms were associated with soil concentrations, mushroom species, and soil properties, including bioavailable metal fractions and soil texture. Among the elements frequently investigated in edible mushrooms, cadmium (Cd), arsenic (As), lead (Pb), mercury (Hg), chromium (Cr), and nickel (Ni) are of particular toxicological relevance. Liu et al. [4] found that As, Cd, and Pb concentrations in wild edible mushrooms from Yunnan Province, China, exceeded national standard values in a number of samples and identified As and Cd as major contributors to potential health risk.

Broader surveys and reviews further demonstrate that elemental accumulation varies considerably among mushroom species and geographical regions [16]. Dowlati et al. [17] reported substantial variability in potentially toxic metal concentrations in edible mushrooms and emphasized their possible contribution to dietary exposure [18]. The ability of mushroom biomass to accumulate metals has also been demonstrated experimentally; Sarwar et al. [19] reported uptake of Cd, Pb, and Hg by living biomass of *Pleurotus ostreatus* and *Agaricus bisporus*. In a large-scale survey of 610 edible mushroom samples, Liu et al. [20] found that most samples were classified as unpolluted, although elevated pollution indices occurred in some species. An et al. [21] likewise reported wide concentration ranges of As, Cd, Hg, and Pb in mushrooms from local markets in South Korea, while estimated dietary exposure remained within acceptable levels under the considered scenario [22]. Collectively, these studies show that mushroom elemental profiles are strongly influenced by species, origin, and environmental context.

Despite the growing literature on PTEs in edible and wild mushrooms, data from urban environments in Central Asia remain comparatively limited. Wild *Agaricus* spp. collected from an urban park in Almaty, Kazakhstan, were therefore investigated as site-specific biological matrices for characterizing elemental accumulation under local urban conditions. Retail-purchased *Agaricus* spp. were included as a comparative reference group. Because their production origin and environmental history were not established, the comparison was intended to characterize differences in elemental profiles rather than to identify source-specific contamination pathways.

In addition to measuring total element concentrations, pretreatment experiments can provide information on the changes in residual element concentrations under controlled extraction conditions. Washing, soaking, blanching, and treatment with complexing agents can alter contaminant concentrations in food matrices. EDTA has a strong capacity to bind metal ions and has been applied for extraction of radionuclides and potentially toxic metals from environmental materials [23]. Citric acid is a low-molecular-weight organic complexing agent with relatively low toxicity and the ability to enhance transfer of several metals into solution [24]. Ultrasound can further enhance mass transfer through cavitation and improved contact between the treatment solution and mushroom tissue [25,26]. Li et al. [27] showed that ultrasound and related pretreatments can alter tissue structure and enhance mass transfer in mushrooms. In the present study, ultrasound-assisted citric acid and EDTA treatments were applied to evaluate changes in residual element concentrations in the mushroom material under the specified extraction conditions. The treatment results are

interpreted as changes in residual concentrations after the combined soaking, ultrasound, and reagent treatment.

Accordingly, this study aimed to:

- Determine aluminium (Al), Cr, Ni, copper (Cu), As, and Cd concentrations in wild *Agaricus* spp. collected from an urban park in Almaty and in retail-purchased *Agaricus* spp.;
- Compare their elemental accumulation profiles;
- Evaluate changes in PTE concentrations following ultrasound-assisted pretreatment with citric acid and EDTA;
- Perform a screening-level assessment of potential dietary exposure.

The study was designed as a screening assessment of mushrooms collected during a single sampling event at the studied urban park, linking their elemental composition with pretreatment response and potential human exposure.

2. Materials and Methods

2.1. Reagents

Analytical-grade reagents were consistently employed throughout the analysis process. Citric acid and ethylenediaminetetraacetic acid disodium salt (EDTA, Trilon B; LenReaktiv, Saint Petersburg, Russia)were used for the preparation of pretreatment solutions. The solutions were prepared at concentrations of 0.5 and 8.0 g/L using deionized water. For ICP-MS calibration, Periodic Table Mix 1 for ICP (10 mg/L, Sigma-Aldrich, St. Louis, MO, USA) was serially diluted in 2.5% HNO_3 (Component-Reaktiv LLC, Moscow, Russia). All glassware and laboratory vessels used for element analysis were pre-cleaned to minimize possible contamination.

2.2. Sampling and Sample Pretreatment

Wild mushrooms of the *Agaricus* spp. were collected from an urban park area in Almaty, Kazakhstan, in November 2025. Sampling was carried out manually using clean disposable gloves and non-metallic tools. Mature fruiting bodies without visible signs of damage, decomposition, or pronounced surface contamination were selected. Each sample was labeled with the collection date and sampling location. The available records support interpretation at the park level, while georeferenced distances to roads and other potential urban sources can be incorporated into future spatial studies.

A total of 18 fruiting bodies were collected from three spatially separated sampling points within the study park, with six fruiting bodies collected at each point. Central coordinates of the study area were 43°15′45.48″ N, 76°58′7.33″ E. Fruiting bodies collected from each sampling point were pooled to form one independent composite biological sample, resulting in three independent wild mushroom samples ($n = 3$). Each composite sample was cleaned, homogenized separately, and subsequently divided into aliquots assigned to the untreated control and the respective pretreatment groups. Thus, each pretreatment was applied independently to all three biological samples.

Retail-purchased *Agaricus* spp. mushrooms purchased from retail stores in Almaty were used as a comparative reference group. The retail group comprised three independent batches of *Agaricus* spp., purchased separately on three independent purchase occasions. Each batch was homogenized separately and divided into aliquots assigned to the untreated control and the four pretreatment conditions. Pretreatment, ashing, acid extraction, and ICP-MS analysis were performed separately for each batch.

After delivery to the laboratory, the samples were cleaned of residual soil and plant material using non-metallic tools. The mushrooms were then divided into subgroups: un-

treated samples and samples subjected to preliminary treatment. For each group, untreated samples were used as controls.

Morphological characteristics supported identification at the genus level. Molecular confirmation was outside the scope of the present screening study, so the samples are consistently referred to as *Agaricus* spp. throughout the manuscript. No corresponding soil samples were collected or analyzed for Cd, Al, or Ni concentrations.

2.3. Citric Acid and EDTA Pretreatment

Separate EDTA and citric acid solutions at concentrations of 0.5 and 8.0 g/L were used as soaking media. The selected concentrations were based on previously reported mushroom-soaking procedures [28,29]. Samples were soaked for 1 h [28,29] in a Sapphire ultrasonic bath (Russia) operating at 40 kHz [30,31] with a maximum ultrasonic generator power of 550 W. The treatment temperature was maintained at 24 to 25 °C. For each treatment, 10 g of mushroom material was combined with 100 mL of solution, corresponding to a solid-to-liquid ratio of 1:10 *w*/*v*. After soaking, the mushrooms were air-dried and homogenized in an agate mortar. The treated samples were ashed at 550 °C, homogenized, and used for subsequent determination of PTE concentrations. The whole fruiting body was analyzed without separation into individual parts.

2.4. Acid Extraction of Ashed Samples

For determination of PTEs, the ashed mushroom samples were subjected to acid extraction before ICP-MS analysis [32–34].

Approximately 2.0 g of ashed material from each sample was placed in a pre-cleaned beaker. To moisten the ash and improve its interaction with the acid solution, 2–3 mL of bidistilled water was added. Subsequently, 15 mL of concentrated hydrochloric acid and 5 mL of concentrated nitric acid were added. Finally, 10 mL of 30% hydrogen peroxide solution was carefully added as an additional oxidizing agent.

The resulting solution was thoroughly mixed for 15 min and then left to stand overnight at room temperature to facilitate further acid extraction of the target elements from the ashed matrix.

The resulting solution was filtered through standard laboratory filter paper into a 100 mL volumetric flask to remove insoluble residue. The filtrate was diluted to volume with bidistilled water and thoroughly mixed to ensure homogeneity. The resulting solutions were used for instrumental determination of the elemental composition. Untreated samples served as controls. The observed changes represent the combined pretreatment effect and cannot be attributed exclusively to citric acid or EDTA.

2.5. ICP-MS Determination

PTE Measurements

The content of PTEs in mushroom samples was determined by inductively coupled plasma mass spectrometry using an Agilent 7500a ICP-MS system (Agilent Technologies, Santa Clara, CA, USA) in accordance with ST RK ISO 17294-2-2006 [35] after acid extraction of the ashed samples.

The radio-frequency power was 1600 W, the reported plasma temperature was 8000 °C, and the signal integration time was 0.1 s. The sample-introduction argon flow was 1.0 L/min and the cooling argon flow was 15 L/min. The measured isotopes were ^{27}Al, ^{52}Cr, ^{60}Ni, ^{63}Cu, ^{75}As, and ^{111}Cd. Arsenic was determined at m/z 75. The acid extracts were diluted to a final volume of 100 mL before ICP-MS analysis to reduce the chloride concentration. Calibration solutions were prepared by serial dilution of Periodic Table Mix 1 for ICP (10 mg/L) with 2.5% HNO_3.

Calibration curves were generated using the instrument software, and the calibration coefficients were ≥0.999 for all determined elements. Reagent blanks were analyzed alongside each batch of samples to monitor background contamination. Analytical precision was assessed by triplicate measurements, with relative standard deviations (RSDs) below 5% for all elements. Additional analytical quality control was performed using two independently prepared standard control solutions analyzed together with the samples. No matrix-certified reference material (CRM), recovery test, or internal standard was used. As no interference-correction equation was applied, the potential contribution of chloride-derived polyatomic interference to the total As signal cannot be fully excluded. The limits of detection (LOD) and quantification (LOQ) for the analyzed elements are presented in Table 1.

Table 1. Limits of detection (LOD) and quantification (LOQ) for ICP-MS determination of the analyzed elements.

Element	LOD (µg/L)	LOQ (µg/L)
^{27}Al	0.2	1.5
^{52}Cr	0.05	0.3
^{60}Ni	0.1	0.5
^{63}Cu	0.05	0.3
^{75}As	0.1	1.0
^{111}Cd	0.03	0.05

2.6. Target Hazard Quotient

Target Hazard Quotient (THQ) was used for the evaluation of non-carcinogenic exposure according to Equation (1) [36,37]:

$$THQ = EDI/R_fD \quad (1)$$

where EDI is the estimated daily intake and R_fD is the oral reference dose. Reference doses of 0.001 mg/kg/day for Cd, 0.04 mg/kg/day for Cu, and 0.01 mg/kg/day for Ni were obtained from the U.S. EPA Regional Screening Levels [38].

THQ values were not calculated for Al or Cr because Al can reflect mineral and matrix-related contributions, whereas Cr was determined as total Cr without speciation. For As, THQ was calculated using the oral reference dose for inorganic As ($R_fD = 6.0 \times 10^{-5}$ mg/kg/day) from the U.S. EPA IRIS database [39]. Because total As was measured, the As THQ represents an upper-bound screening estimate and does not demonstrate inorganic As exposure.

A THQ value below 1 indicates that appreciable non-carcinogenic effects are not expected under the stated exposure assumptions. The results therefore characterize the defined consumption scenario and support comparison among sample groups and treatments. The EDI value was calculated using Equation (2) [40,41]:

$$EDI = (C_m \times CF \times CR)/BW\ [mg/kg/day] \quad (2)$$

CR was estimated using an apparent consumption approach based on national trade statistics and available market production estimates. The annual apparent consumption was divided by the population and by 365 days, resulting in a consumption rate of 0.00164 kg/person/day fresh weight [42]. CF is the factor used to convert a dry-weight concentration to a fresh-weight concentration, which was experimentally determined from the ratio of the dry mass obtained after drying the mushroom samples to constant weight to their initial fresh mass.

The resulting dry-matter fraction was 0.07. Cm is the element concentration in mushrooms on a dry-weight basis (mg/kg), and BW is the average adult body weight of 70 kg. The sum of the THQ values for Ni, Cu, As, and Cd was used to calculate the hazard index (HI) using Equation (3):

$$HI = THQ_{Ni} + THQ_{Cu} + THQ_{As} + THQ_{Cd} \quad (3)$$

An HI value below 1 indicates that appreciable cumulative non-carcinogenic effects are not expected under the stated exposure assumptions.

2.7. Reduction Percentage

The percentage reduction in selected PTE concentrations after pretreatment was calculated using Equation (4):

$$\text{Reduction, \%} = [(C_{untreated} - C_{treated})/C_{untreated}] \times 100 \quad (4)$$

where $C_{untreated}$ is the element concentration in the untreated sample and $C_{treated}$ is the element concentration after pretreatment.

2.8. Statistical Analysis

PTE concentrations are presented as mean ± SD of three independent composite samples ($n = 3$). Triplicate ICP-MS measurements were averaged to obtain one value per sample. Treatment effects were analyzed separately for wild and retail mushrooms using randomized complete-block ANOVA, with biological sample as the blocking factor, followed by Dunnett's test against the untreated control. Statistical significance was set at $p < 0.05$ using GraphPad Prism 10.

3. Results and Discussion

3.1. PTE Concentration

The concentrations of PTEs (mg/kg) in the untreated samples of retail-purchased and wild *Agaricus* spp. are given in Table 2.

Table 2. Concentrations of selected PTEs in untreated retail-purchased and wild *Agaricus* spp.

Sample	Content (mg/kg Dry Weight)					
	Al	**Cr**	**Ni**	**Cu**	**As**	**Cd**
Wild	421.00 ± 15.00	214.00 ± 9.00	1.50 ± 0.30	276.00 ± 10.00	11.20 ± 0.60	6.64 ± 0.09
Retail-purchased	10.60 ± 0.20	32.10 ± 0.20	0.55 ± 0.01	31.00 ± 1.00	2.10 ± 0.10	0.11 ± 0.01

Values are presented as mean ± SD of three independent composite biological samples ($n = 3$). Instrumental triplicates were averaged before statistical analysis.

PTE concentrations in untreated retail-purchased and wild *Agaricus* spp. samples were compared to characterize element accumulation and to provide baseline values for evaluating citric acid and EDTA pretreatments. Particular attention was given to Cd and As because of their toxicological relevance.

The concentrations of all studied elements were higher in wild mushrooms than in retail-purchased samples. The largest contrasts were observed for Cd and Al, with concentrations approximately 60-fold and 40-fold higher, respectively. Cu, Cr, and As were also higher in wild mushrooms. From an ecological perspective, fruiting bodies developing in the studied urban habitat had an elemental profile distinct from that represented by the retail reference samples. However, as the origin and environmental history of the

retail material were not established, the difference cannot be attributed solely to urban environmental conditions.

From an ecological perspective, the elevated Al, Cr, Cu, As, and Cd concentrations are consistent with site-specific elemental accumulation in wild *Agaricus* fruiting bodies from the studied urban habitat.

The particularly large Al and Cd contrasts identify these elements as informative components of the elemental profile at the studied urban site.

For dietary-exposure screening, Cd and total As concentrations were assessed against the values in TR CU 021/2011 [43,44]. These values were used as screening benchmarks rather than as a determination of legal compliance for personally collected mushrooms. Because the benchmarks apply to fresh products and the analytical results were expressed on a dry-weight basis, conversion was performed using the dry-matter fraction of 0.07.

After conversion to fresh weight, Cd and total As in wild samples were 0.465 and 0.784 mg/kg, respectively, and exceeded the corresponding TR CU 021/2011 screening benchmarks. The retail-purchased samples contained 0.0077 mg/kg Cd and 0.147 mg/kg total As and remained below these values (Table 3). These results indicate that the higher element concentrations measured in the analyzed wild samples may result in higher dietary exposure under the defined consumption scenario.

Table 3. Screening comparison of Cd and As levels in wild and retail-purchased mushrooms.

El.	Sample	Converted Concentration, mg/kg (Fresh Weight) *	TR CU 021/2011 Limit, mg/kg	EU Limit, mg/kg Fresh Weight	Interpretation
Cd	Wild	0.4650 ± 0.0060	0.1	0.50 for wild mushrooms	Above the TR CU screening benchmark; below the EU limit for wild fungi
	Retail-purchased	0.0077 ± 0.0007		0.050 for most cultivated fungi	Below both screening values
As	Wild	0.7840 ± 0.0420	0.5	No general EU limit for total As in mushrooms	Above the TR CU screening benchmark
	Retail-purchased	0.1470 ± 0.0070			Below the TR CU screening benchmark

* Values reported on a dry-weight basis were converted to fresh weight using the stated dry-matter fraction of 0.07, which was applied consistently across all samples.

The pretreatment experiment was then used to assess the effects of citric acid and EDTA pretreatments on PTE concentrations in the mushroom samples.

Randomized complete-block ANOVA indicated an overall treatment effect for each evaluated element in wild mushrooms ($p < 0.05$). According to Table 4 and Figure 1, pretreatment of wild *Agaricus* spp. samples led to a decrease in the concentration of several investigated elements. However, the effectiveness of the treatment depended on the type of reagent, its concentration, and the chemical nature of the element. These differences may reflect element-specific interactions with the mushroom matrix, although chemical fractions and binding forms were not determined.

The most pronounced and consistent effect was observed with citric acid treatment, particularly at a concentration of 8 g/L. With this treatment method, the concentrations of Al, Ni and Cd showed the largest decreases: Al from 421 ± 15 to 70 ± 2 mg/kg, Ni from 1.5 ± 0.3 to 0.61 ± 0.07 mg/kg, and Cd from 6.64 ± 0.09 to 2.46 ± 0.02 mg/kg of dry

weight. Citric acid may be compatible with proton-assisted desorption and the formation of soluble citrate complexes. The smaller changes observed after EDTA treatment may reflect differences in pH-dependent complexation, competition among ions, or treatment kinetics. The reduction in Al may indicate the removal of some residual concentrations, including elements associated with surface soil or dust particles. The underlying removal mechanism was not examined directly. The 63.0% reduction in Cd was particularly relevant to food-safety screening because Cd was a major risk-related element in untreated wild mushrooms. After treatment, the fresh-weight Cd concentration was 0.172 mg/kg and remained above the TR CU 021/2011 screening benchmark.

Table 4. Concentrations of PTEs in wild *Agaricus* spp. after pretreatment (mg/kg dry weight).

Treatment	Content (mg/kg Dry Weight)					
	Al	**Cr**	**Ni**	**Cu**	**As**	**Cd**
0.5 g/L Citric acid	115.00 ± 4.00 ***	135.00 ± 8.00 **	1.30 ± 0.10 *	204.00 ± 7.00 **	9.50 ± 0.50 *	4.11 ± 0.09 **
8 g/L Citric acid	70.00 ± 2.00 ***	141.00 ± 6.00 **	0.61 ± 0.07 ***	200.00 ± 8.00 **	9.30 ± 0.40 *	2.46 ± 0.02 ***
0.5 g/L EDTA	209.00 ± 7.00 ***	124.00 ± 5.00 **	0.82 ± 0.09 **	260.00 ± 8.00 *	8.20 ± 0.40 **	5.89 ± 0.07 *
8 g/L EDTA	112.00 ± 4.00 ***	191.00 ± 11.00 *	1.11 ± 0.08 **	262.00 ± 10.00 *	11.00 ± 1.00 *	5.80 ± 0.10 **

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. Values are presented as mean ± SD of three independent composite biological samples ($n = 3$). Instrumental triplicates were averaged before statistical analysis.

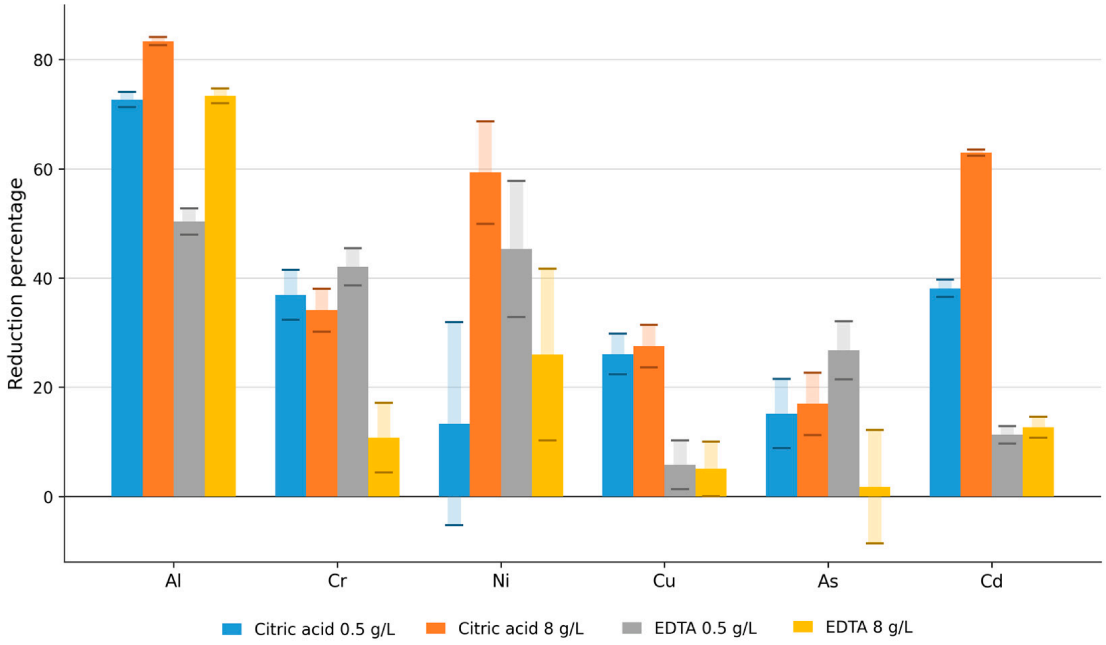


Figure 1. Percentage reduction in selected PTE concentrations in wild *Agaricus* spp. samples after pretreatment.

This trend is consistent with published data on the ability of mushrooms to accumulate Cd and other metals, as well as on the possibility of partial removal of metals through aqueous and thermal treatment. Kalač [45] reported that *Agaricus* spp. can accumulate Cd even without substantial industrial pollution, which is consistent with the higher Cd concentration observed in the wild samples. The reduction in Cd concentration as a result of citric acid treatment is also consistent with the findings of Svoboda et al. [46] on the

leaching of Cd, Pb and Hg from the mushroom matrix during soaking and boiling. The more pronounced effect observed in the present study may be due to the additional contribution of acid leaching and the formation of soluble citrate complexes.

Overall, the results in Table 4 show that 8 g/L citric acid produced the largest and most consistent reductions in Cd, Al, and Ni in wild *Agaricus* spp. samples. The treatments therefore provide an experimental measure of changes in residual element concentrations following pretreatment in the mushroom matrix. Validation using larger, georeferenced sample sets and paired environmental matrices would strengthen the interpretation of pretreatment-associated changes in residual element concentrations.

In retail-purchased *Agaricus* spp. samples, the initial concentrations of PTEs, as shown in Table 2, were lower than those in wild mushrooms, resulting in a less pronounced effect of subsequent treatment. In contrast to the wild samples, where treatment led to substantial reductions in the concentrations of Cd, Al, and Ni, changes in the elemental composition of retail-purchased mushrooms were more moderate, as shown in Table 5. This contrast may reflect differences in substrate composition, cultivation environment, and the chemical forms in which elements were associated with the mushroom matrix.

Table 5. Concentrations of selected PTEs in retail-purchased *Agaricus* spp. after pretreatment (mg/kg dry weight).

Treatment	Content (mg/kg Dry Weight)					
	Al	**Cr**	**Ni**	**Cu**	**As**	**Cd**
0.5 g/L Citric acid	9.80 ± 0.40 *	25.00 ± 2.00 **	0.49 ± 0.05 **	16.00 ± 1.00 **	1.60 ± 0.10 **	0.11 ± 0.01
8 g/L Citric acid	10.00 ± 1.00 *	25.00 ± 3.00 **	0.51 ± 0.01 *	21.00 ± 1.00 **	1.80 ± 0.10 **	0.11 ± 0.01
0.5 g/L EDTA	9.10 ± 0.40 **	27.00 ± 2.00 **	0.53 ± 0.02 *	25.00 ± 1.00 *	1.90 ± 0.10 *	0.11 ± 0.01
8 g/L EDTA	9.80 ± 0.30 *	31.00 ± 2.00 *	0.52 ± 0.02 *	27.00 ± 1.00 *	1.80 ± 0.20 **	0.11 ± 0.01

* $p < 0.05$; ** $p < 0.01$. Values are presented as mean ± SD of three independent composite biological samples ($n = 3$). Instrumental triplicates were averaged before statistical analysis.

In retail-purchased *Agaricus* spp. samples, pretreatment led to a decrease in the content of selected PTEs. However, the effect varied depending on element and treatment type.

Treatment with citric acid had the most consistent effect on the retail-purchased samples, as shown in Figure 2. The largest change was observed for Cu, which decreased from 31 ± 1 to 16 ± 1 mg/kg after treatment with 0.5 g/L citric acid, corresponding to a 48.4% reduction. Treatment with citric acid at a concentration of 8 g/L was less effective in comparison to treatment with 0.5 g/L citric acid, indicating that increasing the concentration of citric acid did not increase the reduction in residual concentration. The concentration of Cr decreased from 32.1 ± 0.2 to 25.0 ± 2 and 25.0 ± 3 mg/kg with application of 0.5 and 8 g/L of citric acid, respectively, whereas application of EDTA showed a weaker effect.

The reduction percentage of Ni and Al showed slight variations, and Cd was unaffected by the different pretreatment treatments. Comparison of retail-purchased and wild *Agaricus* spp. samples shows that pretreatment effectiveness depends on the initial element concentration and the applied reagent. In wild samples, 8 g/L citric acid markedly reduced Cd, Al, and Ni, potentially through larger decreases in residual element concentrations. In retail-purchased samples, lower initial concentrations were accompanied by smaller treatment responses.

Ecologically, the stronger response of the wild samples indicates that their higher total concentrations were accompanied by a stronger pretreatment response. The weaker

response of the retail samples is consistent with their lower initial concentrations and a different elemental association within the cultivated mushroom matrix.

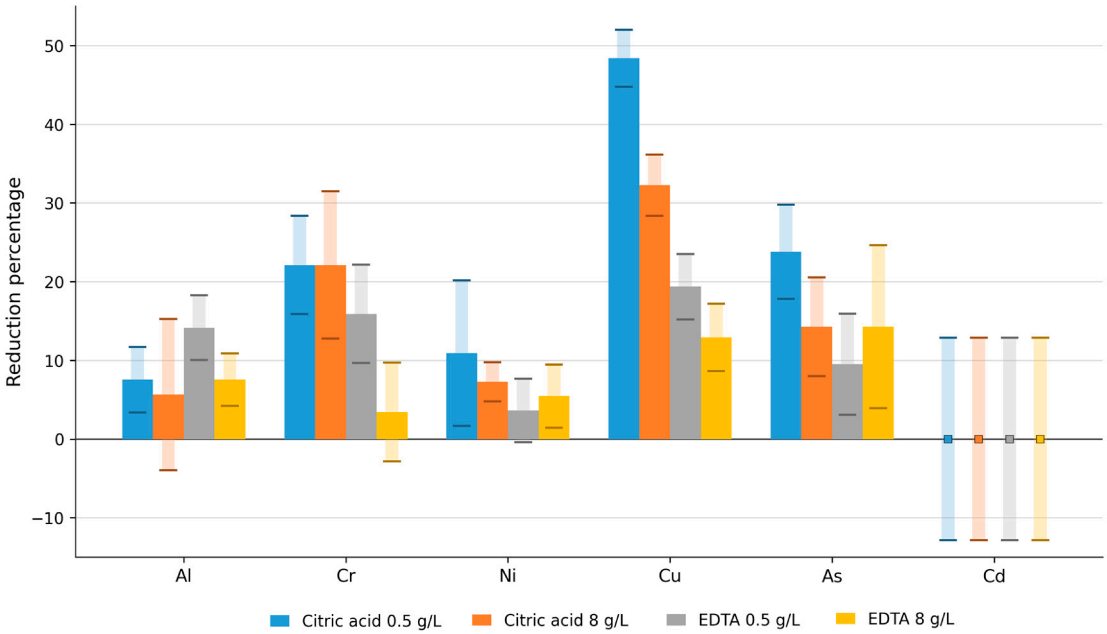


Figure 2. Percentage reduction in selected PTE concentrations in retail-purchased *Agaricus* spp. samples after pretreatment.

Taken together, the results distinguish the analysed wild and retail samples in terms of their initial element concentrations and the magnitude of concentration changes following pretreatment.

Citric acid at 8 g/L produced the most consistent reductions in Cd, Al, and Ni in wild *Agaricus* spp., identifying the strongest pretreatment response among the tested experimental conditions.

3.2. Health Risk Assessment of Selected PTEs

The THQ values for Ni, Cu, As, and Cd were below 1 in all wild and retail-purchased *Agaricus* spp. samples under the specified consumption scenario. This supports a low modeled non-carcinogenic risk at the assumed intake rate. As with any scenario-based assessment, the estimates are interpreted in relation to the selected consumption rate, body weight, conversion factor, and the conservative upper-bound assumption applied to total As.

As shown in Table 6, THQ values were higher in wild *Agaricus* spp. than in retail-purchased *Agaricus*, reflecting higher concentrations of Ni, Cu, As, and Cd. Among the elements studied, As had the largest contribution to the potential non-carcinogenic risk, followed by Cu and Cd in wild-growing samples, while the contribution of Ni was minimal. The highest individual THQ was observed for As in untreated wild *Agaricus* spp. (3.06×10^{-1}), although this value remained below 1.

Treatment with citric acid at 8 g/L reduced the Cd THQ in wild mushrooms from 0.0109 in the untreated sample to 0.00403. This reflects a lower Cd-related contribution to modeled dietary exposure under the specified scenario.

For retail-purchased *Agaricus* spp. samples, according to Table 7, THQ values were lower than for wild mushrooms, indicating lower modeled non-carcinogenic exposure under the specified consumption scenario. In all treatment variants for retail-purchased mushrooms, THQ values for Ni, Cu, As, and Cd remained at a very low level. As made the largest relative contribution in the retail-purchased samples, while Cd and Ni were charac-

terized by the lowest THQ values. Citric acid and EDTA pretreatment of retail-purchased mushrooms had little effect in reducing the potential risk, as the initial concentrations of elements were low. Nevertheless, under the stated assumptions, the analyzed wild samples produced higher modeled exposure estimates than the retail reference samples.

Table 6. Target hazard quotient (THQ) and hazard index (HI) values for selected PTEs in wild *Agaricus* spp.

Treatment	THQ, Ni	THQ, Cu	THQ, As	THQ, Cd	HI
0.5 g/L Citric acid	2.13×10^{-4}	8.36×10^{-3}	2.60×10^{-1}	6.74×10^{-3}	2.75×10^{-1}
8 g/L Citric acid	1.00×10^{-4}	8.20×10^{-3}	2.54×10^{-1}	4.03×10^{-3}	2.67×10^{-1}
0.5 g/L EDTA	1.34×10^{-4}	1.07×10^{-2}	2.24×10^{-1}	9.66×10^{-3}	2.45×10^{-1}
8 g/L EDTA	1.82×10^{-4}	1.07×10^{-2}	3.01×10^{-1}	9.51×10^{-3}	3.21×10^{-1}
Without treatment	2.46×10^{-4}	1.13×10^{-2}	3.06×10^{-1}	1.09×10^{-2}	3.29×10^{-1}

Table 7. Target hazard quotient (THQ) and hazard index (HI) values for selected PTEs in retail-purchased *Agaricus* spp.

Treatment	THQ, Ni	THQ, Cu	THQ, As	THQ, Cd	HI
0.5 g/L Citric acid	8.04×10^{-5}	6.56×10^{-4}	4.37×10^{-2}	1.75×10^{-4}	4.46×10^{-2}
8 g/L Citric acid	8.36×10^{-5}	8.61×10^{-4}	4.92×10^{-2}	1.79×10^{-4}	5.03×10^{-2}
0.5 g/L EDTA	8.69×10^{-5}	1.03×10^{-3}	5.19×10^{-2}	1.79×10^{-4}	5.32×10^{-2}
8 g/L EDTA	8.53×10^{-5}	1.11×10^{-3}	4.92×10^{-2}	1.79×10^{-4}	5.06×10^{-2}
Without treatment	9.02×10^{-5}	1.27×10^{-3}	5.74×10^{-2}	1.80×10^{-4}	5.89×10^{-2}

Overall, the THQ values for Ni, Cu, As, and Cd in all *Agaricus* samples were below 1 under the specified consumption scenario. Wild mushrooms had higher THQ values than retail-purchased samples, and treatment with citric acid at 8 g/L produced the largest reduction in the Cd-related component in wild mushrooms.

The cumulative non-carcinogenic exposure was assessed as the sum of THQ values for Ni, Cu, As, and Cd. In wild *Agaricus* spp., recalculated HI values ranged from 2.45×10^{-1} to 3.29×10^{-1}. The highest value occurred in the untreated sample and the lowest after treatment with 0.5 g/L EDTA. The decrease in HI was mainly associated with the reduction in the As-related component. As showed the largest absolute decrease in THQ, while Cd showed the largest proportional decrease.

Retail-purchased *Agaricus* spp. had recalculated HI values from 4.46×10^{-2} to 5.89×10^{-2}. The untreated sample had the highest HI, while the lowest value occurred after treatment with 0.5 g/L citric acid. The lower values correspond to the smaller element pools measured in the retail mushroom matrix.

All calculated HI values remained below 1 under the assumed average consumption rate. Nevertheless, the consistently higher values for wild *Agaricus* spp. demonstrate that differences between the analyzed wild and retail samples can translate into greater dietary

exposure. For regular collectors from the studied habitat, interpretation will depend on the actual portion size and frequency of consumption.

3.3. Limitations and Future Perspectives

The site-specific sampling design provides a park-level assessment of elemental accumulation rather than a city-wide characterization of the urban environment of Almaty. Because fruiting bodies collected at each sampling point were pooled, the reported variability represents differences among three composite sampling-point samples rather than variability among individual fruiting bodies. Furthermore, the absence of paired soil and atmospheric measurements limits the attribution of the observed elemental enrichment to specific environmental sources. Future studies should include georeferenced and seasonal sampling across multiple urban habitats, together with analysis of soils, road dust, and atmospheric deposition. Elemental speciation could provide further insight into the mobility and transfer of As, Cr, and other potentially toxic elements within the mushroom–substrate system. Such investigations would clarify the ecological pathways controlling elemental accumulation and determine the potential of urban *Agaricus* spp. as indicators of local environmental contamination. In addition, the absence of a matrix-certified reference material, recovery assessment, and internal-standard correction should be considered an analytical limitation of this screening-level study.

4. Conclusions

Wild *Agaricus* spp. contained higher concentrations of Cd, Al, Cu, Cr, and As than retail-purchased mushrooms, showing a distinct elemental profile between the analyzed sample groups. After conversion to fresh weight, Cd and total As in untreated wild samples exceeded the TR CU 021/2011 screening benchmarks. Citric acid at 8 g/L produced the largest decreases in Cd, Al, and Ni concentrations. The pretreatments produced element-dependent changes in residual concentrations within the mushroom material.

THQ values for Ni, Cu, As, and Cd remained below 1 under the specified consumption scenario. Recalculated HI values ranged from 2.45×10^{-1} to 3.29×10^{-1} in wild *Agaricus* spp. and from 4.46×10^{-2} to 5.89×10^{-2} in retail-purchased mushrooms. As was the main contributor to HI, although all calculated values remained below 1 under the specified consumption scenario. These findings apply to the analyzed samples. The higher concentrations measured in the wild samples resulted in higher modeled exposure estimates under the defined consumption scenario and support continued monitoring of mushrooms collected from the studied habitat. Broader ecological interpretation requires a larger number of independent biological samples collected across additional sites and seasons, together with paired environmental sampling.

Author Contributions: Conceptualization, N.N. and I.M.; methodology, N.N. and I.M.; formal analysis, N.N., I.M. and D.S.; investigation, T.M.; resources, N.N. and A.S.; data curation, N.N., T.M. and I.M.; writing—original draft preparation, N.N.; writing—review and editing, I.M. and D.S.; visualization, N.N. and A.S.; supervision, N.N.; project administration, N.N.; funding acquisition, N.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research has been funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant No. AP22684045).

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Acknowledgments: The authors express their gratitude to the Laboratory of Metal Analysis of the Center for Physical and Chemical Research, Al-Farabi Kazakh National University, for assistance in conducting elemental analysis of mushroom samples using the ICP-MS method. During the prepara-

tion of this manuscript, the authors used ChatGPT 4o for the purposes of language improvement. The authors have reviewed and edited the output and take full responsibility for the content of this publication.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

PTEs	Potentially toxic elements
THQ	Target Hazard Quotient
EDI	Estimated daily intake
ICP-MS	Inductively coupled plasma mass spectrometry
HI	Hazard Index
R_fD	Oral reference dose
CR	Consumption rate
CF	Conversion factor
BW	Body weight

References

1. Barua, T.; Bhuian, A.K.M.S.I.; Hossain, S.; Deb, N.; Ahmed, M.; Hossain, S.; Rashid, A.; Khandaker, M.U. The presence of radioactive and metal contaminants in wild mushrooms grown in Chattogram Hill Tracts, Bangladesh. *J. Radioanal. Nucl. Chem.* **2019**, *322*, 173–182. [CrossRef]
2. Čadová, M.; Havránková, R.; Havránek, J.; Zölzer, F. Radioactivity in mushrooms from selected locations in the Bohemian Forest, Czech Republic. *Radiat. Environ. Biophys.* **2017**, *56*, 167–175. [CrossRef] [PubMed]
3. Chungu, D.; Mwanza, A.; Ng'andwe, P.; Chungu, B.C.; Maseka, K. Variation of heavy metal contamination between mushroom species in the Copperbelt Province, Zambia: Are the people at risk? *J. Sci. Food Agric.* **2019**, *99*, 3410–3416. [CrossRef] [PubMed]
4. Liu, B.; Huang, Q.; Cai, H.; Guo, X.; Wang, T.; Gui, M. Study of heavy metal concentrations in wild edible mushrooms in Yunnan Province, China. *Food Chem.* **2015**, *188*, 294–300. [CrossRef] [PubMed]
5. Strumińska-Parulska, D.; Falandysz, J. A review of the occurrence of alpha-emitting radionuclides in wild mushrooms. *Int. J. Environ. Res. Public Health* **2020**, *17*, 8220. [CrossRef] [PubMed]
6. Wichterey, K.; Sawallisch, S. Naturally occurring radionuclides in mushrooms from uranium mining regions in Germany. *Radioprotection* **2002**, *37*, C1-353–C1-358. [CrossRef]
7. Qin, G.; Liu, J.; Zou, K.; He, F.; Li, Y.; Liu, R.; Zhang, P.; Zhao, G.; Wang, T.; Chen, B. Analysis of heavy metal characteristics and health risks of edible mushrooms in the mid-western region of China. *Sci. Rep.* **2024**, *14*, 26960. [CrossRef] [PubMed]
8. Neenu, G.; Ceasar, S.A.; Krishnakumar, N.M. Harnessing Mushrooms as Bioindicators to Monitor Heavy Metal Pollution. *Environ. Qual. Manag.* **2026**, *35*, e70348. [CrossRef]
9. Bucurica, I.A.; Dulama, I.D.; Radulescu, C.; Banica, A.L.; Stanescu, S.G. Heavy metals and associated risks of wild edible mushrooms consumption: Transfer factor, carcinogenic risk, and health risk index. *J. Fungi* **2024**, *10*, 844. [CrossRef] [PubMed]
10. Gürgen, A.; Yıldız, S.; Çevik, U.; Çelik, A. Radionuclide activity concentrations of *Agaricus bisporus* and *Pleurotus ostreatus* mushrooms cultivated by different commercial companies. *J. Int. Environ. Appl. Sci.* **2019**, *14*, 13–20.
11. Kokkoris, V.; Massas, I.; Polemis, E.; Koutrotsios, G.; Zervakis, G.I. Accumulation of heavy metals by wild edible mushrooms with respect to soil substrates in the Athens metropolitan area, Greece. *Sci. Total Environ.* **2019**, *685*, 280–296. [CrossRef] [PubMed]
12. Mleczek, M.; Budka, A.; Siwulski, M.; Budzyńska, S.; Kalač, P.; Karolewski, Z.; Lisiak-Zielińska, M.; Kuczyńska-Kippen, N.; Niedzielski, P. Anthropogenic contamination leads to changes in the mineral composition of soil- and tree-growing mushroom species: A case study of urban versus rural environments and dietary implications. *Sci. Total Environ.* **2022**, *809*, 151162. [CrossRef] [PubMed]
13. Świsłowski, P.; Rajfur, M. Mushrooms as Biomonitors of Heavy Metals Contamination in Forest Areas. *Ecol. Chem. Eng. S* **2018**, *25*, 557–568. [CrossRef]
14. Zsigmond, A.R.; Fejér, I.R.; Kántor, I.; May, Z.; Urák, I. Influence of the urban environment on four mushroom species in the light of their elemental composition. *Chemosphere* **2023**, *335*, 139052. [CrossRef] [PubMed]
15. Stojek, K.; Czortek, P.; Bobrowska-Korczak, B.; Krośniak, M.; Jaroszewicz, B. Fungal species and element type modulate the effects of environmental factors on the concentration of potentially toxic elements in mushrooms. *Environ. Pollut.* **2024**, *353*, 124152. [CrossRef] [PubMed]
16. Liu, S.; Liu, H.; Li, J.; Wang, Y. Research Progress on Elements of Wild Edible Mushrooms. *J. Fungi* **2022**, *8*, 964. [CrossRef] [PubMed]

17. Dowlati, M.; Sobhi, H.R.; Esrafili, A.; Farzadkia, M.; Yeganeh, M. Heavy metals content in edible mushrooms: A systematic review, meta-analysis, and health risk assessment. *Trends Food Sci. Technol.* **2021**, *109*, 527–535. [CrossRef]
18. Senila, M.; Resz, M.-A.; Torok, I.; Senila, L. Nutritional composition and health risk of toxic metals of some edible wild mushrooms growing in a mining area of Apuseni Mountains, Western Carpathians. *J. Food Compos. Anal.* **2024**, *128*, 106061. [CrossRef]
19. Sarwar, A.; Nayyar, B.G.; Irshad, H.; Anwar, P.; Olihk, N.; Ajmal, M. Mycofiltration of heavy metals (Pb, Cd, and Hg) from aqueous solution by living biomass of two mushrooms, *Pleurotus ostreatus* and *Agaricus bisporus*, as biosorbents. *J. Water Chem. Technol.* **2023**, *45*, 599–606. [CrossRef]
20. Liu, S.; Fu, Y.; Shi, M.; Wang, H.; Guo, J. Pollution level and risk assessment of lead, cadmium, mercury, and arsenic in edible mushrooms from Jilin Province, China. *J. Food Sci.* **2021**, *86*, 3374–3383. [CrossRef] [PubMed]
21. An, J.M.; Gu, S.Y.; Kim, D.J.; Shin, H.C.; Hong, K.S.; Kim, Y.K. Arsenic, cadmium, lead, and mercury contents of mushroom species in Korea and associated health risk. *Int. J. Food Prop.* **2020**, *23*, 992–998. [CrossRef]
22. Turhan, Ş.; Akata, I.; Kumru, E.; Altuner, E.M. Heavy metal analysis of wild edible mushrooms grown in Türkiye and assessment of possible carcinogenic and non-carcinogenic risk. *J. Food Compos. Anal.* **2024**, *135*, 106581. [CrossRef]
23. Singh, U.; Jain, S.K.; Doshi, A.; Jain, H.K.; Chahar, V.K. Effects of pretreatments on drying characteristics of button mushroom. *Int. J. Food Eng.* **2008**, *4*, 1. [CrossRef]
24. Asselin, S.; Ingram, J.C. Uranium leaching from contaminated soil utilizing rhamnolipid, EDTA, and citric acid. *Appl. Environ. Soil Sci.* **2014**, *2014*, 462514. [CrossRef] [PubMed]
25. Lagnika, C.; Zhang, M.; Nsor-Atindana, J.; Bashari, M. Effects of ultrasound and chemical treatments on white mushroom (*Agaricus bisporus*) prior to modified-atmosphere packaging for extending shelf life. *J. Food Sci. Technol.* **2014**, *51*, 3749–3757. [CrossRef] [PubMed]
26. Sun, M.; Zhuang, Y.; Gu, Y.; Zhang, G.; Fan, X.; Ding, Y. A comprehensive review of the application of ultrasonication in the production and processing of edible mushrooms: Drying, extraction of bioactive compounds, and post-harvest preservation. *Ultrason. Sonochem.* **2024**, *102*, 106763. [CrossRef] [PubMed]
27. Li, X.; Li, J.; Wang, R.; Rahaman, A.; Zeng, X.A.; Brennan, C.S. Combined effects of pulsed electric field and ultrasound pretreatments on mass transfer and quality of mushrooms. *LWT* **2021**, *150*, 112008. [CrossRef]
28. Bakaytis, V.I.; Che, S.N. Effect of soaking on heavy metals content in mushrooms. *Food Process. Tech. Technol.* **2012**, *4*, 136–139. (In Russian)
29. Coşkuner, Y.; Özdemir, Y. Acid and EDTA blanching effects on the essential element content of mushrooms (*Agaricus bisporus*). *J. Sci. Food Agric.* **2000**, *80*, 2074–2076. DOI. [CrossRef]
30. Marçal, S.; Sousa, A.S.; Taofiq, O.; Antunes, F.; Morais, A.M.M.B.; Freitas, A.C.; Barros, L.; Ferreira, I.C.; Pintado, M. Impact of postharvest preservation methods on the nutritional value and bioactive properties of mushrooms. *Trends Food Sci. Technol.* **2021**, *110*, 418–431. [CrossRef]
31. Zheng, C.; Li, J.; Liu, H.; Wang, Y. Review of postharvest processing of edible wild-grown mushrooms. *Food Res. Int.* **2023**, *173*, 113223. [CrossRef] [PubMed]
32. Dospatliev, L.; Ivanova, M. Determination of heavy metals in mushroom samples by atomic absorption spectrometry. *Bulg. Chem. Commun.* **2017**, *49*, 5–9.
33. Kula, İ.; Solak, M.H.; Uğurlu, M.; Işıloğlu, M.; Arslan, Y. Determination of mercury, cadmium, lead, zinc, selenium, and iron by ICP-OES in mushroom samples from around a thermal power plant in Muğla, Turkey. *Bull. Environ. Contam. Toxicol.* **2011**, *87*, 276–281. [CrossRef] [PubMed]
34. *GOST 26929-94*; Raw Material and Food-Stuffs—Preparation of Samples—Decomposition of Organic Matters for Analysis of Toxic Elements. IPK Standards Publishing House: Moscow, Russia, 2002.
35. *ST RK ISO 17294-2-2006*; Water Quality—Application of Inductively Coupled Plasma Mass Spectrometry (ICP-MS)—Part 2: Determination of 62 Elements. Committee for Technical Regulation and Metrology of the Ministry of Industry and Trade of the Republic of Kazakhstan: Astana, Kazakhstan, 2006; 24p.
36. Turan, H.; Altan, C.O.; Kocatepe, D. Black Sea whiting: Assessment of potential health benefits/risks and differences based on mineral concentrations of meat and roes. *Turk. J. Agric.-Food Sci. Technol.* **2019**, *7*, 2075–2082. [CrossRef]
37. Bogdanović, T.; Ujević, I.; Sedak, M.; Listeš, E.; Šimat, V.; Petričević, S.; Poljak, V. As, Cd, Hg, and Pb in four edible shellfish species from breeding and harvesting areas along the eastern Adriatic coast, Croatia. *Food Chem.* **2014**, *146*, 197–203. [CrossRef] [PubMed]
38. U.S. Environmental Protection Agency. *Regional Screening Level (RSL) Summary Table (TR = 1 × 10^{-6}; HQ = 1), November 2019*; U.S. EPA: Washington, DC, USA, 2019.
39. U.S. Environmental Protection Agency. *IRIS Toxicological Review of Inorganic Arsenic (CASRN 7440-38-2)*; Report EPA/635/R-25/005Fa; U.S. EPA: Washington, DC, USA, 2025.
40. Ben Ameur, W.; Annabi, A.; Rania, K.; Marini, M. Assessment of heavy metal contamination and human health risk in *Parapenaeus longirostris* from coastal Tunisian aquatic ecosystems. *Pollutants* **2025**, *5*, 23. [CrossRef]

41. Tkachenko, H.; Kurhaluk, N.; Kasiyan, O.; Kamiński, P. Dietary nutrients and health risks from exposure to some heavy metals through the consumption of farmed common carp (*Cyprinus carpio*). *J. Environ. Health Sci. Eng.* **2021**, *19*, 793–804. [CrossRef] [PubMed]
42. Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan. *Resources and Use of Selected Products (Goods) and Raw Materials in the Republic of Kazakhstan, 2023*; Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan: Astana, Kazakhstan, 2024.
43. Customs Union Commission. *Technical Regulation of the Customs Union TR CU 021/2011: Concerning Safety of Food Products*; approved by Decision No. 880 of the Customs Union Commission, 9 December 2011; Customs Union Commission: Windhoek, Namibia, 2011.
44. European Commission. Commission Regulation (EU) 2023/915 of 25 April 2023 on maximum levels for certain contaminants in food and repealing Regulation (EC) No. 1881/2006. *Off. J. Eur. Union* **2023**, *L 119*, 103–157.
45. Kalač, P. A review of trace element concentrations in edible mushrooms. *Food Chem.* **2000**, *69*, 273–281. [CrossRef]
46. Svoboda, L. Leaching of cadmium, lead, and mercury from fresh and differently preserved edible mushroom, *Xerocomus badius*, during soaking and boiling. *Food Chem.* **2002**, *79*, 41–45. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.