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Original Article

Evaluation of ^{226}Ra, ^{232}Th, ^{137}Cs and ^{40}K "Agaricus Bisporus" Activity in Cultivated Edible Mushroom formed in Tehran Province- Iran

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Abstract

Introduction
Natural and man made radioactive sources exist in our environment they can enter into our food chains. One of these is the soil-mushroom-human chain. High level doses of natural radiation can cause hazards to humans.

Materials and Methods
Samples of Agaricus bisporus cultivated edible mushroom in Tehran province- Iran were collected from 7 farms. Specific activity of ^{226}Ra, ^{228}Ra, ^{137}Cs, ^{40}K and ^{235}U of the samples were measured by two HPGe detectors.

Results
Specific activity of ^{226}Ra, ^{228}Ra, ^{137}Cs and ^{40}K in the edible mushroom samples were equal to 0.06 ± 0.03 - 0.7 ± 0.2 Bq $kg^{-1}{}_{dry}$, 1.4 ± 0.7 Bq $kg^{-1}{}_{dry}$, 0.1 ± 0.03- 0.3 ± 0.1 Bq $kg^{-1}{}_{dry}$ and 920 ± 400 - 1370 ± 900 Bq $kg^{-1}{}_{dry}$, respectively.

Conclusion
As the measured concentrations of the radionuclides of interest are close or lower than MDA (Minimum Detectable Activity). Consumption of the mushrooms would impose no health consequences to the consumers.

Keywords: Agaricus Bisporus, Edible Mushroom, HpGe Detector, Tehran Province, Radionuclides

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1. Introduction

Release of radioactive material from different nuclear installations have resulted in the increase of radioactivity levels in the environment. Mining operations, mine tailings, the use of phosphate fertilizers, building materials and radioactivity released from burning fossil fuels (e.g., coal) have also added to the levels of radioactivity in the environment. The increase in environmental radioactivity has contributed to the increased radiation dose of general population [1,2]. Uranium, Thorium and Potassium are the main elements contributing to natural terrestrial radioactivity [3]. Ionizing radiation sources exist in our environment; therefore they can enter our food chain. One of the path ways is the soil-mushroom-human chain [4]. Humans are constantly exposed to natural and artificial radiation sources. After the Chernobyl nuclear accident of April 1986, in most countries environmental programs for detailed environmental studies have been developed to obtain early environmental information regarding the available average amount of radioactivity in different areas [5]. This is in case of a nuclear accident to be able to determine the radiation contamination added to the environment and the extent of its distribution in the environment, close or distant to the source of pollutants in the studied regions [5]. Gamma ray spectroscopy using HPGe detectors is to get quantitative analysis of the decay products, including of ^{226}Ra, ^{228}Ra, ^{137}Cs, ^{40}K and ^{235}U in environmental samples. Thus, the current study aims to measure radioactivity levels by Gamma-ray spectrometry, characterizing environmental radioactive materials based on different samples of Agaricus bisporus cultivated edible mushroom in Tehran province- Iran, which can help to obtain the radioactivity map of the region. This map can provide information as a reference in evaluating any change in the radiation levels of the area of interest [4-6].

2. Materials and Methods

2.1. Sampling & Sample Preparation

There are limited numbers of big companies for edible mushroom in Tehran province. Therefore, samples were collected from 7 companies coded W_1-W_7. In this study using random integration and experimental sampling, a combined operation was undertaken to collect samples. Samples of edible mushroom, as ordinary and straight were gathered from various niches with an average weight of 9-11 Kg (wet mushroom from each niche) in different parts of Tehran. Because of the possible source of radioactive contamination in mushroom samples, it was necessary to collect samples of compost (410 g dry weight), soil (293 g) and water (800 cc with pH=2), too. Hence, it was possible to analyze the source of contamination. Table (1) shows the locations of the samples. Average wet weight of each sample was measured and recorded (9–11Kg) mushroom. Samples were washed in distilled water for 10 minutes to remove the soil and other unwanted material. They were then passed through a plastic mold and spread in place allowing preliminary drying.

Table 1. Locations of sampling in Tehran province, Iran

Sample code	City
W_1	Karaj
W_2	Hashtgerd
W_3	Hashtgerd
W_4	Karaj
W_5	Shahriar
W_6	Shahriar
W_7	Shahriar

Using a plastic knife, the mushrooms were chopped into small pieces and were placed in glass containers that are suitable for heating at high temperatures. Most biological samples

such as mushroom samples contain large quantities of water, were placed in an oven at temperatures of 120 °C for 48 hours to allow complete drying. Average weight of dry samples was measured and recorded. Also dry to wet weight ratio of each sample was calculated, and recorded. Analysis was performed on dry samples and the results are presented in terms of wet weight. Dried samples were passed through a special qrinder that had a number one mesh to obtain grinder perfectly fine and uniform samples.

After grinding the samples, a total amount of 617 to 620 gr (for the same configuration of standard sample calibration) was put in a Marinelli beaker for spectroscopy. Using silicone adhesive, containers were sealed for 4 weeks to reach secular equilibrium between ^{238}U, ^{232}Th, and their progeny. Then, Marinelli beakers containing samples were taken to the laboratory for Gamma spectroscopy.

2.2. Spectroscopy and Analysis

Gamma-ray measurements were carried out using two co-axial P-type HPGe detectors with energy resolutions of 1.98 keV and 1.8 keV and relative efficiencies of 38.5% and 55% for the line 60Co, respectively. Each of the detectors was encased by a 10 cm thick lead shield, 2 mm Cadmium and 3 mm Copper to reduce background radiation [7]. Spectrum acquisition was carried out by using the computer software MAESTRO with a multi-channel analyzer (4096-channel), and spectrum analysis was carried out by using the OMNIGAM software. The absolute photopeak efficiency calibrations of the systems were carried out using photopeak from a standard mixed source containing ^{241}Am, ^{109}Cd, ^{57}Co, ^{133}Ba, ^{137}Cs and ^{60}Co which have a geometry identical to those of the mushroom, soil, compost and water samples, separately.

To analyze the samples they were placed in the Marinelli beakers, directly facing the two detectors. The counting geometry of samples and standard mixed sources used for efficiency calibration was kept constant. A wide range of different Gamma-ray energy transition lines ranging from around 100 kev up to 1765 keV, associated with the decay products of the ^{235}U, ^{238}U and ^{232}Th (and their decay progeny), the primordial radionuclide ^{40}K and ^{137}Cs arising from artificially created fission products were analyzed independently to obtain overall results. The photopeak lines of 295.22 and 351.93 keV (^{214}Pb), 609.31 and 1120.28 keV (^{214}Bi) were used to determine ^{238}U. The photopeak lines of 143.76 and 163.33 keV (^{235}U) were used to determine ^{235}U. The photopeak lines of 338.32, 911.2 and 968.97 keV (^{228}Ac) were used to determine ^{232}Th. The Gamma-ray transition of 661.66 keV was used to determine ^{137}Cs and 1461 keV for ^{40}K. Background spectra contributions were subtracted from the peak area in the OMNIGAM software. The counting time of sample spectra was also 80000 S. The activities of the radionuclides found in samples were determined using equation (1), and expressed in Bq/Kg [8]:

$$Act._{(Bq/Kg)} = \frac{C_{net}}{\varepsilon(\%) * (B.R) * T * W} * 100 \quad (1)$$

Where C_{net} is net area counts, $\varepsilon(\%)$ is the absolute photopeak efficiency at a specific energy, (B.R) is branching ratio for the specific energy, T is counting time and W is the mass of the sample in kg.

3. Results

In this study, radioactivities of 6 samples collected from 6 volunteer companies in Tehran province were measured. Activities of the ^{235}U, ^{238}U and ^{232}Th series decay products for these 6 samples are summarized in Tables 2-5, together with the measured activities of ^{40}K and ^{137}Cs [9-11].

Table 2. Specific activity of ^{226}Ra, ^{228}Ra, ^{137}Cs and ^{40}K in edible mushroom samples forms Tehran province, Iran

Sample Code	Ra-226(Bq/Kg)				Ra-228(Bq/Kg)			Cs-137(Bq/Kg)	K-40(Bq/Kg)
	Pb-214	Pb-214	Bi-214	Bi-214	Ac-228	Ac-228	Ac-228	Cs-137	K-40
	295(keV)	351(keV)	609(keV)	1120(keV)	911(keV)	968(keV)	338(keV)	661(keV)	1461(keV)
W1	< MDA	< MDA	0.06±0.03	< MDA	< MDA	< MDA	< MDA	< MDA	927.24±442.43
W2	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	0.26±0.1	1370.57±935.07
W3	< MDA	0.09±0.04	< MDA	< MDA	< MDA	< MDA	< MDA	0.1±0.03	1041.58±497
W4	< MDA	0.11±0.05	< MDA	0.36±0.2	< MDA	< MDA	< MDA	< MDA	997.59±476
W5	< MDA	< MDA	0.7±0.2	< MDA	< MDA	< MDA	< MDA	< MDA	1164.12±794.23
W6	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	1026.9±490
W7	< MDA	0.2±0.1	< MDA	< MDA	1.4±0.7	< MDA	< MDA	0.3±0.1	1216.25±830

Table 3. Specific activity of ^{226}Ra, ^{228}Ra, ^{137}Cs, ^{40}K and ^{235}U in compost samples forms Tehran province, Iran

Sample Code	Ra-226(Bq/kg)				Ra-228(Bq/kg)			Cs-137 (Bq/kg)	K-40(Bq/kg)	U-235(Bq/kg)			
	Pb-214	Pb-214	Bi-214	Bi-214	Ac-228	Ac-228	Ac-228	Cs-137	K-40	U-235	U-235	U-235	U-235
	295(keV)	351(keV)	609(keV)	1120(keV)	911(keV)	968(keV)	338(keV)	661(keV)	1461(keV)	143(keV)	163(keV)	185(keV)	205(keV)
W1	1.04 ± 0.2	1.08 ± 0.1	0.75 ± 0.1	< MDA	< MDA	< MDA	1.3 ± 0.3	0.11 ± 0.03	280.66 ± 2.7	0.59 ± 0.3	< MDA	0.45 ± 0.06	< MDA
W2	4.35 ± 0.9	4.02 ± 0.5	5.1 ± 0.5	6.46 ± 1.6	7.52 ± 1.2	6.83 ± 2.1	4.2 ± 1.2	0.76 ± 0.2	862.2 ± 6.6	< MDA	< MDA	1.6 ± 0.4	< MDA
W3	4.24 ± 0.4	4.04 ± 3	3.59 ± 0.2	3.63 ± 0.8	4.52 ± 0.5	2.76 ± 0.6	5.12 ± 0.7	0.34 ± 0.1	665.62 ± 6.7	2.36 ± 0.7	3.64 ± 1	2.13 ± 0.2	1.29 ± 0.7
W4	18.64 ±1	18.67 ± 1.4	18.58 ± 1	28.4 ± 4.2	17.16 ± 2	12.74 ± 2	13.5 ± 2.8	6.84 ± 0.6	764.76 ± 10.5	5.26 ± 1.9	< MDA	4.34 ± 0.6	< MDA
W5	4.42 ± 0.5	4.6 ± 0.4	4.19 ± 0.3	< MDA	3.4 ± 0.6	< MDA	5.53 ± 1.2	0.38 ± 0.1	120.84 ± 6.9	3.12 ± 0.9	< MDA	2.75 ± 0.2	< MDA
W7	4.62 ± 0.5	4.7 ± 0.3	3.97 ± 0.3	< MDA	6.61 ± 0.6	5.52 ± 0.8	7.21 ± 0.8	0.55 ± 0.1	313.44 ± 7	< MDA	< MDA	2.38 ± 0.2	3.22 ± 1.4

Table 4. Specific activity of ^{226}Ra, ^{228}Ra, ^{137}Cs, ^{40}K and ^{235}U in soil samples forms Tehran province, Iran

Sample Code	Ra-226(Bq/Kg)				Ra-228(Bq/Kg)			Cs-137(Bq/Kg)	K-40(Bq/Kg)	U-235(Bq/kg)			
	Pb-214	Pb-214	Bi-214	Bi-214	Ac-228	Ac-228	Ac-228	Cs-137	K-40	U-235	U-235	U-235	U-235
	295(keV)	351(keV)	609(keV)	1120(keV)	911(keV)	968(keV)	338(keV)	661(keV)	1461(keV)	143(keV)	163(keV)	185(keV)	205(keV)
W1	27.95±0.2	21.44±2	20.6±2	< MDA	21.92±1	< MDA	22.81±3	10.16±0.4	646.87±11	2. 6 ± 0.1	< MDA	4.1 ± 0.3	< MDA
W2	16.89±1	16.14±1	16.45±1	< MDA	14.93±1	14.9±2	< MDA	14.46±0.5	240.8±5	7.46 ± 1	< MDA	7.5 ± 05	11.9 ± 4
W3	20.4±1	21.8±2	21.46±0.8	25.21±3	18.69±1	13.67±1	29.65±4	13.56±0.6	298.25±5	< MDA	< MDA	4.1 ± 0.3	< MDA
W4	93.22±4	94.13±5	86.9±2	95.61±9	< MDA	15.57±2	12.8±6	5.98±3	206.18±13	< MDA	< MDA	6.3 ± 0.4	< MDA
W5	23.63±3	20.45±1	24.72±1	< MDA	15.28±3	11.82±2	21.29±7	9.4±1	499.31±16	10.99 ± 6	< MDA	19.8 ± 1	< MDA
W6	17.83±1	18.9±1	16.8±0.6	15.9±2	20.61±1	17.2±2	20.66±2	51.8±2	268.2±5	< MDA	12.5 ± 8	7.6 ± 0.2	< MDA
W7	43.8±2	46±2	40.2±1	< MDA	25.71±2	19.3±2	26.3±3	29.35±1	346.68±6	5.87 ±1	< MDA	< MDA	8.7 ± 0.7

Table 5. Specific activity of ^{226}Ra, ^{228}Ra, ^{137}Cs and ^{40}K in water samples forms Tehran province, Iran

Sample Code	Ra-226(Bq/L)				Ra-228(Bq/L)			Cs-137(Bq/L)	K-40(Bq/L)
	Pb-214	Pb-214	Bi-214	Bi-214	Ac-228	Ac-228	Ac-228	Cs-137	K-40
	295(keV)	351(keV)	609(keV)	1120(keV)	911(keV)	968(keV)	338(keV)	661(keV)	1461(keV)
W1	1.05±0.3	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	15.76±4.43
W2	< MDA	< MDA	< MDA	< MDA	< MDA	0.68±0.003	< MDA	< MDA	10.56±3.43
W3	< MDA	1.72±0.4	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	18.74±5.3
W4	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	14.72±4.3
W5	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	17.6±5.43
W6	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	15.6±4.3
W7	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	< MDA	19.26±8.43

4. Discussion

The specific activity of ^{226}Ra in the edible mushroom samples was found to be 0.06 ± 0.03 to 0.7 ± 0.2 Bq kg^{-1}_{dry} (with a weight mean value of: 0.38 ± 0.1 Bq kg^{-1}). It should be noted that the values obtained for ^{226}Ra were close to the MDA (Minimum Detectable Activity) of the detection system (0.11 ± 0.01 Bq), meaning samples W_2 and W_6 of the respective companies, have no detectable amounts of this radionuclide. In addition, values obtained in this work for ^{226}Ra, in comparison to studies performed in Japan, Poland and Brazil are very low [4-5]. Specific activity of ^{232}Th, in most samples was less than the MDA (0.11 ± 0.02 Bq). Only sample collected from W_7 company had specific activity of 1.4 ± 0.7 Bq kg^{-1}_{dry} for ^{228}Ra. This value is much lower than the world permissible value [9].

Specific activity of ^{137}Cs measured as an artificial radio-nuclide was 0.1±0.03- 0.3±0.1 Bq kg^{-1}_{dry}, that was lower than that of other countries such as Poland (6.5 Bq Kg^{-1}) [12]. Specific activity of ^{40}K with values of 920 ± 400-1370±900 Bq kg^{-1}_{dry}were in the range of permitted universal levels [4]. ^{40}K had the highest specific activity among the elements studied. This could be as a result of higher transfer factor from the soil to mushrooms for ^{40}K than that for other radio-nuclides, although ^{40}K is an essential biological element and its concentration in human tissues is under metabolic control [13]. According to the activity concentrations in water, soil and compost samples, we expected to have specific activity of much higher levels in mushroom samples, while this did not happen. This may be due to a complex process of radio-nuclide transport through water, soil and compost to mushrooms. Specific activities of ^{226}Ra and ^{232}Th in compost samples were equal 1.04 ± 0.2 - 18.64 ± 1 Bq kg^{-1}_{dry} (with a weight mean value of: 11.38 ± 2.1 Bq kg^{-1}) and 3.4 ± 0.6 -17.16 ± 2 Bq kg^{-1}_{dry} (with a weight mean value of: 10.30 ± 2.5 Bq kg^{-1}), respectively. It should be noted that the highest specific activities were attributed to the samples collected from W_4 Company. Activity of ^{137}Cs as an artificial radio-nuclide was be in the range of 0.11 ± 0.03-6.84 ± 0.6 Bq kg^{-1}_{dry} in compost samples that was higher activity than those found in other plant and soil samples. It should be noted that the highest specific activity, was related to the W_4 Company. Specific activity of ^{40}K was found to be in the range of 120.84±6.9 to 862±6.6 Bq kg^{-1}_{dry} in compost samples that was in permitted world standards. The highest concentration was related to the W_4 company. ^{235}U with a specific activity of 0.45± 0.06 to 5.26±1.9Bq kg^{-1}_{dry} in compost samples showed higher values than MDA (0.08 ± 0.01 Bq). Its highest value belonging to the W_4 company. In soil samples, specific activity of 16.89 ± 1 to 95.61 ± 9 Bq kg^{-1}_{dry} (with a mean weight value of: 55.38 ± 5.1 Bq kg^{-1}) and 14.9 ± 1.2 - 25.7 ± 2 Bq kg^{-1}_{dry} (with a mean weighted value of: 20.30 ± 3.5 Bq kg^{-1}) were achieved for ^{226}Ra and ^{232}Th, respectively. It should be noted that the highest specific activity for ^{226}Ra was related to the W_4 company. Specific activity of ^{137}Cs was found to be in the range of 5.98± 3- 51.8 ± 2 Bq kg^{-1}_{dry} in soil samples. It should be noted that the highest value belonged to the W_6 Company. Concentration of ^{40}K was obtained from 206.18±13 to 646.87±11 Bq kg^{-1}_{dry} that was in permitted world standards [4]. The highest specific activity was related to the W_1 company. ^{235}U with specific activity levels of 2.06±0.1-11±6Bq kg^{-1}_{dry} was found higher than the MDA (0.08 ±0.01 Bq) for soil samples. In this case the highest specific activity was related to the W_4 company [14]. Specific activity in water samples were about the MDA values for the desired detection system.

5. Conclusion

As measured activity of the radionuclides of interest are close or lower than MDA (Minimum Detectable Activity). Consumption of the mushrooms would impose no health consequences to the consumers.

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