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Bioaccumulation of ^{137}Cs in wild mushrooms collected in Poland and Slovakia

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Abstract Activities of caesium in the mushrooms collected at different localities in Poland and Slovakia have been compared. Discrimination factor, defined as [(Bq·kg^{-1} ^{137}Cs in caps)/(Bq·kg^{-1} ^{40}K in caps)]/[(Bq·kg^{-1} ^{137}Cs in stipes)/(Bq·kg^{-1} ^{40}K in stipes)], was used to explain mechanisms of uptake and transport of radiocaesium in fungi. The collected specimens were divided into caps and stipes. Activities of ^{137}Cs and ^{40}K were measured using a multichannel gamma spectrophotometer with HPGe(Li) detector. The highest accumulation of ^{137}Cs was found in the samples of *Xerocomus badius, Suillus luteus* and *Tricholoma equestre* (2.7, 1.9 and 1.2 kBq·kg^{-1}, respectively). *T. equestre* and *S. luteus* proved to hyperaccumulate caesium since ^{137}Cs levels in the caps were two orders of magnitude higher than in the soil while only one order higher in the case of *X. badius*. Transport of ^{137}Cs from stipe to cap in fruitbody is directly related to K concentration with lack of similar dependence in the case of transport from soil to cap. There is no dependence between activity of ^{137}Cs in the analyzed fruitbodies and its activity in the soil, which makes mushrooms controversial bioindicators of ^{137}Cs-pollutted soils.

Key words bioaccumulation of caesium • ^{137}Cs • biomonitoring • mushrooms • potassium

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Introduction

Mushrooms are characterised by high ability to accumulate radiocaesium [1–5, 7], however, huge differences of ^{137}Cs accumulation in fruitbodies of different species have not been explained yet. This phenomenon can be due to unequal level of decay and composition of the substrate. Undoubtedly, it is related to the ability of mycelium to decompose organic substrate and to form mycorrhizal associations with plants.

Caesium radioisotopes are of high environmental concern due to relatively long half-life, emission of gamma radiation and rapid incorporation into living organisms [6]. As we previously described [2], ability of mushrooms to accumulate radiocaesium is mainly due to their genetic constitution. Plant roots absorb caesium less efficiently than its nutrient analogue, potassium [1]. This is illustrated by the so-called Cs/K discrimination factor (DF). DF values greater than 1 unit indicate that ^{137}Cs is more effectively transported than ^{40}K.

The problem of caesium/potasium discrimination in fungi, with respect to the group phylogenesis, has not yet been solved and requires further studies involving a greater number of species. The aim of this study is to compare the fate of caesium in the selected species of mushrooms obtained from various localities in Poland and Slovakia. The Cs/K discrimination factors have been calculated in order to explain the mechanism of uptake and transport of radiocaesium in fungi.

Table 1. Activities of ^{40}K and ^{137}Cs in cap, stipe, soil and discrimination factor for cap/stipe and cap/soil

Family	Species	Locality	Sample	^{40}K [Bq·kg^{-1} d.w.]	^{40}K SD	^{137}Cs [Bq·kg^{-1} d.w.]	^{137}Cs SD	DF cap/stipe	DF cap/soil
Boletaceae	*X. badius*	site 2	cap	1120	9	2700	140.0	0.90	3.01
			stipe	930	80	2500	140.0		
			soil	250	60	200	6.0		
		site 6	cap	1586	301	813	47.0	1.18	3.88
			stipe	1761	340	768	44.0		
			soil	386	60	51	3.0		
	S. bovinus	site 1	cap	630	7	675	37.3	1.46	14.14
			stipe	355	91	261	15.0		
			soil	293	26	22	1.3		
	S. luteus	site 1	cap	696	7	1879	103.0	1.36	37.80
			stipe	387	54	766	42.2		
			soil	278	26	20	1.2		
		site 3	cap	1270	162	534	30.4	3.68	22.16
			stipe	1829	390	209	15.0		
			soil	322	27	6	0.1		
	S. grevillei	site 4	cap	1895	250	516	30.0	2.06	2.22
			stipe	2295	371	304	20.0		
			soil	384	31	47	2.7		
	L. scabrum	site 1	cap	873	8	249	14.0	1.47	2.99
			stipe	440	84	85	5.4		
			soil	273	26	26	1.5		
		site 5	cap	1417	158	40	3.9	0.8	0.83
			stipe	762	133	27	3.0		
			soil	327	28	11	0.9		
		Humenné	cap	1886	27	2	0.4	0.59	
			stipe	1375	34	3	0.8		
	B. edulis	site 1	cap	630	6	450	30.0	1.06	4.53
			stipe	340	50	230	10.0		
			soil	279	28	44	2.5		
		Sajzy	cap	1670	37	200	10.0	0.38	3.29
			stipe	450	110	140	9.0		
			soil	330	26	12	0.9		
		site 5d	cap	1267	140	146	9.2	1.1	6.39
			stipe	768	92	81	5.2		
			soil	355	30	6	0.6		
		site 5b	cap	939	77	80	5.0	1.01	2.47
			stipe	800	215	67	4.9		
			soil	327	28	11	0.9		
		site 8	cap	1360	184	29	3.6	0.81	0.52
			stipe	782	139	20	2.7		
			soil	385	32	16	1.1		
Tricholo-mataceae	*T. equestre*	site 7	cap	1699	140	1180	6.5	6.08	46.79
			stipe	1477	250	169	11.7		
			soil	687	40	10	0.8		
	T. portenosum	site 7	cap	1920	240	110	8.0	2.16	3.86
			stipe	1693	271	45	6.0		
			soil	687	40	10	0.8		
Amanitaceae	*A. citrina*	site 2	cap	909	9	189	10.9	1.31	3.31
			stipe	379	69	51	3.5		
			soil	276	30	45	2.6		

Table 1. continued

Family	Species	Locality	Sample	^{40}K [Bq·kg^{-1} d.w.]	SD	^{137}Cs [Bq·kg^{-1} d.w.]	SD	DF cap/stipe	DF cap/soil
Amanitaceae	*A. muscaria*	site 5b	cap	154	12	24	2.1		
			stipe	1061	115	15	2.1	1.11	0.45
			soil	327	28	11	0.9		
		site 2	cap	1610	130	500	30.0		
			stipe	590	60	140	8.0	1.54	1.26
			soil	320	3	30	2.0		
Russulaceae	*R. foetens*	Jasov	cap	2036	37	118	2.3		
			stipe	1996	75	95	4.4	1.23	
			soil	565	17	56	1.4		
	Russula mix	Soroška	cap	1732	79	13	2.5	0.98	
			stipe	1936	100	15	3.6		
	Russula mix	Svidník	cap	1605	77	8	2.0	0.7	
			stipe	1593	80	12	3.1		
	Russula mix	Lipníky	cap	1474	62	6	1.7	0.5	
			stipe	1432	78	12	3.1		
	L. piperatus	Humenné	cap	1115	28	8	0.7	1.2	
			stipe	1356	53	8	1.5		
Agaricaceae	*M. procera*	Soroška	cap	1876	75	11	2.6	0.39	
			stipe	1266	85	20	4.2		

Materials and methods

The fruitbodies of mushroom species *Macolepiota procera, Lactarius piperatus, Leccinum scabrum, Russula foetens, Russula virescens* and *Russula cyanoxantha* (mix of two species) were collected in certain localities in the East of Slovakia in 2004. The fruitbodies of mushroom species *Xerocomus badius, Leccinum scabrum, Boletus edulis, Suillus luteus, Suillus grevillei, Suillus bovinus, Tricholoma equestre, Tricholoma portenosum, Amanita citrina* and *Amanita muscaria* were collected in Poland, in the forest near Aleksandrów Kujawski (N 52° 54' E 18° 39'). One sample of *B. edulis* was collected near Sajzy village (N 53° 56' E 22° 08'). Aboveground parts of the mushrooms were divided into caps and stipes, dried and homogenized. Specific activities of ^{137}Cs in the obtained samples were measured spectrometrically using a multichannel spectrophotometer with HPGe(Li) detector (Canberra Series 35 Plus). Data acquisition and analysis were carried out using Gamat and Genie 2000 software. Discrimination factor is defined as:

$$DF = \frac{\left(\frac{A\left({}^{137}Cs\right)_{cap}}{A\left({}^{40}K\right)_{cap}}\right)}{\left(\frac{A\left({}^{137}Cs\right)_{stipe}}{A\left({}^{40}K\right)_{stipe}}\right)}$$

where A are specific activities of ^{137}Cs or ^{40}K measured in the cap and stipe stamples, as marked in the subscript.

Results and discussion

The highest activity of ^{137}Cs was found in the samples of *Xerocomus badius, Suillus luteus* and *Tricholoma equestre* (2.7, 1.9 and 1.2 kBq·kg^{-1}, respectively), Table 1. Levels of ^{137}Cs in the caps of *T. equestre* and *S. luteus* were one hundred times higher than in soils, which proves ability of these species to hyperaccumulate caesium. Caps of *Xerocomus badius* and other analyzed mushrooms showed caesium levels to be only 10 times higher than the soil concentration. The both above-mentioned hyperaccumulators have yellow pigmentation, therefore, it is hypothesized that the high accumulation of caesium is a result of pigment-bound caesium. As it has already been described [3, 4], *Macrolepiota procera* accumulates the lowest amounts of radiocaesium. It can be explained by the non-mycorrhizal character of *Macrolepiota* sp. and its anatomy. The most of the species accumulated caesium mainly in the caps. However, dissimilarities in caesium accumulation in various species may be due to different levels of tissue hydration, anatomical constitution and unequal age of the collected specimens.

The data obtained for DF cap/soil indicate that there is no correlation between the ^{137}Cs/^{40}K ratios in cap and the respective ratios in soils (Fig. 1). Nevertheless, as it was assumed earlier [2], this dependence exists between ^{137}Cs/^{40}K ratios in caps and the respective ratios in stipes (Fig. 2). An evidence for linear correlation of these ratios is given for the first time.

Our results (Figs. 1 and 2) indicate differences between mechanisms of uptake and transport of caesium. Lack of correlation between accumulation of ^{137}Cs in

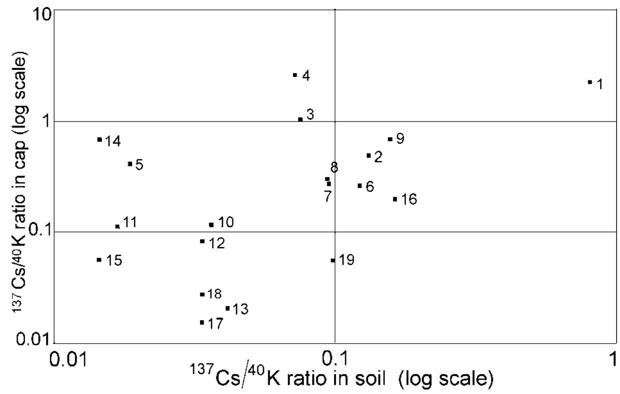

Fig. 1. Correlation between ratios of activities of ^{137}Cs to ^{40}K in cap and ^{137}Cs to ^{40}K in soil. Numbers in brackets indicates points in figure. *X. badius*: site 2(1), site 6(2); *S. bovinus*: site 1(3); *S. luteus*: site 1(4), site 3(5); *S. grevillei*: site 4(6); *L. scabrum*: site 1(7), site 5(8); *B. edulis*: site 1(9), Sajzy (10), site 5d(11), site 5b(12), site 8(13); *T. equestre*: site 7(14); *T. portenosum*: site 7(15); *A. citrina*: site 2(16); *A muscaria*: site 5b(17), site 2(18); *R. foetens*: Jasov (19).

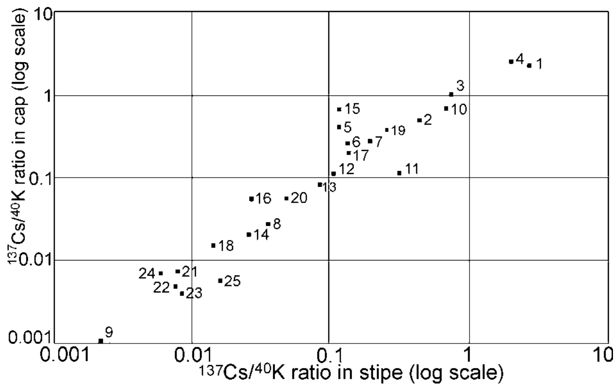

Fig. 2. Correlation between ratios of activities of ^{137}Cs to ^{40}K in cap and ^{137}Cs to ^{40}K in stipe. Numbers in brackets indicates points in figure. *X. badius*: site 2(1), site 6(2); *S. bovinus*: site 1(3); *S. luteus*: site 1(4), site 3(5); *S. grevillei*: site 4(6); *L. scabrum*: site 1(7), site 5(8), Humenné (9); *B. edulis*: site 1(10), Sajzy (11), site 5d(12), site 5b(13), site 8(14); *T. equestre*: site 7(15); *T. portenosum*: site 7(16); *A. citrina*: site 2(17); *A. muscaria*: site 5b(18), site 2(19); *R. foetens*: Jasov (20); *Russula* mix: Soroška (21), Svidník (22), Lipníky (23); *L. piperatus*: Humenné (24); *M. procera*: Soroška (25).

fruitbodies and $^{137}Cs/^{40}K$ ratio in soils (Fig. 1) shows the genus-dependent capability of wild mushrooms to accumulate ^{137}Cs. However, transport of ^{137}Cs from stipe to cap (Fig. 2) depends directly on ^{40}K concentration. The results show that transport of ^{137}Cs within the fruitbody carries on through the potassium channels, which is a much simpler mechanism than the corresponding transport in plants [2]. This shows a high efficiency of caesium transport and explains hyperaccumulation of ^{137}Cs in the fruitbodies of *T. equestre* and *S. luteus*. Lack of dependence between activity of ^{137}Cs in fruitbodies and soils makes mushrooms rather controversial bioindicators of ^{137}Cs soil pollution.

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