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RADIOCESIUM CONTENT IN WILD BOAR MEAT ORIGINATING FROM SERBIA

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Abstract. Radiocesium content in wild boar meat, originating from Serbia, was determined. It ranged from 0.01 to 1.11 Bq/kg and 0.09 to 5.18 Bq/kg, for ^{134}Cs and ^{137}Cs, respectively. The corresponding average effective dose equivalents ranged from 0.003 to 0.337 μSv, thus do not represent a health risk for humans.

Key words: wild boar meat, radiocesium, radioactive pollution.

1. INTRODUCTION

Wild boar meat is highly appreciated meat in Serbia, due to its high nutritional value, low fat and cholesterol content and favorable ratio of unsaturated and saturated fatty acids [1, 2]. Because natural forage is the main feed, it is considered naturally organic. However, undesirable substance, such as radionuclides may be present in wild boar meat [3–5]. Regarding its potential harmful health impact, consumers' demands nowadays are increasing, which emphasize the determination of meat safety parameters.

Radionuclides are ubiquitous in the environment due to natural and anthropogenic activities [6]. Soil-plants-animals-humans is the main pathway of radionuclides transfer to humans [6, 7]. Plants can uptake ^{137}Cs from soil, along with nutrients during mineral intake. Although, the main feed of wild boars are acorns and beechnuts, wild boars are omnivores. Its diet consist of plant origin (acorns, fruits, berries, tubers, roots and mushrooms) and animal origin nutrients (insects, eggs etc.). Due to high consumption of roots and mushrooms, ^{134}Cs and ^{137}Cs can accumulate in wild boar [8]. Consequently, radioactivity of ^{137}Cs in wild boars is higher compared to other wildlife animals [4, 9].

Radionuclides content in wild boar meat is affected by numerous biological factors (level of soil contamination, availability of feed sources, feed habits, movements etc.) [3, 8]. The seasonal variation of ^{137}Cs content in muscle tissue of wild animals has been demonstrated [4, 10]. Radiocaesium-137 is substitutable with monovalent cations, and has high bioavailability (absorption and transfer rates). Due to similar chemical properties to monovalent cation potassium, ^{137}Cs is absorbed by negatively charged sites in muscle cells, and can accumulate in muscle tissue [11].

Higher activity of ^{137}Cs in wild boars compared to other wildlife species has been proven [4, 12], thus there has been concern about long term accumulation of ^{137}Cs in wild boars.

Wild boars are widespread, and have the ability to inhabit different areas (plains, mountains, forests etc.) [13], thus it may serve as bioindicators of potential radiological contamination of different environments.

In Serbia, the anthropogenic radioactive contamination is a result of the nuclear accident in Chernobyl (1986), with total deposition of ^{137}Cs about 5 kBq/m^2 [14]. The highest radionuclides activity were determined in mountain areas of Serbia (Zlatibor, Ovčar Banja and Užicka Požega) [15]. It was detected primarily in soil, plants, mushrooms and game meat [16, 17]. ^{134}Cs and ^{137}Cs are still present in the environment, and can be transferred to various ecosystems. In wildlife, radionuclides may have harmful effects at the individual and population level, posing a risk for humans [18, 19]. Thus, to prevent the risk of chronic radiation exposure it is significant to determine the distribution and variation of radionuclides in wildlife species. Accordingly, prediction of radionuclide concentration patterns in wild boars is needed.

The aim of the study is to determine the activity concentration of ^{134}Cs and ^{137}Cs in wild boar meat, originated from different location in Serbia, and to calculate the effective dose equivalent due to ingestion of ^{137}Cs present in wild boar meat.

2. MATERIALS AND METHODS

2.1. SAMPLING

The wild boar were hunted in four regions of Serbia, during the hunting seasons (*i.e.* from May 1st to January 31st) in 2020 and 2021 years (Table 1). Animals were hunted in accordance with the Law on hunting of the Republic of Serbia [20] and marked according to the EC 853/2004 and EC 854/2004 [21, 22]. In total 40 animals were hunted (Table 1) and transported to Department of Radiation Hygiene, Serbian Institute of Veterinary Science. Hunted wild boars weighted between 120 and 140 kg and aged about one year.

Table 1

Wild boar meat hunting area

Region	Municipality	Hunting area	Number of samples	Region	Municipality	Hunting area	Number of samples
North Serbia (Vojvodina region)	Sremska Mitrovica	Vranjaš	2	West Serbia			
		Karakuša	2		Bajina Bašta	Soko	2
	Sombor	Bački Monoštor	2		Arilje	Mali Rzav	4
	Novi Sad	Koviljski rit	2		Ivanjica	Čemernica	2
		Kaćka šuma	1			Golija	2
	Pančevo	Donje Podunavlje	1				
Eastern Serbia	Zaječar	Kraljevica	2	Central Serbia	Smederevo	Šumadija	2
		Rtanj	3			Jezava	2
	Bor	Bakar-Lučki most	2			Ralja	2
	Negotin	Deli Jovan	3				
	Đerdap	Boljetinska reka	2				
		Đerdap	2				

2.2. RADIONUCLIDES CONTENT

For gamma spectrometric analyses the samples of muscle, *m. longissimus dorsi,* were taken from each animals, homogenized and until analyses stored at the –18°C. Gamma-ray spectrometric determination of ^{134}Cs and ^{137}Cs was performed on high-purity germanium detectors (ORTEC) with a relative efficiency of 22% and 30%, and energy resolution 1.85 keV (1332.5 keV of ^{60}Co). The counting time for the samples was 3600 s and measurements geometry were Marinelli dishes of 1l.

Energy calibration as well as detector efficiency calibration was performed using the Amersham radioactive standard (Mixture: ^{241}Am, ^{109}Cd, ^{139}Ce, ^{57}Co, ^{60}Co, ^{137}Cs, ^{113}Sn, ^{85}Sr, ^{88}Y, ^{203}Hg).

Wild boar meat is not a conventional food in Serbia, thus official institutions have not published data on its average consumption. In the present study, average effective dose equivalent was estimated for intake of 1 kg of wild boar meat.

The average effective dose equivalent, due to the ingestion of wild boar meat by adult members of the population, was calculated using the following formula [3, 8, 23]:

$$E\ (\mu\text{Sv}) = Y \times C \times \mathrm{d}k \tag{1}$$

where *E* is the effective dose from the consumption of ^{137}Cs in wild boar meat (μSv), *Y* is the intake of wild boar meat (calculated for 1 kg per person), *C* is the activity concentration of ^{137}Cs (Bq/kg) and d*k* is dose coefficient (conversion factor), equal to 1.3×10^{-8} Sv/Bq for ^{137}Cs [23].

2.3. STATISTICAL ANALYSES

Descriptive statistic of data were performed by using Graph Pad Prism 6.0. software (Graph Pad Software Inc., San Diego, CA, USA). All values are expressed as means and standard error of means, minimum and maximum.

3. RESULTS AND DISCUSSION

The activity concentration of ^{134}Cs and ^{137}Cs in wild boar meat are presented in Tables 2 and 3. The ^{134}Cs was detectable in all examined samples, with rang of activity from 0.01 to 1.11 Bq/kg. The highest content of ^{134}Cs was detected in wild boar from Eastern Serbia, municipality of Negotin, hunting area Deli Jovan (1.11 Bq/kg). The highest average activity concentration of ^{134}Cs was detected in region of West Serbia, and the minimum in region of North Serbia.

Table 2

Activity concentrations of ^{134}Cs in wild boar meat (Bq/ kg)

Region	Average	Standard error	min-max
Central Serbia	0.06	0.01	0.02–0.09
North Serbia	0.05	0.01	0.01–0.07
West Serbia	0.46	0.09	0.17–0.96
Eastern Serbia	0.35	0.09	0.02–1.11

The radiocesium-137 was detectable in all examined samples, with rang of activity from 0.09 to 5.18 Bq/kg. The maximum detected value was determined in the same sample as ^{134}Cs, which originated from Eastern Serbia, municipality of Negotin, hunting area Deli Jovan, while highest average content of ^{137}Cs was determined in Western Serbia.

Table 3

Activity concentrations of ^{137}Cs in wild boar meat (Bq/ kg)

Region	Average	Standard error	min-max
Central Serbia	0.22	0.04	0.09–0.41
North Serbia	0.19	0.03	0.05–0.38
West Serbia	2.32	0.46	0.87–5.03
Eastern Serbia	1.78	0.46	0.21–5.18

The values of average effective dose equivalent due to sample ingestion by adult members of the population is presented in Table 4. Lowest average effective dose equivalent is calculated for North Serbia, and highest for West Serbia, which is in line with determined values for ^{137}Cs for each region.

Table 4

Average annual effective dose equivalent due to ingestion of wild boar meat by adult members of the population

Region	^{137}Cs (μSv)	Rang
Central Serbia	0.003	0.001–0.005
North Serbia	0.002	0.0007–0.005
West Serbia	0.03	0.001–0.06
Eastern Serbia	0.02	0.003–0.07

The artificial radionuclides ^{134}Cs and ^{137}Cs were detected in all examined samples in the current study, but below the permissible limit (150 Bq/kg) specified by Serbian legislation [24]. According to EU regulation the maximum permitted level of ^{137}Cs is 600 Bq/kg for game meat [25]. ^{134}Cs was excluded from control and monitoring, due to its short half-life (approximately 2 years), which means that 10 periods of its half-life has already passed since the Chernobyl accident.

Due to its long physical half-life (30.17 years) and accumulation in the soil and food chain, radiocesium-137 is regarded as the most important manmade radionuclide [26, 27]. The amount of radiocaesium in the soil varies and depends primarily on the extent of contamination that occurred after the Chernobyl accident. Its potential to transfer from abiotic to biotic components of the environment may have long-term repercussions to the living organisms [26].

In spite of the gradual decline of ^{137}Cs in the environment its content in game meat are still detectable, and vary with the season, weather conditions and resulting changes in available feed sources and dietary habits of animals [27, 28]. According to the monitoring program conducted in Germany on 2021, the maximum detected level of ^{137}Cs in wild boar meat was 360 Bq/kg, and 0.72 Bq/kg for the ^{134}Cs [29]. In Italy, Reggio Calabria district, determined content of ^{137}Cs were lower than in our study, and ranged from 0.13 to 2.14 Bq/kg [8].

In wild boar meat hunted in Slovakia, maximum reported level of ^{137}Cs was 37.2 Bq/kg [27]. High ^{137}Cs activity (up to 10,699 Bq/kg) were reported in the wild boars muscles from Czech Republic [30], where in 2012, the highest measured value was 14,252 Bq/kg [31]. In Croatia, measured content of ^{137}Cs in wild boar meat, during the 2000 and 2002, varied from 0.4 to 611.5 Bq/kg [32]. Disagreements in determining levels of radioactive pollution reflect differences in Chernobyl fallout across Europe, allowing the identification of locations with varying amounts of contamination.

It was observed that content of ^{137}Cs in wild boar meat does not decrease linearly, along with lowering radiocesium content in the environment. Škrkal *et al.* [5] examined the radiocesium content in game meat, from 2004 to 2012 year, and proved the descending trend in ^{137}Cs content for red deer and roe deer. As opposed to in wild boar meat, the highest radioactivity of ^{137}Cs were in 2011 and 2012 (31 Bq kg/kg and 25 Bq/kg, respectively). This may be the consequence of several factors: wheatear conditions (long, cold winter), increased mushroom production, shortage of other feed sources. This is in line with Steinhauser and Paul [33] who reported that the activity concentration of ^{137}Cs in wild boars was almost constant, but it decreases continuously in soil due to its effective half-life.

In the present study, determined level of radionuclides in wild boar meat were several times higher in the mountains areas compared to other investigated sites. That is in line with results published by other authors who reported that the content of ^{137}Cs in soil and plants in Vojvodina region, Serbia, were two time lower, compared to mountain area [7, 34]. Positive relationship between the activity concentration of ^{137}Cs in wild boar meat and soil was found [4, 35, 36]. Nemoto *et al.* [4] has reported the mean activity concentration of ^{137}Cs from Fukushima Prefecture was 900 Bq/kg in wild boar meat and 129,919 Bq/kg in soil.

As opposed to, Vilić *et al.* [32] determined that ^{137}Cs content in wild boar meat in Croatia from areas with approximately equal levels of contamination differed significantly. This fact suggests that the main cause for high values of ^{137}Cs in wild boar meat could be the feed, and secondary contamination degree of soil and environment.

It has been found that wild boar meat contains more ^{137}Cs than other ungulate species due to the composition of the wild boar diet [9, 37]. Škrkal *et al.* [5] monitored radioactive contamination of game meat and proved the highest level of ^{137}Cs in wild boar meat, followed by red deer meat and roe deer meat (mean value 5.1 Bq/kg, 1.9 Bq/kg and 0.77 Bq/kg, respectively). Contamination of wild boar is mainly caused by the presence of fungus, tubers, roots, and earthworms in their diet. Fungi can accumulate ^{137}Cs in greater extent than green plants, due to its heterotrophic metabolism and dependence on the supply of final organic compounds [38–40]. Distribution of ^{137}Cs differs with the part of the mushroom body (higher activity was determined in the mushroom caps) [41], growth phase, as well as among different species [42]. Thus, fungus consumption represents the potential health risk problem [43, 44] for wild boars, and subsequently humans.

Average effective dose equivalent due to ingestion of 1 kg of wild boar meat by adult members of population determined in the present study varied from 0.0007 to 0.07 µSv, which is less than 1 mSv/a, set by Serbian law [24]. That indicates that the meat of wild boars in the territory of Serbia is safe for human consumption. The obtained results are in line with Caridi *et al.* [8], who estimated the effective dose for ^{137}Cs ranged from 0.01 to 0.11 µSv/a for wild boar meat ingestion, in Southern Italy. Cui *et al.* [3] reported the average effective dose for ingestion of wild boar meat, hunted in Fukushima prefecture, ranged from 0.12 to 0.30 μSv/a, for adults, which is higher than our results.

The evaluation of effective dose is with limitations, because the wild boar meat is not eaten uniformly in population, but depends primarily of eating habits and availability of wild boar meat. Higher effective dose is present in persons involved in hunting sports. It has been proven that people who consume game meat more than 10 times per year have approximately eightfold higher average annual game consumption [45]. Regarding that, often the same population members are exposed to these sources of radiation, and in that manner to chronic low doses of radiation.

4. CONCLUSION

Wild boars may serve as bioindicators of radioactive pollution, due to accumulation of radionuclides. Determined radiocesium activity concentration in wild boar reflects differences in radioactive contamination of environment, climate and bioavailability of the radionuclide.

The activity concentration of ^{137}Cs in wild boar meat in Serbia is low, thus do not represent an increased health risk for humans. Significant fallout of radiocaesium can be excluded. However, improvement of present study with long-term monitoring is needed in order to identify a long-term comprehensive risk evaluation such as internal exposure dose.

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