published by

EQA - International Journal of Environmental Quality
ISSN 2281-4485 - Vol. 70 (2025): 66 - 75
Journal homepage: https://eqa.unibo.it/

Heavy metals bioaccumulation in wild edible mushrooms of an Indo Burma biodiversity hotspot: Suitability assessment for safe consumption and food safety/security implications

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Article info
Received 18/4/2025; received in revised form 20/5/2025; accepted 14/6/2025
DOI: 10.6092/issn.2281-4485/21806

Abstract
Fungi can bio-accumulate heavy metals (HMs) from the contaminated soil which makes them a valuable tool and potential bio-agent for environmental remediation and agro-ecosystem restoration. However, it is essential to analyse the potential risks associated with the consumption of the HMs contaminated wild edible mushrooms to maintain the food safety/-security. To this end, HMs content was assessed in three wild edible mushrooms species collected from different regions of Aizawl Mizoram, North East India, which is underlying in an Indo Burma biodiversity hotspot. The analysis of HMs was carried out using atomic absorption spectrometry (AAS) to determine the contents of copper (Cu), zinc (Zn), manganese (Mn), iron (Fe), nickel (Ni), lead (Pb) and cadmium (Cd) in mushrooms' biomass on dry weight basis. The overall heavy metal content in the studied mushrooms was also found to follow the order: Cd (0.003–0.018 mg/kg) < Pb (0.034–0.182 mg/kg) < Ni (0.033–0.058 mg/kg) < Mn (3.3445–6.109 mg/kg) < Cu (7.085–12.285 mg/kg) < Zn (19.089–31.878 mg/kg) < Fe (30.589–49.203 mg/kg). Results revealed that all the HMs in these mushrooms were within safe limits for human consumption, thereby imposing negligible human health risks. However, long-term consumption of mushrooms with elevated Ni levels should be approached with caution. Nevertheless, sustained long-term HMs monitoring and estimation of human health risk assessment indices are warranted in biodiversity hotspots to mitigate the human health risks. Last, the extrapolation of present study is necessary in urbanized and industrial landscapes with intense HMs contamination.

Keywords: *bioaccumulation, edible mushrooms, food safety/-security, heavy metals, human health*

Introduction

Heavy metals (HMs) in the Anthropocene contaminated the biosphere, ascribed to the rapid pace of industrialization and urbanization. This contamination is pervasive, affecting both aquatic and terrestrial habitats as pollutants are released into the multiple environmental matrices, especially air and water (Rai, 2009; Shetty et al., 2024). Excessive accumulation of HMs beyond certain thresholds can be harmful to human health mediated through perturbations in human metabolomics and potentially leading to illness, morbidity, and mortality (Jaishankar et al., 2014; Rai et al., 2019). Numerous studies are conducted to address heavy metal removal from the environment, yet the issue persists in terms of selectivity, sustainability, and edible plants/food-stuffs contamination (Rai, 2022). The bioaccumulation and trophic level transfer of HMs in edible plants is of global concern in view of safe consumption and food safety/security implica-

DOI: 10.6092/issn.2281-4485/21806

tions (Rai et al., 2023; Guerrieri et al., 2024). Wild edible mushrooms are acknowledged for their nutritional properties, with essential minerals and other ingredients that are beneficial to human health (Manzi et al., 1999; Nakalembe et al., 2015). Past studies evidenced that wild mushroom species can accumulate significant levels of HMs (Kalac and Svoboda, 2000; Ndimele et al., 2017; Fu et al., 2020) even in soils moderately contaminated with metals (Isildak et al., 2007). Several studies observed that wild mushrooms tend to accumulate higher levels of HMs than many agricultural crops, vegetables, cultivated edible mushrooms, and fruits (Zhu et al., 2011; Liu et al., 2022). Also, it has been widely established that mushrooms are potential options to safeguard the food security in view of their nutritional values (Thachunglura et al., 2025). Nevertheless, high levels of heavy metals bioaccumulation in their fruiting body can make them unsafe for human consumption, hence endanger the food safety and human health (Árvay et al., 2014; Liu et al., 2015; Pająk et al., 2020). HMs uptake by mushrooms can be species-specific, with significant variations in their capabilities to bioaccumulate and tolerate the oxidative stress (Chen et al., 2009; Kokkoris et al., 2019). Furthermore, the metabolic strategies and the nutritional composition of the substrate/growth media of mushrooms can significantly influence their ability to bioaccumulate HMs bio-indicators due to their metal homeostasis mechanisms by signalling environmental changes, especially under the event of metallic contaminant levels exceeding threshold limits (Ediriweera et al., 2022). A plethora of studies already established that bio/phyto-remediation is a promising solution for addressing environmental pollution caused by heavy metals (Rai, 2011; Yan et al., 2020). However, the plants growing on marginal/degraded lands and macrophytes in wetlands are preferred bio-agent as they do not conflict with land-use assigned for agriculture to help maintain food security and concomitantly do not impose human health risks due to their non-edible nature (Rai et al., 2024). Therefore, present article attempts to initially provide an overview on HMs remediation aspects through fungal biomass and then couple it with our research on their bioaccumulation in wild edible mushrooms which is inextricably linked with human health/well-being. The present study is novel in terms of assessing the health risks, arising due to HMs bioaccumulation in wild edible mushrooms which is inadequately explored in biodiversity hotspot regions. Insufficient knowledge about pollutant degradation by various fungal species hinders the possible use of them in mycoremediation in a more specific manner (Hyde et al., 2019). In addition, the HMs bioaccumulation in edible crops is another facet which needs to be investigated to mitigate human health risks, especially in an Indo Burma hotspot region. It is worth mentioning that a great deal of mushroom biodiversity is of immense relevance to environment, ecosystem services, human dietary requirements, and socioeconomy / livelihood of indigenous local tribes thriving in this region of extreme ecological importance. Wild edible mushrooms of Mizoram (North East India) have recently being explored in this region in view of its intricate association with human nutrition, livelihood, and food security (Thachunglura et al., 2024a). To this end, certain wild edible mushroom species have gained popularity for consumption by human society, including Mizo people across different districts over other varieties (Zothanzama et al., 2018). Unfortunately, the consumption of a wide variety of mushrooms has also been limited due to past poisoning incidents, and people in the urban areas of Mizoram appear to be more mycophobic (Zothanzama et al., 2018). To raise the scientific awareness and remove this fear of mushroom consumption, extensive research has been conducted on the biochemical and nutritional aspects of wild edible mushrooms of Mizoram (Thachunglura et al., 2023; Thachunglura et al., 2024a). Recently, specific species from the group of polypores and brittle gills have also been documented within the state of Mizoram (Chawngthu et al., 2023). Nevertheless, heavy metal contamination in wild edible mushrooms of Mizoram has not been extensively explored (Chawngthu et al., 2024; Thachunglura et al., 2024b). Despite the sufficient documentation of potential risks associated with heavy metal uptake by mushrooms, there has been limited/negligible research in this Indo Burma hotspot, especially in context of Mizoram, North East India. The present study is therefore composed to play a crucial role in addressing this knowledge gap by investigating the uptake of HMs by different species of mushrooms and hence assess the food safety and potential health implications for indigenous people of this biodiversity hotspot region.

Materials and methods

Chemicals

Nitric acid (Hi-LR™, AS008), sulfuric acid (Hi-LR™,

DOI: 10.6092/issn.2281-4485/21806

AS016), and hydrogen peroxide (PCT1511) were purchased from HiMedia Laboratories Pvt. Ltd., Maharashtra, India, and were of analytical grade.

Collection and identification

During the rainy season of 2021-2022, we collected samples of wild edible mushrooms from Aizawl District, Mizoram. These specimens of mushrooms were collected for identification in view of their rich abundance and wide intake by traditional local people. The specimens were carefully cleaned from forest debris, properly labelled and stored them in air-tight containers before transporting them to the laboratory. Three commonly distributed mushroom species were selected from this collection, and their identification involved a combined approach that utilized both macro and micro-morphological characteristics authenticcated by referring to several authors (Karunarathna et al., 2011; Davis et al., 2012; Zothanzama et al., 2018), and later deposited in the National History Museum of Mizoram (NHMM), Mizoram University.

Sample preparation

The mushroom samples were dried in a hot air oven at 45°C for 48 h. Once fully dried, the samples were homogenized and placed in pre-cleaned polyethylene bottles until further analysis. One gram of each sample was put into a porcelain crucible and heated to 450 °C for 18 to 20 h to perform the chemical analysis following Isildak et al. (2004). The resulting ash was dissolved in 1 mL of concentrated nitric acid (HNO_3) and heated once more to 450°C for an additional four hours to enable complete combustion of the sample. Following this, 1 mL of concentrated sulfuric acid (H_2SO_4), 1 mL of HNO_3, and 1 mL of hydrogen peroxide (H_2O_2) were added to the ash and filtered with syringe filter (0.2 μm). To get the final amount of 10 mL, the solution was diluted with deionized water (Milli-Q). Three blank samples were treated the same way, and an Atomic Absorption Spectrometer (AA 7000 Shimadzu; Shimadzu Corporation, Japan) was used to determine the metal content [copper (Cu), zinc (Zn), manganese (Mn), iron (Fe), nickel (Ni), lead (Pb), and cadmium (Cd)] in the samples, with detection limits ranging between 0.01 to 0.09 ppm.

Human health risk assessment

Human health risk assessment indices/indicators such as 'estimated daily intake (EDI)' of the elements was calculated (Fu et al., 2020), which was in fact based on the daily intake of the respective food items, the averaged exposure time, and the average contents of each food sample.

$$EDI = \frac{MC \times IR \times EF \times ED}{ET \times BW} \quad [1]$$

where, MC is the element content in wild edible mushroom (mg/kg in dw), IR = food ingestion rate (6.6×10^{-3} kg/person/day). EF = exposure frequency (365 days/year), ED = exposure duration for an adult (70 years), ET = averaged exposure time (365 days/ year × 70 year or 25550 days/year), and BW - mean body weight of consumers (60 kg).

In this context, another health indicator i.e., 'Target hazard quotient (THQ)' was used to evaluate the potential health risks of human consumption following the equation.

$$THQ = \frac{EDI}{RfD} \quad [2]$$

where, R_fD is the oral reference dose of the HMs in mg/kg/day (USEPA 2012; USEPA 2017).

The 'Hazard Index (HI)' is calculated by adding up the THQ values for each food type assessment element (Fu et al., 2020). The risk for chronic systemic effects is considered acceptable if the resulting HI is less than 1. However, if the HI equals or exceeds 1, it indicates possible long-term consumption risks associated with adverse non-carcinogenic health effects. In such cases, there is the potential for harm due to non-carcinogenic health effects.

$$HI=THQ_{Cu}+THQ_{Zn}+THQ_{Mn}+TH_{Fe}+TH_{Ni}+TH_{Pb}+TH_{Cd} \quad [3]$$

In terms of human health risk assessment, the 'Incremental Lifetime Cancer Risk (ILCR)' is a vital index that assesses the risk of cancer development due to exposure to carcinogens through consumption of mushroom. ILCR was calculated by multiplying the EDI by the corresponding oral cancer slope factor (CSF) (Hu et al., 2017). Metals such as Cu, Zn, Mn, and Fe in traces are rather essential for normal metabolic functioning and are not classified as carcinogens at normal exposure levels. Their toxicity is typically evaluated based on non-cancer endpoints, such as liver damage or neurological effects. As a result, Cd, Pb, and Ni were the metals assessed for ILCR values, as they are known carcinogens with established CSFs. The CSF values for Cd, Pb and Ni were provided by USEPA (2010). An ILCR value bet-

DOI: 10.6092/issn.2281-4485/21806

ween 10^{-4} and 10^{-6}. In terms of human health risk assessment, the 'Incremental Lifetime Cancer Risk (ILCR)' is a vital index that assesses the risk of cancer development due to exposure to carcinogens through consumption of mushroom. ILCR was calculated by multiplying the EDI by the corresponding oral cancer slope factor (CSF) (Hu et al., 2017). Metals such as Cu, Zn, Mn, and Fe in traces are rather essential for normal metabolic functioning and are not classified as carcinogens at normal exposure levels. Their toxicity is typically evaluated based on non-cancer endpoints, such as liver damage or neurological effects. As a result, Cd, Pb, and Ni were the metals assessed for ILCR values, as they are known carcinogens with established CSFs. The CSF values for Cd, Pb and Ni were provided by USEPA (2010). An ILCR value between 10^{-4} and 10^{-6} is generally considered an acceptable risk level. Values exceeding 10^{-4} indicate a potential carcinogenic risk, while an ILCR below 10^{-6} is considered negligible (Li et al., 2013; Hu et al., 2017).

Results and Discussion

The three collected specimen was identified as *Fistulina hepatica* (Schaeff.) With, *Panus roseus* Karun., K.D.Hyde. and Zhu L.Yang N. Vinjusha and T.K.A. Kumar, and *Schizophyllum commune* Fr. The fruiting body (Fig 1) along with their family (order), collection site and other details are given in Table 1. *S. commune*, locally known as 'Pasi' in Mizo, is a favoured edible in the region and can easily be seen in the markets. During our fieldwork, we observed that *P. roseus* (= *Lentinus roseus*) was consumed by few mushrooms foragers due to the resemblance of other *Lentinus* species and the prevailing mushroom myth among the Mizos that mushrooms growing on wood are typically non-poisonous. *Lentinus* species such as *L. polychrous* (Pa chang in Mizo), *L. squarrosulus*, *L. sajor-caju* (Pa khangbun) and *L. tigrinus* (Pa hnahkhar) were also consumed in some parts of Mizoram and is well documented (Zothanzama et al., 2018). However, recognition of these three identified species is simplified by their distinct morphological features.

Heavy metals in wild edible mushrooms

The contents of seven metals (Cu, Zn, Mn, Fe, Ni, Pb and Cd) in all of the edible mushroom samples are shown in Table 2. The metal contents in the fruiting body of mushrooms vary over a wide range which

Table 1. *Sampling information of collected edible fungal species*

Species	Family (Order)	Collection site	Coordinates	Edibility	Accession number (NHMM)
Fistulina hepatica (Schaeff.) With	Fistulinaceae (Agaricales)	Mizoram University Campus	23°27'22"N 92°45'15"E	Edible	NHMM-F/0023
Panus roseus Karun., K.D.Hyde and Zhu L.Yang N. Vinjusha and T.K.A. Kumar	Panaceae (Polyporales)	Lungleng Forest	23°44'22"N 92°39'55"E	Edible	NHMM-F/0033
Schizophyllum commune Fr	Schizophyllaceae (Agaricales)	Hmuifang Forest	23°40'00"N 92°39'41"E	Edible	NHMM-F/0025

Figure 1. (A) *Fistulina hepatica* - (B) *Panus roseus* - (C) *Schizophyllum commune*

DOI: 10.6092/issn.2281-4485/21806

Table 2. *Metal contents in mushrooms (mg/kg dried weight basis)*

Fungal species	Cu	Zn	Mn	Fe	Ni	Pb	Cd
Fistulina hepatica	12.285 ±0.157	31.878 ±0.254	6.109 ±0.007	46.054 ±0.228	0.058 ±0.002	0.182 ±0.002	0.003 ±0.000
Panus roseus	7.085 ±0.029	26.522 ±0.293	3.3445 ±0.004	49.203 ±0.521	0.047 ±0.000	0.034 ±0.003	0.006 ±0.001
Schizophyllum commune	7.511 ±0.014	19.089 ±0.143	4.7695 ±0.042	30.589 ±0.358	0.033 ±0.002	0.054 ±0.010	0.018 ±0.001

Results are presented as mean ± SEM (*n* = 3)

was species, in fact dependent on sample collection site, age of fruiting bodies and mycelium, and distance from source of pollution (García et al., 2009; Falandysz and Borovička, 2013; Ndimele et al., 2017). *F. hepatica* (12.285 mg/kg) was found to contained highest contents of Cu, followed by *S. commune* (7.511 mg/kg) and lowest in *P. roseus* (7.085 mg/kg). This is consistent with the range of 2.1-8 mg/kg reported by Nakalembe et al. (2015) in five edible mushroom species. Kalacˇ and Svoboda (2000) reported that Cu levels less than 300 mg/kg in dry matter is not considered as a health risk. Zinc is a vital micronutrient essential for growth, immune function, and cellular processes, playing a pivotal role in organ system health, growth, and tissue repair through a delicate balance of absorption and elimination in the body (Gu and Lin, 2010; Sangeetha et al., 2022). *F. hepatica* exhibited the highest zinc contents at 31.878 mg/kg, followed by *P. roseus* at 26.522 mg/kg, with the lowest contents found in *S. commune* at 19.089 mg/kg. The zinc contents of previous studies were between 10.4 mg/kg to 93.8 mg/kg (Kakoti et al., 2021) and 56.5 mg/kg to 1132 mg/kg (López et al., 2022). It is also known that the cap contained higher zinc levels than in the stipe (Elekes et al., 2010). Zinc as well as other essential minerals and metals are concentrated in the cap where the reproductive functions, including spore production take place. Mn content exhibited a range, from 0.3445 mg/kg in *P. roseus* to 1.109 mg/kg in *F. hepatica*. Mn levels observed in our study appear significantly lower when compared to the findings of Ouzouni et al. (2009), where Mn contents were reported to be within the range of 7.19 to 62.63 mg/kg. Fe was found to be the dominant elemental ion when compared with other HMs among the studied species. In our study, Fe content ranged from 30.589 mg/kg in *S. commune* in case of 49.203 mg/kg *P. roseus*. Adequate Fe consumption is critical for preventing anaemia as it is essential for haemoglobin production, distributing oxygen in the body, and reducing the risk of fatigue and weakness. In this line, Mallikarjuna et al. (2013) also estimated Fe contents ranging from 62.7 mg/kg to 353 mg/kg in both wild and cultivated mushrooms. On the other hand, Salihović et al. (2021) reported Fe contents varying from 12.72 mg/kg to 213.07 mg/kg. In present assessment, *F. hepatica* (0.058 mg/kg) accumulated the highest contents of Ni, followed by *P. roseus* (0.047 mg/kg) and lowest was recorded in *S. commune* (0.033 mg/kg). In this sense, another assessment by Chen et al. (2009) also observed Ni contents varying between 0.11 mg/kg and 1.35 mg/kg. In contrast, Zhu et al. (2011) reported higher levels, ranging from 0.76 mg/kg to 5.08 mg/kg, which were notably higher compared to the findings in our study. Pb was estimated highest in *F. hepatica* (0.182 mg/kg) followed by *S. commune* (0.054 mg/kg), while lowest content was recorded in case of *P. roseus* (0.034 mg/kg). There is indeed variation in metal contents among the three selected species of wild edible mushrooms. It is important to note that the content of metals can differ significantly from one species to another. In this context, Uzun et al. (2011) found Pb content ranging from <0.010 to 2.3 mg/kg in 45 different mushroom samples. Another study by Kaya et al. (2011), Pb was not detected in 25 wild edible mushroom species, while the remaining 5 species had Pb contents ranging from 0.32 to 3.10 mg/kg in terms of dried weight basis. The contents of Cd was found to be highest in *S. commune* (0.018 mg/kg), followed by *P. roseus* (0.006 mg/kg) and lowest was observed in case of *F. hepatica* (0.003 mg/kg). In this sense, Fu et al. (2020) also noted Cd contents ranging from 0.21 mg/kg to 20.5 mg/kg. On the contrary, our results showed significantly lower levels of Cd. Long-term exposure to Cd, a toxic heavy metal found in various environmental sources, can result in cancer, kidney damage, lung problems, and other human health risks (Chen et al., 2009).

DOI: 10.6092/issn.2281-4485/21806

Health risk assessment

To assess the health risks associated with HMs in the studied mushrooms, we determined the estimated daily intake of these metals (Cu, Zn, Mn, Fe, Ni, Pb and Cd). The estimated daily intake represents the amount of each metal that individuals consume through mushroom consumption. - -

The values for the EDI, target hazard THQ and HI in the mushroom samples were shown in Table 3. The estimated daily intake of *F. hepatica*, *P. roseus* and *S. commune* were within the limits of the maximum tolerable daily intake of Food and Agriculture Organization/World Health Organization (FAO/WHO, 2011).

Table 3. *Estimated daily intake (EDI) of wild edible mushroom, target hazard quotient (THQ) and hazard index (HI)*

	Estimated Daily Intake (EDI)						
Fungal species	Cu	Zn	Mn	Fe	Ni	Pb	Cd
	($\times 10^{-3}$)						
Fistulina hepatica	1.3514	3.5066	0.6720	5.0659	0.0064	0.0200	0.0003
Panus roseus	0.7793	2.9174	0.3679	5.4123	0.0052	0.0037	0.0007
Schizophyllum commune	0.8262	2.0998	0.5246	3.3648	0.0036	0.0059	0.0020
	Target Hazard Quotient (THQ)						
	Cu	Zn	Mn	Fe	Ni	Pb	Cd
Fistulina hepatica	0.0338	0.0117	0.0048	0.0072	0.0003	0.0057	0.0003
Panus roseus	0.0195	0.0097	0.0026	0.0077	0.0003	0.0011	0.0007
Schizophyllum commune	0.0207	0.0070	0.0037	0.0048	0.0002	0.0017	0.0020
	Hazard Index (HI)						
Fistulina hepatica	0.0638						
Panus roseus	0.0416						
Schizophyllum commune	0.0401						

The THQ values for heavy metal in this study were found in the increasing order of Ni (0.0008) < Cd (0.0028) < Pb (0.0085) < Mn (0.0111) < Fe (0.0197) < Zn (0.0284) < Cu (0.0740). In this respect, Cu has calculated with the highest THQ values while Ni has the lowest value. However, all the elements HI values from the three different edible mushrooms were less than 1. Certain species from the same location have safe profiles while others exceed safety limits, which can pose health risks (Sarikurkcu et al., 2020; Liu et al., 2021). This variability depends on both the collection site and the species. THQ value in the present study were also too low as compared to the results of THQ values in wild mushrooms reported by Salihović et al. (2021) from Bosnia and Herzegovina, Sun et al. (2017) from Yunnan Province, China. The HI exhibited its highest value in *F. hepatica* (0.0638) followed by *P. roseus* (0.0416) and lowest in *S. commune* (0.0401). Consequently, the levels of the HMs in the mushroom species from the three different sites are low and do not pose any significant health risk and thus indicating the three sampling sites were not polluted. The ILCR values (Cd, Pb and Ni) of three edible species were presented in Table 4. The ILCR values show that *S. commune* has the highest Cd content (1.22×10^{-6}), followed by *P. roseus* (4.27×10^{-7}) and *F. hepatica* (1.83×10^{-7}). For Pb, *F. hepatica* show the highest levels (1.7×10^{-7}), followed by *S. commune* (5.015×10^{-8}) and *P. roseus* (3.145×10^{-8}). *F. hepatica* has the highest content of Ni (1.088×10^{-5}), followed by *P. roseus* (8.84×10^{-6}) and lowest in *S. commune* (6.12×10^{-6}).

Table 4. *ILCR value of wild edible mushrooms (Cd, Pb and Ni) species*

Fungal Species	Cd	Pb	Ni
Fistulina hepatica	1.83×10^{-7}	1.7×10^{-7}	1.088×10^{-5}
Panus roseus	4.27×10^{-7}	3.145×10^{-8}	8.84×10^{-6}
Schizophyllum commune	1.22×10^{-6}	5.015×10^{-8}	6.12×10^{-6}

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The ILCR analysis indicated that Ni is the primary contributor to cancer risk in the studied mushroom species, with *S. commune* showing the highest risk due to elevated Ni and Cd levels. However, all ILCR values falled within the acceptable range (10^{-6} to 10^{-4}) or below the negligible risk threshold (< 10^{-6}) (Hu et al., 2017), meaning the mushrooms are not excessively dangerous in terms of heavy metal-induced cancer risk. While long-term consumption of mushrooms with higher Ni levels should be cautious, the overall risk remains manageable. Past studies demonstrated that mushrooms growing in heavily polluted areas, such as those in close proximity to highways with heavy traffic, sewage sludge landfills, and emission zones like urban areas, have exhibited a substantial presence of elevated heavy metal levels (Das, 2005; Falandysz and Borovička, 2013). Mizoram, on the other hand, stands out for its small industrial and manufacturing footprint. The samples were collected from isolated, off-the-beaten-path sites, particularly deep within the forested areas. Therefore, the samples were likely to yield lower contents of HMs due to the absence of significant human activity and pollution in these unspoiled areas.

Conclusions

The overall assessment of heavy metal content in the studied mushrooms revealed the following order: Cd (0.003–0.018 mg/kg) < Pb (0.034–0.182 mg/kg) < Ni (0.033–0.058 mg/kg) < Mn (3.3445–6.109 mg/kg) < Cu (7.085–12.285 mg/kg) < Zn (19.089–31.878 mg/kg) < Fe (30.589–49.203 mg/kg). Present findings highlight Fe as the most abundant metal, while Cd was present in the lowest content across all analysed species. The extent of heavy metal accumulation varies based on the collection site, type of species, and other environmental factors. Fortunately, in the selected Indo Burma hotspot site, the mushroom samples were free from significant heavy metal contamination which otherwise can pose threat to human health and can jeopardize food safety. Wild edible mushrooms are a valuable natural resource, rich in proteins, vitamins, and minerals, making them an important source of nutrition and a potential source of medicinal compounds. They have a historical record of being used in various countries for medicinal and culinary purposes. However, it is important to note that wild edible mushrooms can also absorb heavy metals from their surroundings. In the perspective of health risk, this study suggests that the wild edible mushrooms collected from Mizoram, India are safe for consumption and do not pose a threat to human health. Nevertheless, to comprehensively assess the accumulation of heavy metals in wild edible mushrooms and their potential health implications, continuous long-term monitoring and risk assessment is warranted. Such studies should encompass various collection sites, including those in more polluted areas, degraded or marginal landscapes, and urban forests exposed to increased anthropogenic perturbations.

Acknowledgment

The authors wish to express their gratitude to the Department of Chemistry, Mizoram University for granting us permission to utilize their Atomic Absorption Spectrophotometer (AAS). Moreover, the authors extend their gratitude to the Department of Environmental Science and the Department of Biotechnology, Mizoram University for their valuable assistance and support.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

ÁRVAY J., TOMÁŠ J., HAUPTVOGL M., KOPERNICKÁ M., KOVÁČIK A., BAJČAN D., MASSÁNYI P. (2014) Contamination of wild-grown edible mushrooms by heavy metals in a former mercury-mining area. Journal of Environmental Science and Health, Part B 49 (11): 815–827. https://doi.org/10.1080/03601234.2014.938550

CHAWNGTHU Z., THACHUNGLURA V.L., ZOTHANZAMA J., KHUMLIANLAL J. (2024) Risk assessment of heavy metals in wild mushroom from Mizoram, India. Environmental Pollution and Management, 1: 147–151. https://doi.org/10.1016/j.epm.2024.09.001

CHAWNGTHU Z., TLUANGA L., ZOTHANZAMA J., THACHUNGLURA V.L., LALBIAKMAWIA B., RENTHLEI L. (2023) Wood rotting polyporales from the biodiversity reserves within the Indian subtropical habitat. Indian Journal of Microbiology Research, 10(3): 140–148. https://doi.org/10.18231/j.ijmr.2023.025

CHEN X.H., ZHOU H.B., QIU G.Z. (2009) Analysis of several heavy metals in wild edible mushrooms from regions of China. Bulletin of Environmental Contamination and Toxicology, 83(2): 280–285. https://doi.org/10.1007/s00128-009-9767-8

DAS, N. (2005) Heavy metal biosorption by mushrooms. Natural Product Radiance, 4, 454-459.

DOI: 10.6092/issn.2281-4485/21806

DAVIS, R.M., SOMMER, R., MENGE, J.A. (2012) Field guide to mushrooms of Western North America. Berkeley: University of California Press, 335–336.

EDIRIWEERA A.N., KARUNARATHNA S.C., YAPA P.N., SCHAEFER D.A., RANASINGHE A.K., SUWANNARACH N., XU J. (2022) Ectomycorrhizal mushrooms as a natural bio-indicator for assessment of heavy metal pollution. Agronomy, 12(5): 1041. http://dx.doi.org/10.3390/agronomy12051041.

ELEKES C.C., BUSUIOC G., IONITA G. (2010) The bioaccumulation of some heavy metals in the fruiting body of wild growing mushrooms. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 38: 147–151. https://doi.org/10.15835/nbha3824736.

FALANDYSZ J., BOROVIČKA J. (2013) Macro and trace mineral constituents and radionuclides in mushrooms: health benefits and risks. Applied Microbiology and Biotechnology, 97(2): 477–501. https://doi.org/10.1007/s00253-012-4552-8.

FAO/WHO. (2011) Food standards programme Codex Committee on Contaminants in Foods, 5th Session. The Hague, 468–469. http://www.fao.org/input/download/report/ 758/REP11_CFe.pdf.

FU Z., LIU G., WANG L. (2020) Assessment of potential human health risk of trace elements in wild edible mushroom species collected from Yunnan Province, China. Environmental Science and Pollution Research, 27(23): 29218–29227. https://doi.org/10.1007/s11356-020-09242-w.

GARCÍA M.Á., ALONSO J., MELGAR M.J. (2009) Lead in edible mushrooms: levels and bioaccumulation factors. Journal of Hazardous Materials, 167(1–3): 777–783. https://doi.org/10.1016/j.jhazmat.2009.01.058

GU Q., LIN R.L. (2010) Heavy metals zinc, cadmium, and copper stimulate pulmonary sensory neurons via direct activation of TRPA1. Journal of Applied Physiology, 108(4): 891–897. https://doi.org/10.1152/japplphysiol.01371.2009

GUERRIERI N., MAZZINI S., BORGONOVO G. (2024) Food plants and environmental contamination: an update. Toxics, 12(5): 365. https://doi.org/10.3390/toxics12050365.

HU B., JIA X., HU J., XU D., XIA F., LI Y. (2017) Assessment of heavy metal pollution and health risks in the soil-plant-human system in the Yangtze River Delta, China. International Journal of Environmental Research and Public Health, 14(9): 1042. https://doi.org/10.3390/ijerph14091042.

HYDE K.D., XU J., RAPIOR S., JEEWON R., LUMYONG S., NIEGO A.G.T., ABEYWICKRAMA P.D., ALUTHMUHANDIRAM J.V.S., BRAHAMANAGE R.S., BROOKS S., CHAIYASEN A., CHETHANA K.W.T., CHOMNUNTI P., CHEPKIRUI C., CHUANKID B., DE SILVA N.I., DOILOM M., FAULDS C., GENTEKAKI E., STADLER M. (2019) The amazing potential of fungi: 50 ways we can exploit fungi industrially. Fungal Diversity, 97(1): 1–136. https://doi.org/10.1007/s13225-019-00430-9.

ISILDAK O., TURKEKUL I., ELMASTAS M., ABOUL-ENEIN H.Y. (2007) Bioaccumulation of heavy metals in some wild-grown edible mushrooms. Analytical Letters, 40(6): 1099–1116. https://doi.org/10.1080/00032710701297042.

ISILDAK Ö., TURKEKUL I., ELMASTAS M., TUZEN M. (2004) Analysis of heavy metals in some wild-grown edible mushrooms from the Middle Black Sea Region, Turkey. Food Chemistry, 86(4): 547–552. https://doi.org/10.1016/j.foodchem.2003.09.007.

JAISHANKAR M., TSETEN T., ANBALAGAN N., MATHEW B.B., BEEREGOWDA K.N. (2014) Toxicity, mechanism and health effects of some heavy metals. Interdisciplinary Toxicology, 7(2): 60–72. https://doi.org/10.2478/intox-2014-0009.

KAKOTI M., HAZARIKA D., PARVEEN A., DULLAH, S., GHOSH A., SAHA D., BAROOAH M., BORO R. (2021) Nutritional properties, antioxidant and antihaemolytic activities of the dry fruiting bodies of wild edible mushrooms consumed by ethnic communities of Northeast India. Polish Journal of Food and Nutrition Sciences, 71(4): 463–480. https://doi.org/10.31883/pjfns/144044.

KALAC P., SVOBODA,L. (2000) A review of trace element concentrations in edible mushrooms. Food Chemistry, 69: 273–281. https://doi.org/10.1016/S0308-8146(99)00264-2.

KARUNARATHNA S.C., YANG Z.L., ZHAO R.L., VELLINGA E.C., BAHKALI A.H., CHUKEATIROTE E., HYDE K.D. (2011) Three new species of Lentinus from Northern Thailand. Mycological Progress, 10(4): 389–398. https://doi.org/10.1007/s11557-010-0701-6.

KAYA A., GENÇCELEP H., YUSUF UZUN Y., DEMIREL, K. (2011) Analysis of trace metal levels in wild mushrooms. Asian Journal of Chemistry, 23(3): 1099–1103.

KOKKORIS V., MASSAS I., POLEMIS E., KOUTROTSIOS G., ZERVAKIS G.I. (2019) Accumulation of heavy metals by wild edible mushrooms with respect to soil substrates in the Athens metropolitan area (Greece). Science of The Total Environment, 685: 280–296. https://doi.org/10.1016/j.scitotenv.2019.05.447.

LI P.H., KONG S.F., GENG C.M., HAN B., LU B., SUN R.F., ZHAO R.J., BAI Z.P. (2013) Assessing the hazardous risks of vehicle inspection workers' exposure to particulate heavy metals in their workplaces. Aerosol and Air Quality Research, 13(1): 255–265. https://doi.org/10.4209/aaqr.2012.04.0087.

DOI: 10.6092/issn.2281-4485/21806

LIU B., HUANG Q., CAI H., GUO X., WANG T., GUI M. (2015) Study of heavy metal concentrations in wild edible mushrooms in Yunnan Province, China. Food Chemistry, 188: 294–300. https://doi.org/10.1016/j.foodchem.2015.05.010.

LIU S., FU Y., SHI M., WANG H., GUO J. (2021) Pollution level and risk assessment of lead, cadmium, mercury, and arsenic in edible mushrooms from Jilin Province, China. Journal of Food Science, 86(8): 3374–3383. https://doi.org/10.1111/1750-3841.15849.

LIU S., LIU H., LI J., WANG Y. (2022) Research progress on elements of wild edible mushrooms. Journal of Fungi, 8(9): 964. https://doi.org/10.3390/jof8090964.

LÓPEZ A.R., BAREA-SEPÚLVEDA M., BARBERO G. F., FERREIRO-GONZÁLEZ M., LÓPEZ-CASTILLO J.G., PALMA M., ESPADA-BELLIDO E. (2022) Essential mineral content (Fe, Mg, P, Mn, K, Ca, and Na) in five wild edible species of Lactarius mushrooms from Southern Spain and Northern Morocco: Reference to daily intake. Journal of Fungi, 8(12): 1292. https://doi.org/10.3390/jof8121292.

LUO D., XIE Y.F., TAN Z.L., LI X.D. (2013) Removal of Cu^{2+} ions from aqueous solution by the abandoned mushroom compost of *Flammulina velutipes*. Journal of Environmental Biology, 34 (2): 359–365.

MALLIKARJUNA S.E., RANJINI A., HAWARE D.J., VIJAYALAKSHMI M.R., SHASHIREKHA M.N., RAJARATHNAM S. (2013) Mineral composition of four edible mushrooms. Journal of Chemistry, 1–5. https://doi.org/10.1155/2013/805284.

MANZI, P., GAMBELLI, L., MARCONI, S., VIVANTI, V., PIZZOFERRATO, L. (1999) Nutrients in edible mushrooms: An inter-species comparative study. Food Chemistry, 65(4): 477–482. https://doi.org/10.1016/s0308-8146(98)00212-x.

NAKALEMBE I., KABASA J. D., OLILA D. (2015) Comparative nutrient composition of selected wild edible mushrooms from two agro-ecological zones, Uganda. SpringerPlus, 4: 433. https://doi.org/10.1186/s40064-015-1188-z.

NDIMELE C.C., NDIMELE P.E., CHUKWUKA K.S. (2017) Accumulation of heavy metals by wild mushrooms in Ibadan, Nigeria. Journal of Health and Pollution, 7(16): 26–30. https://doi.org/10.5696/2156-9614-7.16.26.

OUZOUNI P.K., PETRIDIS D., KOLLER W.D., RIGANAKOS K.A. (2009) Nutritional value and metal content of wild edible mushrooms collected from West Macedonia and Epirus, Greece. Food Chemistry, 115(4): 1575–1580. https://doi.org/10.1016/j.foodchem.2009.02.014.

PAJĄK M., GĄSIOREK M., JASIK M., HALECKI W., OTREMBA K., PIETRZYKOWSKI M. (2020) Risk assessment of potential food chain threats from edible wild mushrooms collected in forest ecosystems with heavy metal pollution in Upper Silesia, Poland. Forests, 11(12): 1240. https://doi.org/10.3390/f11121240.

RAI P.K. (2009) Heavy metal phytoremediation from aquatic ecosystems with special reference to macrophytes. Critical Reviews in Environmental Science and Technology, 39(9): 697–753. https://doi.org/10.1080/10643380801910058.

RAI P.K. (2011) An eco-sustainable green approach for heavy metals management: Two case studies of developing industrial region. Environmental Monitoring and Assessment, 184(1): 421–448. https://doi.org/10.1007/s10661-011-1978-x.

RAI P.K. (2022) Novel adsorbents in remediation of hazardous environmental pollutants: Progress, selectivity, and sustainability prospects. Cleaner Materials, 3: 100054. https://doi.org/10.1016/j.clema.2022.100054.

RAI P.K., LEE S.S., ZHANG M., TSANG Y.F., KIM K.H. (2019) Heavy metals in food crops: Health risks, fate, mechanisms, and management. Environment International, 125: 365–385. https://doi.org/10.1016/j.envint.2019.01.067.

RAI P.K., NONGTRI E.S., LALAWMPUII SYNGKLI R.B. (2024) *Pistia stratiotes* based heavy metals phytoremediation of a Himalayan river impacted by hydroelectric plant in an Indo-Burma hotspot region. Chemistry and Ecology, 40(7): 796–815. https://doi.org/10.1080/02757540.2024.2350050.

RAI P.K., SONNE C., KIM K.H. (2023) Heavy metals and arsenic stress in food crops: Elucidating antioxidative defense mechanisms in hyperaccumulators for food security, agricultural sustainability, and human health. Science of The Total Environment, 874: 162327. https://doi.org/10.1016/j.scitotenv.2023.162327.

SALIHOVIĆ M., PAZALJA M., ŠAPČANIN A., DOJČINOVIĆ B.P., ŠPIRTOVIĆ-HALILOVIĆ S. (2021) Element contents and health risk assessment in wild edible mushrooms of Bosnia and Herzegovina. Plant, Soil and Environment, 67(11): 668–677. https://doi.org/10.17221/423/2021-pse.

SANGEETHA V.J., DUTTA S., MOSES J.A., ANANDHARAMAKRISHNAN, C. (2022) Zinc nutrition and human health: Overview and implications. EFood, 3(5). https://doi.org/10.1002/efd2.17.

SARIKURKCU C., POPOVIĆ-DJORDJEVIĆ J., SOLAK M.H. (2020) Wild edible mushrooms from Mediterranean region: Metal concentrations and health risk assessment. Ecotoxicology and Environmental Safety, 190: 110058. https://doi.org/10.1016/j.ecoenv.2019.110058.

SHETTY, B.R., PAI, B.J., SALMATAJ, S.A., NAIK, N. (2024) Assessment of carcinogenic and non-carcinogenic

DOI: 10.6092/issn.2281-4485/21806

risk indices of heavy metal exposure in different age groups using Monte Carlo simulation approach. Scientific Reports, 14(1). https://doi.org/10.1038/s41598-024-81109-3

SUN L., CHANG W., BAO C., ZHUANG Y. (2017) Metal contents, bioaccumulation, and health risk assessment in wild edible Boletaceae mushrooms. Journal of Food Science, 82(6): 1500–1508. https://doi.org/10.1111/1750-3841.13698.

THACHUNGLURA V.L., CHAWNGTHU Z., RAI P.K., ZOTHANZAMA J. (2024b) Evaluation of nutritional value, heavy metals content, and health risk assessment of wild edible mushrooms in Mamit District, Mizoram, North East India. International Journal of Plant and Environment, 10(3): 79–85. https://doi.org/10.18811/ijpen.v10i03.08.

THACHUNGLURA V.L., RAI P.K., KHUMLIANLAL J., ZOTHANZAMA J. (2024a) A checklist of wild mushrooms in Mizoram, Northeast India. Plant Pathology and Quarantine, 14(1): 125–142. https://doi.org/10.5943/ppq/14/1/11.

THACHUNGLURA V.L., RAI P.K., ZOHMANGAIHA LALBIAKMAWIA B, LALMUANSANGI ZOTHANZAMA J. (2023) *Pleurotus giganteus* as a valuable source of nutrients. Indian Journal of Science and Technology, 16 (sp1): 89–94. https://doi.org/10.17485/ijst/v16sp1.msc12.

THACHUNGLURA V.L., ZOTHANZAMA J., CHAWNGTHU Z., BOCHUNG L., VANLALMALSAWMI R., RAI P.K. (2025) Molecular identification and proximate composition of wild edible wood growing mushrooms of Mizoram, North East India for food safety and livelihood. Journal of Applied and Natural Science, 17(1): 265–276. https://doi.org/10.31018/jans.v17i1.6338.

USEPA (2012) Integrated Risk Information System of the US Environmental Protection Agency. Washington, https://www.epa.gov/iris.

USEPA (2017) United States Environmental Protection Agency: IRIS Assessments. https://www.epa.gov/iris.

UZUN Y., GENÇCELEP H., KAYA A., AKCAY M.E. (2011) The mineral contents of some wild edible mushrooms. Ekoloji, 20(80): 6–12. https://doi.org/10.5053/ekoloji.2011.802.

YAN A., WANG Y., TAN S.N., MOHD YUSOF M.L., GHOSH S., CHEN Z. (2020) Phytoremediation: A promising approach for revegetation of heavy metal-polluted land. Frontiers in Plant Science, 11. https://doi.org/10.3389/fpls.2020.00359.

ZHU F., QU L., FAN W., QIAO M., HAO H., WANG X. (2011) Assessment of heavy metals in some wild edible mushrooms collected from Yunnan Province, China. Environmental Monitoring and Assessment, 179(1–4): 191–199. https://doi.org/10.1007/s10661-010-1728-5.

ZOTHANZAMA J., BLANCHETTE A.R., LALRINAWMI H. (2018) Identification of the edible and poisonous mushrooms of Mizoram. Project Report – New Land Use Policy. Memo No. B.15012/1/2016. Government of Mizoram, 1–24.