Journal of Environmental Radioactivity 231 (2021) 106549

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: http://www.elsevier.com/locate/jenvrad

^{137}Cs and ^{40}K activities and total K distribution in the sclerotia of the *Wolfiporia cocos* fungus from China

Jerzy Falandysz [a,b,c,1,*], Yuanzhong Wang [c,d], Michał Saniewski [e]

[a] University of Gdańsk, Environmental Chemistry & Ecotoxicology, 80-308, Gdańsk, Poland
[b] Environmental and Computational Chemistry Group, School of Pharmaceutical Sciences, Zaragocilla Campus, University of Cartagena, 130015, Cartagena, Colombia
[c] Medicinal Plants Research Institute, Yunnan Academy of Agricultural Sciences, Kunming, 650200, China
[d] Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Kunming, 650223, China
[e] Institute of Meteorology and Water Management – Maritime Branch, National Research Institute, 42 Waszyngtona Av., 81-342, Gdynia, Poland

ARTICLE INFO

Keywords:
Asia
Functional foods
Medicinal fungi
Potassium
Radiocaesium
Traditional medicines

ABSTRACT

The activity concentration of ^{137}Cs and ^{40}K and total K content in the sclerotia of the Chinese medicinal fungus *Wolfiporia cocos* collected mainly from Yunnan province of China during the period 2013–2015 were investigated. *W. cocos* in Yunnan is collected from the wild and is cultivated in field conditions and the wood substrate used is derived from the local pine (*Pinus yunnanensis* Franch.) logs from neighborhood forests. The outer part of sclerotia was found to be richer than the inner one in both ^{137}Cs and ^{40}K with median values of 7.3 and 3.2 Bq kg^{-1} dry weight (dw) for ^{137}Cs, 220 and 140 Bq kg^{-1} dw for ^{40}K. The median K concentrations were 6800 mg kg^{-1} dw in the outer and 3700 mg kg^{-1} dw in the inter parts. No statistically significant correlation was found for activity concentrations between the inner and outer parts, both for ^{137}Cs and ^{40}K ($p > 0.05$). Using the median activities of ^{137}Cs, the nominal values of effective dose (mSv) for exposed adults annually consuming 50 g of sclerotia, were estimated at 0.0035 mSv and 0.084 mSv (outer part), and 0.0020 mSv and 0.040 mSv (inner part) *per capita*, respectively. Sclerotia of *W. cocos* seemed to be a relatively good source of K.

1. Introduction

Traditional herbal medicines are an important part of the traditional welfare and economy in some Asian countries. In particular, Chinese herbal medicines are prospering in continental Asia and overseas. The products used in herbal medicine include various herbal plants, teas and fungi that can be vulnerable to contamination with radionuclides including radiocaesium and other contaminants (Zaidman et al., 2005). Traditional Chinese herbal medicine uses many fungal (mushroom) products including the sclerotia of the fungus *Wolfiporia cocos* which are also used as functional foods with physiological benefits (Fig. 1) (Chang and Wasser, 2012).

Sclerotia (singular, sclerotium) refer to the dense mass of mycelium that is produced underground by some saprophytic fungi that grow in the warmer regions of the world (Kibar, and Pekşen, 2012). The sclerotium or storage tuber of wood-decaying fungi is buried within the decaying wood or in the underlying soil substrate. As a tuber, the sclerotium stores energy in proteins and polysaccharides and is also rich in other food nutrients. For example, the sclerotia of *Pleurotus tuber-regium* (Ósu), called king tuber oyster or tiger milk mushroom, is a food resource used in the tropical and subtropical regions of the word (Nnorom et al., 2013).

The *Wolfiporia cocos* (Schwein.) Ryvarden & Gilb. [previous names *Wolfiporia extensa* (Peck) Ginns or *Poria cocos* F.A. Wolf.] (Species Fungorum, 2019), is a species of wood rotting fungi (brown-rot) that colonise dead wood buried in soil (Ríos, 2011). This fungus growing in the wild can produce sclerotia of large sizes that can reach more than 20 kg in fresh weight (Wiejak et al., 2016). Fungi extract mineral nutrients and pollutants from soil and other substrates in which their mycelia grow and their capacity to bio-accumulate certain mineral constituents including radiocesium ($^{134/137}Cs$) in the fruiting bodies is astonishing (Falandysz et al., 2016).

In China, *W. cocos* is widely collected from the wild and is also cultivated in large quantities (the estimated annual production of dried product was 19,000 tonnes in 2009 (Yu et al., 2011), and 30,000 tonnes in recent years) (Chen et al., 2019). A review by Wang et al. (2013)

* Corresponding author. University of Gdańsk, Environmental Chemistry & Ecotoxicology, 80-308, Gdańsk, Poland.
E-mail address: jerzy.falandysz@gmail.com (J. Falandysz).
[1] visiting professor (JF).

https://doi.org/10.1016/j.jenvrad.2021.106549
Received 6 May 2020; Received in revised form 15 November 2020; Accepted 30 January 2021
Available online 13 February 2021

noted that the sclerotia of *W. cocos* was: "one of the most important crude drugs and is traditionally used as a medicinal mushroom in the Chinese and Japanese traditional medicines". The medicinal properties of the *W. cocos* sclerotia are considered to be related to the presence of various triterpenes and polysaccharides (Wang et al., 2013). They can be also a source of minerals for consumers (Falandysz et al., 2017a) of this fungi, but this aspect has been little studied so far apart from a few studies on the sclerotial bio-accumulation of common environmental contaminants such as mercury (Hg) and radionuclides (Wang et al., 1998, 2015; Wiejak et al., 2016).

Pollution of forest ecosystems due to deposition of airborne radionuclides from nuclear weapon detonations and nuclear power plant accidents can affect plants and various foods (Steinhauser et al., 2014). Mushrooms, the fruiting bodies of fungi of any kind, can be prone to this long lasting contamination with radionuclides aerially deposited (dry and wet fallout) in forests and woodlands and meadows and fields as well, especially with radiocaesium (Betti et al., 2017; Cocchi et al., 2017; Falandysz et al., 2016; Saniewski et al., 2016; Türkekul et al., 2018). The reason is that: (i) the physical half-life time of ^{137}Cs is relatively long ($t_{1/2}$ = 30.15 years), (ii) deposited ^{137}Cs is strongly retained in the organic layer of forest soil (Koarashi et al., 2019), which also contains large numbers of the mycelia and rhizomorphs network of many fungal species (van der Heijden et al., 2015; Yafetto, 2018), (iii) radiocaesium very slowly infiltrates deeper soil layers, (iv) mycelia easily absorb monovalent ions such as K^+, Rb^+, Cs^+ from soil solution, (v) while the concentration of stable cesium (^{133}Cs) in different fungi differ, there appears to be to some degree a species-specific predilection for uptake of ^{133}Cs and hence also favorable accumulation of radiocaesium and regardless hypothetical availability of Cs isotopes from contaminated soil (it is not currently clear if Cs is an element essential for fungi) (Falandysz et al., 2019, 2020), and (vi) ^{137}Cs found in the fruiting bodies (sporocarps, pileus) is extracted from whole layer of soil where mycelium lives including a deeper layers of soil (up to 50 cm) in case of some species (no mention about a role of rhizomorphs, whose role so far has not been studied regarding participation in accumulation of radiocaesium in fruiting bodies), but when these decay and breakdown ^{137}Cs remains (through the biogeochemical cycle to some extent) in the top layer of forest soils, ensuring availability for a longer time (Falandysz et al., 2019).

The objective of this study was to obtain an insight into the occurrence, distribution and possible exposure to ^{137}Cs and the intake of the total K from sclerotium of *W. cocos,* by analysis, for the first time, of both the outer and inner parts (layers) of the farmed and wild type sclerotia products collected largely from the Yunnan province of China during the period 2013–2014.

2. Experimental method

As in other locations in Asia, *W. cocos* that grows in the southern and south-western regions of China is found in pine forests. In Yunnan province this fungus is found on red and yellow earths, latosols and lateritic red earths (according to the Chinese soil classification system) that are polymetallic and humid. The conditions used by cultivars of *W. cocos* largely mimic that of wild growing individuals and the wood used for its cultivation are mostly pieces of pine (*Pinus yunnanensis*) trunks. Seasonally, in Yunnan, sclerotia are excavated in November,

Fig. 1. Sclerotia of *Wolfiporia cocos* (colour figure available on-line). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

December and January. Sclerotia of the fungus *Wolfiporia cocos* (Schwein.) Ryvarden & Gilb. were obtained either directly from the cultivars: 10 composite samples from collectors across the Yunnan province, 1 sample from Anhui province, 6 composite samples (wild type) from Yunnan province collected during the period 2013–2015 with majority in 2014 (Fig. 2) and two samples of the inner part of sclerotia of unknown origin were collected from retail outlets of traditional Chinese herbal medicine products (Table 1).

The sampling sites of sclerotia from Yunnan province were localized at 617–2560 m above sea level. The collected individual sclerotia pieces, which were perfectly cleaned from soil/wood debris by using a soft brush (Li and Wang, 2018), were used. Each solely piece of sclerotium (from 4 to 63 individual pieces per site; Table 1) was separated into the outer (brownish) and inner (white; called *fu-ling* in Mandarin) parts. But, the sclerotium size varied among individuals. Therefore, for individuals at the small size (like < ~10 cm diameter; ~100 g dw), the whole individuals were used to make a composite sample and for the bigger ones, was cut and selected a part of the individuals (~100 g dw) to make a composite samples. The numbers for diameter or dry weight biomass were estimated, because we didn't measure them. Next, the sclerotia parts within a pool were sliced using a ceramic knife into small pieces and dried at 105 °C for 24 h, then powdered in a porcelain mortar. The composite samples of ground dried sclerotia (from 300 to 700 g) were divided into two parts (ca. 100 g and 600 g, respectively) that were placed into sealed low density polyethylene bags and kept in dry and clean condition. The ~100 g part was reserved for nuclides analysis.

The activity concentrations of ^{137}Cs and ^{40}K in the dehydrated samples (extra lyophilized for 48 h before analysis; biomass was in the range from 10 to 25 g dry weight and were measured in cylindrical dishes, φ 40 mm) were determined using a gamma spectrometer with a coaxial HPGe detector with a relative efficiency of 18% and a resolution of 1.9 keV at 1.332 MeV. All measurements of the fungal materials were preceded by background measurement (time 80,000 s or 250,000 s), which were subtracted (the GENIE, 2000 program) from the sample measurement. The equipment was calibrated using a multi-isotope standard and the method was fully validated. The laboratory participates in national and international intercalibration trials annually. Each year are determined the activity concentrations of ^{90}Sr and ^{137}Cs in sea water and every few years also in other materials including certified reference materials for radionuclides in Bikini Atoll sediment (IAEA-410) and Pacific Ocean sediment (IAEA-412) in 2013, certified reference material IAEA-446 for radionuclides in Baltic Sea seaweed in 2011 and reference material (IRMN-426) wild (blue) berries in 2011, and reliability and accuracy of the measurements were accepted (Pham et al., 2016).

The detector system was calibrated using the gamma mixed standards (Standard solution of gamma-emitting isotopes, code BW/Mix-γ/14/16) produced at the IBJ-Świerk near Otwock in Poland. The radionuclides used in the reference solution during equipment calibration were ^{241}Am, ^{109}Cd, ^{57}Co, ^{51}Cr, ^{113}Sn, ^{85}Sr, ^{137}Cs, ^{54}Mn, ^{65}Zn, ^{60}Co and approximation errors were at a level of 0.8–2.1%. This reference solution was used for preparing reference samples for equipment calibration. For equipment calibration, reference samples were analyzed in cylindrical plastic containers (φ 40 mm) with the same geometry as those applied for sclerotia samples. The calibration was carried out using standards with a density of approximately 1 g cm^{-3} (liquid) with different heights: 1, 3, 5, 7, 10, 15, 20, 25 mm, in order to match samples varying in thickness layer. The reliability and accuracy of the measurements, as well as comparability, were positively verified by the participation in the intercalibrations organized within the National Atomic Energy Agency in Poland (PAA) and analysis organized yearly by IAEA-MEL Monaco where activity of ^{137}Cs were analyzed in water samples. In the IAEA intercalibration trial, the reported laboratory result for ^{137}Cs in water sample was 0.24 ± 0.01 Bq dm^{-3} (assigned value was 0.26 ± 0.01 Bq dm^{-3}), and in the PAA trial was 18.52 ± 0.52 Bq dm^{-3} (assigned 18.78 ± 0.56 Bq dm^{-3}). The results were decay corrected back to the time of sclerotia samples collection.

Concentrations of stable K (Table 1) were calculated using the activity concentration of ^{4} K in natural potassium which ranges between 27.33 and 31.31 Bq g^{-1} of potassium (Samat et al., 1997). Statistical analysis was performed using R 3.5.3 (R. Core Team, 2019).

3. Results and discussion

3.1. ^{137}Cs, ^{40}K and total K in sclerotia

As given in Table 1, the determined activity levels of ^{137}Cs in the composite samples of sclerotia differed according to the period and site

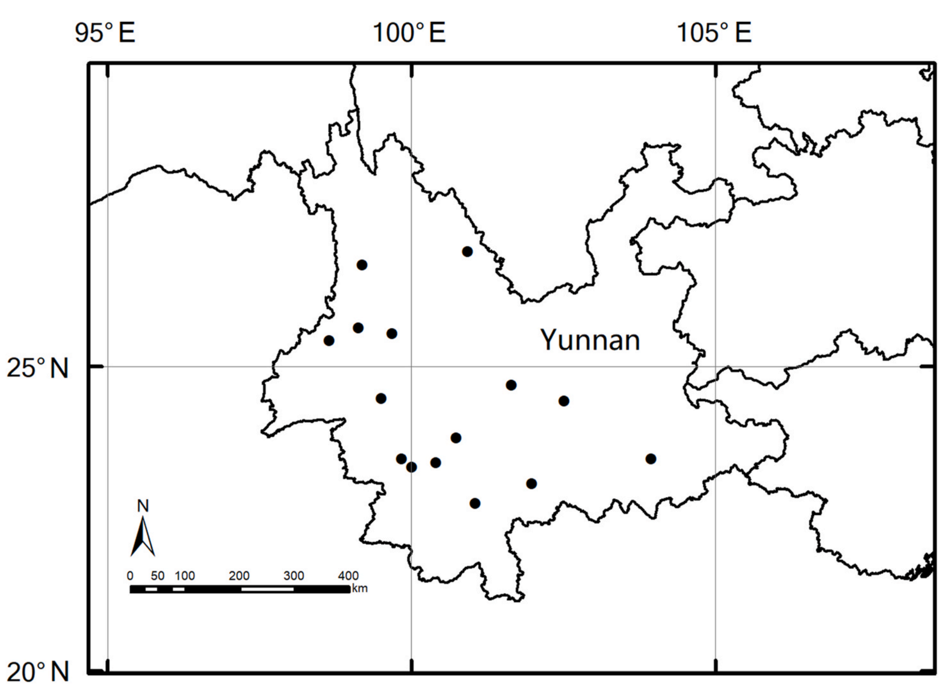

Fig. 2. Localization of the sampling sites of *W. cocos* from China.

Table 1
^{137}Cs and ^{40}K activity concentrations and K (total) contents in sclerotia of *Wolfiporia cocos* from China.

Region, sampling place and kind of sclerotia	Year[#]	Height a.s.l. (m)	Coordinates (North: East)		n*	^{137}Cs (Bq kg^{-1} dw)		^{40}K (Bq kg^{-1} dw)		Total K (mg kg^{-1} dw)	
						Part					
						Outer	Inner	Outer	Inner	Outer	Inner
Lijiang, Ninglang[c]	2014	2560	26°52′59.49″	100°55′39.13″	38	< 4.8[b]	< 2.6	< 130	130 ± 63	< 3700	3700 ± 1900
Nujiang, Lanping[d]	2013	2495	26°39′48.19″	99°11′23.84″	22	5.9 ± 1.2[a]	3.9 ± 0.9	340 ± 94	130 ± 60	6800 ± 4400	6900 ± 2000
Nujiang, Lanping[d]	2014	2495	26°39′48.19″	99°11′23.84″	8	5.7 ± 1.9	4.9 ± 1.0	220 ± 150	230 ± 69	9900 ± 2800	3700 ± 1800
Dali, Yunlong[d]	2014	2066	25°38′9.7512″	99°7′55.0811″	13	8.0 ± 2.1	3.1 ± 1.2	310 ± 150	180 ± 65	9200 ± 4300	5400 ± 1900
Chuxiong, Shuangbai[d]	2014	2062	24°41′28.21″	101°38′57.42″	21	11 ± 2	< 2.2	440 ± 150	< 73	13000 ± 4000	< 2200
Baoshan, Changning[c]	2014	2011	24°28′08.51″	99°30′11.47″	22	7.3 ± 1.7	WD	210 ± 110	WD	6200 ± 3200	WD
Pu'er, Mojiang[c]	2014	1979	23°4′3.4824″	101°58′35.50″	8	9.1 ± 1.9	8.6 ± 1.0	210 ± 130	240 ± 64	6200 ± 3800	7100 ± 1900
Dali, Yongping[d]	2013	1943	25°32′09.82″	99°41′05.70″	20	7.4 ± 1.7	< 1.4	340 ± 110	180 ± 60	9900 ± 3300	5400 ± 1800
Pu'er, Zhenyuan[c]	2014	1892	23°49′12.04″	100°44′26.82″	5	7.3 ± 1.7	3.4 ± 1.1	170 ± 130	140 ± 73	5100 ± 3700	4000 ± 2200
Yuxi, Hongta[c]	2014	1720	24°25′54.7″	102°31′5.6″	21	< 3.0	< 3.0	< 150	220 ± 75	<4400	6500 ± 2200
Baoshan, Tengchong[c]	2014	1582	25°25′20.32″	98°39′08.66″	18	< 5.8	3.7 ± 0.8	440 ± 150	150 ± 61	13000 ± 4400	4100 ± 1800
Wenshan, Baozhu[d]	2014	1504	23°28′29.99″	103°56′50.35″	63	< 4.7	5.3 ± 1.1	220 ± 120	79 ± 64	6400 ± 3500	2300 ± 1900
Lincang, Shuangjiang[c]	2014	1438	23°20′55.478″	100°0′17.0856″	15	10 ± 3	3.7 ± 0.9	340 ± 150	120 ± 65	10000 ± 5000	3600 ± 1700
Pu'er, Simao[c]	2014	1474	22°44′55.295″	101°3′22.6368″	4	< 5.7	4.7 ± 1.1	< 570	< 80	< 16000	< 2400
Pu'er, Jinggu[c]	2014	1077	23°25′13.454″	100°24′15.678″	19	7.8 ± 1.6	< 2.7	310 ± 150	120 ± 69	10000 ± 3000	3700 ± 2000
Lincang, Shuangjiang[c]	2014	1052	23°28′40.537″	99°50′16.134″	11	< 6.8	< 2.8	550 ± 170	< 77	16000 ± 5000	< 2300
Yuexi, Anhui Province[c]	2015	617	31°4′8.584″	116°6′49.1472″	16	12 ± 2	3.0 ± 1.3	< 140	170 ± 70	< 4100	5100 ± 2100
Guangxi Province[e]						WD	2.5 ± 0.7	WD	< 74	WD	<2200
Pu'er, Simao[e]						WD	3.1 ± 0.6	WD	<83	WD	<2400
Mean						5.4	3.0	270	130	7900	3800
SD						3.2	2.0	130	64	4800	1900
Median[f]						7.3	3.2	220	140	6800	3700
Minimal						< 3.0	< 1.4	< 130	< 73	< 3700	< 2200
Maximal						12 ± 2	8.6 ± 1.0	550 ± 170	240 ± 64	16000 ± 5000	6900 ± 2000

Notes: Year[#]: Usually excavated in winter time (November–January); n* (number of a solely sclerotia in a pool).
WD (without data, material not available).
[a] Activity concentration and measurement uncertainty.
[b] If < LOD, a half of the value was used for calculation of mean content.
[c] cultivated.
[d] Wild.
[e] Commodity samples purchased from a Chinese herbal medicine market.
[f] Without the commodity products.

of collection, but were relatively low, ranging from < 3 Bq kg^{-1} dw to 12 ± 2 Bq kg^{-1} dw in the outer part (median 7.3 Bq kg^{-1} dw), and from < 1.4 Bq kg^{-1} dw to 8.6 ± 1.0 Bq kg^{-1} dw in the inner part (median 3.2 Bq kg^{-1} dw). The outer, brownish parts of sclerotia samples from Yunnan and from Anhui province (one sample) in this study showed on average, around twice the activity levels of ^{137}Cs as compared to the inner white parts. Also in the case of ^{40}K, around twice higher activity was found for the outer part, and consequently they showed also greater concentration of total K than the inner parts, which may have structural reasons due to differentiation of shell (outer part) and core (inner part). ^{137}Cs activity levels in the two commodity products of unknown origin were 2.5 and 3.1 Bq kg^{-1} dw. The ^{137}Cs activity in the inner parts of sclerotia as noted in this study were similar to the results in corresponding parts of samples collected previously in Yunnan in 2012 showing median activity concentration at 3.4 Bq kg^{-1} dw (range < 1.4–7.2 Bq kg^{-1} dw) (Wang et al., 2015), while two products from an indoor cultivar in Taiwan (collected in 1994; no information on the activity levels of the substrate used for indoor cultivation has been provided) showed < 1.0 Bq kg^{-1} dw (Wang et al., 1998).

W. cocos has some potential to accumulate radiocaesium in sclerotia and clearly the outer layers were more contaminated than the inner, but there was no statistically significant correlation between the activity concentration in the inner and outer parts ($p > 0.05$; $y = -0.316X + 8.586$, where X is the activity concentration in the inner part, and Y is the activity concentration in the outer part; Pearson linear correlation). Similarly, the potassium concentration in the inner part of sclerotia also did not correlate with the concentration of this element in the outer part ($p > 0.05$; $y = -0.7921X + 401.4008$, where X is the activity concentration in the inner part, and Y is the activity concentration in the outer part), and there was also no correlation between the activity concentrations of ^{137}Cs and ^{40}K in the inner part ($p > 0.05$; $y = 13.25X + 100.76$, where X is the ^{137}Cs activity concentration, and Y is the ^{40}K activity concentration) and in the outer part ($p > 0.05$; $y = -7.638X + 341.132$, where X is the ^{137}Cs activity concentration, and Y is the ^{40}K activity concentration). On the other hand, the mercury concentration in the inner part of sclerotia was highly dependent ($p < 0.001$; $r = 0.82$) on the concentration of the element in the outer layer (Falandysz et al., 2020b). Hence, a lack of a relationship between the parameters examined in this study cannot be used to make a subjective selection of the inner and outer parts when processing sclerotia. The element K is essential for fungi and it is also the major mineral constituent in their flesh (Jarzyńska and Falandysz, 2012). On the other hand, the element Cs is a relatively minor mineral constituent of sclerotia [total Cs (^{133}Cs and ^{137}Cs) in the inner layer was in the range from < 0.001 mg kg^{-1} dw to 0.043 mg kg^{-1} dw)] (Falandysz et al., 2017a).

The activity concentrations of ^{137}Cs in both layers of sclerotia in this study are within the values reported in caps and stipes of fruiting bodies of numerous edible and medicinal fungi collected from the wild in Yunnan in the period 2010–2016, which rarely contained this nuclide at activity levels exceeding 12 Bq kg^{-1} dw (Falandysz et al., 2015a,b; 2016; 2017a,b; 2018; 2020c; Tuo et al., 2017). In this study, the higher, above median values of the activity of ^{137}Cs in sclerotia (outer layer) from several sites (Shuangbai and Shuangjiang at 1438 m a.s.l. in Yunnan province or in Yuexi in Anhui province) may be related to local differences in past radioactive fallout and local weather patterns (local rain).

This observed low contamination with ^{137}Cs of the sclerotia collected in Yunnan can be explained due to the feeding behaviour of *W. cocos* as a dead wood decomposer and by a low level of soil contamination with this nuclide, which is characterized by activity concentrations of 0.7 ± 0.5 to 2.8 ± 0.8 Bq kg^{-1} dw in the 0–1 cm layer, at 4.9 ± 0.6 to 7.5 ± 0.7 Bq kg^{-1} dw in the 1–5 cm layer, and 0.5 ± 0.4 to 3.3 ± 0.3 Bq kg^{-1} dw in the 5–10 cm layer in a site in the Changning County (24.8503°N 99.5986°E) in Baoshan and in the Mengman site (22.1808 °N 100.1355 °E) in the Pu'er (Simao) region (samples collected in 2016) (Falandysz et al., 2018). The wood substrate used in cultivation of *W. cocos* as well as in natural conditions where mycelia develops is in a surface layer of soil (Wang et al., 2013). The natural distribution and cultivation of *W. cocos* is widespread in the central and southern regions of the province in the humid subtropical highlands and almost true tropical environments in the south, with the exception being the high mountain area in the northwest of Yunnan Province, including Weixi County on the Hengduan Mountains (around 1380–4000 m above sea level), where the climate is cooler. A noted degree of soil pollution with ^{137}Cs in the mentioned sites can be considered as typical for central and southern Yunnan in the period of *W. cocos* sampling in this study (Table 1). In earlier studies, surface soils collected from 45 sites [5 soil samples (10 cm × 10 cm x 10 cm for each) per site were pooled] in Yunnan province in 1982–1987 were little contaminated with ^{137}Cs, i.e. showed mean concentration activity at 6.2 ± 5.4 Bq kg^{-1} dw (range 1.9 ± 0.3 to 31.6 ± 0.8 Bq kg^{-1} dw) (An et al., 1988). Moreover, in the territory of Yunnan where *W. cocos* may normally be found, the concentration activity of ^{137}Cs in surface soils sampled before 2001 was in the range from 0.20 Bq kg^{-1} dw (Yuxi) to 29.6 Bq kg^{-1} dw (Nujiang) (Sun and Yu, 2002). At elevation of 3000 m above sea level, top-soils from the eastern slope of the Minya Konka (Gongga Shan) mountain in the Eastern Tibetan Plateau showed ^{137}Cs activity concentrations in the range of 41 ± 1 to 79 ± 2 Bq kg^{-1} dried soil in the 0–10 cm layer in 2012, and in consequence, also at a higher level in ectomycorrhizal mushrooms when compared to Yunnan (Falandysz et al., 2018).

Topography, due to the high altitude, cold temperature and humidity can play a role in ^{137}Cs contamination in montane soils (Le Roux et al., 2010; Pyuskyulyan et al., 2019). However, being a mountain province, Yunnan, has wide variations in topography and climate, and apart from the north westernmost edge with glacier caped mountains is a warm region with subtropical and tropical jungles in the south. Hence, this variability may explain the lack of a clear, general relationship between activity level of ^{137}Cs in sclerotia and altitude above sea level. Nevertheless, two observations were available from the site Shuangjiang in Lincang region at 1438 m a.s.l. and 1052 m a.s.l. with activities in the outer parts at 10 ± 3 and <6.8 Bq kg^{-1} dw, respectively (Table 1). This can suggest an existing relationship between a degree of sclerotia contamination with ^{137}Cs (and hence also soil/local environment at the site) and elevation above sea level, but a larger number of data (sampling points from the same high mountain/s) would be required to support such an observation. It has to be noted that *W. cocos* in Yunnan is cultivated in field conditions (harvesting is usually) and the wood substrate used is derived from the local pine (*Pinus yunnanensis* Franch.) logs from neighborhood (Wang et al., 2013). So this condition of cultivation is largely similar to wild *W. cocos*. However, sclerotia from cultivar are younger when harvested (typically is 10–12 months old) and hence also usually are smaller in size compared to wild specimens and what was without consequence for the activity levels of ^{137}Cs or ^{40}K, which in this study were in the range from < 1.4 to 11 ± 2 and from < 2.7 to 10 ± 3 Bq kg^{-1} dw of ^{137}Cs and from < 73 to 440 ± 150 and from < 77 to 550 ± 170 Bq kg^{-1} dw of ^{40}K in the wild type and cultivated products, respectively (Table 1).

The quantity of data published on ^{137}Cs in fungi which develop sclerotia or fruiting bodies underground is highly limited. For comparison, brown desert truffles *Terfezia claveryi* collected from Al-Salman desert in Samawah in the south of Iraq in February 2016 showed low level of ^{137}Cs activity that were comparable with activities in the sclerotia of *W. cocos* in this study, i.e. from 1.8 Bq kg^{-1} dw (range 0.11–3.4 Bq kg^{-1} dw), and the mean activity of ^{40}K was 260 Bq kg^{-1} dw (range 76–420 Bq kg^{-1} dw) (Mohammed et al., 2018).

The ^{40}K activity concentrations (and hence also total K concentration) in sclerotia fluctuated across the range of sampling locations, i.e. the medians in outer and inner layers were 220 Bq kg^{-1} dw and 140 Bq kg^{-1} dw respectively (range < 130 to 550 ± 170 Bq kg^{-1} dw and < 73 to 240 ± 64 Bq kg^{-1} dw) (Table 1). Hence, the activity from ^{40}K exceeded that of ^{137}Cs, on average, by 30 to 40-fold. In another study, ^{40}K in the inner white part of sclerotia was not detected above the concentration activity of 83 Bq kg^{-1} dw (Wang et al., 2015).

Potassium, as mentioned, is the major metallic intracellular cation in fungi and, due to its osmotic properties and fundamental role as regulator of the moisture content but also co-factor in enzymes, it undergoes a marked and selective absorption by them in mycelium and fruiting bodies from any substrate (Stijve, 1996). Hence, the fungal products and meals can be considered as a valued source of K for human consumers.

Variations and greater concentration above the median value of K in sclerotia of this wood-decay fungus from the selected sites (Shuangbai, Shuangjiang at 1052 m a.s.l. or Tengchong) could be due to the higher fertility of the local soils and hence also in wood substrate used by the fungus. These values on ^{40}K activity in the outer layer of sclerotia are roughly similar to that cited above for brown truffles from Iraq. The desert truffles have size from 5 to 15 cm in diameter (Mohammed et al., 2018). Hence, they are smaller than sclerotia of *W. cocos* from wild (Fig. 1).

Based on the median values of the ^{137}Cs activity concentrations in the sclerotia sampled in this study, the nominal values of effective dose (mSv) estimated for an exposed adult person eating annually 50 g of sclerotia could be 0.0035 mSv (outer part) and 0.0020 mSv (inner part) *per capita*. However, the consumed quantities of sclerotia and products containing it can vary between the individuals. Intake recommendation of sclerotia, after the Chinese Pharmacopoeia 2020, is 10–15 g daily for dry inner part only and 15–30 g daily for dry shell only.

Being only slightly contaminated with ^{137}Cs, sclerotia appear to be a relatively good source of total K. The median value of K in the outer part was 6800 mg kg^{-1} dw (range < 3700 to 16,000 ± 5000 mg kg^{-1} dw) and in the inner part 3700 mg kg^{-1} dw (range < 2200 to 6900 ± 2000 mg kg^{-1} dw) (Table 1). It has to be emphasized that sclerotia is a dense mass of mycelia and fresh sclerotia of *W. cocos* have 41 ± 7% of moisture (Kubo et al., 2006). If expressed on the whole (wet) weight basis, the K concentration of fresh sclerotia equals at 2800 mg kg^{-1} ww in the outer and 1500 mg kg^{-1} ww in the inner part. Sclerotia of *W. cocos* are used or sold as dried commodity. A 50 g portion of dried sclerotia (could provide, on average, 340 mg (outer part) and 185 mg inner part) of K, which is relatively high. These concentrations of K are similar to what has been found in valued mushroom such as King Bolete *Boletus edulis*(Falandysz et al., 2011). The daily recommended intake of K is 4700 mg (National Institute of Health, 2019).

4. Conclusions

In Yunnan province in China, the ^{137}Cs activity concentrations both of the outer (shell) and inner (white) parts of the sclerotia of *W. cocos* are low and could be explained by low contamination of the local soil. A more refined study would be required to show a possible relationship between ^{137}Cs sclerotia contamination and elevation above sea level. Sclerotia were moderately rich in potassium and both the outer and inner parts of sclerotia appear to be a good source of this element. No statistically significant correlations were found for ^{137}Cs and ^{40}K (total K) in the sclerotia of *W. cocos*.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was in part supported by the National Natural Science Foundation of China under project number 31860584.

References

An, G., Liu, P., Xiong, J., Hu, P., 1988. Content and distribution of radionuclides in soils from Yunnan province. Chin. J. Radiol. Med. Prot. 8 (Suppl. 2), 101–104 in Chinese.

Betti, L., Palego, L., Lucacchini, A., Giannaccini, G., 2017. ^{137}Caesium in samples of wild-grown *Boletus edulis* Bull. from Lucca province (Tuscany, Italy) and other Italian and European geographical areas. Food Addit. Contam. A. 34, 49–55.

Chang, S.T., Wasser, S.P., 2012. The role of culinary-medicinal mushrooms on human welfare with pyramid model for human health. Int. J. Med. Mushrooms 14, 95–134.

Chen, B., Zhang, J., Han, J., Zhao, R., Bao, L., Huang, Y., Liu, H., 2019. Lanostane triterpenoids with glucose-uptake stimulatory activity from peels of the cultivated edible mushroom *Wolfiporia cocos*. J. Agric. Food Chem. 67, 7348–7364.

Cocchi, L., Kluza, K., Zalewska, T., Apanel, A., Falandysz, J., 2017. Radioactive caesium (^{134}Cs and ^{137}Cs) in mushrooms of the genus *Boletus* from the reggio emilia in Italy and pomerania in Poland. Isot. Environ. Health Stud. 53, 620–627.

Falandysz, J., Zalewska, T., Krasińska, G., Apanel, A., Wang, Y., Pankavec, S., 2015a. Evaluation of the radioactive contamination in fungi genus *Boletus* in the region of europe and yunnan province in China. Appl. Microbiol. Biotechnol. 99, 8217–8224.

Falandysz, J., Zhang, J., Zalewska, T., Apanel, A., Wang, Y., Wiejak, A., 2015b. Distribution and possible dietary intake of radioactive ^{137}Cs, ^{40}K and ^{226}Ra with the pantropical mushroom *Macrocybe gigantea* in SW China. J. Environ. Sci. Health Part A 50, 941–945.

Falandysz, J., Zalewska, T., Apanel, A., Drewnowska, M., Kluza, K., 2016. Evaluation of the activity concentrations of ^{137}Cs and ^{40}K in some Chanterelle mushrooms from Poland and China. Environ. Sci. Pollut. Res. 23, 20039–20048.

Falandysz, J., Chudzińska, M., Barałkiewicz, D., Saba, M., Wang, Y., Zhang, J., 2017a. Occurrence, variability and associations of trace metallic elements and arsenic in sclerotia of medicinal *Wolfiporia extensa* from polymetallic soils in Yunnan, China. Acta Pol. Pharm. Drug Res. 74, 1379–1387.

Falandysz, J., Zhang, J., Zalewska, T., 2017b. Radioactive artificial ^{137}Cs and natural ^{40}K activity in 21 edible mushrooms of the genus *Boletus* species from SW China. Environ. Sci. Pollut. Res. 24, 8189–8199.

Falandysz, J., Saniewski, M., Zhang, J., Zalewska, T., Liu, H., Kluza, K., 2018. Artificial ^{137}Cs and natural ^{40}K in mushrooms from the subalpine region of the Minya Konka summit and Yunnan Province in China. Environ. Sci. Pollut. Res. 25, 615–627.

Falandysz, J., Saniewski, M., Zalewska, T., Zhang, J., 2019. Pollution by radiocaesium of fly agaric *Amanita muscaria* in fruiting bodies decrease with a developmental stage. Isot. Environ. Health Stud. 55, 317–324.

Falandysz, J., Barałkiewicz, D., Hanć, A., Zhang, J., Treu, R., 2020a. Metallic and metalloid elements in various developmental stages of *Amanita muscaria* (L.) Lam. Fungal Biology 124, 174–182.

Falandysz, J., Frankowska, A., Jarzyńska, G., Dryżałowska, A., Kojta, A.K., Zhang, D., 2011. Survey on composition and bioconcentration potential of 12 metallic elements in King Bolete (*Boletus edulis*) mushroom that emerged at 11 spatially distant sites. J. Environ. Sci. Health Part B. 46, 231–246.

Falandysz, J., Saba, M., Zhang, J., Hanć, A., 2020b. Occurrence, distribution and estimated intake of mercury and selenium from sclerotia of the medicinal fungus *Wolfiporia cocos* from China. Chemosphere 247, 125928.

Falandysz, J., Zhang, J., Saniewski, M., Wang, Y., 2020c. Artificial radioactivity (^{137}Cs) and natural ^{40}K and total potassium in medicinal fungi from Yunnan in China. Isot. Environ. Health Stud. 56, 324–333.

Jarzyńska, G., Falandysz, J., 2012. Trace elements profile of Slate Bolete (*Leccinum duriusculum*) mushroom and associated upper soil horizon. J. Geochem. Explor. 121, 69–75.

Kibar, B., Pekşen, A., 2012. Sclerotia obtained from mushrooms and its use as functional food. Iğdır University Journal of the Institute of Science and Technology 2, 23–36.

Koarashi, J., Nishimura, S., Atarashi-Andoh, M., Muto, K., Matsunaga, T., 2019. A new perspective on the ^{137}Cs retention mechanism in surface soils during the early stage after the Fukushima nuclear accident. Sci. Rep. 9, 7034.

Kubo, T., Terabayashi, S., Takeda, S., Sasaki, H., Aburada, M., Aburada, M., Miyamoto, K.-I., 2006. Indoor cultivation and cultural characteristics of *Wolfiporia cocos* sclerotia using mushroom culture bottles. Biol. Pharm. Bull. 29, 1191–1196.

Le Roux, G., Duffa, C., Vray, F., Renaud, Ph, 2010. Deposition of artificial radionuclides from atmospheric nuclear weapon tests estimated by soil inventories in French areas low-impacted by Chernobyl. J. Environ. Radioact. 101, 211–218.

Li, Y., Wang, Y., 2018. Differentiation and comparison of *Wolfiporia cocos* raw materials based on multi-spectral information fusion and chemometric methods. Sci. Rep. 8, 13043. https://doi.org/10.1038/s41598-018-31264-1.

Mohammed, R.S., Ahmed, R.S., Bdaljalil, A.O., 2018. Uranium, thorium, potassium, and cesium radionuclides concentrations in desert truffles from the governorate of Samawah in southern Iraq. J. Food Protect. 81, 1540–1548.

National Institute of Health, 2019. https://ods.od.nih.gov/factsheets/Potassium-Health Professional/ retrieved on April 23, 2019.

Nnorom, I.C., Jarzyńska, G., Drewnowska, M., Kojta, A.K., Pankavec, S., Falandysz, J., 2013. Trace elements in sclerotium of *Pleurotus tuber-regium* (Ósu) mushroom - dietary intake and risk in Southeastern Nigeria. J. Food Compos. Anal. 29, 73–81.

Pham, M.K., van Beek, P., Carvalho, F.P., Chamizo, E., Degering, D., Engeler, CC., et al., 2016. Certified reference materials for radionuclides in Bikini Atoll sediment (IAEA-410) and Pacific Ocean sediment (IAEA-412). Appl. Rad. Isotop. 109, 101–104.

Pyuskyulyan, K., LaMont, S.P., Atoyan, V., Belyaeva, O., Movsisyan, N., Saghatelyan, A., 2019. Altitude-dependent distribution of ^{137}Cs in the environment: a case study of Aragats massif, Armenia. Acta Geochim 39 (1). https://doi.org/10.1007/s11631-019-00334-0.

R. Core Team, 2019. A Language and Environment to Statistical Computing. R Foundation for statistical Computing, Vienna, Austria. https://www.R-project.org.pl.

Ríos, J.L., 2011. Chemical constituents and pharmacological properties of *Poria cocos*. Planta Med. 77, 681–691.

Samat, S.B., Green, S., Beddoe, A.H., 1997. The ^{40}K activity of one gram of potassium. Phys. Med. Biol. 42, 407–413.

Saniewski, M., Zalewska, T., Krasińska, G., Szylke, N., Wang, Y., Falandysz, J., 2016. ^{90}Sr in King Bolete *Boletus edulis* and certain other mushrooms consumed in Europe and China. Sci. Total Environ. 543, 287–294.

Species Fungorum, 2019. http://www.speciesfungorum.org/Names/SynSpecies.asp?RecordID= 106545. Retrieved on August 16, 2019.

Steinhauser, G., Brandl, A., Johnson, T.E., 2014. Comparison of the Chernobyl and Fukushima nuclear accidents: a review of the environmental impacts. Sci. Total Environ. 470–471, 800–817.

Stijve, T., 1996. Potassium content and growth rate of higher fungi. Australasian Mycol. Newslett. 15, 70–71.

Sun, Y., Yu, D., 2002. Study on distribution of ^{137}Cs in soils in yunnan province (in Chinese). Radiation Protection Bull 22, 30–32.

Tuo, F., Zhang, J., Li, W., Yao, S., Zhou, Q., Li, Z., 2017. Radionuclides in mushrooms and soil-to-mushroom transfer factors in certain areas of China. J. Environ. Radioact. 180, 59–64.

Türkekul, I., Yeşilkanat, C.M., Cirişc, A., Kölemen, U., Çevik, U., 2018. Interpolated mapping and investigation of environmental radioactivity levels in soils and mushrooms in the Middle Black Sea Region of Turkey. Isot. Environ. Health Stud. 54, 262–273.

van der Heijden, M.G.A., Martin, F.M., Selosse, M.-A., Sanders, I.R., 2015. Mycorrhizal ecology and evolution: the past, the present, and the future. New Phytol. 205, 1406–1423.

Wang, J.-J., Wang, C.-J., Lai, S.-Y., Lin, Y.-M., 1998. Radioactivity concentrations of ^{137}Cs and ^{40}K in basidiomycetes collected in taiwan. Appl. Radiat. Isot. 49, 29–34.

Wang, Y., Zhang, J., Zhao, Y., Li, T., Shen, T., Li, J.Q., Li, W.Y., Liu, H.G., 2013. Mycology, cultivation, traditional uses, phytochemistry and pharmacology of *Wolfiporia cocos* (Schwein.) Ryvarden et Gilb.: a review. J. Ethnopharmacol. 145, 265–276.

Wang, Y., Zalewska, T., Apanel, A., Zhang, J., Wiejak, A., Falandysz, J., 2015. ^{137}Cs, ^{134}Cs and natural ^{40}K in sclerotia of *Wolfiporia extensa* fungus collected across of the Yunnan land in China. J. Environ. Sci. Health Part B. 50, 654–658.

Wiejak, A., Wang, Y., Zhang, J., Falandysz, J., 2016. Mercury in sclerotia of *Wolfiportia extensa* (Peck) Ginns fungus collected across of the Yunnan land. Spectrosc. Spectr. Anal. 36, 3083–3086.

Yafetto, L., 2018. The structure of mycelial cords and rhizomorphs of fungi: a mini-review. Mycosphere 9, 984–998. https://doi.org/10.5943/mycosphere/9/5/3.
Yu, X.B., Zan, J.F., Wang, J.B., Wang, K.Q., Liu, Y.W., 2011. Resource survey on the main producing areas of Poria. Lishizhen Medicine and Materia Medica Research 22, 714–716.
Zaidman, B.Z., Yassin, M., Mahajna, J., Wasser, S.P., 2005. Medicinal mushroom modulators of molecular targets as cancer therapeutics. Appl. Microbiol. Biotechnol. 67, 453–468.