

Bioaccumulation Patterns and Nutritional Profiles of Wild Morels (*Morchella* spp.) in Southwest Anatolia: Implications for Food Safety and Commercial Harvesting

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Abstract—Wild edible mushrooms, such as species of *Morchella* (morels), are globally prized for their culinary and nutritional value but pose potential health risks due to their ability to accumulate toxic trace elements. This study provides a systematic assessment of heavy metal (Cd, Pb, Co, Ni), trace element (Cu, Fe, Mn, Zn), major nutrient (Ca, K, Mg, Na), and protein contents in five commercially harvested *Morchella* taxa (*M. angusticeps*, *M. esculenta*, *M. deliciosa*, *M. elata*, and *M. rotunda*) from Southwest Anatolia, Turkey—a key region for global morel exports. Using flame atomic absorption spectroscopy and nitrogen analysis, significant interspecific variations were identified: *M. angusticeps* exhibited concerningly high cadmium (12.78 ± 4.16 mg/kg) and lead (3.66 ± 0.48 mg/kg), exceeding EU safety thresholds for cultivated mushrooms, while *M. rotunda* emerged as a nutritionally rich, low-risk species with elevated protein (34.27%) and iron (386 ± 66 mg/kg). Cobalt and lead were undetectable in *M. elata*, suggesting species-specific exclusion mechanisms. These findings underscore the dual role of morels as nutrient-dense foods and potential vectors of toxic metals, emphasizing the need for species- and region-specific guidelines to safeguard consumers and inform sustainable harvesting practices in Anatolia's burgeoning mushroom trade.

Keywords: Wild edible mushroom, *Morchella*, trace element, heavy metal, protein

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INTRODUCTION

Wild edible mushrooms occupy a unique niche at the intersection of gastronomy, nutrition, and environmental science. Turkey's exceptional fungal biodiversity, particularly in Mediterranean and Aegean regions, is well-documented through extensive surveys of macrofungi in Kütahya, Datça Peninsula, and Muğla (Allı et al., 2017; Tirpan et al., 2018; Demirel et al., 2019; Şen et al., 2017). These ecosystems support not only commercially harvested *Morchella* taxa but also other novel species (Demirel et al., 2019), reflecting the region's underexplored mycological richness.

Revered globally for their umami flavor and culinary versatility, species such as *Morchella* (morels) are increasingly recognized as nutrient-dense foods rich in protein, essential minerals, and bioactive compounds with antioxidative and antitumoral properties (Malinowska et al., 2004; Racz et al., 1996). However, their ecological role as bioaccumulators introduces a critical paradox: while valued as health-promoting resources, mushrooms can concentrate toxic trace elements like cadmium (Cd) and lead (Pb), particularly in environments impacted by urbanization, agriculture, or industrial activity (Demirbaş, 2000).

True morels (*Morchella* spp.) are members of the family Morchellaceae, within the class Pezizomycetes, and belong to the phylum Ascomycota and are among the most highly valued edible mushrooms worldwide (Hibbett et al., 2007). The identification of these taxa is often complicated due to insufficient microscopic diagnostic features and the considerable variation in ascocarp color and morphology during development (Sa et al., 2022). In Turkey, nearly 40 *Morchella* species have been identified based on morphological characteristics (Richard et al., 2015; Taylor et al., 2000). Previous studies have examined true morel (*Morchella* spp.) specimens collected and isolated from various regions of Turkey, focusing on their molecular identification and macro-morphological characteristics. These investigations have contributed significantly to the understanding of species diversity and regional distribution patterns within the country (İşiloğlu et al., 2010; Soylu, 2024). Wild morels are primarily collected and exported from countries such as China, India, Pakistan, Turkey, and North America. In Turkey, the annual export value of fresh wild mushrooms is approximately USD 6.2 million, with true morels accounting for about 34.4% of this total. The average market price for dried morels in Turkey

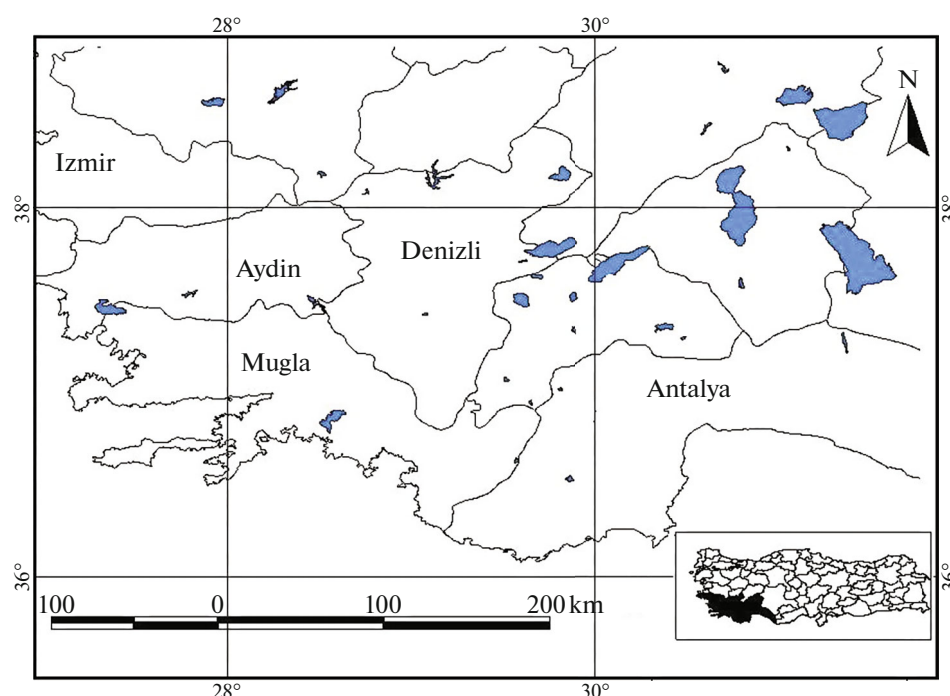


Fig. 1. Map of Southwest Anatolia (Turkey) showing the collection sites for the *Morchella* samples.

ranges between USD 115 and 190 per kilogram (Alli et al., 2017).

Within this context, morels (*Morchella* spp.) stand out as a globally coveted genus, driving a lucrative trade network centered in Anatolia, Turkey. The country's diverse ecosystems—particularly the Mediterranean and Aegean regions—foster prolific *Morchella* growth, with species such as *M. angusticeps* and *M. rotunda* harvested intensively for export to European and North American markets (Gursoy et al., 2009). Southwest Anatolia, a hub for morel commercialization, combines mild climates, post-fire forest succession, and calcareous soils to support robust fungal diversity (Royse et al., 1990).

Despite this economic and ecological significance, no comprehensive studies have evaluated the elemental composition of Anatolian morels, leaving critical gaps in understanding their safety for consumption and export compliance.

This study addresses these gaps by analyzing trace elements, major nutrients, and protein content in five commercially harvested *Morchella* taxa from Southwest Anatolia. By correlating interspecific variation in bioaccumulation patterns with EU regulatory thresholds, we aimed to identify species posing contamination risks, highlight nutrient-rich taxa with low toxic metal burdens, and provide data to inform food safety protocols and sustainable harvesting practices in Turkey's burgeoning mushroom industry.

MATERIALS AND METHODS

Materials. Mushroom samples were collected from the routine field studies villages and provinces in Southwest Anatolia between 2020 and 2024 (Fig. 1).

For the morphological and ecological characteristics of the macrofungi, they were recorded and photographed in their natural habitats and then they brought to the laboratory. Their spore prints were taken and spores were photographed. Dried specimens were numbered and placed in locked bags. In addition, they were put into a deep freeze for a week against internal and external parasite. The specimens were identified with the help of macroscopic and microscopic features. Also previous literatures by Clowez and Moreau (2021), have been utilized. All specimens collected have been kept into the fungarium of the Muğla Sıtkı Koçman University.

Sample collection and taxonomic identification. Five *Morchella* taxa (*M. angusticeps*, *M. esculenta*, *M. deliciosa*, *M. elata*, and *M. rotunda*) were collected during field surveys (2022–2024) across Southwest Anatolia. Specimens were documented in situ through morphological descriptions and digital photography. Spore prints and microscopic features were used for taxonomic identification (Clowez and Moreau, 2021). Voucher specimens were deposited in the Muğla Sıtkı Koçman University Fungarium (MUG-MYCO).

Chemical analysis. Protein Quantification: Total protein was determined via the Dumas combustion method (LECO FP-528 analyzer), calculated as $\%N \times 6.38$.

Table 1. Trace metal concentrations of *Morchella* taxa

Taxa	SN	Value	Elements (mg/kg dry matter)							
			Cd	Co	Cu	Fe	Mn	Ni	Pb	Zn
<i>M. angusticeps</i>	6	M ± SD	12.78 ± 4.16	1.17 ± 0.48	38.5 ± 8.7	24.63 ± 4.16	25.66 ± 6.92	3.04 ± 0.48	3.66 ± 0.48	120 ± 9.08
		Min–Max	7.56–18.98	0.63–2.04	25.3–47.2	19.8–30.86	17.65–33.76	2.46–3.92	2.88–4.24	109–134
<i>M. esculenta</i>	6	M ± SD	1.08 ± 0.26	1.96 ± 0.44	16.4 ± 2.6	31.37 ± 4.36	17.77 ± 1.48	16.02 ± 4.24	0.12 ± 0.02	136 ± 18
		Min–Max	0.85–1.52	1.45–2.63	12.43–22.12	25.98–37.23	15.94–20.28	9.68–23.9	0.1–0.15	106–156
<i>M. deliciosa</i>	4	M ± SD	0.72 ± 0.33	0.24 ± 0.08	10.79 ± 3.44	320 ± 52	19.58 ± 4.2	3.86 ± 0.61	0.22 ± 0.09	53.08 ± 9.37
		Min–Max	0.45–1.21	0.16–0.34	8.2–15.8	260–380	15.86–24.34	3.14–4.56	0.18–0.34	43.9–64.8
<i>M. elata</i>	9	M ± SD	3.52 ± 0.58	ND	25.12 ± 5.02	32.48 ± 4.65	10.02 ± 1.19	21.2 ± 2.82	ND	113 ± 9
		Min–Max	2.8–4.65		20.2–33.4	27.56–40.12	8.49–12.24	18.5–26.3		105–128
<i>M. rotunda</i>	3	M ± SD	0.89 ± 0.41	0.27 ± 0.06	13 ± 3.15	386 ± 66	19.58 ± 3.1	4.82 ± 0.4	0.26 ± 0.04	66.8 ± 6.2
		Min–Max	0.54–1.34	0.22–0.34	10.2–16.4	324–456	21.2–27.3	4.44–5.24	0.22–0.3	61.2–73.4

ND: Not determined.

Elemental Analysis: Dried samples were microwave-digested in HNO₃ : HCl (4 : 1 v/v) and analyzed via flame atomic absorption spectroscopy (FAAS; Pye Unicam 929) and flame photometry (Jenway PFP7). Quality assurance included NIST-certified reference materials (1547 Peach Leaves) and spike recovery tests (92–107%).

Statistical analysis. Analysis of variance (ANOVA) for one-way randomized factor design was used to test whether or not mushroom species influenced element concentrations of tested fungi. The statistical software package, Minitab, was used.

RESULTS

Trace and Major Element Composition. Morels are recognized as nutrient-dense fungi, rich in proteins, dietary fiber, amino acids, essential vitamins, minerals, and polyunsaturated fatty acids. With growing interest in plant-based diets and reduced meat consumption, morels are gaining attention as a sustainable alternative protein source. Moreover, with their significant medicinal properties, they are widely appreciated as a dual-purpose fungus, valued for both culinary and therapeutic applications (Lang, 2020; Tziva et al., 2020; Bi et al., 2024). Minerals play vital roles in the human body, forming essential structural components such as bones and teeth. They also function as cofactors for various enzymes, help regulate cell membrane permeability, and contribute to maintaining the body's acid-base balance. Morels are frequently utilized as a nutritional supplement in dietary therapies (Bi et al., 2024). Wild mushrooms are widely recognized for their considerable mineral content. In a comparative study, (Altaf et al., 2020), reported that *Morchella conica* exhibited the highest concentration of magnesium (55.5 ppm) and a significantly elevated level of iron (531 ppm) among four wild mushroom species, including *Apioperdon pyriforme*, *Helvella elastica*, and *Rhizopogon luteolus*. *Morchella conica* exhibited the highest average protein content, reaching

24.5 g per 100 g (Altaf et al., 2020). Under optimized cultivation substrate formulations, the protein content can be further enhanced to 28.1/100 g, while the dietary fiber content may reach up to 16.2/100 g (He et al., 2018). In another study remarkably, the crude protein content of fermented mycelia of *M. esculenta* was as high as 39.4%, which is much higher than the average protein level of its fruiting body (Li et al., 2022). A possible explanation is that during fermentation, complex carbohydrates can be broken down into simpler sugars, which can then be used by the mycelia to produce more protein. Three major soluble monosaccharides were detected in morels, with glucose (42.3 µg/g) being the highest, next to fructose and galactose (Wang et al., 2019; Rossbach, et al., 2019).

Comparative data indicate considerable variability in the elemental composition of morel fruiting bodies from different countries. Notably, morels collected in Germany also exhibit significant variation, particularly in aluminum (Al) and arsenic (As) levels, with reported differences of up to 87.4 and 145%, respectively (Rossbach et al., 2019). Phosphorus is the primary nutrient that fungi supply to tree roots through mycorrhizal associations. Polyphosphate, a phosphorus storage form in fungi, has the ability to adsorb various metal cations, including K, Ca, Mn, Mg, Zn, Fe, Cu, Cd, and Al. While most of these elements serve as essential nutrients for trees, cadmium (Cd) and especially aluminum (Al) are toxic. Fungi are believed to mitigate the transfer of these toxic elements to tree roots by forming stable complexes within the mycelia, such as Al-hydroxy phosphate complexes (İşildak et al., 2004).

Cadmium and Lead: *M. angusticeps* exceeded EU limits (Cd: 2.0 mg/kg; Pb: 3.0 mg/kg) with 12.78 ± 4.16 mg/kg Cd and 3.66 ± 0.48 mg/kg Pb. *M. elata* excluded Pb entirely (Table 1).

Iron and Protein: *M. rotunda* exhibited the highest Fe (386 ± 66 mg/kg) and protein (34.27 ± 3.99%), surpassing cultivated species like shiitake (Table 2).

Table 2. The concentrations of the major elements (g/kg dry matter) and protein concentrations (%) of *Morchella* taxa shown in

Elements (g/kg dry matter) and protein (%)							
Taxa	SN	Value	Ca	K	Mg	Na	Protein
<i>M. angusticeps</i>	6	M ± SD	1.82 ± 1.25	155 ± 10	2.09 ± 0.2	0.96 ± 0.06	27.11 ± 1.9
		Min–Max	1.83–2.34	140–164	1.92–2.46	0.89–1.04	24.75–29.6
<i>M. esculenta</i>	6	M ± SD	0.25 ± 0.05	125 ± 13	1.11 ± 0.13	0.55 ± 0.03	25.87 ± 4.72
		Min–Max	0.21–0.32	120–145	0.92–1.29	0.5–0.6	18.62–30.31
<i>M. deliciosa</i>	4	M ± SD	0.35 ± 0.05	60.76 ± 5.46	0.52 ± 0.09	0.28 ± 0.06	24.36 ± 1.01
		Min–Max	0.31–0.42	56.3–68.7	0.44–0.62	0.23–0.35	23.44–25.75
<i>M. elata</i>	9	M ± SD	1.19 ± 0.2	134 ± 16	1.56 ± 0.23	0.5 ± 0.03	28.33 ± 2.6
		Min–Max	0.92–1.42	125–143	1.34–1.88	0.46–0.56	26.14–32.66
<i>M. rotunda</i>	3	M ± SD	0.44 ± 0.04	75.5 ± 6.2	0.65 ± 0.06	0.35 ± 0.04	34.27 ± 3.99
		Min–Max	0.4–0.49	68.9–81.2	0.6–0.72	0.31–0.39	31.12–38.76

Regional Variability: Mn levels in *M. elata* (10.02 ± 1.19 mg/kg) diverged sharply from Central European populations (81.3 ± 7.5 mg/kg) (Commission Regulation (EC) 2001).

Contents of Cd, Co, Cu, Fe, Mn, Ni, Pb and Zn as trace elements in *Morchella* taxa are given Table 1. The contents of elements in these samples were found to be in the ranges; 0.45–18.98 for Cd, 0.16–2.63 for Co, 8.2–47.2 for Cu, 19.8–456 for Fe, 8.49–33.76 for Mn, 2.46–26.3 for Ni, 0.1–4.24 for Pb and 43.9–156 for Zn mg/kg dry matter (DM).

To the best of our knowledge based on the available literature, several studies have reported concentrations of element in *Morchella* sp. The maximum level for certain contaminants in food-stuffs established by Commission of the European Communities (Commission Regulation (EC) 2001) is set at about 0.2 and 0.3 mg/kg wet weight for Cd and Pb, respectively, in cultivated fungi. Assuming that the dry matter content of mushrooms is 10% (Kalač and Svoboda, 2001), these same limits for dry material will be ten times higher and approach 2.0 and 3.0 mg/kg dry weight for Cd and Pb, respectively.

The Cd concentration of most samples was comparatively low (mean 1.56 mg/kg). Concentration well above the mean was only seen in *M. angusticeps* (12.7 mg/kg). Cd average contents of samples of *Morchella* taxa in the Black Sea region have been reported as 1.1 µg/kg for *M. esculenta*, 1.4 mg/kg for *M. elata*, 0.3 mg/kg for *M. vulgaris* (Tuzen, 2003) and 1.08 mg/kg for *M. esculenta* (Sabir et al., 2003). There is on significant difference in the results of cadmium between this study and the given above except *M. angusticeps*.

The Pb of lead concentration in *Morchella* taxa is low (0.20 mg/kg) with some samples below detection limit (0.1 mg/kg) especially in *M. elata*. In the studies done by Işıldak et al. (2004) and Tuzen (2003);

1.43 mg/kg for *M. esculenta*, 3.5 mg/kg for *M. esculenta* and *M. elata*, 2.1 mg/kg for *M. vulgaris* (Kalač and Svoboda, 2001) have been found. When compared the results to the *Morchella* species in literature, mean concentrations of this study have been found to be lower. Only *M. angusticeps* has high amount of lead as an average of 3.66 mg/kg.

The mean value for Mn concentrations was 19.53 mg/kg and did not differ markedly between studied species. *M. deliciosa* (19.58 ± 4.2 mg/kg) and *M. rotunda* (19.58 ± 3.1) for Mn are the same. The mean concentration of Mn (10.05 mg/kg) in *M. elata* in this study was lower than the literature data (81.3 ± 7.5 mg/kg) (Tuzen, 2003).

The mean concentrations of Fe in different species range from 25 to 386 mg/kg. Relatively high levels of Fe were recorded for two species belonging to *M. deliciosa* 320 ± 52 mg/kg and *M. rotunda* 386 ± 66 mg/kg. The lowest Fe content was reported as 24.63 ± 4.16 mg/kg in *M. angusticeps*.

The mean level of Cu concentrations was 20.4 mg/kg for all samples. The highest mean content of Cu was 38.5 mg/kg for the species *M. angusticeps*, whereas the lowest Cu content was 10.79 mg/kg for the species *M. deliciosa*.

The mean amount of Co in these species was between 0.24 and 1.85 mg/kg. In *M. elata*, the level of cobalt was lower than the detection limit. Cobalt level in *M. esculenta* and *M. angusticeps* was slightly more than the others.

The mean of Ni contents of studied species were ranged from 3.06 to 21.73 mg/kg. The mean values of Ni were very similar to *M. angusticeps* (3.04 mg/kg) and *M. deliciosa*. The highest mean Ni level was seen in *M. elata*. The data of Ni reported by Işıldak et al. (2004), 2.5 mg/kg for *M. esculenta*, 7.9 mg/kg for *M. elata*, 2.8 mg/kg for *M. vulgaris* did not differ too much.

The mean levels of Zn for *M. esculenta*, *M. angusticeps* and *M. elata* were higher than the others two. The lowest mean level of Zn was seen as 43.9 mg/kg in *M. deliciosa* and the highest as 156 mg/kg in *M. esculenta*.

Contents of Ca, K, Mg, Na as major elements and protein in *Morchella* taxa are shown in Table 2. The contents of elements and protein in the samples were found to be in the ranges; 0.21–2.34 for Ca, 56.3–164 for K, 0.44–2.46 for Mg, 0.23–1.04 for Na and 18.62–38.76 for protein g/kg dry matter.

The highest mean levels of Ca, K, Mg, Na were found to be 2.09, 155, 2.09 and 0.96 g/kg in *M. angusticeps*, respectively. The lowest mean levels of K, Mg and Na were determined to be 60.76, 0.52 and 0.28 g/kg in *M. deliciosa*. The lowest mean level of Ca was observed as 0.25 g/kg in *M. esculenta*.

The lowest mean level of protein was found in *M. deliciosa* (24.36%) and the highest in *M. rotunda* (34.27%). However, the variation within the taxa was low. Nutritional analysis of shiitake was reported 26% of dry matter protein (Tuzen, 2003). Protein contents of *Volvariella bombycina* and *Flammulina velutipes* in the literature were determined to be 30.56 and 25.32%, respectively (Sabir et al., 2003). Protein level of *Pleurotus laciniatocrenatus* was found as 12.4% (Salusso and Morana, 1997). When compared to the literature, protein contents of *Morchella* sp. are in good level. When taking the protein contents in morels into consideration, these mushrooms play an important role for our health.

The ratio between the highest and the lowest protein concentration may be an indicator (Rudawska and Leski, 2005) of how some metal elements are absorbed by studied *Morchella* taxa. The max/min ratio of each element for the studied species of *Morchella* was between 1.0 and 3.24. It can be concluded that all elements are normally absorbed by these species depending on the max/min ratio range of the elements.

Elevated levels of Cd, Pb, Mn and Cu was only found in case of all *M. angusticeps*. In addition, relatively high level of major elements, Ca, Mg, Na, and K was observed in the samples of *M. angusticeps*. It may be concluded that bioconcentration with respect of the definition done by Tyler (1980), in the case of Cd and Pb in samples of *M. angusticeps* and bioexclusion in the case of Pb in samples of *M. elata* was noticed.

In light of the data presented above, these findings are largely consistent with previous studies, with only minor deviations (Gursoy et al., 2009; Tyler, 1980). These slight differences may be attributed to variations in geographical origin, environmental factors, soil composition, and host plant associations, all of which can influence the mineral and nutritional composition of wild morels. The limited number of studies on *Morchella* species in Turkey further highlights the importance of the current research in con-

tributing to a more comprehensive understanding of their ecological and nutritional profiles.

DISCUSSION

The bioaccumulation potential of Anatolian fungi is evidenced by studies in various locations, where wild mushrooms showed significant uptake of metals (Şen et al., 2012; Işıldak et al., 2004). This highlights species- and substrate-dependent metal dynamics relevant to food safety.

M. angusticeps emerged as a hyperaccumulator of Cd and Pb, posing significant health risks at current EU consumption guidelines. In contrast, *M. rotunda*'s high protein and iron content positions it as a safe, nutrient-dense alternative. Regional disparities in Mn accumulation highlight the influence of soil geochemistry on fungal metal uptake, complicating global safety benchmarks (Tuzen, 2003; Sabir et al., 2003; Salusso and Morana, 1997; Rudawska and Leski, 2005; Tyler, 1980; Şen et al., 2012; World Health Organization 1989, 1993; Mendil et al., 2005).

The lack of correlation between protein content and metal levels ($p > 0.05$) underscores the need for species-specific monitoring. We propose trade restrictions on *M. angusticeps* and labeling mandates to protect consumers.

Future monitoring should leverage Turkey's documented macrofungal biodiversity (Allı et al., 2017; Tırpan et al., 2018) and region-specific contamination patterns (Şen et al., 2012) to establish species- and site-specific harvesting guidelines.

CONCLUSIONS

This study demonstrates that *Morchella* taxa in Southwestern Anatolia exhibit significant species differences in their element profiles, which has critical implications for food safety and nutritional value. The presence of elevated concentrations of cadmium (Cd) and lead (Pb) in *M. angusticeps*, which exceed the EU regulatory thresholds, underscores the potential for consumer health concerns and underscores the necessity for rigorous monitoring of this species within contaminated regions, and the implementation of harvesting restrictions. Conversely, *M. rotunda* emerges as the most commercially viable species for harvesting, exhibiting a combination of high protein content (34.27%) and substantial iron levels (386 mg/kg), while exhibiting minimal toxic metal accumulation. Its favourable nutritional profile and low contamination risk make *M. rotunda* nutritionally the most suitable and commercially viable option for sustainable use. The absence of detectable lead in *M. elata* further highlights the role of species exclusion mechanisms in metal uptake. These findings advocate for the implementation of regional and species guidelines, including the strict monitoring of high-risk taxa such as *M. angusticeps*, targeted harvesting protocols prioritis-

ing low-risk species such as *M. rotunda*, and the mandatory labelling of morel mushroom species in commercial trade. The implementation of such measures is of paramount importance in ensuring the protection of public health, the maintenance of regulatory compliance within international markets, and the preservation of the economic viability of Turkey's wild mushroom industry, which is of significant economic importance.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This article does not contain any studies with human participants performed by any of the authors.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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