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Levels of trace elements in the fruiting bodies of macrofungi growing in the East Black Sea region of Turkey

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Abstract

Contents of Hg, Pb, Cd, Fe, Cu, Mn, Zn, Co and As have been determined spectrometrically in fruiting bodies of 109 wild and two cultivated macrofungi specimens. The specimens of macrofungi were collected from the East Black Sea region in Turkey. The habitat, edibility and the distributions of the taxa to the families are listed

1. Introduction

Macrofungi are among the most mysterious life forms. The ancient Greeks believed they came from Zeus's lightning because they appeared after rains and reproduced and grew inexplicably. In the New World, some hallucinogenic mushrooms have been called "the food of the gods" and invested with supernatural powers. They had, in fact, been out of sight, growing underground or beneath bark. Some species contain dangerous toxins, many of which are not yet fully understood. Some mushrooms are of course edible. Since Roman times, fungi have been famous as gourmet fare (Lincoff, 1988).

Numerous investigations have dealt with the heavy metal contents of macrofungi. The elemental contents of the seven selected species of edible mushrooms, have been determined by the method of Instrumental Neutron Activation Analysis (INAA) (Latiff, Daran, & Mohamed, 1996).

Trace element concentrations in fungi are considerably higher than those in agricultural crop plants, vegetables and fruit. This would suggest that fungi possess a very effective mechanism that enables them to take up some trace elements from the substrate more readily. This mechanism may be more effective in the parasitic and saprophytic fungi trophic groups than in the mycorrhizal fungi group (Lepsová, & Mejstrik, 1988).

The uptake of metals in fungi is in many respects different from that of plants. Most macrofungi contain significantly more zinc and copper than green plants and the strong accumulation of mercury and cadmium in certain species are examples of these differences (Kojo, & Lodenius, 1989).

The highest concentration of zinc was found in *Amanita rubescens* Pers.: Fr. and in *Lycoperdaceae* Progn. (Zachara, Borowska, Koper, & Wasowicz, 1986).

Studies show that the concentrations of trace elements in the fruiting bodies of fungi tend to be species-specific. The concentrations were found to depend on the physiology of the species and particularly on its trophic pattern (Lepsová, & Mejstrik, 1988).

There were significant differences for both cadmium and mercury and no correlation between the metal contents and size (dry weight) of the fruiting body could be detected (Kojo, & Lodenius, 1989).

The concentrations of four heavy metals in 149 samples of mushroom fruiting bodies, representing 11 species, mainly all edible were determined by atomic absorption spectroscopy (Kalač, Burda, & Staskova, 1991).

The arsenic and cadmium contents of 88 samples of mushrooms were determined by Vetter. The data offer new information about the concentration of two toxic elements of particular mushroom species. These data are of great importance in the contexts of toxicology, food chemistry and, partly, environmental protection (Vetter, 1994).

The arsenic content of 225 samples representing 79 species of edible mushrooms were determined by

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hydride generation atomic absorption spectrophotometry (Stijve, & Bourqui, 1991).

117 samples of fungi were analysed for their lead, cadmium and mercury contents (Lilja, Kuusi, Laasksovirta, Lodenius, & Piepponen, 1983).

Contents of Cd, Cu, Pb and Zn have been determined in wild growing mushrooms in polluted and unpolluted regions (Gast, Jansen, Bierling, & Haanstra, 1988).

The selenium contents of edible mushroom in Finland were assayed, after a modified wet and dry ashing, by atomic-absorption spectrophotometry, using the hydride technique (Piepponen, Lilja, & Kuusi, 1983).

For various wildlife mushrooms from the geological districts of eastern Croatia, and Slovania, contents of aluminium, lead and cadmium were determined (Mandic, Grgic, Grgic, & Seruga, 1992).

Turkey is located in southeastern Europe and Asia. It is bordered on the north by the Black Sea, on the south by Iraq, Syria, and the Mediterranean, on the west by the Aegean Sea, on the northeast by Georgia and Armenia, on the northeast by Bulgaria and Greece.

Turkey can be separated into seven geographic regions. One of them is the Black Sea region. The Black Sea region can be separated into three smaller geographic regions. The East Black Sea region (Fig. 1) is one of them. In this region, the climate is mild and rainy. The seasons are normally wet with mild temperatures. The climate during the year, especially, in spring and autumn, is ideal for fungal growth.

The Black Sea region for which specimens were collected by the author, has a rich macrofungal flora (Sesli, & Baydar, 1996; Sesli, 1997, 1998).

The purpose of the present study was the determination of Pb, Cd, Hg, Fe, Cu, Mn, Zn, Co and As contents, by using an AAS method, in the fruiting bodies of macrofungi specimens collected from the East Black Sea region of Turkey. Hg concentrations in the macrofungi specimens were determined by CVAAS. As contents in the samples were determined by linear hydride generation AAS. The heavy metals were determined in the flame medium.

2. Materials and methods

The macrofungi specimens were collected from locations in the East Black Sea region of Turkey in 1997. In addition to these wild growing mushrooms, samples [samples for *Agaricus bisporus* (Lange) Imbach and *Pleurotus ostreatus* (Jacq.: Fr.) Kumm] were also taken from commercial mushroom farms.

In all, a total of 444 samples were analysed, representing 111 different macrofungi species.

For the identification of specimens, the colour, odour and other apparent properties of the macrofungi and vegetation were noted. Photographs were taken using Fuji colour negative film and a macro objective of normal focal length with an extension tube. A spore print was made to determine the colour of the spores and the spores were then used to determine the measurements. Microscopic examinations were performed using Nikon research microscopes. Excised pieces of fungus caps were moistened by the addition of a few drops of Clemencon's solution and were placed in a damp chamber to soften completely. The sections were made with a previously unused razor blade under a binocular loupe on white paper. The macrofungi were identified using the reference books of European Flora (Breitenbach, & Kränzlin, 1984, 1986, 1991).

Collected mushrooms were cleaned, cut into slices and the samples were washed with demineralized water. Each sample was dried at 50°C overnight and crushed in a mortar and pestle. Digestion of mushroom samples was performed using an oxi–acidic mixture of HNO_3: H_2SO_4: H_2O_2 (4:1:1) (12 ml for 2–4 g sample) and heating at 75°C for 3 h. After cooling, 20 ml demineralized water was added, the digest was again heated up to 150°C for 4 h and brought to a volume of 25 ml with demineralized water.

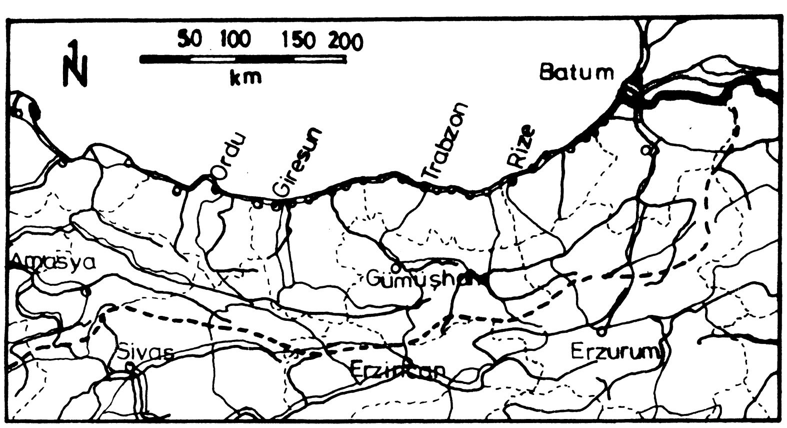

Fig. 1. Collection sites of specimens.

Table 1
Habitat, edibility and the families of macrofungi species

No	Class, family and species of macrofungi	Habitat	Edibility
	ASCOMYCETES De Bary		
	Xylariaceae Hill		
001	*Hypoxylon fuscum* (Pers.: Fr.) Fr.	On dead branches of trees	Not edible
	Geoglossaceae Corda		
002	*Spathularia flavida* Pers.: Fr.	In coniferous forests on needle-covered ground	Edible
	Helotiaceae Dennis		
003	*Bulgaria inguinans* (Pers.: Fr.) Fr.	On dead wood of deciduous trees	Not edible
	Helvellaceae Dum.		
004	*Helvella acetabulum* (L: Fr.) Quél.	Amongst leaf litter in woods	Poisonous
005	*Helvella* sp.	On the ground	
	Pezizaceae Fr.		
006	*Peziza* sp.	On manure and rich soil	
	BASIDIOMYCETES Classe		
	Tremellaceae Fr.		
007	*Sebacina incrustans* (Pers.: Fr) Tul.	In crusting grass, twigs and other organic debris	Not edible
	Dacrymycetaceae Bref.		
008	*Calocera viscosa* (Pers.: Fr.) Fr.	On conifer stumps and roots	Not edible
	Clathraceae Chev.		
009	*Clathrus ruber* Pers.: Pers.	On soil in hardwood forests and park grounds	Not edible
	Phallaceae Corda		
010	*Phallus impudicus* L.: Pers.	Buried in the soil, in gardens and woodland	Edible
	Nidulariaceae Fr.		
011	*Cyathus* sp.	On soil and organic debris	
	Geastraceae Corda		
012	*Geastrum fimbriatum* Fr.: Fr.	On rich humus under deciduous trees	Not edible
	Lycoperdaceae Brogn.		
013	*Lycoperdon perlatum* Pers.: Pers.	Woodland	Edible
014	*Lycoperdon saccatum* Vahl.	On waste ground	Edible
015	*Lycoperdon* sp.	On sandy soil	
016	*Calvatia utriformis* (Bull.: Pers.) Jaap	In pastures on sandy soil	Edible
017	*Calvatia* sp.	On heaths	
	Sclerodermataceae Corda		
018	*Scleroderma aurantium* Pers.	In rich woodland on sandy soil	Not edible
019	*Scleroderma* sp.	Amongst sparse grass	
	Tulostomataceae E. Fish		
020	*Tulostoma brumale* Pers.: Pers	In sandy calcareous soil	Not edible
	Cantharellaceae Schroet.		
021	*Cantharellus cibarius* (Fr.: Fr.) Fr.	In all kinds of woodland	Edible
022	*Cantharellus subalbidus* A.H.S. & Morse	On the ground	Choice
023	*Cantharellus tubaeformis* (Bull.: Fr.)	On acid soils in woods	Edible
024	*Cantharellus* sp.	On sphagnum moss in bogs	
025	*Craterellus cornucopioides* (L.Fr.) Pers.	Amongst the leaf litter of deciduous woods	Edible(Good)
026	*Pseudocraterellus sinuosus* (Fr.) Reid	Amongst the leaf litter of deciduous woods	Edible(Good)
	Gomphaceae Donk.		
027	*Gomphus clavatus* (Pers.: Fr.) S.F. Gray	On the ground under conifers	Choice
	Clavariaceae Chev.		
028	*Ramaria flava* (Sch.: Fr.) Quel.	On the ground in mixed woods	Edible
029	*Ramaria* sp.	On the ground near conifers	
	Hydnaceae Chev.		
030	*Hydnum repandum* L.: Fr.	Deciduous or coniferous woods	Edible (Excellent)
	Thelephoraceae Chew.		
031	*Thelephora palmata* (Scop.: Fr.) Fr.	On the ground near conifers	Not edible
	Bankeraceae Donk		
032	*Sarcoden imbricatus* (L.: Fr.) P. Karst.	Coniferous woods	Edible
033	*Hydnellum concrescens* (Pers.: Schw) Bank.	Coniferous and deciduous woods	Unknown
034	*Hydnellum peckii* Bank. In Peck	Coniferous woods	Not edible
035	*Phellodon* sp.	Coniferous and mixed woodland	
	Hymenochaetaceae Donk		
036	*Inonotus hispidus* (Bull.: Fr.) P. Karst.	On ash	Not edible
	Polyporaceae Corda		
037	*Cerrena unicolor* (Bull.: Fr.) Murr.	On wood	Not edible

Table 1—*(continued)*

No	Class, family and species of macrofungi	Habitat	Edibility
038	*Meripilus giganteus* (Pers.: Fr.) P. Karst.	On deciduous trees	Not edible
039	*Polyporus squamosus* (Huds.: Fr.) Fr.	Parasitic on deciduous trees	Edible
040	*Polyporus sulphureus* Bull.: Fr.	On deciduous trees	Edible
	Coriolaceae Sign.		
041	*Daedalea guercina* (L.: Fr.) Pers.	On dead deciduous wood	Not edible
042	*Trametes gibbosa* (Pers.: Fr.) Fr.	On dead deciduous trees	Not edible
	Bjerkanderaceae Julich		
043	*Tyromyces stipticus* (Pers.: Fr.) Kotl. & Pouz.	On dead conifers	Not edible
	Schizophyllaceae Quel.		
044	*Schizophyllum commune* L.: Fr.	On dead wood of deciduous trees	Not edible
	Boletaceae Chew.		
045	*Boletus edulis* Bull.: Fr.	Coniferous, broad-leafed or mixed woodland.	Edible (Excellent)
046	*Boletus erythropus* Pers.	In coniferous, broad-leafed and mixed woodland	Edible
047	*Boletus* sp.	In mixed woodland	
048	*Leccinum carpini* (Schulz.) Moser.	With hazel or oak	Edible
	Reid		
049	*Suillus granulatus* (L.: Fr.) Rousse	With conifers	Edible
	Paxillaceae Lotsy		
050	*Paxillus atrotomentosus* (Batsch: Fr.) Fr.	On stumps of conifers	Not edible
	Hygrophoraceae Lotsy		
051	*Cuphophyllus virgineus* (Wulf.: Fr.) Bon	Amongst short grass in pasture and open woodland	Edible (Good)
052	*Hygrocybe sciophana* (Fr.: Fr.) Wün.	In grassland	Edible
053	*Hygrocybe* sp.	In short grass	
054	*Hygrophorus chrysodon* (Batsc: Fr.) Fr.	In mixed deciduous wood	Edible
055	*Hygrophorus gliocyclus* Fr.	Among needle litter near conifers	Edible
056	*Hygrophorus russula* (Sch.: Fr.) Quel.	In hardwood forests	Edible (Good)
057	*Hygrophorus unicolor* Gröger	In beech forests	Edible
	Tricholomataceae Roze		
058	*Armillaria mellea* (Vahl: Fr.) Kumm	On trunks or stumps of trees	Edible
059	*Laccaria amethystina* (Bolt.) Murr.	Coniferous or deciduous woods	Edible
060	*Laccaria laccata* (Scop.: Fr.) Bk. & Br.	In woods or heaths	Edible
061	*Lepista inversa* (Scop.) Pat.	In leaf litter in woods	Edible
062	*Lepista* sp.		
063	*Tricholoma terreum* (Sch.: Fr.) Kumm.	In woods	Edible
064	*Tricholomopsis rutilans* (Sch.: Fr.) Sing.	On conifer stumps	Edible
065	*Clitocybe houghtonii* (Bk. & Br.) Dennis	In beech litter	Unknown
066	*Clitocybe* sp	In grassland	
	Marasmiaceae Kühn.		
067	*Marasmius oreades* (Bolt.: Fr.) Fr.	In short grass of pasture	Edible
068	*Marasmius* sp.	In lawns	
069	*Collybia dryophila* (Bull.: Fr.) Kum	In deciduous woods	Edible
070	*Oudemansiella mucida* (Schrad.: Fr.) Höhn.	On the trunks of beech	Edible
071	*Oudemansiella radicata* (Relh.: Fr.) Sing.	Near deciduous trees	Edible
	Pleurotaceae K. & R.: Kühn.		
072	*Panellus stipticus* (Bull.: Fr.) P. Karst.	On dead branches or stumps	Not edible
073	*Pleurotus ostreatus* (Jacq.: Fr.) Kumm	Culture	Edible
	Coprinaceae Gaüm.		
074	*Coprinus comatus* (Müll.: Fr.) Pers.	In grass by roadsides	Edible (Good)
075	*Coprinus micaceus* (Bull.: Fr.) Fr.	On or around broad leafed stumps	Edible
076	*Coprinus* sp.	In grass	
	Strophariaceae Sing. & Smith		
077	*Kuehneromyces mutabilis* (Scop.: Fr.) Sing. & Smith	On stumps or trunks of deciduous trees	Edible(Good)
078	*Hypholoma capnoides* (Fr.: Fr.) Kumm.	Conifer stumps	Edible
079	*Hypholoma fasciculare* (Huds.: Fr.) Kumm.	On stumps of trees	Not edible
080	*Hypholoma sublateritium* (Fr.) Quel.	Stumps of deciduous trees	Not edible
081	*Hypholoma* sp.	On trunks	
	Cortinariaceae Roze		
082	*Cortinarius auroturbinatus* (Secr.) Lange	Beech woods on chalk	Unknown
083	*Cortinarius bulliardii* (Pers.: Fr.) Fr.	Deciduous wood.	Unknown
084	*Cortinarius subbalastinus* Hry.: Hry.	With birch	Unknown
085	*Cortinarius subturbinatus* Hry.: Or.	Under beech	Unknown
086	*Cortinarius* sp	Under beech	

Table 1—*(continued)*

No	Class, family and species of macrofungi	Habitat	Edibility
087	*Hebeloma sinapizans* (Paul.: Fr.) Gill.	In deciduous and mixed woods	Poisonous
	Agaricaceae Fr.		
088	*Agaricus bisporus* (Lange) Imbach	Culture	Edible
089	*Agaricus campestris* L.: Fr.	In pasture land	Edible (Excellent)
090	*Agaricus silvicola* (Vitt.) Sacc.	In woods	Edible (Good)
091	*Agaricus* sp.	In woods	
092	*Cystoderma amianthinum* (Scop.) Fayod	On heaths	Edible
093	*Lepiota cristata* (Bolt.: Fr.) Kumm.	In woods	Not edible
094	*Macrolepiota gracilenta* (Krombh.) Wasser	In woods	Edible
	Amanitaceae Roze		
095	*Amanita muscaria* (L.: Fr.) Hook.	With birch trees	Poisonous
096	*Amanita rubescens* Pers.: Fr.	In woodland	Edible
097	*Amanita vaginata* (Bull.: Fr.) Vitt.	In deciduous woods or on heaths	Edible
098	*Amanita* sp.	In woodland	
	Russulaceae Lotsy		
099	*Lactarius acerrimus* Britz	Under broad leafed trees	Unknown
100	*Lactarius azonites* (Bull.) Fr.	Under broad leafed trees	Not edible
101	*Lactarius deliciosus* (L.: Fr.) S.F. Gray	Under pines or spruce	Edible (Good)
102	*Lactarius piperatus* (Scop.: Fr.) S.F. Gray	Deciduous woods	Edible
103	*Lactarius rufus* (Scop.: Fr.) Fr.	Under pine	Not edible
104	*Lactarius scrobiculatus* Scop.: Fr.	Under conifers	Poisonous
105	*Lactarius volemus* (Fr.: Fr.) Fr.	Under trees	Edible(Good)
106	*Lactarius* sp.	Under conifers	
107	*Russula cyanoxantha* (Sch.) Fr.	Under broad leafed trees	Edible
108	*Russula delica* Fr.	Under trees	Edible
109	*Russula foetens* Pers.: Fr.	Under broad leafed trees or conifers	Not edible
110	*Russula virescens* (Sch.) Fr.	Under beech	Edible
111	*Russula* sp.	Under broad leafed trees	

For analysis of mercury, the technique described was as follows: One-half gram was taken from the dried homogenized sample and its digestion was carried out using 7 ml of a HNO_3:H_2SO_4:H_2O_2 acid mixture at a ratio of 4:1:1; digestion was carried out at 60°C in a thermostatic bath, being completed in about 1.5 h. For oxidation of the sample, a solution of potassium permanganate at 6%, w/v, was used. The excess of permanganate was reduced with a solution of hydroxylamine sulphate (Hatch, & Ott, 1968).

Hg levels in the samples were determined by cold vapour AAS. The determinations of Hg contents were carried out by Pye Unicam SP9 series AAS equipped with a cold vapour system and a Hg hollow cathode lamp, adjusted to 253.7 nm and fitted to the Pye Unicam mercury/hydride system, using 3%, w/v sodium borohydride in 1%, w/v NaOH as a reducing solution. The analysis was done following conditions: wavelength 253.7 nm; slit 0.7 nm; carrier gas (Purified N_2) pressure 2.5 kg/cm^2 and carrier gas flow rate 1100 ml/min. For determination of arsenic the linear hydride generation atomic absorption spectrometry (AAS) was used. Digestion of mushroom samples was carried out as for mercury analysis. The analysis was done following the conditions: wavelength: 193.7 nm; flame air/acetylene: carrier gas nitrogen. The lamp was allowed to stabilise for at least 1 h. The optical beam was adjusted through the quartz cell. By means of the peristaltic pump distilled water was aspirated into the hydride generator for 10 min, then HNO_3:H_2SO_4:H_2O_2 (4:1:1) and sodium borohydride solution. After about 5 min absorbency was zeroed. Similarly, standard solutions were aspirated and then tested at 2 min intervals. Each solution was measured three times with a signal integration time of 6 s.

The analyses of Pd, Cd, Fe, Cu, Mn, Zn and Co were performed using a Thermo Jarrel Ash–Smith Hieftje 1000 atomic absorption spectrophotometer (AAS) with an oxidising air acetylene flame and background correction of the deuterium lamp. The standard-addition procedure was used in all determinations.

The wavelength and slit values in nm used for the determination of Pd, Cd, Fe, Cu, Mn, Zn and Co were: 217.0 and 1.0; 228.8 and 0.5; 248.3 and 0.2; 324.7 and 0.5; 279.5 and 0.2; 213.9 and 0.5; 240.7 and 0.2, respectively (Table 1).

3. Results and discussion

The trace elements are of great biochemical interest and they have nutritional and clinical importance. Selenium and zinc play very important roles in human and animal metabolism, because they are constituents of various enzymes of clinical significance (Zachara, Borowska, Koper, & Wasowicz, 1986).

Table 2
Trace element contents of the examined macrofungi samples (μg/g, dry weight)

Sample no	Hg	Pb	Cd	Fe	Cu	Mn	Zn	Co	As
001		1.43 ± 0.28	2.63 ± 0.45	88.5 ± 10.2	28.5 ± 2.3		34.3 ± 2.8	0.25 ± 0.07	1.27 ± 0.72
002		1.24 ± 0.32	1.73 ± 0.41	108 ± 10.7	24.1 ± 4.7	32.4 ± 1.7	52.1 ± 2.6	0.19 ± 0.10	1.33 ± 0.25
003		0.78 ± 0.17	1.21 ± 0.17	142 ± 20.6	37.4 ± 1.9	17.4 ± 1.5	41.4 ± 1.9	0.33 ± 0.13	1.08 ± 0.53
004	0.88 ± 0.20	0.97 ± 0.23		245 ± 28	75.3 ± 3.7	89.2 ± 3.7	107 ± 4.7	0.54 ± 0.24	0.76 ± 0.35
005	0.94 ± 0.17	1.27 ± 0.36		197 ± 16	64.1 ± 2.8	54.3 ± 2.4	162 ± 5.2	0.42 ± 0.17	0.88 ± 0.28
006	0.65 ± 0.10	0.83 ± 0.26	1.26 ± 0.20	340 ± 61	75.4 ± 3.6	64.5 ± 3.2	87.4 ± 3.4	0.28 ± 0.12	0.75 ± 0.34
007		1.20 ± 0.32	2.71 ± 0.52	167 ± 25.4	47.3 ± 5.4		18.2 ± 1.3	0.42 ± 0.17	1.62 ± 0.85
008		1.19 ± 0.27	1.54 ± 0.41	521 ± 69	49.0 ± 5.5	33.2 ± 2.7	63.5 ± 8.4	0.24 ± 0.11	1.64 ± 0.45
009		1.10 ± 0.23	1.50 ± 0.36	89.4 ± 6.7	28.3 ± 2.3	24.2 ± 2.5	32.1 ± 4.4	0.24 ± 0.05	0.94 ± 0.17
010		0.89 ± 0.25	2.66 ± 0.57		32.5 ± 3.6	38.0 ± 3.5	39.5 ± 1.4	0.26 ± 0.06	
011		0.88 ± 0.21	1.23 ± 0.15	136 ± 14	32.5 ± 3.8	19.5 ± 1.6	29.7 ± 3.5	0.17 ± 0.07	0.82 ± 0.25
012		0.78 ± 0.13		103 ± 24.5	23.4 ± 1.8		27.6 ± 2.8	0.18 ± 0.05	0.82 ± 0.37
013	0.28 ± 0.05	0.94 ± 0.25	1.36 ± 0.22	471 ± 68	127 ± 12	68.4 ± 5.7	116 ± 6.2	0.33 ± 0.11	
014	0.12 ± 0.03		0.76 ± 0.23	240 ± 17	63.4 ± 7.1	34.2 ± 2.7	24.3 ± 2.5		1.24 ± 0.33
015	0.16 ± 0.06	1.14 ± 0.32	1.54 ± 0.35	507 ± 49	133 ± 14	73.9 ± 4.5	128 ± 4.5	0.44 ± 0.21	
016	0.21 ± 0.05		0.82 ± 0.35	365 ± 47	82.5 ± 6.3	38.5 ± 1.8	26.7 ± 3.4		1.46 ± 0.40
017	0.63 ± 0.08	1.34 ± 0.23	1.63 ± 0.38	210 ± 24	52.0 ± 5.4	41.2 ± 2.9	34.2 ± 4.7		1.15 ± 0.17
018	1.65 ± 0.41	1.94 ± 0.31	1.83 ± 0.63		48.4 ± 4.2	24.5 ± 2.2	61.7 ± 3.6	0.35 ± 0.04	
019	1.20 ± 0.50	1.87 ± 0.39	2.10 ± 0.72		52.6 ± 5.7	21.2 ± 1.8	50.3 ± 2.8	0.27 ± 0.13	
020		0.64 ± 0.12	1.23 ± 0.33	419 ± 47	67.3 ± 6.8	30.6 ± 2.1	42.4 ± 3.4	0.34 ± 0.17	1.20 ± 0.36
021	1.21 ± 0.46	1.42 ± 0.26	1.92 ± 0.32	765 ± 67	89.5 ± 5.4	51.4 ± 3.4	62.7 ± 3.6	0.31 ± 0.12	0.85 ± 0.20
022		0.83 ± 0.26	2.25 ± 0.42	510 ± 50	71.2 ± 8.0	47.1 ± 1.9	93.2 ± 5.2	0.22 ± 0.10	0.65 ± 0.14
023	1.01 ± 0.20	1.63 ± 0.44	2.05 ± 0.50	852 ± 47	125 ± 17	65.3 ± 2.7	82.5 ± 4.7	0.27 ± 0.07	0.72 ± 0.18
024		0.77 ± 0.21	1.83 ± 0.48	678 ± 42	93.8 ± 4.4	74.3 ± 4.4	49.1 ± 3.7	0.24 ± 0.14	0.93 ± 0.26
025	0.60 ± 0.15	1.28 ± 0.32	1.78 ± 0.52	105.4 ± 7.6	21.6 ± 1.7	32.5 ± 3.5	62.5 ± 3.5	0.14 ± 0.07	1.25 ± 0.33
026		1.44 ± 0.36	1.23 ± 0.16	94.8 ± 6.3	27.5 ± 2.3	24.6 ± 2.7	83.1 ± 4.5	0.22 ± 0.13	0.62 ± 0.25
027	1.61 ± 0.47	2.14 ± 0.73		470 ± 26	17.8 ± 3.0	52.6 ± 8.1	107 ± 6.2	0.34 ± 0.12	0.89 ± 0.17
028	0.68 ± 0.27	1.48 ± 0.36	1.24 ± 0.17	578 ± 34	41.3 ± 3.7		70.3 ± 4.5	0.25 ± 0.06	0.45 ± 0.14
029	0.95 ± 0.33	1.57 ± 0.33	1.73 ± 0.26	617 ± 41	28.4 ± 4.1		61.9 ± 3.8	0.18 ± 0.05	0.58 ± 0.24
030	0.45 ± 0.14	2.08 ± 0.51	3.61 ± 0.55	125 ± 12	16.3 ± 1.14	24.2 ± 2.5	21.3 ± 1.6	0.33 ± 0.12	0.75 ± 0.18
031		1.63 ± 0.35	1.76 ± 0.38	265 ± 42		88.3 ± 4.5	185 ± 10		1.64 ± 0.36
032		1.24 ± 0.35	1.67 ± 0.32	367 ± 38	28.4 ± 3.4	25.2 ± 1.7	43.6 ± 2.7	0.27 ± 0.08	0.85 ± 0.23
033	0.75 ± 0.36	1.28 ± 0.30		341 ± 47	31.5 ± 2.5	25.3 ± 2.5	50.4 ± 2.5	0.52 ± 0.18	0.85 ± 0.17
034	0.67 ± 0.17	1.85 ± 0.42	2.15 ± 0.76	414 ± 36	37.2 ± 1.9	28.2 ± 1.8	44.3 ± 1.7	0.48 ± 0.14	0.62 ± 0.23
035	1.14 ± 0.38		1.29 ± 0.32		45.1 ± 5.8	34.5 ± 1.8	75.4 ± 4.2	0.41 ± 0.27	1.20 ± 0.36
036		0.71 ± 0.26	1.32 ± 0.21	194.6 ± 19.3	26.8 ± 1.5	16.8 ± 1.3	31.3 ± 2.6	0.31 ± 0.12	0.55 ± 0.20
037		1.33 ± 0.28	1.23 ± 0.16	463 ± 44	59.5 ± 6.8	33.2 ± 2.5	84.5 ± 3.6	0.35 ± 0.05	1.83 ± 0.52
038	0.60 ± 0.25	0.69 ± 0.14	1.05 ± 0.32	237 ± 28.5	17.4 ± 2.3	19.5 ± 2.4	40.4 ± 3.2	0.16 ± 0.05	
039	0.20 ± 0.05	1.11 ± 0.28	1.87 ± 0.60	241 ± 34.5	41.3 ± 8.2	140 ± 3.4	203 ± 24	0.33 ± 0.15	0.87 ± 0.32
040		0.85 ± 0.17	1.51 ± 0.25	215 ± 14	32.4 ± 2.8	84.3 ± 2.7	150 ± 14	0.28 ± 0.12	0.92 ± 0.25
041		0.86 ± 0.12	0.94 ± 0.24	217.5 ± 38.7	34.1 ± 2.7	24.1 ± 1.8	51.2 ± 1.4	0.27 ± 0.14	1.47 ± 0.32
042		1.47 ± 0.28	1.82 ± 0.27	175 ± 16.2	38.5 ± 6.2	71.4 ± 2.3	67.3 ± 5.4		1.72 ± 0.45
043		0.74 ± 0.14	1.36 ± 0.17	146.7 ± 14.5	25.2 ± 4.1	40.3 ± 4.5	52.5 ± 6.2	0.25 ± 0.14	1.02 ± 0.28
044		1.25 ± 0.32	1.43 ± 0.15	435 ± 26		67.5 ± 6.0	60.1 ± 5.7		1.35 ± 0.28
045	0.51 ± 0.20	0.80 ± 0.24	1.14 ± 0.27	160.5 ± 16.8	12.5 ± 1.3	21.3 ± 1.4	40.7 ± 3.5	0.32 ± 0.11	1.07 ± 0.27
046	0.44 ± 0.18	1.20 ± 0.35	1.53 ± 0.31	144 ± 26.5	16.4 ± 2.4	18.5 ± 1.2	36.4 ± 1.7	0.47 ± 0.14	1.32 ± 0.18
047	0.75 ± 0.14	0.94 ± 0.15	1.18 ± 0.24	58.2 ± 4.3	15.0 ± 0.74	14.2 ± 2.75	29.5 ± 2.4	0.29 ± 0.17	1.24 ± 0.35
048		0.75 ± 0.08	1.28 ± 0.14	240 ± 27	47.9 ± 7.0	25.1 ± 2.3	51.2 ± 3.4	0.36 ± 0.17	0.70 ± 0.22
049		1.24 ± 0.10	1.38 ± 0.42	87.6 ± 9.5	10.3 ± 1.2	17.0 ± 1.7	62.4 ± 3.6	0.45 ± 0.24	0.72 ± 0.26
050	0.78 ± 0.26		0.98 ± 0.16	1025 ± 63	58.1 ± 3.4	152 ± 12	252 ± 4.3	0.44 ± 0.25	1.25 ± 0.36
051	0.24 ± 0.05	0.74 ± 0.09		341 ± 67	30.3 ± 4.2	24.8 ± 3.8	107 ± 6.5	0.41 ± 0.25	1.05 ± 0.52
052	0.33 ± 0.08	1.35 ± 0.24		418 ± 49	26.5 ± 2.5	31.5 ± 2.6	44.4 ± 3.8	0.36 ± 0.32	0.72 ± 0.63
053	0.48 ± 0.21	1.63 ± 0.40	1.25 ± 0.36	570 ± 78	37.8 ± 3.4	49.3 ± 2.2	36.3 ± 4.5	0.24 ± 0.13	0.85 ± 0.26
054	0.53 ± 0.19	0.95 ± 0.18	1.35 ± 0.27		132 ± 11	67.4 ± 5.4	51.4 ± 6.8	0.16 ± 0.07	0.72 ± 0.17
055	0.64 ± 0.15	1.35 ± 0.44		875 ± 120	105 ± 17	58.2 ± 3.1	87.3 ± 5.4	0.18 ± 0.05	0.65 ± 0.24
056	0.84 ± 0.35	1.47 ± 0.25		971 ± 88	128 ± 9	47.5 ± 2.5	67.4 ± 4.7	0.19 ± 0.11	0.82 ± 0.19
057		1.68 ± 0.57	1.23 ± 0.38	1190 ± 172	145 ± 18	67.3 ± 3.4	145 ± 8.8	0.24 ± 0.12	0.61 ± 0.24
058	0.93 ± 0.28	1.29 ± 0.30	2.50 ± 0.36	88.3 ± 7.5	21.4 ± 1.7	26.3 ± 2.5	75.4 ± 5.5	0.41 ± 0.15	1.82 ± 0.14
059	0.74 ± 0.26	1.23 ± 0.25	2.70 ± 0.57	161 ± 21	28.1 ± 4.2	29.0 ± 1.6	40.1 ± 3.8	0.25 ± 0.14	0.72 ± 0.15
060		1.35 ± 0.41	1.63 ± 0.50	147 ± 18	34.5 ± 3.7	36.4 ± 2.8	32.1 ± 2.4	0.20 ± 0.07	0.67 ± 0.25
061	1.98 ± 0.30	2.86 ± 0.48		163.1 ± 17.8	38.1 ± 6.2	27.5 ± 1.7	45.2 ± 3.7	0.17 ± 0.06	1.26 ± 0.33

Table 2—*(continued)*

Sample no	Hg	Pb	Cd	Fe	Cu	Mn	Zn	Co	As
062	1.83 ± 0.25	3.41 ± 1.20	2.75 ± 0.18	186 ± 20.5	47.4 ± 2.3	16.4 ± 2.1	54.7 ± 4.5	0.12 ± 0.08	1.57 ± 0.45
063	0.75 ± 0.31	0.82 ± 0.23	0.83 ± 0.25	49 ± 7	77.2 ± 5.7	12.3 ± 1.4	17.0 ± 1.5	0.35 ± 0.17	0.94 ± 0.27
064	0.41 ± 0.16		1.62 ± 0.45	67.5 ± 10.3	82.1 ± 6.5	19.1 ± 1.9	28.5 ± 3.2	0.39 ± 0.21	0.85 ± 0.19
065	1.93 ± 0.62	2.21 ± 0.75	3.60 ± 0.45	360 ± 86	83.0 ± 4.8	40.2 ± 5.7	52.7 ± 7.2	0.36 ± 0.17	0.44 ± 0.12
066	1.60 ± 0.47	1.83 ± 0.63	2.14 ± 0.20	271 ± 47	61.3 ± 4.4	28.4 ± 1.6	161 ± 11.7	0.28 ± 0.12	0.58 ± 0.17
067		0.63 ± 0.19	1.16 ± 0.26	270 ± 39	61.5 ± 1.8	44.1 ± 5.7	77.4 ± 5.3	0.27 ± 0.09	1.75 ± 0.36
068		0.92 ± 0.22	1.22 ± 0.28	195 ± 23	74.3 ± 2.7	37.7 ± 6.3	62.5 ± 4.8	0.32 ± 0.14	1.62 ± 0.43
069		0.82 ± 0.24	1.28 ± 0.15	113 ± 14		16.7 ± 2.3	46.4 ± 5.4	0.17 ± 0.07	0.75 ± 0.14
070		1.24 ± 0.36	1.58 ± 0.45		26.1 ± 3.6	18.1 ± 2.3	42.7 ± 3.9	0.27 ± 0.12	1.15 ± 0.36
071		0.71 ± 0.25	1.35 ± 0.28		34.5 ± 5.5	23.2 ± 1.7	36.5 ± 4.3	0.21 ± 0.14	1.43 ± 0.45
072	0.44 ± 0.18	1.26 ± 0.35	2.63 ± 0.54	170 ± 16.7	26.3 ± 1.5		79.2 ± 4.7	0.27 ± 0.08	
073	0.35 ± 0.018	0.17 ± 0.06	0.67 ± 0.25	57.5 ± 10.2	7.16 ± 1.28	12.5 ± 1.4	43.1 ± 2.5	0.20 ± 0.07	
074	0.064 ± 0.02	0.67 ± 0.12	1.43 ± 0.36	264 ± 36	71.4 ± 6.3	12.3 ± 1.7	32.0 ± 2.6	0.32 ± 0.15	1.24 ± 0.28
075	0.085 ± 0.02	0.58 ± 0.17	1.67 ± 0.42	197 ± 21	62.8 ± 7.2	8.5 ± 2.2	22.5 ± 1.8	0.28 ± 0.11	1.37 ± 0.17
076	1.21 ± 0.34	0.87 ± 0.23	1.80 ± 0.61	203 ± 29	51.4 ± 6.7	19.1 ± 1.6	24.5 ± 3.2	0.22 ± 0.05	1.07 ± 0.20
077		0.75 ± 0.19	2.14 ± 0.78		43.7 ± 7.0	24.2 ± 2.5	45.7 ± 4.5	0.17 ± 0.03	0.87 ± 0.25
078	0.068 ± 0.01	4.10 ± 1.45	3.24 ± 0.71	97.8 ± 6.4	10.9 ± 1.4	10.1 ± 2.3	44.5 ± 3.5	0.18 ± 0.06	1.25 ± 0.32
079	0.42 ± 0.08	5.64 ± 1.20	2.25 ± 0.21	67 ± 5	18.2 ± 1.45	17.3 ± 1.4	20.1 ± 1.7	0.16 ± 0.05	1.43 ± 0.28
080	0.06 ± 0.008	2.15 ± 0.50	2.67 ± 0.42	217 ± 36		47.5 ± 3.5	35.3 ± 4.6	0.24 ± 0.09	0.85 ± 0.26
081	0.14 ± 0.07	1.75 ± 0.37	1.65 ± 0.29	254 ± 41		38.4 ± 2.4	48.6 ± 3.7	0.30 ± 0.12	0.95 ± 0.22
082	1.60 ± 0.41	1.55 ± 0.34	1.23 ± 0.12	240 ± 71	85.4 ± 4.1	26.4 ± 1.7	75.9 ± 7.7	0.17 ± 0.05	0.43 ± 0.15
083	0.78 ± 0.025	1.28 ± 0.41	1.51 ± 0.17	296 ± 67	73.2 ± 5.4	24.5 ± 2.5	145 ± 3.4	0.21 ± 0.09	0.68 ± 0.24
084	0.36 ± 0.14	1.34 ± 0.28	1.65 ± 0.32	380 ± 29	97.5 ± 6.2	32.3 ± 1.7	169.4 ± 6.7	0.24 ± 0.11	0.72 ± 0.36
085		0.92 ± 0.14	0.87 ± 0.12	167 ± 18	105 ± 5.7	27.5 ± 2.4	120 ± 5.5	0.18 ± 0.07	1.12 ± 0.45
086	0.18 ± 0.05	0.87 ± 0.23	1.42 ± 0.26	246 ± 30	126 ± 4.3	31.1 ± 4.2	101 ± 6.4	0.22 ± 0.10	0.94 ± 0.36
087		0.82 ± 0.20	1.26 ± 0.34	144 ± 17	41.5 ± 2.7	31.3 ± 2.4		0.32 ± 0.13	0.88 ± 0.25
088	0.03 ± 0.009	0.28 ± 0.04	0.74 ± 0.21	31.3 ± 4.7	13.5 ± 2.3	3.61 ± 0.62	22.5 ± 1.7	0.09 ± 0.04	
089	0.65 ± 0.08	1.58 ± 0.34	1.63 ± 0.36	550 ± 54	111 ± 6.4	100 ± 6.4	138 ± 6.7	0.12 ± 0.10	0.88 ± 0.24
090	0.42 ± 0.04	1.38 ± 0.41	1.26 ± 0.32	420 ± 92	83.5 ± 3.7	53.6 ± 2.7	83.4 ± 4.8	0.17 ± 0.08	0.75 ± 0.32
091	0.74 ± 0.20	1.87 ± 0.60	2.37 ± 0.48	385 ± 78	99.4 ± 6.7	46.1 ± 3.2	75.4 ± 2.9	0.11 ± 0.05	0.69 ± 0.18
092		1.54 ± 42	2.23 ± 0.44	105 ± 21	34.7 ± 3.8	28.4 ± 1.6		0.27 ± 0.12	1.26 ± 0.35
093	0.32 ± 0.05	0.74 ± 0.10	0.97 ± 0.24		21.3 ± 1.8	25.3 ± 1.9		0.27 ± 0.15	0.93 ± 0.17
094		0.27 ± 0.05	1.17 ± 0.16	851 ± 82	70.4 ± 5.2	104 ± 10.3	176 ± 8.2	0.45 ± 0.23	1.27 ± 0.33
095	0.35 ± 0.14	2.24 ± 0.65	2.20 ± 0.25	603 ± 41	102 ± 5.8	67.6 ± 5.8	75.1 ± 4.3	0.54 ± 0.15	1.78 ± 0.26
096	0.80 ± 0.31	1.34 ± 0.42	1.27 ± 0.18	142 ± 6.7	46.3 ± 7.7	16.2 ± 1.24	88.3 ± 1.6	0.62 ± 0.24	2.15 ± 0.35
097	0.63 ± 0.10	1.70 ± 0.46	2.17 ± 0.32	241 ± 27	58.4 ± 6.9	39.5 ± 3.4	196 ± 8.9	0.47 ± 0.15	2.36 ± 0.67
098	0.76 ± 0.11	1.94 ± 0.72	1.63 ± 0.21	671 ± 58.6	86.2 ± 5.5	127 ± 10.5	125 ± 6.6	0.38 ± 0.21	2.05 ± 0.53
099	0.10 ± 0.02	1.80 ± 0.44	1.94 ± 0.78	209 ± 36.2	36.5 ± 1.7	24.4 ± 4.6	62.7 ± 3.5	0.25 ± 0.09	1.23 ± 0.42
100	0.15 ± 0.05	1.26 ± 0.30	1.44 ± 0.32	319.5 ± 26.8	41.9 ± 2.5	31.3 ± 3.5	54.2 ± 2.6	0.32 ± 0.07	0.95 ± 0.24
101	0.18 ± 0.06	1.60 ± 0.54	1.76 ± 0.51	695.2 ± 118	54.3 ± 8.1	71.4 ± 3.7	87.0 ± 5.3	0.28 ± 0.15	0.75 ± 0.17
102	0.43 ± 0.04	3.08 ± 0.64	0.75 ± 0.24	141 ± 26	21.4 ± 2.5	8.14 ± 1.42	29.5 ± 3.1	0.35 ± 0.17	0.86 ± 0.25
103	0.21 ± 0.08	0.70 ± 0.25	1.14 ± 0.26	125 ± 17.4	42.5 ± 7.3	7.14 ± 1.17	67.8 ± 6.2	0.18 ± 0.08	1.26 ± 0.53
104	0.081 ± 0.01	0.98 ± 0.32	0.82 ± 0.17	103 ± 12.8	36.7 ± 7.1	8.20 ± 1.04	46.3 ± 6.8	0.29 ± 0.13	1.45 ± 0.38
105	0.098 ± 0.01	1.45 ± 0.34	1.20 ± 0.26	62.8 ± 5.1	21.3 ± 2.8	5.45 ± 0.94	23.4 ± 1.3	0.36 ± 0.15	1.27 ± 0.44
106	0.448 ± 0.06	2.88 ± 0.65	1.31 ± 0.42	85.7 ± 9.5	27.4 ± 5.2	6.40 ± 1.05	33.2 ± 2.6	0.41 ± 0.12	1.45 ± 0.37
107	0.15 ± 0.04	2.18 ± 0.84	3.26 ± 0.75	57.2 ± 6.7	19.8 ± 3.4	13.8 ± 2.4	27.4 ± 3.7	0.21 ± 0.09	1.12 ± 0.27
108	0.062 ± 0.01	3.60 ± 1.15	2.28 ± 0.46	61.4 ± 8.6	16.1 ± 2.9	14.2 ± 3.5	22.3 ± 1.5	0.15 ± 0.10	1.24 ± 0.36
109	0.05 ± 0.009	2.40 ± 0.55	1.63 ± 0.34	168 ± 24.6	35.4 ± 6.1	24.4 ± 3.2	47.8 ± 4.3	0.28 ± 0.12	0.89 ± 0.28
110	0.084 ± 0.01	2.04 ± 1.25	2.17 ± 0.68	128 ± 12.3	32.3 ± 4.5	17.3 ± 2.8	39.7 ± 1.6	0.32 ± 0.08	0.44 ± 0.21
111	0.053 ± 0.01	3.86 ± 1.38	1.28 ± 0.32	75.1 ± 4.9	18.7 ± 2.3	7.12 ± 1.50	30.5 ± 2.8	0.24 ± 0.11	0.63 ± 0.14

The amounts of trace element contents are related to species of mushroom, collecting site of the sample, age of fruiting bodies and mycelium, and distance from the source of pollution (Kalač, Burda, & Staskova, 1991).

The heavy metal concentrations in the mushroom are hardly affected by pH and organic matter content of the soil (Gast, Jansen, Bierling, & Haanstra, 1988).

The trace element contents of the species depend on the ability of the species to extract elements from the substrate, and on the selective uptake and deposition of elements in tissues. An interesting aspect of our study is that different samples of the same species differ considerably in their trace element contents. According to our studies, no difference between saprophytic and mycorrhizal-forming species was observed.

We identified 109 species of macrofungi belonging to 37 families. Some species live saprophytically on various dead

Table 3
Statistical analysis results for *Agaricus* sp. mushroom

Calculated values	Hg	Pb	Cd	Fe	Cu	Mn	Zn	Co	As
Average, x (μg/g)	0.74	1.87	2.37	385	99.4	46.1	75.5	0.11	0.69
Standard deviation, (S)	0.20	0.60	0.48	78	6.7	3.2	2.9	0.05	0.18
Relative (S)	27.0	32.1	20.3	20.3	6.7	6.9	3.8	45.5	26.1
Confidence interval	0.74 ± 0.25	1.87 ± 0.74	2.37 ± 0.60	385 ± 97	99.4 ± 8.3	46.1 ± 3.9	75.5 ± 3.6	0.11 ± 0.06	0.69 ± 0.22

For all experiments: $t = 2.776$ for $n = 5$.

materials, some are parasitic and some are considered to form ectomycorrhizae with trees.

Trace element concentrations in the species analysed (Table 2) are not different from values reported within Europe (Seeger, Meyer, & Schönhut, 1976; Seeger, 1978; Tyler, 1980).

The trace element concentrations were highest in macrofungi of the family *Tricholomataceae*.

The heavy metal contents of 111 macrofungi species are shown in Table 2. From the table, in the macrofungi supplied from the East Black Sea Region, the highest Hg level was found as 1.98 μg/g for the species of *Lepista inversa*, whereas the lowest Hg level was 0.03 μg/g in *Agaricus bisporus*. The highest Pb level was 5.64 μg/g for the species *Hypholoma fasciculare*, which was collected near the vicinity of the road. The lowest Pb levels were 0.17 μg/g in the species of *Pleurotus ostreatus* and 0.27 μg/g in *Macrolepiota gracilenta*. The highest Cd level was determined as 3.61 μg/g for *Hydnum repandum*. Among the wild macrofungi, the lowest Cd level was 0.75 μg/g for the species of *Lactarius piperatus*, which is used as food in the region.

According to previous studies, it appears that certain taxonomical groups have a significantly higher cadmium content than other (Vetter, 1994). In our study, the species living on dead organic debris on earth accumulate cadmium more than the other species of macrofungi.

The highest Fe and Cu levels were 1190 and 145 μg/g, respectively, for the species *Hygrophorus unicolor*. The lowest Fe levels were 31.3 μg/g for a culture species of *Agaricus bisporus* and 49 μg/g for an edible species of *Tricholoma terreum* collected from woods. The lowest Cu levels were 7.16 μg/g for *Pleurotus ostreatus* and 10.3 μg/g for *Suillus granulatus*. The highest Mn level (152 μg/g) and the highest Zn level (252.3 μg/g) were determined for the species *Paxillus atrotomentosus*. The highest levels of Co (0.62 μg/g) and As (2.15 μg/g) were determined for the species of *Amanita rubescens*. The lowest Mn and Co levels were 3.61 μg/g and 0.09 μg/g for the species *Agaricus bisporus*. The lowest Zn level was 17.0 μg/g for the species of *Tricholoma terreum*. The lowest As level was 0.43 μg/g for the species *Cortinarius auroturbinatus*. A statistical analysis was carried out for *Agaricus* sp. mushroom (Table 3).

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