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Research Paper

Radionuclide Activity Concentrations of *Agaricus bisporus* and *Pleurotus ostreatus* Mushrooms Cultivated in Different Commercial Companies

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Abstract: In this study, it was determined the specific activities of some important radionuclides such as thorium (^{232}Th), uranium (^{238}U), potassium (^{40}K) and cesium (^{137}Cs) accumulated in *Agaricus bisporus* and *Pleurotus ostreatus* commercial mushrooms and in their compost. Additionally, the annual effective dose rates received by individuals were calculated. ^{137}Cs activity was not detected in any tested mushrooms. The specific activity concentrations of ^{232}Th, ^{238}U, ^{40}K were determined in range of 2.1-9.2, 14.6-26.6 and 330.4-739.7 Bq/kg, respectively in both mushroom species obtained from different firms. Same radionuclides' activity concentrations were calculated in range of 11.0-19.1, 27.8-45.1, 126.7-304.5 Bq/kg, respectively, in their compost. Among the *Agaricus* species, the highest ^{232}Th and ^{238}U activity concentration was calculated in the mushroom obtained from D firm. The highest ^{40}K activity concentration was detected in the mushroom provided from A firm. The lowest ^{238}U and the highest ^{232}Th concentrations were determined in *Pleurotus ostreatus.* Generally, all radionuclides were found different from each other statistically. However, all investigated parameters revealed that there was no any health risk in both mushroom species cultivated in different firms.

Keywords: *Radioactivity, effective dose, cultivated mushroom.*

Introduction

In many countries, people consume both wild edible mushrooms and commercially cultivated mushrooms. However, cultivated mushrooms are generally preferred to wild mushrooms due to more reliable source of supply. Therefore, the production and consumption of cultivated mushrooms has been increasing all over the world (Chang, 1999). In Turkey, production of cultivated mushroom was 40,874 tons in 2017, while was 23,426 tons in 2007 (Turkish Statistical Institute, 2018).

Mushrooms have been consumed as delicacy nutrition for many years. Most mushroom poor in fat and calories, rich in protein values (Wang et al., 2014) have medicinal properties such as antioxidant and antimicrobial (Smolskaitė et al., 2015; Akgul et al., 2017), antitumor/anticancer activity (Kosanić et al., 2016; Meng et al., 2016). Mushrooms are also known as bio indicators thanks to ability of accumulate heavy metals (Yilmaz et al., 2016a; Sevindik et al., 2018) in both of natural and artificial radionuclides (Racz et al., 2000; Pourimani and Rahimi, 2016). Determining radioactivity in environment and foodstuff is very important for to know the risk level which affect mammals direct or indirect. In this sense; researchers more closely need to study edible mushrooms which accumulate some radionuclides such as ^{137}Cs, ^{238}U, ^{232}Th and ^{210}Pb (Rühm et al., 1997). Until now, various studies accomplished for edible wild mushrooms including artificial radionuclide such as ^{137}Cs radionuclide to examine the possible danger to human health of wild mushrooms (Korky and Kowalski, 1989; Inagaki et al., 2015; Chiaravalle et al., 2018). On the other hand, limited data are available about activity concentrations of radionuclides (^{232}Th, ^{238}U, ^{40}K etc.) in cultivated mushrooms.

The main objectives of this study were

(i) to determine ^{232}Th, ^{238}U, ^{40}K (natural radionuclides) and ^{137}Cs (artificial radionuclide) activity concentrations of *Agaricus bisporus* and *Pleurotus ostreatus* cultivated mushrooms obtained from different companies in Trabzon province (Turkey)
(ii) to determine the radionuclide contents in the composts
(iii) to calculate the effective dose for each mushroom.

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Material and method

Material

In this study, it has been studied with two different cultivated mushroom species (*Pleurotus ostreatus, Agaricus bisporus*). The mushrooms were provided from mushroom manufacturing companies in Trabzon province located in the Eastern Black Sea region in Turkey. *P. ostreatus* mushroom was obtained from only one (1) commercially firm and *A. bisporus* mushroom was obtained from four (4) different commercially firms. Ethically; all commercial mushroom firms were encoded as A, B, C and D. The morphological properties (cm) and numbers (n) of tested mushrooms were presented in Table 1.

Table 1. Morphological properties (cm) and numbers (n) of tested mushrooms

Mushroom	Diameter of fruit bodies $\overline{X}$ ± SD	Diameter of stipe $\overline{X}$ ± SD	Length of stipe $\overline{X}$ ± SD	Total (n)
Agaricus bisporus (A, B, C, D)	4.4 ± 0.8	0.25±0.5	4.1 ± 0.3	44*
Pleurotus ostreatus	5.2 ± 1.6	0.96 ± 0.8	2.9 ± 0.6	9

*: *11 samples were used for each mushroom obtained different firm (A, B, C, D)*

Samples preparation

All the mushroom samples and their composts were sliced and dried at a drying machine at until they were completely dehydrated. Mushroom and compost samples were crushed for passing a 40-mm mesh sieve. They were put in plastic cylindrical container of uniform size (50 mm in height, 60 mm in diameter) and sealed for a period of 4 weeks in order to allow for radon and its short-lived progenies to reach secular radioactive equilibrium prior to gamma spectroscopy (Turhan et al., 2007).

Radioactivity measurements

Radioactivity measurements were performed by using a HPGe computer controlled detector having the resolution of 1.9 keV for the 1332 keV energy line of ^{60}Co with conventional electronics and 15% relative efficiency (Canberra, GC1519 model) and Genie 2000 as the software. The detector was shielded with a 10 cm thick lead layer to reduce the background due to the cosmic rays and the radiation nearby the system (Cevik et al., 2009).

Decay corrections were performed according to the sampling date. The energy calibration and absolute efficiency calibration of the spectrometer were carried out using calibration sources which contained ^{133}Ba, ^{57}Co, ^{22}Na, ^{137}Cs, ^{54}Mn, and ^{60}Co peaks for the energy range between 80 and 1400 keV (calibration sources supplied by Isotope Products Laboratories) (Cevik et al., 2007). The reference material of the International Atomic Energy Agency (IAEA-375) and the Gamma Acquisition & Analysis program were used to calibrate the efficiency of the gamma detector.

The gamma-ray lines of 295.2 keV from ^{214}Pb, 352.0 keV from ^{214}Pb and 609.4 keV from ^{214}Bi were used to evaluate the ^{238}U activity concentration, while 583.1 keV gamma-ray from ^{208}TI, 238.6 keV from ^{212}Pb and 911. keV from ^{228}Ac were used to determine to the ^{232}Th activity concentration. The activity concentrations of ^{40}K and ^{137}Cs were determined by using their 1460 keV and 661 keV gamma-ray lines, respectively.

After the samples and gamma spectroscopy system (with energy and yield calibrations) were prepared for measurement, the radioactivity analysis of each sample was performed for 80.000 seconds. At the end of this period, the spectra of the radioactive isotopes from the samples were calculated (Figure 1).

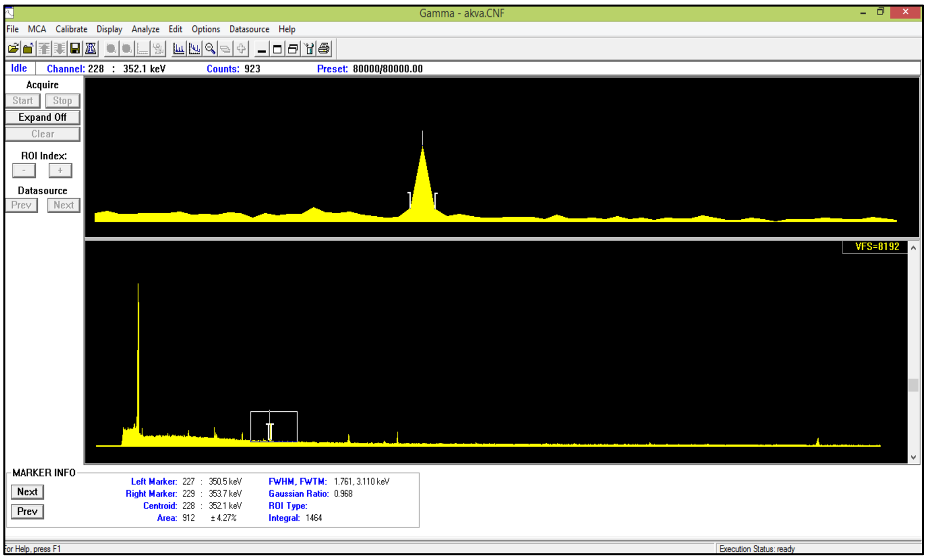

Figure 1. Calculation of the peak area of *Pleurotus ostreatus* mushroom in 352.0 keV

The specific activity of each sample was then calculated utilizing the following Equation 1 (Changizi et al., 2012);

$$A = \frac{C_{net}}{\varepsilon \times I_\gamma \times t \times m} \qquad (1)$$

where;
C_{net} was the net area of the total absorption line,
A was the activity of the isotope in Bq/kg,
I_γ was the absolute intensity of the transition,
t was the sample measurement time,
ε was the full energy peak efficiency and
m was the mass of the sample.

The minimum detectable activity (MDA) of the present measurement system was calculated as follows Equation 2 (Currie, 1968),

$$MDA = \frac{\sigma\sqrt{B}}{\varepsilon P t w} \qquad (2)$$

where;
MDA is in Bq/kg,
σ was the statistical coverage factor equal to 1.645 (confidence level 95%),
B was the background for the region of interest of a certain radionuclide,
P was the absolute transition of gamma decay,
ε was the full energy peak efficiency,
t was the counting time in seconds and
w was weight of the dried sample in kg.

Average annual effective dose

A possible risk of radioactivity for human being that consume these mushrooms is expressed by the effective dose (E) given in µSv/y (Faweya et al., 2015). The average annual effective dose equivalent that an individual receives due to the radionuclides ingestion from contaminated mushrooms was calculated using the following formula (International Atomic Energy Agency, 2001):

$$E = C \times H \times DF \qquad (3)$$

where;
E was annual effective dose from consumption of nuclide in foodstuff (µSv/y),
C was the concentration of radionuclide in foodstuff (Bq/kg),
H was the consumption rate for foodstuff p (kg/y) and
DF was the dose coefficient for ingestion of radionuclide (µSv/Bq). The values of this conversion factor for adults were: 0.28, 0.23, 1.3×10^{-2} and 6.2×10^{-3} µSv/Bq for ^{238}U, ^{232}Th, ^{137}Cs and ^{40}K, respectively.

In this study, the average annual consumption of mushrooms by adult Turkish people was taken as 0.360 kg.

Statistical analysis

Experimental results were recorded as mean ± standard deviation. Data were analyzed by one-way analysis of variance (ANOVA) using SPSS (version 23.0). The level of statistical significance was realized using Duncan's multiple range tests. Also, pearson correlation coefficient was used to determine the relationship between the radionuclides.

Results and Discussion

Radioactivity measurements

Radioactivity in mushrooms

Radionuclide concentrations for ^{232}U, ^{232}Th, ^{137}Cs and ^{40}K (Bq/kg dry weight) in cultivated mushroom samples were presented in Table 2 with statistical analysis results and levels of radionuclides in the mushrooms were showed in Figure 2.

Table 2. Natural and artificial radionuclides in mushrooms (Bq/kg)

Mushroom	**^{238}U**	**^{232}Th**	**^{137}Cs**	**^{40}K**
	$\bar{X}$ ± SD	$\bar{X}$ ± SD	$\bar{X}$ ± SD	$\bar{X}$ ± SD
Agaricus bisporus (A)	22.4 ± 1.3^{c}	2.1 ± 0.2^{a}	ND*	739.7 ± 25.2^{c}
Agaricus bisporus (B)	23.2 ± 1.6^{c}	6.4 ± 0.4^{c}	ND	528.4 ± 27.2^{b}
Agaricus bisporus (C)	17.5 ± 0.9^{b}	2.9 ± 0.3^{b}	ND	530.2 ± 22.4^{b}
Agaricus bisporus (D)	26.6 ± 1.8^{d}	7.1 ± 0.5^{d}	ND	486.5 ± 24.1^{b}
Pleurotus ostreatus	14.6 ± 1.3^{a}	9.2 ± 0.7^{e}	ND	330.4 ± 18.3^{a}

**ND: Not detected*

[a] Means having the same superscript letter(s) are not significantly different (p>0,05) by Duncan's multiple range test.

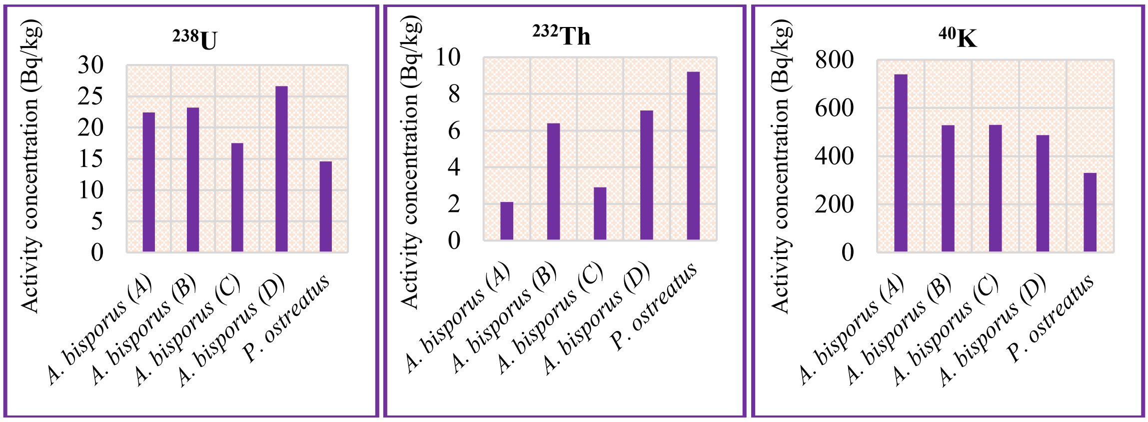

Figure 2. Levels of radionuclides in mushrooms

As can be seen Table 2; ^{238}U activity concentrations were found to be ranging from 14.6 ± 1.3 to 26.6 ± 1.8 Bq/kg. The highest activity concentration of ^{238}U was found in *A. bisporus* (D) with 26.6 ± 1.8 Bq/kg and the lowest activity concentration of ^{238}U in *P. ostreatus* (14.6 ± 1.3 Bq/kg). Our values were comparable with some wild mushrooms such as *Pleurotus squarrosulus* and *Pleurotus tuber-regium* studied in Nigeria [21.64 ± 7.23, 17.64 ± 5.98 Bq/kg, respectively; (Faweya et al., 2015)] and higher than *Amanita muscaria*, *Hebeloma cylindrosporum* and *Tricholoma terreum* collected from Spain[(2.3 ± 0.3, 3.2 ± 0.3, 1.9 ± 0.5 Bq/kg, respectively; (Baeza and Guillén, 2006)].

^{232}Th activity concentrations were found to be ranging from 2.1 ± 0.2 to 9.2 ± 0.7 Bq/kg (Fig 1). The highest activity concentration of ^{232}Th (9.2 ± 0.7 Bq/kg) was found in *P. ostreatus*. The lowest one (2.1 ± 0.2 Bq/kg) was found in *A. bisporus* (A). Our values were higher than wild mushroom such as *Pleurotus eryngii* and *Tricholoma equestre* [(0.56 ± 0.05, 1.44 ± 0.07 Bq/kg, respectively; (Baeza et al., 2006)]. In a previous study, ^{238}U and ^{232}Th activity concentration of 50 mushroom samples from Turkey were reported between 51 ± 6 and 41 ± 6 Bq/kg (Türkekul et al., 2018). Also, in our previous study, the highest ^{232}Th of wild mushroom *Agaricus campestris* collected from different province (Erzurum and Kahramanmaraş) of Turkey were determined as 11.7 and 13.4 Bq/kg, respectively (Yilmaz et al., 2016a). ^{232}Th activity concentrations were found lower than mentioned our previous study. It can be concluded that radioactivity levels of cultivated mushrooms are lower than wild mushrooms.

^{238}U activity concentrations of mushrooms were found higher than ^{232}Th activity concentrations. This difference may be result of using phosphate fertilizer in cultivating mushrooms. Because it is reported that ^{238}U activity concentrations were very higher than ^{232}Th activity concentrations in phosphate fertilizers (Cevik et al., 2010).

In regards to ^{40}K; it was observed that radionuclide levels varied between 330.4 ± 18.3 and 739.7 ± 25.2 Bq/kg. The highest activity concentration of ^{40}K (739.7 ± 25.2 Bq/kg) was found in *A. bisporus* (A). Our values were comparable with other *Agaricus bisporus* data produced in Brazil [(764 ± 3 Bq/kg; (De Castro et al., 2012)] and lower than some wild mushrooms such as *Lactarius deliciosus*, *Russula cessans*, *Tricholoma terreum, Agaricus campestris*, *Boletus aereus*, *Amanita caesarea* studied in Spain [(938 ± 32, 1256 ± 37, 1729 ± 25, 2334 ± 68, 1232 ± 41, 1264 ± 39 Bq/kg, respectively; (Baeza et al., 2004)]. In addition, our average values were higher than some wild mushrooms such as *Xylaria longipes* analyzed in Poland [355 ± 106 Bq/kg; (Mietelski et al., 2010)].

According to the Fig. 2; the highest ^{232}U, ^{232}Th, and 4^{0}K activity concentrations were observed in *A. bisporus* (D), *P. ostratus* and *A. bisporus* (A), respectively. Therefore, it has not been detected a name of the firm or mushroom species which especially had drawn attention.

^{137}Cs was not detected in any mushroom species. Generally, radionuclides concentrations were found significantly different ($p>0.05$) each other by Duncan's multiple range test. The differences in radionuclide concentrations can be attributed to the amount of radioactive deposition, concentration of stable elements or their analogues, taxonomic and ecological characteristics of the fungus (Oolbekkink and Kuyper, 1989) and cultivation methods (Ban-Nai et al., 2004).

Radioactivity in compost

Among the firms that cultivate *A. bisporus*, only B company has sent the compost sample for the analysis. Natural and artificial radionuclides (^{232}U, ^{232}Th, ^{137}Cs and ^{40}K, Bq/kg in dry weight) presented in compost samples (Table 3) were analyzed for *A. bisporus* (B) and *Pleurotus ostreatus*. The analysis results were presented in Table 3.

Table 3. Natural and artificial radionuclides in compost samples (Bq/kg)

Compost	**^{238}U**	**^{232}Th**	**^{137}Cs**	**^{40}K**
	$\overline{X}$ ± SD	$\overline{X}$ ± SD	$\overline{X}$ ± SD	$\overline{X}$ ± SD
Agaricus bisporus (B)*	45.1 ± 2.7	11.0 ± 0.6	ND**	304.5 ± 12.7
Pleurotus ostreatus	27.8 ± 1.2	19.1 ± 0.9	ND**	126.7 ± 5.2

**: Among the Agaricus bisporus firms, only B company has sent the compost sample for the analysis.*
***ND: Not detected*

The radionuclide activity concentrations of ^{232}Th, ^{238}U, ^{40}K in the mushrooms' composts were found to be ranging from 11.0 ± 0.6 to 19.1 ± 0.9, 27.8 ± 1.2 to 45.1 ± 2.7, 126.7 ± 5.2 to 304.5 ± 12.7 Bq/kg, respectively. ^{137}Cs was not detected in both compost samples, too. ^{232}Th, ^{238}U contents in compost samples were found higher than the ^{232}Th, ^{238}U contents in mushroom samples for both mushroom species. ^{40}K activity concentrations of substrate were lower than ^{40}K activity concentrations of mushrooms. In a study, ^{40}K activity concentrations of cap, stalk of mushroom (*Xerocomus badius*) and soil had been reported 1120±420, 910±390, 350±46 Bq/kg, respectively (Malinowska et al., 2006). Our data were agreement with the literature.

Effective dose

The effective doses (µS/y) of five cultivated mushrooms in Trabzon province were presented in Figure 3.

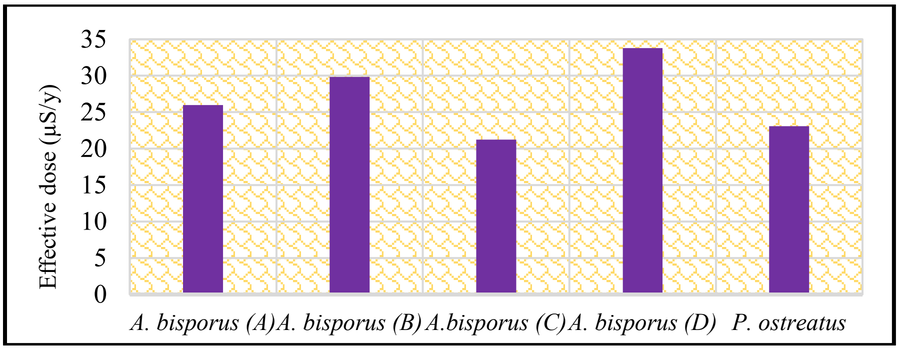

Figure 3. Annual effective doses

It has not been exactly known consumption amounts of per capita mushrooms in Turkey. In our previous study, mushroom consumption per capita was found around 0.75 kg/month (Yilmaz et al., 2016b). However, this value was calculated only for people living in the Trabzon. Therefore, this value is considered not to represent the avarege mushroom consumption of Turkey. The avarege mushroom consuption was taken as 0.360 kg because of the mentioned situation. The highest and lowest annual effective dose was seen in *A. bisporus* mushroom obtained from D firm and *A. bisporus* mushroom obtained from C firm, respectively. Half of the results were slightly higher than some wild mushroom's effective dose such as *Hebeloma* sp., *Tricholoma* sp. *Lactarius* sp. analyzed in Spain (with a range 0.37–24 µSv/y); (Baeza *et al*., 2004) and annual effective dose due to the ingestion of vegetables and their derived products consumed in Brazil [14.5 µS/v; (Santos et al., 2002)]. All effective doses were found below the world average value [(290 µSv/y), (Turkish Atomic Energy Authority, 2014)]. The low contamination levels in analyzed mushrooms reveals that the consumption of culture mushroom supplied from the mentioned companies will not cause any health problems for human body.

Correlation coefficients among the radionuclides are presented in Table 4. The results showed that there was a negative correlation between ^{232}Th and ^{40}K (r=-0.846), between ^{232}Th and ^{238}U (r=-0.114). In addition, there was a positive correlation between ^{238}U and ^{40}K (r=0.488)

Table 4. Correlation coefficients among the radionuclides of mushrooms

	^{238}U	^{232}Th	^{40}K
^{238}U	1		
^{232}Th	-0.114	1	
^{40}K	0.488	-0.846**	1

***. Correlation is significant at the 0.01 level (2-tailed).*

Conclusion

In this study the radioactivity of some cultivated mushroom species (*A. bisporus*, *P. ostratus*), obtained from different firms in Trabzon province, was determined. ^{137}Cs radionuclide was not detected in any mushroom species. The highest ^{232}U, ^{232}Th, and ^{40}K activity concentrations were observed in *A. bisporus* (D), *P. ostratus* and *A. bisporus* (A), respectively. Therefore, it has not been detected a name of the firm or mushroom species which especially had drawn attention. Generally, all radionuclides were found different from each other statistically. This situation can be attributed to the contamination arising from natural pollution and agricultural pollutant sources. Additionally, the chemicals used for hygiene in commercial production companies during the cultivation process can be effect the results. In conclusion, all investigated parameters revealed that there was no any health risk in commercially cultivated mushrooms (*A. bisporus* and *P. ostreatus*) obtained from different firms, in Trabzon. In the future more sophisticated studies which include the analysis of various natural and artificial radionuclides on different mushroom species obtained from different firms, can be performed.

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