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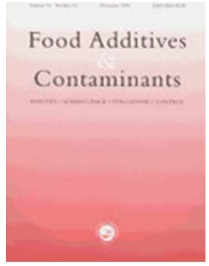
Jerzy Falandysz, Anna Katarzyna Kojta, Grażyna Jarzyńska, Malgorzata Drewnowska, Anna Dryżalowska, Daria Wydmańska, Izabela Kowalewska, Anna Wacko, Monika Szlosowska, Kannan Kurunthachalam, et al.



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Complete List of Authors:	Falandysz, Jerzy; University of Gdańsk, Institute of Environmental Sciences & Public Health Kojta, Anna; University of Gdańsk, Chemistry; University of Gdańsk, Institute of Environmental Sciences & Public Health Jarzyńska, Grażyna; University of Gdańsk, Institute of Environmental Sciences & Public Health Drewnowska, Małgorzata; University of Gdańsk, Institute of Environmental Sciences & Public Health Dryżałowska, Anna; University of Gdańsk, Institute of Environmental Sciences & Public Health Wydmańska, Daria; University of Gdańsk, Institute of Environmental Sciences & Public Health Kowalewska, Izabela; University of Gdańsk, Institute of Environmental Sciences & Public Health Wacko, Anna; University of Gdańsk, Institute of Environmental Sciences & Public Health Szlosowska, Monika; University of Gdańsk, Institute of Environmental Sciences & Public Health Kurunthachalam, Kannan; Wadsworth Center, NYS Department of Health Szefer, Piotr; Medical University of Gdańsk, Department of Food Sciences
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J. Falandysz[a], A.K. Kojta[a*,] , G. Jarzyńska[a], M. Drewnowska[a], A. Dryżałowska[a], D. Wydmańska[a], I. Kowalewska[a], A. Wacko[a], M. Szlosowska[a], K. Kannan[b] and P. Szefer[c]

[a]*Research Group of Environmental Chemistry, Ecotoxicology & Food Toxicology, Institute of Environmental Sciences & Public Health, University of Gdańsk, 18 Sobieskiego Str., PL 80-952 Gdańsk, Poland*

[b]*Wadsworth Center, New York State Department of Health, and Department of Environmental Health Sciences, School of Public Health, State University of New York at Albany, Empire State Plaza, Albany, NY 12201-0509, USA*

[c]*Department of Food Sciences, Medical University of Gdańsk, 107 Hallera Ave., PL 80-416 Gdańsk, Poland*

* Corresponding author. Email:annakojta@gmail.com

Abstract

Concentrations of mercury (Hg) were determined in 221 specimens of Bay Bolete and in 221 samples of corresponding forest topsoil layer (0-10 cm) collected from 18 sites across geographically and industrially diverse regions of Poland in 2000-2008. Mercury concentrations in caps and stipes of Bay Bolete were strongly correlated ($p < 0.0001$), whereas the relationship between the Hg concentrations in soil and mushrooms varied depending on the sampling location. The Bay Bolete showed a lower bioconcentration potential of Hg at sites with elevated soil Hg concentrations and a higher at sites with lower Hg concentrations in soil. In a view of Hg content, the consumption of Bay Boletes (caps or a whole mushrooms) at the regions surveyed at least at a rate up to 2.5 kg *per capita* weekly in a mushrooming season is safe and will not result in exceeding of currently allowable Hg intake doses.

Keywords: food contamination; heavy metals; mushrooms; nutrition; mercury.

Introduction

Contamination of food resources with Hg from environmental releases of this hazardous metal is a continuous threat to food safety (Olivero et al., 2002). In order to protect human exposure from Hg found in the food supply, the Joint FAO/WHO Expert Committee on Food Additives established for total Hg a new provisional tolerable weekly intake (PTWI) of 0.004 mg kg^{-1} body weight in 2010 (JECFA, 2010). A few earlier studies have shown that wild mushrooms can accumulate mercury from the soil to a considerable amount (Alonso et al., 2000; Chudzyński et al., 2009 and 2011; Falandysz et al., 2001a, 2002a-b, 2003a-d and 2004; Melgar et al., 2009; Stijve and Cardinale, 1974; Zimmermannova et al., 2001). The Bay Bolete mushroom, due to its size and seasonal abundance, is by volume, one of the dominant species of mushrooms harvested in wild each year in Poland. For example, 1705 tons of mushrooms have been harvested from the wild by commercial harvesters in Poland in 2000, and it was 5914 tons in 2008, of which 3275 tons were solely of the genera *Xerocomus* (*X. badius, X. subtomentosus, X. chrysenteron*) (GUS, 2009). These quantities do not account for the amount harvested annually by numerous non-commercial collectors in Poland, where wild mushroom picking is a traditional activity.

Some species of higher fungi (macromycetes) are known for their ability to accumulate metallic elements including hazardous heavy metals such as Hg, Cd or Pb (Brzostowski et al., 2009 and 2011a-b; Chudzyński and Falandysz, 2008; Doğan et al., 2006; Falandysz et al., 2001b, 2007a-c, 2008a-b and 2011; Frankowska et al., 2010; Gast et al., 1988; Gucia et al., 2011a-b; Jarzyńska et al., 2011; Kojta et al., 2011; Malinowska et al., 2004; Melgar et al., 1998; Stijve and Besson, 1976). Concentrations of trace elements in underlying soil or other substratum and bioavailability are among the factors that can affect the concentrations of metals in fruiting bodies (carpophores) of fungi (Bargagli and Baldi, 1984; Borovička et al., 2010; Falandysz et al., 1994; Řanda and Kučera, 2004; Stijve et al., 2004).

Nevertheless, in nature, it is difficult to establish quantitative relationship between the concentrations of metallic element and metalloid content in mushrooms and the underlying substratum (Gast et al., 1988; Falandysz et al., 2011). If mushrooms and topsoil were collected concurrently from both contaminated and background (free of local pollution sources) areas, it is possible to elucidate the relationship soil metal concentrations and residue levels in mushrooms (Barcan et al., 1998; Falandysz et al., 2002c; Carvalho et al., 2005; Stijve and Roschnik, 1974).

In background areas, Cd concentrations in fruiting bodies of the King Bolete (*Boletus edulis*) fungus increased with Cd concentrations in topsoil (Falandysz et al., 2011). A positive association was found between soil methyl mercury concentrations and the concentrations in fruiting bodies of fungi, although the number of evidences is very limited (Fischer et al., 1995). A similar relationship was also observed for total Hg in Parasol Mushroom (*Macrolepiota procera*) (Falandysz and Chwir, 1997).

In this study, we determined total Hg concentrations in Bay Bolete (*X. badius*), and in forest topsoil layer below the fruit bodies, at eighteen sites distantly distributed across Poland. We examined bioconcentration potential of Hg in Bay Bolete and daily intake rates of Hg from mushroom consumption. Bay Bolete is a mycorrhizal fungus associated with coniferous woodland and mixed woodland. The symbiotic trees are supplied by fungus with portion of minerals absorbed by mycelium. Nevertheless, plants are very poor in Hg while mushrooms are relatively abundant in Hg (Cibulka et al., 1996).

Materials and methods

Bay Bolete, *Xerocomus badius* (Fr.) Kühn, is a mycorrhizal mushroom and is a common species found in mixed woodlands of several European countries. The mushroom and topsoil samples (0-10 cm layer; ca. 100 g) were collected from eighteen, geographically diverse regions of Poland during 2000-2008 (Figure 1; Table 1). Mushrooms were cleaned up from adhering plant material and soil particles with a plastic knife and brush and, if necessary, the bottom part of stipe was cut away. Next, the fruiting bodies were initially air-dried for 48 h, and then were oven-dried at 65 °C to a constant weight. Dried mushrooms were crushed and ground in a ceramic mortar to fine powder and kept in a sealed polyethylene bags. Soil substrate samples, after the removal of visible organisms, stones, sticks, and leaves, were air-dried for approximately 10 weeks and then sieved through a 2 mm sieve (Falandysz, 2002; Falandysz et al., 2003a).

Analysis of total Hg content in fruiting bodies and soil was conducted using a direct sample thermal decomposition coupled with gold wool trap, desorption and cold-vapor atomic absorption spectroscopy (CV–AAS; Mercury analyzer type MA–2000, Nippon Instruments Corporation, Takatsuki, Japan) determination (Jarzyńska and Falandysz, 2011a). The procedure for Hg determination was validated through analysis of several certified reference materials including: CS-M-1 (dried fruiting bodies of mushroom, Cow Bolete *Suillus bovinus*); CTA-OTL-1 (tobacco leaves) and INCT-TL-1 (tea leaves) produced by the Institute of Nuclear Chemistry and Technology in Warsaw, Poland. The declared total Hg contents of the certified reference materials were: 0.174±0.018 µg g^{-1} dw for CS-M-1 (our measurements were 0.179±0.008 µg g^{-1} dw; $n = 3$); 0.043 µg g^{-1} dw for CTA-OTL-1 (our measurements were 0.046±0.002 µg g^{-1} dw; $n = 3$); and 0.005±0.001 µg g^{-1} dw for INCT-TL-1 (our measurements were 0.005±0.000 µg g^{-1} dw; $n = 3$). In addition, with every set of 10 mushroom or soil samples analyzed, one procedural blank was included; no contamination or interference was found in blanks (Jarzyńska and Falandysz, 2011a).

Data were evaluated statistically using the computer software Statistica version 8.0. Mercury concentrations in mushrooms and soils have no Gaussian distribution. Data transformation, which aimed to obtain their log-normal distribution, was unsuccessful. Moreover, data variances were heterogeneous (Barlett test). Consequently, statistical analyses were performed with nonparametric tests. A nonparametric Tukey-type multiple comparisons (Nemenyi test) following nonparametric analysis of variance (Kruskall-Wallis test) were applied to indicate diversity of Hg content in soil substratum, and caps and stipes or whole fruiting bodies of specimens from the certain sampling sites surveyed. Further examination of differences in Hg concentrations between the caps (also stipes and soil) from certain localizations was made using Mann–Whitney *U* test.

Results and discussion

Hg in fruiting bodies

Concentrations of total Hg in caps and stipes of Bay Bolete were high in specimens collected from Złotoryja (site *12* Z), and these concentrations differed significantly from samples collected at other locations (Figure 3). The arithmetic mean concentrations of Hg in Bay Bolete's cap varied between 0.051±0.030 and 1.0±1.1 µg g^{-1} dw, depending on the location. The corresponding concentrations of Hg in stipes of Bay Bolete at these sites were between 0.027±0.018 and 0.68±0.86 µg Hg g^{-1} dw. The whole fruiting bodies collected from Kłodzka Dale (*14* KD) contained 0.26±0.06 µg Hg g^{-1} dw. A total Hg concentration of 1.0 µg g^{-1} dw (0.1 µg g^{-1} wet weight) exceeded in two specimens from Włoszczowa (*15* W) and two from Złotoryja (*12* Z) (Table 1).

Mercury concentrations in Bay Bolete at sites that are considered as background (unpolluted) areas varied between 0.051±0.030 and 0.32±0.17 µg g^{-1} dw in caps and between 0.027±0.018 and 0.23±0.12 µg g^{-1} dw in stipes (Table 1). These concentrations are relatively small and comparable to a range of values between 0.26±0.17 and 0.50±0.10 µg g^{-1} dw in caps, and between 0.089±0.026 and 0.16±0.07 µg g^{-1} dw in stipes, reported for the mushroom Larch Bolete (*Suillus grevillei*) as well as between 0.095±0.082 and 0.28±0.07 µg g^{-1} dw in caps and between 0.045±0.018 and 0.13±0.02 µg g^{-1} dw in stipes reported for Slippery Jack (*Suillus luteus*) in Poland (Chudzyński et al., 2009 and 2011). The fungus, Bay Bolete, can be considered as a weak accumulator of Hg in fruiting bodies in comparison with King Bolete (*Boletus edulis*) which contained between 1.2±1.4 and 7.6±3.1 µg Hg g^{-1} dw in caps or with Parasol Mushroom (*Macrolepiota procera*) which contained between 1.1±1.0 and 8.4±7.4 µg Hg g^{-1} dw in caps (Falandysz and Gucia, 2008; Falandysz et al., 2007b and 2008a).

The caps of Bay Bolete, on average, contained higher concentrations of Hg than the stipes (Table 1). The median value for caps to stipe Hg concentration quotient ($Q_{C/S}$), calculated for 221 specimens collected across Poland, was 1.7, and the arithmetic mean was 1.8±0.8 (0.1-6.6).

Nevertheless, the total Hg content in caps of Bay Bolete was significantly correlated with the content in stipes ($r = 0.95$; $p < 0.0001$; Figure 2).

Hg content in topsoil and its relation to concentrations in mushroom

Soil Hg content is an important factor that affects the concentrations of this element in terrestrial plants and edible mushrooms. A concentration of Hg of 1.0 μg g^{-1} dw has been suggested as a reference value for agricultural soil (Rundgren et al., 1992). No such value has been reported for forest soils in Poland. The median Hg concentrations in topsoil at most sampling sites in this study were below 0.1 μg g^{-1} (Table 1). In our earlier surveys, we found that the median values of total Hg concentrations in forest soils in central and northern Europe were below 0.1 μg g^{-1} (Chudzyński et al., 2009 and 2011; Falandysz and Bielawski, 2001 and 2007; Falandysz and Brzostowski, 2007; Falandysz and Chwir, 1997; Falandysz et al., 2001a, 2002a-c, 2003a-d and 2004). It is known that the forest upper layer of soil that is rich in organic matter can easily absorb Hg deposited from the atmosphere and from weathering of parent bedrocks (Suchara and Sucharová, 2002). Nevertheless, the content of organic matter in the top 0-10 cm forest soil layer vary greatly depending on the region, bedrock, vegetation, and age of the forest. The Critical Limit (CL) proposed for Hg(II) in soil is 0.13 μg g^{-1} (when soil properties are taken into account, the value ranges between 0.04 and 1.2 μg g^{-1}). The soil organic matter (SOM) normalized CL is 3.3 μg Hg g^{-1} of SOM (varies between 0.03 and 3.3 μg g^{-1}). This CL value is greater than the value of 0.5 μg g^{-1} SOM, used to estimate Hg effects in European soil ecosystems (Tipping et al., 2010). The total Hg content in forest topsoil (0-10 cm layer) in this study, and in our earlier studies across Poland, was well below the recently proposed CL value for Hg(II) of 0.13 μg g^{-1}.

In earlier two studies, the concentrations of Hg in forest soils were found not dependent on soil type and texture or were elevated in soils of loose sands and slightly clayey relatively rich

161 in humus type (Falandysz et al., 2002b and 2003a). It is worth to mention that no relation with Hg of fruiting bodies and organic matter content or pH of the soils could be observed for fungi in a several studies (Falandysz and Bielawski, 2007; Falandysz and Brzostowski, 2007). No such relation could be observed also between soils organic matter content or pH and metals such as Cd and Pb sequestered in fruiting bodies of several fungi (Gast et al., 1998), as well as of Ag, Al, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Na, Ni, Sr, Pb, Rb and Zn by Pioson Pax, *Paxillus involutus*, mushroom (Brzostowski et al., 2011a), while uptake and sequestration in fruiting bodies of metallic elements essential to fungi (K, Na, Ca, Mg, Zn, Cu) is largely regulated by species. In other words, either organic matter content or pH of soils was found as not important factors that can determine the trace metals bioavailability to fungi. Nevertheless, in the complex process of minerals gaining and absorption by mycelium, and in case of mycorrhizal fungi theirs further transfer to symbiotic plant (tree) and also transfer and sequestering in fruiting bodies there are an unknown underlying variables.

174 The soils Hg concentrations increase moving from the north to the south of Poland (Figure 3). This spatial trend can be related to the degree of industrialization and urbanization of the areas surveyed. Dolnośląskie Voivodeship (the sites nos. 11–14; Fig, 1) is a highly industrialized and urbanized region in Southern Poland and differences in soils bedrock composition between the regions. Furthermore, industrial activities are predominant in Świętokrzyskie Voivodeship (the sites nos. 15 and 16; Southern Poland), where soil Hg concentrations varied considerably (Figs. 1 and 3, Table 1). Of the 18 locations surveyed in this study, 17 locations exhibited no clear relationship between Hg concentration in Bay Bolete and corresponding soil Hg content. At Karpacz (*13* K), a tendency of increasing content of Hg in caps/stipes with increasing soil Hg content was found.

A potential of minerals uptake by fungus from the soil and further sequestration in fruiting bodies is assessed using the common concept of bioconcentration factor (BCF) or otherwise transfer factor or enrichment factor. They are simply the mushroom's constituent concentration divided by the soil (or other substratum media) mineral constituent concentration. The value of BCF for a given trace element is a measure of its site-specific bioavailability for fungus.

Elevated concentration of Hg in topsoil and in parallel a good bioavailability are the reasons for great concentrations of Hg in fruiting bodies of Bay Bolete at the Złotoryja site (Table 1; site *12* Z). However, for the two highly contaminated specimens from the Włoszczowa site (*15* W; containing 2.7 and 1.4 µg Hg g^{-1} dw in caps and 0.89 and 0.87 µg Hg g^{-1} dw in stipes), the driving force for elevated concentrations seems to be great Hg bioavailability (BCF was 80 and 16 for caps and 26 and 10 for stipes).

Hg content of topsoil from the Karpacz site was elevated (compared to the other locations surveyed), although Hg concentration in Bay Bolete in that site was low. This can be attributed to low bioavailability of Hg at this site. Content of methylmercury (MeHg) and its proportion to inorganic Hg in soils can impact amount of total Hg sequestered in fruiting bodies (Fischer et al., 1995). At the Włoszczowa site (*15* W), relatively elevated Hg content was found (0.28 and 0.17 µg g^{-1} dw) in topsoil, while concentrations in caps (0.081 and 0.073 µg g^{-1} dw) and in stipes (0.017 and 0.040 µg g^{-1} dw), were low (BCF between 0.3 and 0.4 for caps and 0.06 and 0.2 for stipes). Thus, the concentrations of Hg accumulated in fruiting bodies varied widely ($p < 0.05$; Mann-Whitney *U* test) among the locations surveyed (Table 1).

Bioconcentration potential

Our results indicate that Bay Bolete can bioconcentrate Hg from the soil. Mercury was found in Bay Bolete, even in unpolluted areas where the BCF (bioconcentration factor) in caps was up to

208 11±6 (Table 1). Bioconcentration factor or transfer factor (TF) is a quotient of Hg concentration
209 in caps or stipes to soil Hg concentration. BCF value below 1 suggests exclusion or bio-exclusion
210 whereas the value above 1 suggests bioconcentration. The values of BCF of Hg in Bay Bolete
211 decreased with increasing soil Hg concentration (Figure 4).

212 ***Hg intake rates***

213 Both cap and stipe of Bay Bolete are edible and accumulation of Hg in both parts of this
214 mushroom is a human health concern. In a well-grown fruiting body of this fungus, cap is much
215 larger in mass than stipe, while in young specimens, the proportion is approximately equal, and in
216 much younger specimens, stipe is larger than cap. Nevertheless, there is no published data on Hg
217 content in caps, stipes or whole fruiting bodies of Bay Bolete collected at different growth stages.
218 The mushroom collectors harvest forest mushrooms daily and individuals, who are late during a
219 mushroom collection day, collect even young fruiting bodies. There are no limits regarding
220 allowable size or allowable daily harvest for mushroom collection or a mushroom species that
221 could be collected by an individual in Poland. For the assessment of daily intake rate of Hg from
222 Bay Bolete, we assumed that the fruiting bodies were collected from mature specimens.

223 Although mushrooms do not constitute a significant portion of human diet, they are
224 popular food items worldwide especially during their seasonal abundance. The data regarding
225 intake rates of wild-grown edible mushrooms at local, regional, national, or international scale
226 are highly limited. For example, as discussed by Zhang et al. (2010), consumption rate of wild-
227 grown mushrooms in Sweden was 1 kg *per capita* annually and Common Chanterelle
228 (*Cantharellus cibarius*) is the most commonly consumed mushroom in that country. In rural
229 areas of Sweden, as well as in rural areas of many other European countries, wild-mushroom
230 picking is a common practice and the intake rates *per capita* are expected to be greater than 1 kg
231 annually. In Czech Republic, 72 % of families take part in wild-mushroom picking, with an

average yield of 7 kg fresh weight *per familia* annually, while annual intake rate by some individuals can be up to 10 kg *per capita* fresh weight. In Sichuan Province in China, the annual wild mushroom consumption rate exceeded 20-24 kg *per capita* (Zhang et al., 2010).

In Poland, a meal of up to 300 g of fresh mushroom is considered as the common intake rate in a single dish *per capita* during a week period among mushroom dish fanciers or individuals with low income rural household. A single dish of up to 500 g of fruiting bodies (fresh weight) collected in wild has been used as daily intake rate of mushrooms *per capita*. (Zhang et al., 2010).

Mushrooms, depending on the species, are cooked in several ways. Any mushroom, wild or cultivated, should not be eaten fresh. Blanching (boiling in water for 10 minutes) of fresh fruiting bodies is a common procedure. Blanched mushrooms could be further baked, used as soup ingredients, pickled, or frozen. Dried mushrooms could be grounded (powdered) and used as a condiment. Dried mushrooms can be soaked in water and added (together with or without broth) to certain traditional dishes and further cooked without loss of mineral constituents. Soaking of fresh fruiting bodies of Bay Bolete in salt (2% of table salt per fresh mushroom weight) water at 20 ºC for 5-15 min resulted in 5-10 % loss of total Hg content, while boiling for 15 min resulted in 15 % loss of this element (Svoboda et al., 2001).

It is not known if both organic and inorganic forms of Hg are leached during blanching or other type of processing. A 15 % loss of total Hg contained in fruiting bodies during blanching of Bay Bolete is considered to be low (Svoboda et al., 2001). Based on the large variation in total Hg content in Bay Bolete (Table 1), the 15% loss rate from food processing step can be ignored in the assessment of Hg intake rates by consumers.

For the assessment of potential risks from intake of Hg in the fruiting bodies of Bay Bolete, a reference dose (RfD; 0.0003 mg kg^{-1} bm daily) and a Provisional Tolerable Weekly

Intake values (PTWI; 0.005 mg kg^{-1} bm) have been used (JECFA, 1978, US EPA, 1987). The PTWI of 5 µg kg^{-1} body weight for total Hg established by the JECFA in 1978 was revised in 2010 (JECFA, 2010). The JECFA established a PTWI of 0.004 mg kg^{-1} bw for inorganic Hg in 2010, based on the assumption that the predominant form of Hg in foods, other than fish and shellfish, is inorganic Hg**.** A meal made with 300-500 g of fresh caps of Bay Bolete collected from the Złotoryja site can result in Hg intake of 0.00025-0.0004 mg kg^{-1} bw (assuming a 60 kg body weight), based on the median Hg concentration of 0.058 µg g^{-1} wet weight. If the intake is calculated from the arithmetic mean of 0.10 µg Hg g^{-1} wet weight (assuming 90 % water content in caps), the intake rate will be 0.00043-0.0007 mg kg^{-1} bw.

Wild mushrooms are more frequently and at higher rate eaten in a mushrooming season in late summer and early fall, while usually much less in other periods of the year. In a view of Hg content, the consumption of Bay Boletes (caps or a whole mushrooms) at the regions surveyed at least at a rate up to 2.5 kg *per capita* weekly in a mushrooming season is safe and will not result in exceeding of currently allowable Hg intake doses.

Bay Bolete collected from the Sierakowice site (an unpolluted area) contained the greatest Hg concentration (Table 1). Consumption of fresh caps of Bay Bolete collected at this site at a rate up to 7.5 kg should not result in Hg intake values exceeding the PTWI limit for a person weighing 60 kg, assuming that no Hg from other foods is ingested. Forest soil at the Złotoryja and Karpacz sites contained elevated concentrations of Hg, and Bay Bolete at the Złotoryja site contained high levels of Hg (Figure 3; Table 1). Consumption of up to 2.4 kg of fresh caps of Bay Bolete from Złotoryja should not exceed the PTWI limit, if no Hg from other foods is ingested.

Selenium in mushroom can provide protective role against Hg (Jarzyńska and Falandysz, 2011b). It is presumed that co-occurrence of selenium and MeHg or total Hg in stoichiometric ratio could prevent the toxic effects of Hg in foods (Yoneda and Suzuki, 1997; Stijve and

Cardinale, 1974; Stijve and Besson, 1976). A review of published data on selenium content in a limited number of Bay Bolete samples collected in Europe indicated that selenium content in fruiting bodies usually varies around 0.20 µg g^{-1} dw (Falandysz, 2008), which is comparable to Hg content found in Bay Bolete in this study (Table 1).

The PTWI for MeHg is 0.0016 mg kg^{-1} bw (JECFA, 2007).We did not analyze MeHg content in Bay Bolete in this study. Fischer et al. (1995) reported that 0.70 to 1.1 % of total Hg content in Bay Bolete is in the form of MeHg in a highly contaminated area (15-35 µg Hg g^{-1} dw). Pilz et al. (2011) in a recent study reported on MeHg content of five species of fungi: an unknown fungus, Cordoncella mushroom (King Bolete?), *Pleurotus djamer*, *P. citrinopileatus* and *P. ostreatus*, where this compound varied a somehow between the species but largely varied depending on the extraction method used, i.e. by ultrasonic (from 3 to 38 % of total Hg) or microwave assisted extraction (from 15 to 41 % of total Hg). Data available on MeHg in wild mushrooms are sparse and controversial. As reviewed recently, reported MeHg content of King Bolete (*Boletus edulis*) varied highly (from 0.6 to 39 % of total Hg) between the authors (Falandysz, 2010).

Conclusions

Hg concentrations in pooled caps of Bay Bolete collected from unpolluted areas in Poland were below 1.0 µg Hg g^{-1} dw. Mercury concentrations in caps and stipes of Bay Bolete were strongly correlated ($p < 0.0001$). The relationship between the concentrations of Hg in soil and in mushrooms varied depending on the location. The bioconcentration potential of Hg in Bay Bolete at sites with elevated soil Hg concentrations was lower than that in soils with low Hg content. In a view of Hg content, the consumption of Bay Boletes (caps or a whole mushrooms) at the regions surveyed at least at a rate up to 2.5 kg *per capita* weekly in a mushrooming season is safe and will not result in exceeding of currently allowable Hg intake doses.

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Figure Captions

Figure 1. Locations of the sampling sites of Bay Bolete in Poland. Abbreviations: The communes of Sierakowice (1) and Lipusz in Pomorskie Voivodeship (2); Augustowska Forest in Podlaskie Voivodeship (3); Olsztynek (4) Szczytno in Warmia and Mazury Voivodeship (5); Commune of Olszewo-Borki in Mazowieckie Voivodeship (6); Notecka Forest (7), Porażyn (8), Rogalin (9) Turek in Wielkopolska Voivodeship (10); Lower Silesia Forest (11), Złotoryja (12), Karpacz (13) and Kłodzka Dale in Dolnośląskie Voivodeship (14); Włoszczowa (15) and Starachowickie Forest in Świętokrzyskie Voivodeship (16); Poniatowa in Lubelskie Voivodeship (17); Chochołowska Valley in Małopolska Voivodeship (18).

Figure 2. Plot of Hg concentrations in caps against its concentrations in stipes of 221 fruit bodies of Bay Bolete collected from Poland ($y = 0.0231 + 1.4949*x$; $r = 0.95$; $r^2 = 0.89$; $p < 0.0001$).

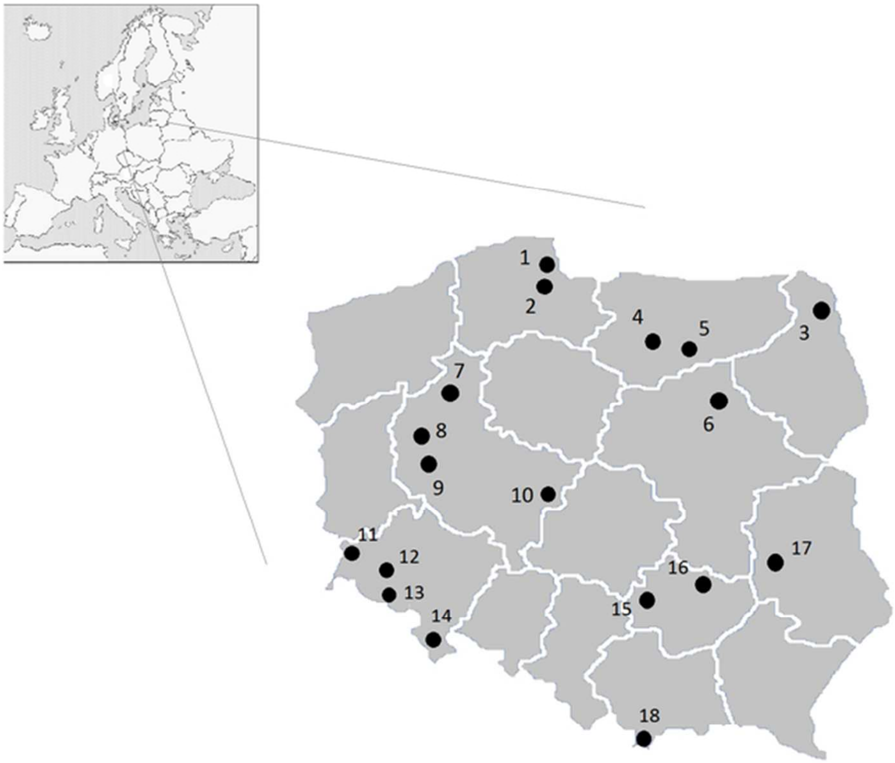
Figure 3. Median values of Hg concentration in caps or in whole specimens of Bay Bolete and in soil substrate collected under mushrooms: the sampling sites are displayed starting from the north to the south of Poland. Abbreviations: **CS** (1) Mojusz in Commune of Sierakowice and **CL** (2) Commune of Lipusz in Pomorskie Voivodeship; **AF** (3) Augustowska Forest in Podlaskie Voivodeship; **O** (4) Olsztynek and **S** (5) Szczytno in Warmia and Mazury Voivodeship; **O**-B (6) Commune of Olszewo-Borki in Mazowieckie Voivodeship; **NF** (7) Notecka Forest, **P** (8) Porażyn, **R** (9) Rogalin and **T** (10) Turek in Wielkopolska Voivodeship; **LSF** (11) Lower Silesia Forest, **Z** (12) Złotoryja, **K** (13) Karpacz and **KD** (14) Kłodzka Dale in Dolnośląskie Voivodeship; **W** (15) Włoszczowa and **SF** (16) Lipie in Starachowickie Forest in Świętokrzyskie Voivodeship; **P-LV** (17) Poniatowa in Lubelskie Voivodeship; **CH** (18) Chochołowska Valley in Małopolska Voivodeship.

Table 1. Mean, standard deviation, range and median values of total mercury concentration in fruiting bodies of mushroom and soil, and cap to stipe concentration quotient and bioconcentration factor (BCF) values for mercury.

Site, year and number of samples	Hg (μg g-1 dw)			$Q_{C/S}$	BCF	
	Cap	Stipe	Soil		Cap	Stipe
1 (CS) Mojusz, Commune of Sierakowice, Pomorskie Voivodeship, 2007 *n = 12*	0.32±0.17 (0.13-0.65) 0.29	0.23±0.12 (0.081-0.43) 0.21	0.11±0.09 (0.024-0.26) 0.053	1.4±0.3 (0.95-2.1) 1.4	5.4±5.4 (0.86-17) 3.3	4.1±4.1 (0.42-13) 2.4
2 (CL) Commune Lipusz, Pomorskie Voivodeship, 2006 *n = 15*	0.14±0.09 (0.080-0.41) 0.10	0.070±0.02 (0.039-0.13) 0.063	0.046±0.033 (0.022-0.14) 0.037	2.0±1.3 (1.3-6.6) 1.6	3.9±2.5 (0.60-8.4) 3.1	2.0±1.3 (0.45-5.1) 1.6
3 (AF) Augustowska Forest, Podlaskie Voivodeship, 2007 *n = 15*	0.099±0.033 (0.062-0.20) 0.091	0.067±0.020 (0.042-0.12) 0.060	0.075±0.046 (0.020-0.19) 0.046	1.5±0.1 (1.3-1.7) 1.5	2.0±1.4 (0.54-4.5) 1.5	1.3±0.8 (0.37-2.8) 1.2
4 (O) Olsztynek, Warmia and Mazury Voivodeship, 2002 *n = 15*	0.080±0.020 (0.052-0.13) 0.077	0.044±0.013 (0.031-0.083) 0.040	0.051±0.043 (0.013-0.20) 0.041	1.9±0.4 (1.1-2.5) 1.9	2.2±1.3 (0.29-5.1) 2.1	1.2±0.7 (0.21-2.9) 1.1
5 (S) Szczytno, Warmia and Mazury Voivodeship, 2002 *n = 15*	0.061±0.013 (0.041-0.093) 0.062	0.040±0.009 (0.029-0.058) 0.039	0.040±0.010 (0.022-0.054) 0.042	1.6±0.2 (1.3-2.0) 1.6	1.6±0.6 (1.0-2.8) 1.4	1.1±0.4 (0.65-2.0) 0.97
6(O-B) Commune of Olszewo – Borki, Mazowieckie Voivodeship, 2007 *n = 15*	0.20±0.09 (0.047-0.39) 0.18	0.12±0.06 (0.025-0.22) 0.12	0.026±0.022 (0.0063-0.079) 0.022	1.7±0.6 (1.2-3.8) 1.6	11±6 (1.6-22) 13	7.2±5.2 (1.0-19) 4.4
7(NF) Notecka Forest, Wielkopolska Voivodeship, 2008 *n = 15*	0.057±0.028 (0.028-0.13) 0.055	0.048±0.023 (0.007-0.091) 0.043	0.038±0.027 (0.009-0.072) 0.028	1.5±1.0 (0.68-4.4) 0.98	2.0±1.3 (0.46-5.2) 1.7	1.9±1.5 (0.18-5.5) 1.9
8 (P) Porażyn, Wielkopolska Voivodeship, 2008 (*15*)	0.052±0.025 (0.011-0.092) 0.057	0.031±0.017 (0.009-0.073) 0.032	0.073±0.030 (0.010-0.12) 0.077	1.7±0.5 (0.31-2.8) 1.8	1.1±1.3 (0.16-5.4) 0.78	0.64±0.71 (0.074-3.0) 0.45
9 (R) Rogalin, Wielkopolska Voivodeship,	0.092±0.050 (0.019-0.19)	0.042±0.021 (0.013-0.088)	0.10±0.08 (0.010-0.27)	2.2±0.7 (0.67-3.2)	2.3±2.8 (0.12-8.8)	1.0±1.3 (0.091-4.1)

2008 *n = 14*	0.088	0.041	0.098	2.3	1.2	0.50
10 (T) Turek, Wielkopolska	0.051±0.030	0.027±0.018	0.048±0.006	2.3±1.4	1.1±0.6	0.58±0.38
Voivodeship,	(0.016-0.11)	(0.0055-0.057)	(0.038-0.057)	(1.1-5.0)	(0.40-2.0)	(0.12-1.1)
2001-2002 *n = 11*	0.041	0.027	0.046	1.7	0.76	0.47
11 (LSF) Lower Silesia	0.21±0.21	0.095±0.095	0.15±0.10	2.3±0.9	1.7±1.7	0.72±0.62
Forest, Dolnośląskie	(0.071-0.78)	(0.026-0.37)	(0.044-0.41)	(1.3-4.2)	(0.44-5.0)	(0.22-2.3)
Voivodeship,	0.13	0.079	0.12	2.0	1.0	0.49
2008 *n = 11*						
12 (Z) Złotoryja,	1.0±1.1	0.68±0.86	0.37±0.16	1.0±0.7	3.2±3.1	2.0±2.4
Dolnośląskie Voivodeship,	(0.38-3.7)	(0.21-2.8)	(0.18-0.71)	(0.13-2.3)	(0.82-10)	(0.43-7.8)
2008 *n = 9*	0.58	0.30	0.36	1.0	1.5	1.0
13 (K) Karpacz,	0.25±0.14	0.13±0.06	0.50±0.20	2.1±0.9	0.55±0.31	0.28±0.13
Dolnośląskie Voivodeship,	(0.087-0.53)	(0.059-0.24)	(0.16-0.77)	(0.39-4.5)	(0.19-1.2)	(0.12-0.49)
2008 *n = 15*	0.19	0.092	0.46	2.0	0.49	0.28
14 (KD) Kłodzka Dale,	0.26±0.06		0.15±0.01***		1.3±0.5	
Sudety Mountains,	(0.18-0.32)		(0.13-0.17)		(1.3-2.4)	
Dolnośląskie Voivodeship,	0.26		0.14	ND	1.8	
2001 *n = 5***						
15 (W) Włoszowa,	0.36±0.73	0.17±0.31	0.068±0.073	2.7±1.0	9.3±20.0	3.8±7.2
Świętokrzyskie Voivodeship,	(0.064-2.7)	(0.017-0.88)	(0.011-0.28)	(1.6-4.8)	(0.29-80)	(0.059-26)
2007 n = *15*	0.098	0.042	0.047	2.5	2.3	1.1
16 (SF) Lipie,	0.11±0.03	0.084±0.040	0.14±0.05	1.5±0.4	0.87±0.39	0.68±0.49
Starachowickie Forest,	(0.073-0.20)	(0.038-0.17)	(0.074-0.21)	(0.55-2.1)	(0.34-1.7)	(0.18-2.2)
Świętokrzyskie Voivodeship,	0.11	0.075	0.15	1.6	0.75	0.51
2000 n = *15*						
17 (P-LV) Poniatowa,	0.16±0.04	0.082±0.028		2.0±0.5		
Lubelskie Voivodeship,	(0.12-0.2)	(0.062-0.13)		(1.7-2.1)		
2008 *n = 15*	0.14	0.070	ND	1.7	ND	ND
18 (CH) Chochołowska Dale,	0.24±0.10	0.15±0.01		1.5±0.4		
Małopolska Voivodeship,	(0.10-0.42)	(0.13-0.17)		(0.84-2.4)		
Tatra Mountains, 2000 *n = 9*	0.24	0.14	ND	1.5	ND	ND

Notes: *Number of samples and number of specimens (in parentheses); ND, not determined; **a whole fruiting bodies; ***15 samples



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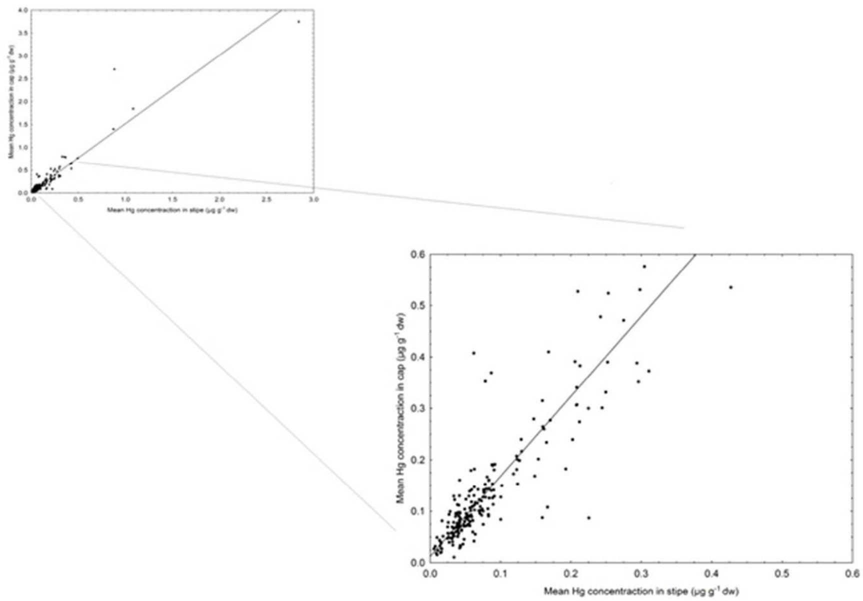

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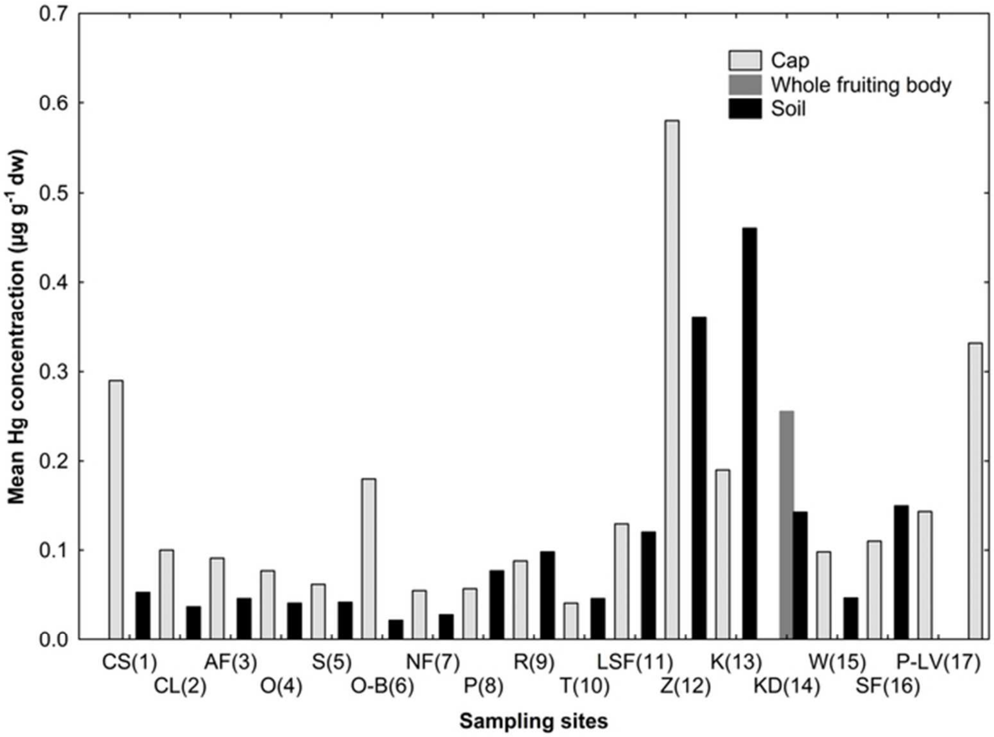

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