137Cs, 40K, and K in raw and stir-fried mushrooms from the Boletaceae family from the Midu region in Yunnan, Southwest China

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Abstract

The parallel batches of the same species and geographical origin mushrooms both raw and stir-fried were investigated to get an insight into the content and intake of 137Cs, 40K, and K from mushroom meals. The Boletaceae family species (Baorangia bicolor, Boletus bainiugan, Butyriboletus roseoflavus, Retiboletus griseus, Rugiboletus extremiorientalis, and Sutorius magnificus) were collected from the Midu County (Dali Bai Autonomous Prefecture) in 2018. The activity concentrations of 137Cs in the caps of dried raw mushrooms were in the range 14 ± 1 Bq kg⁻¹ dry biomass (db) (R. griseus) to 34 ± 2 Bq kg⁻¹ db (R. extremiorientalis), and in stems from 16 ± 1 Bq kg⁻¹ db (B. bicolor and B. bainiugan) to 23 ± 1 Bq kg⁻¹ db (R. extremiorientalis). The mean activity concentration in the whole fruiting bodies in all six species was 18 ± 4 Bq kg⁻¹ db. The activity concentrations of 137Cs were roughly the same in both dehydrated materials, stir-fried, and raw mushrooms, while the contents of 40K and stable K were around 2- to 3-fold smaller in stir-fried than raw product. The raw and stir-fried mushrooms on a whole (wet) weight basis showed activity concentrations of 137Cs in the range from 1.2 to 3.2 Bq kg⁻¹ ww (mean 1.9 ± 0.6 Bq kg⁻¹ ww) and 6.0 to 9.4 Bq kg⁻³ ww (mean 7.0 ± 1.2 Bq kg⁻¹ ww), respectively. Evidently, when expressed on a whole (wet) weight basis, the cooked mushrooms showed on average around 3.5-fold greater activity concentration of 137Cs when compared with raw mushrooms. The 137Cs, 40K, and total K enrichment in stir-frying (in a whole (wet) weight basis for the meal), confronted with the results for dehydrated raw and fried mushrooms, show the direct correlation with loss of mass (largely moisture) during the cooking procedure but not much of 137Cs and 40K. Edible wild mushrooms from Yunnan were little contaminated with radiocaesium. As assessed, the mean radioactivity dose from natural 40K in around 9.3-fold exceeded the dose obtained for artificial 137Cs from stir-fried mushroom meals, which both were very low doses.

Keywords Boletus · Cooking · Foods · Fungi · Radionuclides

Introduction

Mushrooms that grow in the wild are known to be sensitive to contamination with radiocaesium (134Cs/137Cs) that originates from atmospheric fallout. Historically, the accident at the Chernobyl nuclear power plant in 1986 caused high and long-lasting pollution over significant parts of continental Europe. This included contamination of forest soils with 137Cs in many regions, and consequently also of the wild mushrooms that grow in these forests (Betti et al. 2017; Chiaravalle et al. 2018; Falandysz et al. 2015; Grodzynska 2018; Orita et al. 2017; Travnikova et al. 2002; Tucaković et al. 2018). More recently, a failure of the Fukushima Dai-ichi nuclear power plant in also caused pollution with 137Cs of mushrooms in a region of Japan (Prand-Stritzko and Steinhauser 2018; Steinhauser et al. 2014). There was...
province of China, which has high biodiversity with nearly 900 edible species (Wu et al. 2010). Twenty years before the nuclear accident at Chernobyl, mushrooms were already recognized as a possible source of $^{137}$Cs contamination (coming from the nuclear weapon explosions) for humans (Kiefer and Maushart 1965). However it has also been observed that intake through this pathway could be reduced by cooking processes, e.g., blanching or boiling with excess of water, can decrease the mushroom content of artificial $^{137}$Cs and the alkali metals, e.g., Li and Cs, which leak into the discarded water phase (Consiglio et al. 1990; Daillant et al. 2013; Pankavec et al. 2019; Skibniewska and Smoczyński 1999; Stijve 1994).

In a number of Asian cuisines, stir-frying of foods including mushrooms, in a wok type pan, is a popular method of cooking. Information on the possible effect of stir-frying mushrooms in a wok, on the $^{137}$Cs, $^{40}$Potassium ($^{40}$K), and total Potassium (K) content and their intake from such stir-fried mushrooms meals, are not available in the literature. We investigated the potential effect of stir-frying in a moderate volume of oil using traditional Chinese cooking practice, on the content of $^{137}$Cs, $^{40}$Potassium ($^{40}$K), and total Potassium (K) in dishes made of six species of mushrooms widely foraged in Yunnan.

Materials and methods

Fungal materials

Mushrooms were collected from the geochemically anomalous region from the Midu County (Dali Bai Autonomous Prefecture) located in the west-central region of Yunnan province in China in 2018 (Fig. 1). Species such as *Baorangia bicolor* (Kuntze) G. Wu, Halling & Zhu L. Yang (earlier called *Boletus bicolor* Peck) and the sample whole (fresh) weight was 433 g ($n = 21$) for uncooked and 402 g ($n = 22$) for stir-fried fruiting bodies; *Boletus bainiugan* Dentinger (earlier called in SW China *Boletus edulis* Bull.) weighing 280 g ($n = 5$) and 292 g ($n = 6$); *Butyriboletus roseoflavus* (earlier called *Boletus speciosus* Forst.) weighing 299 g ($n = 5$) and 342 g ($n = 5$); *Reitiboletus griseus* (Frost) Manfr. Binder & Bresinsky (earlier called *Boletus griseus* Frost) weighing 366 g ($n = 8$) and 341 g ($n = 8$); *Rugiboletus extreminiortalis* (Lj.N. Vassiljeva) G. Wu & Zhu L. Yang (earlier called *Leccinum extreminiortale* (Lj.N. Vassiljeva)) weighing 440 g ($n = 12$) and 312 g ($n = 12$), and *Sutorius magnificus* (W.F. Chiu) G. Wu & Zhu L. Yang (earlier called *Boletus magnificus* W.F. Chiu) weighing 154 g ($n = 6$) and 312 g ($n = 7$) (Cui et al. 2016; Feng et al. 2012) were sampled.
Cooking

Fruiting bodies that were randomly selected for stir-frying pools were collected at the same time and location as the raw counterpart pools. Each collected fruiting body within a pool was individually cleaned from foreign debris, and the morphological parts (cap and stem) were separated. All specimens not subjected for stir-frying were sliced and dried for 24 h to a constant mass at 65 °C in a food dehydrator (Ultra FD1000, Ezidri, Australia), and ground to a fine powder using a clean porcelain mortar and pestle and stored dry in sealed polyethylene bags until analysis.

All specimens subjected for stir-frying were sliced, separately caps and stems, pooled accordingly and stir-fried using one of the traditional Yunnan methods in moderate amount of hot vegetable oil (15 to 55 g and depending on the sample size) in a wok pan for 10 min. After cooking, the excess oil was drained away and the fried mushrooms were cooled and transferred into fresh polyethylene jars (screw capped, 0.5 L), weighted, deep frozen (−20 °C), freeze-dried for 72 h, then reweighed (to calculate moisture content), homogenized using a blender with steel-less blades and plastic bowl, and kept tightly closed in screw capped polycarbonate jars which were packed individually into sealed polyethylene bags and stored in a refrigerator. Immediately prior to the instrumental analysis, all the fungal materials were deep frozen (−20 °C) and freeze-dried for 72 h (Labconco Freeze Dry System, Kansas City, MO, USA), so that the activity levels of nuclides were determined in fully dehydrated materials.

Analysis

Activity concentrations of $^{137}$Cs and $^{40}$K were determined using a gamma spectrometer with a coaxial HPGe detector and with a relative efficiency of 18% and a resolution of 1.9 keV at 1.332 MeV (with associated electronics). Quantitation was carried out using the equation:

$$A_i = \frac{N_i}{t \varepsilon(E) y}$$  \hspace{1cm} (1)

where $N_i$ is the number of counts after background correction, $\varepsilon(E)$ is the detector efficiency for photons with energy E, $y$ is the emission probability, and $t$ is the measurement time in seconds.

All measurements were preceded by a background measurement (time 80,000 s or 250,000 s), and background counts were subtracted (using the GENIE 2000 program). The lower limit of detection was at 0.10 Bq kg$^{-1}$ dry biomass (db). The equipment was calibrated using a multi-isotope standard, and the method was fully validated (Falandysz et al. 2019d; Wang et al. 2015). The reference material “Standard solution of gamma emitting isotopes, code BW/Z-62/27/07” produced at the IBJ-Świerk near Otwock in Poland was used for preparing reference samples for equipment calibration. The radionuclides used in the multicomponent reference solution during equipment calibration were $^{137}$Cs at 1.5% and several other nuclides with an approximation uncertainty level at 0.80-2.1%.

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Fig. 1 Map of the area from the Dali Autonomous Prefecture in Yunnan Province where mushrooms were collected; 25° 20' 34" N 100° 29' 35" E (Google maps)
The same geometry of cylindrical dishes with 40 mm diameter (as used for the measurement of collected samples) was used for reference samples during equipment calibration. Calibration was carried out using standards with a density of approximately 1 g cm$^{-3}$ (liquid) with different heights: 3, 6, 9, 15, and 25 mm, which allows the selection of the appropriate calibration for samples of different thickness layer. All numerical data obtained were recalculated for dehydrated fungal material (freeze-dried), and all data were decay-corrected back to the time of sampling. Concentrations of total (stable) K (Table 2) were calculated from the $^{40}$K activity concentration (mean value) in natural K, which is in the range 27.33 to 31.31 Bq g$^{-1}$ of K (Samat et al. 1997).

**Results and discussion**

$^{137}$Cs, $^{40}$K, and K in dried raw mushrooms

The activity concentrations of $^{137}$Cs in pooled samples of caps of the species were in the range 14 ± 1 Bq kg$^{-1}$ db in *Retiboletus griseus* to 34 ± 2 Bq kg$^{-1}$ db in *Rugiboletus extremiorientalis*. Values of $^{137}$Cs in the pooled samples of stems were from 16 ± 1 Bq kg$^{-1}$ db in *Boarangia bicolor* and *Boletus bainiugan* to 23 ± 1 Bq kg$^{-1}$ db in *Rugiboletus extremiorientalis*. The mean activity concentration in the whole fruiting bodies in all six species was 18 ± 4 Bq kg$^{-1}$ db (Table 1).

The data obtained for $^{137}$Cs confirm that wild mushrooms foraged from the Yunnan province in China show low contamination levels, and the activity concentrations were within the range of values reported so far both in wild and cultivated mushrooms from southwestern Asia (Falandysz et al. 2015, 2016, 2017, 2018; Tuo et al. 2014; Wang et al. 2015). However, $^{137}$Cs at a somewhat greater activity concentration, i.e., 210 Bq kg$^{-1}$ db (range 150 ± 9 to 340 ± 22 Bq kg$^{-1}$ db) has been found in the shaggy (scaly or woolly) chanterelle *Gomphus floccosus* (Schw.) Sing in one study (Tuo et al. 2014), current name *Tubinellus floccosus* (Schwein.) Earle ex Giachini and Castellano (Index Fungorum 2020). Also, mushrooms from the subalpine region of the Minya Konka (Mount Gongga or Gongga Shan) in the Eastern Tibetan Plateau, showed, on average, higher levels of $^{137}$Cs than the present study, i.e., in the range 62 ± 6 to 280 ± 150 Bq kg$^{-1}$ db in caps and 62 ± 6 to 400 ± 72 Bq kg$^{-1}$ db in stems (Falandysz et al. 2018).

$^{40}$K in caps was in the range 890 ± 96 Bq kg$^{-1}$ db (*Boarangia bicolor*) to 1100 ± 93 Bq kg$^{-1}$ db (*Retiboletus griseus*) and in stems 500 ± 110 Bq kg$^{-1}$ db (*Sutorius magnificus*) to 1000 ± 110 Bq kg$^{-1}$ db (*Retiboletus griseus*). The whole fruiting bodies showed activity concentrations of $^{40}$K in the range from 740 Bq kg$^{-1}$ db (*Boarangia bicolor*) to 1100 Bq kg$^{-1}$ db (*Retiboletus griseus*), and the mean value for all six species was 840 ± 120 Bq kg$^{-1}$ db. The distribution of $^{137}$Cs and $^{40}$K between morphological parts of the fruiting bodies (Quotient $^{137}$Cs/Cap/Stem) was similar (Q$_{C/S}$ ~ 1) in *Boletus bainiugan*, *Rugiboletus extremiorientalis*, and *Retiboletus griseus*, but favored the caps (mean Q$_{C/S}$ 1.6) in *Boarangia bicolor*, *Butyriboletus roseoflavus*, and *Sutorius magnificus*. The overall mean distribution ratios for all the fruiting bodies sampled were Q$_{C/S}$ 1.1 ± 0.2 for $^{137}$Cs and Q$_{C/S}$ 1.5 ± 0.3 for $^{40}$K.

The total K content determined was in the range of 32,000 ± 3400 mg kg$^{-1}$ db (*Boarangia bicolor*) to 40,000 ± 3300 mg kg$^{-1}$ db (*Retiboletus griseus*) in the caps, and 19,000 ± 3000 mg kg$^{-1}$ db (*Boarangia bicolor* and *Sutorius magnificus*) to 37,000 ± 3800 mg kg$^{-1}$ db (*Retiboletus griseus*) in the stems. Soil mushrooms, including species of the family Boletaceae, are rich in K. In the present study, the total K contents in the whole fruiting bodies were in the range 26,000 ± 3200 mg kg$^{-1}$ db (*Boarangia bicolor*) to 39,000 ± 3500 (*Retiboletus griseus*) mg kg$^{-1}$ db, and the overall mean was 30,000 ± 4400 mg kg$^{-1}$ db.

Data obtained on K in species in the present study agree with the results obtained for *B. edulis* that grows in European forests, which contained the element in the range 25,000 ± 4000 to 29,000 ± 3000 mg kg$^{-1}$ db (caps) and 16,000 ± 4000 to 20,000 ± 3000 mg kg$^{-1}$ db (stems) (Falandysz et al. 2011; Frankowska et al. 2010; Zhang et al. 2010). The small fluctuation in the concentration range of K in species such as *Boletus edulis* from a range of the geographical regions is relatively narrow. It is thought to be a result of the essentiality and homeostatic regulation of this major metallic element absorbed from soil by mushrooms (Stijve 1996).

$^{137}$Cs, $^{40}$K, and K in stir-fried mushrooms

The activity concentrations of $^{137}$Cs were roughly the same in both dehydrated samples, stir-fried and raw mushrooms, while the contents of $^{40}$K and stable K were around 2- to 3-fold smaller in stir-fried than raw produce (Table 1). In detail, the overall mean of the activity concentration of $^{137}$Cs in the stir-fried mushrooms (whole fruiting bodies) for six species was 16 ± 4 Bq kg$^{-1}$ db (range 11 ± 2 to 22 ± 2 Bq kg$^{-1}$ db), and of $^{40}$K, was 320 ± 92 Bq kg$^{-1}$ db (range 190 ± 80 to 480 ± 110 Bq kg$^{-1}$ db). The overall mean content of K in stir-fried mushrooms was 11,000 ± 4600 mg kg$^{-1}$ db, and the range for all species was 7000 ± 2800 to 18,000 ± 3600 mg kg$^{-1}$ db (Table 1). Clearly, the content of $^{40}$K and K in the stir-fried mushrooms when normalized to dry biomass basis was far less than in dehydrated raw mushrooms (humidity in the range from 88.2% in *Rugiboletus extremiorientalis* to 91.7% in *Retiboletus griseus*) (Falandysz et al. 2019c). The vegetable oil used in stir-frying of mushrooms showed activity concentration of $^{137}$Cs in 0.24 ± 0.05 Bq per g, and was free of K.
Data obtained (Table 1) shows higher retention of $^{137}$Cs than of $^{40}$K (and stable K) in the course of stir-frying. This may be due to the difference in the distribution of Cs and K in cell structures and their binding sites. Potassium is a major monovalent element that is found in high concentrations in mushrooms and is a key component of the cellular protoplasm. Breakout from cell walls due to the effects of high-temperature cell shrinkage during the course of stir-drying can favor the release of K, but can have a lower effect on Cs. Also, a preferable leaching of K from cells into the residual oily phase is possible. Stir-frying causes partial dehydration of cooked foodstuffs and resulting in an increase in the proportion of dry matter in a mushroom meal but also of some less volatile or non-volatile compounds of the metallic elements, e.g., mercury (Falandysz et al. 2019a, c). The volume or proportion of oil per unit of stir-fried mushrooms depends on the cooking practice or on local tradition in the different regions of Yunnan. In the present study, fried mushrooms lost from 36 to 55% of the original humidity and absorbed almost all the entire volume of the oil added (from 24 to 32 g of oil per 100 g) to raw (fresh) mushrooms, leaving a small residual volume (0.82 to 5.7 g per dish) (Falandysz et al. 2019c).

Data from the literature shows that when frying (flat pan) mushrooms Cantharellus cibarius and Boletus edulis, a substantial portion of $^{137}$Cs leaked out into the oily residue, which could be discarded, but the possible intake of $^{137}$Cs with fried mushroom meals has not been estimated (Steinhauser and Steinhauser 2016). Wetting or wet-cleaning of Cantharellus cibarius and Boletus edulis from foreign debris before frying could increase the loss of $^{137}$Cs into the oily residue. The rate

### Table 1

Values of $^{137}$Cs and $^{40}$K activity concentrations (Bq kg$^{-1}$ dry biomass) and concentration of total K (mg kg$^{-1}$ dry biomass) in raw (fresh) and stir-fried (whole weight) mushrooms (mean ± SD)

| Species and morphological part of fruitbody | Raw mushrooms | Stir-fried mushrooms |
|-------------------------------------------|---------------|----------------------|
|                                           | $^{137}$Cs     | 40K                  | $^{137}$Cs     | 40K                  |
|                                           | K             |                      | K             |                      |
| **Baorangia bicolor**                     |               |                      |               |                      |
| Caps                                      | 16 ± 1        | 890 ± 96             | 32,000 ± 3400 | 8.5 ± 0.9            | 190 ± 51             | 6800 ± 1800           |
| Stems                                     | 16 ± 1        | 550 ± 83             | 19,000 ± 2900 | 18 ± 2               | 200 ± 100            | 7300 ± 3800           |
| Whole                                     | 16 ± 1        | 740 ± 91             | 26,000 ± 3200 | 11 ± 2               | 190 ± 80             | 7000 ± 2800           |
| **Boletus bainiugan**                     |               |                      |               |                      |
| Caps                                      | 19 ± 2        | 940 ± 120            | 34,000 ± 4200 | 18 ± 2               | 480 ± 110            | 17,000 ± 3900         |
| Stems                                     | 16 ± 1        | 730 ± 89             | 26,000 ± 3300 | 12 ± 1               | 250 ± 78             | 9100 ± 2800           |
| Whole                                     | 17 ± 1        | 870 ± 100            | 29,000 ± 3700 | 15 ± 2               | 350 ± 95             | 12,000 ± 3300         |
| **Butyriboletus roseoflavus**             |               |                      |               |                      |
| Caps                                      | 18 ± 2        | 1000 ± 100           | 37,000 ± 3500 | 18 ± 2               | 300 ± 120            | 11,000 ± 4300         |
| Stems                                     | 17 ± 2        | 630 ± 100            | 23,000 ± 2500 | 17 ± 2               | 200 ± 110            | 7000 ± 4000           |
| Whole                                     | 18 ± 2        | 830 ± 100            | 30,000 ± 3100 | 18 ± 2               | 250 ± 120            | 9000 ± 4200           |
| **Retiboletus griseus**                   |               |                      |               |                      |
| Caps                                      | 14 ± 1        | 1100 ± 93            | 40,000 ± 3300 | 10 ± 1               | 460 ± 59             | 17,000 ± 2100         |
| Stems                                     | 17 ± 2        | 1000 ± 110           | 37,000 ± 3800 | 23 ± 2               | 530 ± 150            | 20,000 ± 5200         |
| Whole                                     | 15 ± 1        | 1100 ± 100           | 39,000 ± 3500 | 14 ± 2               | 480 ± 110            | 18,000 ± 3600         |
| **Rugiboletus extremiorientalis**         |               |                      |               |                      |
| Caps                                      | 34 ± 2        | 960 ± 97             | 34,000 ± 3500 | 18 ± 1               | 350 ± 100            | 12,000 ± 3800         |
| Stems                                     | 23 ± 1        | 630 ± 30             | 23,000 ± 2500 | 14 ± 1               | 250 ± 58             | 9100 ± 2100           |
| Whole                                     | 27 ± 2        | 750 ± 54             | 27,000 ± 2800 | 15 ± 1               | 280 ± 70             | 10,000 ± 2700         |
| **Sutorius magnificus**                   |               |                      |               |                      |
| Caps                                      | 18 ± 2        | 960 ± 140            | 34,000 ± 4900 | 23 ± 2               | 480 ± 140            | 17,000 ± 5100         |
| Stems                                     | 19 ± 2        | 500 ± 110            | 19,000 ± 3000 | 20 ± 2               | 200 ± 130            | 7100 ± 4800           |
| Whole                                     | 18 ± 2        | 760 ± 120            | 27,000 ± 3900 | 22 ± 2               | 350 ± 130            | 12,000 ± 4900         |
| Overall mean (caps)                       | 20 ± 7        | 970 ± 71             | 35,000 ± 3000 | 16 ± 5               | 380 ± 120            | 13,000 ± 4200         |
| Overall mean (stems)                      | 18 ± 3        | 670 ± 180            | 24,000 ± 7000 | 17 ± 4               | 270 ± 130            | 10,000 ± 5000         |
| Overall mean (whole)                     | 18 ± 4        | 840 ± 120            | 30,000 ± 4400 | 16 ± 4               | 320 ± 130            | 11,000 ± 4600         |

Notes: Data on percentage of moisture content of the fresh and cooked mushrooms, fresh and dry biomass share between caps and stems of the fruiting bodies, percentage of hidden oil sorbed by fried mushrooms, percentage of moisture loss by cooked mushrooms due to dehydration, and proportion between fresh mushrooms biomass and oil sorbed in the course of frying on are given in detail in an earlier report (Falandysz et al. 2019c).
of leaching of $^{137}$Cs in washed chanterelles was 19 to 29%, and from 2 to 16% from mushrooms that were cleaned dry. The corresponding rates for *Boletus edulis* were 6% and 0% respectively (Steinhauser and Steinhauser 2016).

In an earlier study, Kenigsberg et al. (1996) reported that frying of mushrooms decreased the activity concentration of $^{137}$Cs by 70% (probably when calculated on a dry biomass basis in relation to the activity concentration in dehydrated uncooked mushrooms) but without information on the mushroom species studied or on the intake of the nuclide based on the whole weight of the fried mushroom meal.

$^{137}$Cs, $^{40}$K, and K in mushroom meals, possible intake, and exposure to radioactivity

All of the species surveyed in this study were edible, both stems and caps of the fruiting bodies. Thus, data on $^{137}$Cs, $^{40}$K, and K in raw mushrooms and mushroom meals were recalculated for appropriate meal portions for stems and caps, and are expressed for the whole fruiting bodies on a whole weight basis (Table 2).

The raw mushrooms and stir-fried mushroom meals on a whole weight showed activity concentrations of $^{137}$Cs respectively in the range from 1.2 to 3.2 Bq kg$^{-1}$ ww (mean 1.9 ± 0.6 Bq kg$^{-1}$ ww) and from 6.0 to 9.4 Bq kg$^{-1}$ ww (mean 7.0 ± 1.2 Bq kg$^{-1}$ ww). Evidently, when expressed on a whole (produce) weight basis, the stir-fried meals showed on average 3.5-fold greater activity concentration of $^{137}$Cs when compared with raw mushrooms.

In the case of $^{40}$K, the activity concentration in raw mushrooms was in the range of 82 to 91 Bq kg$^{-1}$ ww (mean 87 ± 4 Bq kg$^{-1}$ ww), and in the stir-fried mushroom meals, in the range of 100 to 200 Bq kg$^{-1}$ ww (mean 140 ± 32 Bq kg$^{-1}$ ww). Analogically, the content of stable K in fresh mushrooms was in the range from 2700 to 3200 mg kg$^{-1}$ ww (mean 3100 ± 200 mg kg$^{-1}$ ww) and in cooked produce, from 3800 to 7700 mg kg$^{-1}$ ww (mean 5000 ± 1300 mg kg$^{-1}$ ww).

Potassium (both $^{40}$K and total K) were slightly enriched in the whole weight stir-fried mushroom meals when compared with the whole weight raw mushrooms (Table 2), and this outcome was very different when compared with data expressed on dry biomass basis (Table 1). Thus, it can be expected that in the course of stir-frying, a large portion of potassium escaped out of the mushroom meals, while for $^{137}$Cs, the rate of loss was lower.

It has been estimated from a previous report (Falandysz et al. 2019c) that during the mushroom foraging season in southwestern China, certain elements of the population can consume a 100-g portion of stir-fried mushrooms daily, per capita, over a period of several weeks. On this basis, the estimated average intake of $^{137}$Cs, $^{40}$K, and total K with a single meal per capita would be 0.70 ± 0.12 Bq, 14 ± 3 Bq, and 500 ± 130 mg, and 4.9 ± 0.9 Bq, 96 ± 23 Bq, and 3500 ± 910 mg respectively for weekly intake. The estimated daily intake of $^{137}$Cs, $^{40}$K, and total K normalized to per kilogram of body mass (bm; typical weight of 60 kg per individual) was 12 ± 2 mBq, 230 ± 52 mBq, and 8.3 ± 2.2 mg respectively, and the corresponding weekly intake was 82 ± 14 mBq, 1600 ± 360 mBq, and 58 ± 15 mg respectively (Table 3).

The average effective daily and weekly doses of gamma radioactivity received per capita from $^{137}$Cs and $^{40}$K contained in stir-fried mushroom meals in this study have been estimated as 0.0091 ± 0.0015 μSv and 0.064 ± 0.011 μSv for $^{137}$Cs and 0.085 ± 0.019 μSv and 0.60 ± 0.14 μSv for $^{40}$K (Table 3). The average daily and weekly effective doses received by consumers from $^{137}$Cs and $^{40}$K expressed per kilogram of body mass have been assessed as 0.00015 ± 0.00003 μSv and 0.0011 ± 0.0007 μSv for $^{137}$Cs and 0.0014 ± 0.0004 μSv and 0.010 ± 0.002 μSv for $^{40}$K (Table 3). Therefore, on a single meal or annual basis, a mean radioactivity dose from natural $^{40}$K (0.51 μSv per kilogram of body mass) in around 9.3-fold exceeded the dose obtained for artificial $^{137}$Cs (0.055 μSv), which both are very low.

### Table 2

| Species (whole fruiting bodies) | Raw mushrooms |  | Stir-fried mushrooms |
|-------------------------------|---------------|----|----------------------|
|                               | $^{137}$Cs    | $^{40}$K | K | $^{137}$Cs | $^{40}$K | K |
| *Baorangia bicolor* | 1.8 | 82 | 2900 | 6.1 | 100 | 3900 |
| *Boletus bainiugan* | 1.6 | 82 | 2700 | 6.0 | 140 | 4800 |
| *Butyriboletus roseoflavus* | 1.9 | 88 | 3200 | 7.7 | 110 | 3800 |
| *Retiboletus griseus* | 1.2 | 91 | 3200 | 6.0 | 200 | 7700 |
| *Rugiboletus extremiorientalis* | 3.2 | 88 | 3200 | 7.0 | 130 | 4700 |
| *Sutorius magnificus* | 1.9 | 90 | 3200 | 9.4 | 150 | 5100 |
| Overall mean | 1.9 ± 0.6 | 87 ± 4 | 3100 ± 200 | 7.0 ± 1.2 | 140 ± 32 | 5000 ± 1300 |
Adequate potassium daily intake for adults has been set for 4700 mg (NIH 2019), and a serving composed of 100 g stir-fried (whole weight) mushroom meals containing between 380 and 770 mg of K (mean 500 ± 130 mg; Table 2) and assuming that absorption rate by body is 85 to 90% classifies the mushroom meals in this study among a good potential dietary source of potassium. Mushrooms that are conserved are much poorer source of potassium (Pankavec et al. 2019) than the stir-fried products.

Conclusions

Examination of the parallel batches of the same species and geographical origin both uncooked and stir-fried mushrooms showed that the activity concentrations of $^{137}$Cs were roughly the same in both dehydrated samples, stir-fried, and raw mushrooms, while the contents of $^{40}$K and stable K were around 2- to 3-fold smaller in stir-fried than raw produce. The stir-fried mushroom meals on a whole (wet) weight exhibited on average around 3.5-fold greater activity concentration of $^{137}$Cs when compared with raw mushrooms. The $^{137}$Cs enrichment in cooking, and less of $^{40}$K (in a whole (wet) weight basis for the meal), confronted with the results for dried raw and fried mushrooms show the direct correlation with loss of mass (largely moisture during the cooking procedure) but not much of $^{137}$Cs and $^{40}$K; therefore, activity concentrations of both nuclides in stir-fried mushrooms increase. Hence, exposure to radioacesium from meals made of the stir-fried mushrooms substantially contaminated with this nuclide can be a more significant source than speculated earlier. However, edible wild mushrooms from Yunnan are little contaminated with radioacesium. An assessed, the mean radioactivity dose from natural $^{40}$K in around 9.3-fold exceeded the dose obtained for artificial $^{137}$Cs from stir-fried mushroom meals in Yunnan, which both were very low doses. The effect of the stir-frying process on $^{137}$Cs and other mineral constituent content in mushroom meals has to be clarified from the ongoing studies.

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