Accumulation and distribution of $^{40}$K in the chaga mushroom

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ABSTRACT

This work is the first report on activity concentrations of $^{40}$K in *Inonotus obliquus* sampled in a virgin forest of Siberia. The results have shown that the chaga conk is characterized by high activity concentrations of $^{40}$K, averaging 1,641 Bq/kg dry weight (DW) and peaking at 3,502 Bq/kg DW. Activity concentrations of $^{40}$K in chaga conks have been defined to increase from the near-trunk stratum to the crust of the conk with increased exposure to the solar radiation. Our measurements have revealed the samples to be mildly contaminated with $^{137}$Cs. Intensive assimilation of $^{40}$K by chaga conks has been shown as a normal and innate feature of the wild chaga mushroom.

Keywords: activity concentration, cesium, *Inonotus obliquus*, medicinal mushroom, potassium

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Popov & Shpan’ko, 2000). We have also measured $^{137}$Cs in chaga to evaluate anthropogenic impacts on the study area.

The study areas are located in the eastern part of the Lena river basin, Eastern Siberia, Russia. This is an underpopulated region characterized by sparse, small-scale settlements, mining industry, public works infrastructure, and spacious wildland areas (Degtyarev, 2016). Due to its geographical location, climate, and significant orographic isolation, the region is least exposed to global fallout. The region is located beyond the impacts of peaceful underground nuclear explosions performed in Yakutia (Chevy chelov & Sobakin, 2017; Goryachenkova et al., 2017).

White-barked tree species of the birch of the Lena basin are represented by Betula pendula, B. pubescens, and B. ermanii. Betula pendula, silver birch, is ubiquitous and is the most well-known host of $^{137}$Cs. Betula pendula occurs, as a rule, in mixed forests in taiga, in post-fire and post-logging communities, and, rarely, as birch groves. Birch groves, their size ranging from a few square meters to several hectares, are patchily distributed over wide river valleys. They form parts of wetlands usually surrounding lakes, marshes, and bogs.

We have collected 57 chaga conks from 11 locations, 1–300 km apart, in the Central Yakutian plain ($62°14'–60°19'N, 129°5'E$; clayic turbic cryosols) and the Yudomo-Maiskoe upland (59°24'–60°19'N, 133°4'–135°3'E; clayic, and fluvic turbic cryosols) in 2012–2018. Our five samples have been collected in upland woodlands (clayic turbic cryosol, mixed forests) on 25–40 y old birch trees, and the rest in riparian woodlands (fluvic turbic cryosol, mixed forests, and birch groves) on 25–70 y old birch trees. Five conks have been found growing on one trunk. Three dead conks have been found on three dead birch trees. We have also collected a chaga basidiocarp, unaffected wood, bark with phloem from four cross-sections of the affected birch logs, 18 samples taken from uninfected 10–60 y old birch trees, and 18 fruiting bodies of $Fomes fomentarius$, a polypore and saprophyte, from dead birch trees. The shading and aspect of the collected conks have been identified in the process of sampling. Here, the term “aspect” refers to the compass direction that a conk faces. We determine a conk aspect as the position of the conk center as an angle measure, clockwise and counterclockwise to 180° from a southerly direction, as the reference point (0°). The scale interval is 5°. Prior to being dried, five larger conks have been prepared for a layer-by-layer analysis by their separation into the crust (less than 1 cm-size hardened and crumbly outer dead tissue), the middle stratum (3–5 cm-size), and the innermost near-trunk stratum (2–3 cm-size). One affected birch tree has been dissected, and the volume of the chaga basidiocarp has been measured. The density of dried tissue of the basidiocarp has been calculated. Based on the obtained values of the volume and density, the dry weight of the basidiocarp has been calculated. The samples have been oven-dried to the constant weight, grinded and analyzed by the scintillation gamma spectrometer (Scientific Production Company "Doza", Ltd, Zelenograd, Russia), using the NaI(Tl) 63 mm detector (the minimum detectable activity 40 Bq for $^{40}$K and 3 Bq for $^{137}$Cs; the reference standard IEC 61563; the uncertainty of determination ±10%). The value below the minimum detectable activities has been taken as zero.

The maximum and average activity concentrations of $^{40}$K in the collected conks are much higher, as compared with those in the basidiocarp of $F. fomentarius$ (Table 1), and are comparable with those in many other fungi in Eurasia. Some of them, e.g., $Hygrophoropsis aurantiaca$ and $Tricholoma terreum$, are capable of concentrating up to 4,000 Bq/kg dry weight (DW) (Kalac, 2001; Turhan et al., 2007; Mietelski et al., 2010; Falandysz et al., 2015, 2017). As the activity concentrations of $^{40}$K of the three dead conks from dead birch trees fall within the range observed in living conks, these concentrations are maintained for a long time after the tree and the conk have died (Table 1). The obtained data have revealed that activity concentrations of $^{40}$K in the collected conks depend on the aspect and shading of the conk. The $^{40}$K values highly correlate ($r = −0.62$) with the angle of the conk position in relation to the southerly direction, and they decrease with the conk displacement from the southerly to the northerly aspect (Figs. 1, 2). This is also apparent from the variety of radionuclide activity concentrations in five conks growing on the same trunk (Fig. 3). Also, higher values of $^{40}$K have been observed in conks grown on well-lighted (sparse or isolated) trees on the edge of birch forests, and, vice versa, its lower values have been found in conks from mixed forests, where infected birches are shaded by conifers (Table 1). We assume that $^{40}$K accumulation increases with an increased exposure to sunlight. Higher insolation heats the conk, thus intensifying evaporation and sap inflow. The morphology of the conk itself suggests intense water metabolism. Due to continuous weathering and cracking, the crust of the chaga conk is dull-black and crumbly, thus developing higher sunlight-absorption and the larger evaporation surface.

| Sample | Sample size | Mean value | Standard error | Minimum value | Maximum value | Value range | Median value | Standard deviation |
|--------|-------------|------------|----------------|---------------|---------------|-------------|--------------|-------------------|
| Chaga conk | 52 | 1,641 | 103 | 509 | 3,502 | 2,993 | 1,500 | 741 |
| Chaga conk sampled in the Central Yakutian plain | 4 | 1,636 | 230 | 1,326 | 2,316 | 990 | 1,450 | 459 |
| Chaga conk sampled in the Yudomo-Maiskoe upland | 48 | 1,642 | 110 | 509 | 3,502 | 2,993 | 1,509 | 763 |
| Chaga conk sampled in riparian woodlands | 47 | 1,650 | 112 | 509 | 3,502 | 2,993 | 1,519 | 769 |
| Chaga conk sampled in upland forests | 5 | 1,563 | 192 | 1,276 | 2,316 | 1,040 | 1,400 | 429 |
| Chaga conk grown on Betula pendula | 51 | 1,653 | 114 | 509 | 3,502 | 2,993 | 1,500 | 745 |
| Chaga conk grown on Alnus sibirica | 1 | 1,149 | — | — | — | — | — | — |
| Chaga conk grown on birch in sparse wood edge | 5 | 2,781 | 269 | 2,023 | 3,502 | 1,479 | 2,625 | 601 |
| Chaga conk grown on birch shadowed by conifers | 4 | 1,185 | 256 | 509 | 1,693 | 1,184 | 1,269 | 512 |
| Dead chaga conk collected from dead birch | 3 | 1,662 | 812 | 670 | 3,272 | 2,602 | 1,044 | 1,407 |
| Chaga conk crust | 5 | 2,684 | 3,96 | 1,248 | 3,548 | 2,300 | 2,943 | 885 |
| Chaga conk middle stratum | 5 | 1,756 | 405 | 923 | 1,866 | 2,305 | 1,631 | 906 |
| Chaga conk near-trunk stratum | 8 | 1,045 | 138 | 703 | 1,491 | 788 | 961 | 309 |
| Chaga conk grown in cross-section of affected birch | 4 | 1,555 | 212 | 1,158 | 2,143 | 985 | 1,459 | 423 |
| Chaga basidiocarp in cross-section of affected birch | 4 | 356 | 126 | 0 | 642 | 642 | 318 | 281 |
| Radial wood in cross-section of affected birch | 4 | 46 | 46 | 0 | 187 | 187 | 0 | 94 |
| Bark with phloem in cross-section of affected birch | 4 | 127 | 89 | 0 | 475 | 475 | 72 | 199 |
| Wood of non-infected birch | 18 | 23 | 12 | 0 | 159 | 159 | 0 | 49 |
| $Fomes fomentarius$ basidiocarp | 18 | 31 | 19 | 0 | 324 | 324 | 0 | 79 |

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A layer-by-layer analysis has revealed activity concentrations of $^{40}$K in the samples of chaga conks to be unevenly distributed. $^{40}$K values here strongly correlate ($r = 1.00$) with the layer position, and increase from the near-trunk stratum to the crust (Table 1). The crust is dead tissue consolidated by weathering, and the highest levels of $^{40}$K activity concentration in the crust result from external physical impacts that have densified the crust (the density of the inner tissues and the crust of the conk are 0.2–0.3 g DW/cm$^3$ and 1.0–1.1 g DW/cm$^3$, respectively).

The analysis of the wood of the non-infected birch trees and a cross-section of the birch log affected by *I. obliquus* has shown that the fungus accumulates $^{40}$K in its basidiocarp. The intensive assimilation of $^{40}$K has been found to be in agreement with intensive assimilation of the total potassium (up to 10% of ash has been measured) by the conk (Shivrina et al., 1959; Popov & Shpan’ko, 2000), which is a normal physiological process for the fungus. Extremely low activity concentrations of $^{40}$K in the wood of the non-infected birch trees and the cross-sections of the affected birch logs have shown that *I. obliquus* absorbs $^{40}$K mainly from the sap passing through tree tissues (Table 1). This is readily illustrated by the ratio of activities in the basidiocarp and the wood utilized by the fungus. The dissected birch affected by *I. obliquus* has the conk of 100 g ($140$ Bq) and contains the 11,000 cm$^3$ basidiocarp. Judging by the measured density (0.36 g DW/cm$^3$), the weight of the basidiocarp.

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Fig. 1. Variations of activity concentrations of $^{40}$K in reference to aspect changes of conk in the chaga.

Fig. 2. Variations of activity concentrations of $^{137}$Cs in reference to aspect changes of conk in the chaga.
makes 4,000 g (about 2,600 Bq). The unaffected wood of the dissected birch of the same weight reveals the activity below 120 Bq. Thus, having digested the volume of the host wood equal to the aggregated volume of the basidiocarp and the conk, the chaga mushroom can not have obtained 2,740 Bq (140 Bq + 2,600 Bq). This implies that the true transfer factor should be calculated in relation to the tree sap.

Unlike 40K, the activity concentrations of 137Cs in all our samples are low (Table 2), thus substantiating the inferences that global fallout has had minor impacts on ecosystems of the region (Chevychelov & Sobakin, 2017). The mean value of activity concentrations of 137Cs in the conk agrees with the lowest values measured in chaga obtained from Russian and Chinese markets (11–13 Bq/kg DW), and ranks slightly above the activity concentrations in North Korean samples (3 Bq/kg DW) (Lee et al., 2008). It should be noted that chaga conks without the crust may be available on the market, i.e., a conk containing the maximal activity concentration of 137Cs may have been peeled off from its crust. The mean value of 137Cs in the collected chaga is equal to the lowest values or incomparably low values reported for short-living fungi (Korky & Kovalski, 1989; Bakken & Olsen, 1990; Kalac, 2001; Lee et al., 2008; Turhan et al., 2007; Mietelski et al., 2010; Gwynn et al., 2013; Yamada 2013; Trappe et al., 2014; Falandysz et al., 2015; Ohnuki et al., 2016). The activity concentrations of 137Cs in the chaga conks, like those of 40K, strongly correlate (r = 0.95) with the layer position, revealing minimal values in the near-trunk stratum and maximum in the crust (the conk outer layer). 137Cs, as an artificial radionuclide, occurs in low quantities in areas least exposed to global fallout.

![Fig. 3. Variations of activity concentrations in reference to aspect changes of conks grown on one trunk in the chaga.](image)

### Table 2. Measured activity concentrations of 137Cs in the samples (Bq/kg DW).

| Sample                                | Sample size | Mean value | Standard error | Minimum value | Maximum value | Value range | Median value | Standard deviation |
|---------------------------------------|-------------|------------|----------------|---------------|---------------|-------------|--------------|--------------------|
| Chaga conk                            | 52          | 10.5       | 1.8            | 0             | 64.2          | 64.2        | 7.2          | 12.7              |
| Chaga conk sampled in the Central Yakutian plain | 4           | 7.3        | 4.3            | 0             | 15.8          | 15.8        | 6.8          | 8.5               |
| Chaga conk sampled in the Yudomo-Maiskoe upland | 48          | 10.7       | 1.9            | 0             | 64.2          | 64.2        | 7.2          | 13.0              |
| Chaga conk sampled in riparian woodlands | 47          | 10.6       | 1.9            | 0             | 64.2          | 64.2        | 6.9          | 13.1              |
| Chaga conk sampled in upland forests  | 5           | 9.1        | 3.7            | 0             | 16.2          | 16.2        | 13.5         | 8.4               |
| Chaga conk grown on Betula pendula    | 51          | 10.5       | 1.8            | 0             | 64.2          | 64.2        | 6.9          | 12.8              |
| Chaga conk grown on Alnus hirsute     | 1           | 9.2        | —              | —             | —             | —           | —            | —                 |
| Chaga conk grown on birch in sparse wood edge | 5           | 10.2       | 4.5            | 0             | 22.1          | 22.1        | 8.1          | 10.0              |
| Chaga conk grown on birch shadowed by conifers | 4           | 17.9       | 7.1            | 0             | 34.7          | 34.7        | 18.4         | 14.2              |
| Dead chaga conk collected from dead birch | 3           | 13.1       | 6.7            | 0             | 22.1          | 22.1        | 17.2         | 11.6              |
| Chaga conk crust                      | 5           | 10.4       | 2.6            | 3.0           | 18.4          | 18.4        | 11.8         | 5.9               |
| Chaga conk middle stratum             | 5           | 9.4        | 5.1            | 0             | 28.6          | 28.6        | 7.2          | 11.3              |
| Chaga conk near-trunk stratum         | 5           | 6.0        | 2.2            | 1.9           | 13.5          | 13.5        | 4.1          | 4.9               |
| Chaga conk in cross-section of affected birch | 4           | 0         | —              | —             | —             | —           | —            | —                 |
| Chaga basidiocarp in cross-section of affected birch | 4           | 10.6       | 3.6            | 0             | 19.9          | 19.9        | 12.5         | 8.0               |
| Radial wood in cross-section of affected birch | 4           | 3.7        | 2.6            | 0             | 11.0          | 11.0        | 1.8          | 5.2               |
| Bark with phloem in cross-section of affected birch | 4           | 12.4       | 4.8            | 4.0           | 30.5          | 26.5        | 8.7          | 10.8              |
| Wood of non-infected birch            | 18          | 3.5        | 1.2            | 0             | 17.3          | 17.3        | 1.6          | 4.9               |
| *Fomes fomentarius* basidiocarp        | 18          | 12.1       | 8.9            | 0             | 148.0         | 148.0       | 0            | 37.7              |

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contaminant, is distributed unevenly in natural ecosystems, and the values of its activity concentrations in chaga show less evident correlations ($r = 0.14$) with the conk aspect and shading (Table 2; Figs. 2, 3). While they are chemical analogues, $^{137}$Cs and $^{40}$K are supposed to differ in biological metabolism, as these isotopes reveal different patterns of transfer and accumulation in the soil–plant system (Marčiulioniene, Lukšiene, & Jefanova, 2015). The similar results have found that accumulations of $^{40}$K and $^{137}$Cs in the chaga conk depend on the substratum from which the mushrooms take nutrients (Guilén & Baeza, 2014; Kalac, 2019).

High values of $^{40}$K in chaga appear worthy of investigation in view of its curative properties, notably, the possible contribution of certain levels of $^{40}$K activity concentrations, along with organic substances, to chaga antitumor and other medicinal properties and the possible side effects in administration of chaga as medicine. We have found that accumulations of $^{40}$K and $^{137}$Cs in the chaga conk depend on the conk aspect, and increase with its exposure to sunlight. The activity concentrations of $^{40}$K in the conk have been identified to be unevenly distributed and to increase from the near-trunk stratum to the crust. The results provide a good indication of suitable materials for selection of raw chaga, a way to obtain chaga tissues with various activity concentrations of $^{40}$K, and a basis for setting requirements and elaborating guidelines for chaga collects.

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