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^{226}Ra, ^{228}Ra and ^{40}K Concentrations in Some Plant Seeds Consumed in Jordan

Khaled A. Al-Khaza'leh

Department of Physics, Al-albayt University, P.O.BOX 130040, Mafraq 25113, Jordan.

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Abstract: Eleven types of seeds consumed by Jordanian people were investigated to determine the concentration levels of ^{226}Ra, ^{228}Ra and ^{40}K radionuclides. The calculated concentration ranges from 0.214 ± 0.017 to 7.583 ± 0.592 Bq/kg_{dry}, 10.629 ± 0.914 Bq/kg_{dry} and 92.0 ± 7.61 to 576 ± 46.22 Bq/kg_{dry} for ^{226}Ra, ^{228}Ra and ^{40}K, respectively. The total annual effective dose that resulted from consuming the selected seeds by ingestion was 35.17 *μSv/year*, whereas the cancer risk ranges between 1.58×10^{-6} from fennel and 23.53×10^{-6} due to beans. However, the average cancer risk value was 7.74×10^{-6}, which is less than the world average cancer risk value *3mSv/year*.
Keywords: Radionuclides, Concentration, Annual effective dose, Cancer risk.

Introduction

Radium belongs to the primordial radionuclide group, as it always has natural radionuclides. In addition, the radionuclides ^{228}Ra and ^{226}Ra decay through two distinct series of radionuclides (Thorium and Uranium natural series, respectively). Besides, the natural decay series of ^{40}K contributes with a lot of irradiation to the human body.

Compared to ^{226}Ra which is an alpha emitter, ^{228}Ra is rather a weak β-emitter (E_{max}= 39.0 *keV* [60%] and 14.5 *keV* [40%]). Both alpha and beta emitters cannot penetrate the dead skin layer of the body to ionize the live cells. About 90% of radium enters the human body through food under normal environmental conditions [1]. Furthermore, plant contamination could be either directly correlated to the deposition of radioactive materials from the atmosphere [2, 3] or indirectly correlated to the absorption of radionuclides from soil by roots which are eventually transported to other parts of the plant [4]. The presence of radionuclides in edible parts of crops causes human internal exposure [5, 6]. Moreover, both types of radium (^{226}Ra and ^{228}Ra) were known as the most radiotoxic elements [7]. In addition, the high biological half life leads to long time internal irradiation exposure. However, ^{40}K is radiotoxic, yet naturally important [7].

In this study, we will determine the natural radionuclide (^{226}Ra, ^{228}Ra and ^{40}K) concentrations in some plant seeds consumed by Jordanian people.

Materials and Methods

Eleven types of plant seeds used very often in Jordanian food were purchased from a local market in Ramtha city. These seeds are: black pepper, black cumin, cumin, anise, coriander, fenugreek, fennel, chickpeas, beans, peas and corn. Each of these samples weight was 250g.

Sample Preparation

The pre-treated samples were made according to the recommendations given by International Atomic Energy Agency [8]. First of all, the samples were dried overnight at 105°C to reach a constant weight. All the dried samples were grounded into fine powder. Next, each sample was saved in a 90 ml capacity beaker. After that, all the samples were left for about 28 days to

Corresponding Author: Khaled A. Al-Khaza'leh **Email**: khazalih@aabu.edu.jo

allow reaching secular equilibrium of ^{226}Ra and ^{228}Ra and their daughters [14].

Furthermore, radioactivity was determined in the Gamma Spectroscopy Laboratory in Jordan Atomic Energy Commission (JAEC). Radionuclides were analyzed by gamma spectroscopy with a high-purity germanium detector (HPGe) connected to a multi-channel analyzer (MCA) of Genie-2000 software. The relative efficiency of this detector is about 50% with a resolution of 2.0 *keV*. The activity concentration of ^{226}Ra was determined through its daughter products ^{214}Pb (295.2 *keV* and 351.9 *keV*) and ^{214}Bi (609.3 *keV*). Besides, the activity of ^{228}Ra was determined through its daughters ^{212}Pb (238.6 *keV*) and ^{228}Ac (911.2 *keV* and 969 *keV*). However, the ^{40}K activity can be determined by its own gamma peak of 1461 *keV*.

Theoretical Calculations

Annual Effective Dose

The annual effective dose due to ingestion occurring through contaminated food by radionuclides can be calculated using Eq. (1) [9]:

$$AD = \mu CA \quad (1)$$

where (AD) is the annual effective dose (*Sv/year*), μ is the dose coefficient (*Sv/Bq*), C is the concentration of the radionuclide in the sample (*Bq/kg*) and A is the annual consumption (*kg/year*). The dose coefficients were 2.8×10^{-7} *Sv/Bq* for ^{226}Ra, 6.7×10^{-7} *Sv/Bq* for ^{228}Ra and 6.2×10^{-9} *Sv/Bq* for ^{40}K [2].

Excess Lifetime Cancer Risk

Excess lifetime cancer risk due to exposure through ingestion was calculated using Equation (2) [10-12].

$$Rc = Cd \times RF\ (Sv^{-1}) \quad (2)$$

where RF is the risk factor (0.05) as (ICRP 1990) and Cd is the lifetime of the effective dose. The lifetime of the effective dose is a measure of the total effective dose received over an average lifetime of 50 years following ingestion of a radionuclide and was calculated using UNSCEAR 2000 [13]:

$$Cd = 50 \times D \quad (3)$$

where D is the total effective dose to an individual.

Results and Discussion

As presented in Table (1), ^{226}Ra concentrations range from 0.214±0.017 *Bq/kg* in black cumin and 7.583 ± 0.592 *Bq/kg* in coriander. Additionally, ^{228}Ra concentrations were not detectable in beans and chickpeas. However, the ^{228}Ra concentration for black pepper was found 10.629 ± 0.914 *Bq/kg*. Finally, the ^{40}K concentrations were found 92 ± 7.612 *Bq/kg* and 576 ± 46.22 *Bq/kg* for both black pepper and fennel, respectively. From the above, clearly ^{40}K has the highest concentration in all samples (refer to Table 1). This could be correlated to the high concentration of potassium in soil, where plants absorb it in different amounts [14].

From Fig. 1, coriander has the maximum concentration of ^{226}Ra followed by corn, anise and fennel. The concentrations of ^{226}Ra in beans, black cumin and chickpeas are much less than in other seeds. On one hand, the maximum concentration of ^{228}Ra in black pepper is far less than in other seeds and not detectable in both beans and chickpeas (refer to Fig. 2). Fennel has the maximum concentration of ^{40}K followed by cumin, then by beans, anise and coriander with black pepper having the minimum concentration of ^{40}K, (refer to Fig. 3).

Fig. 4 shows a comparison between ^{226}Ra and ^{228}Ra concentrations in all seeds under study. As we can see from Fig. 4, ^{226}Ra concentrations are greater than ^{228}Ra concentrations in all samples under investigation with the exceptions in black pepper and black cumin.

TABLE 1. The concentrations of ^{226}Ra, ^{228}Ra and ^{40}K in selected plant seeds in Bq/kg_{dry}.

Plant seed	^{226}Ra	^{228}Ra	^{40}K
Black Pepper	4.257±0.331	10.629±0.914	92.0±7.61
Black cumin	0.214±0.017	2.271±0.212	336±27.03
Cumin	3.610±0.294	1.583±0.130	550±43.92
Anise	5.247±0.418	3.220±0.263	468±37.65
Coriander	7.583±0.592	2.061±0.158	448±36.41
Fenugreek	2.543±0.224	1.629±0.135	297±22.94
Fennel	4.821±0.378	4.254±0.361	576±46.22
Chickpeas	0.615±0.055	Not detectable	320±26.31
Beans	0.273±0.023	Not detectable	462±36.61
Peas	2.425±0.220	1.665±0.141	261±20.41
Corn	6.352±0.493	1.462±0.120	191±15.47

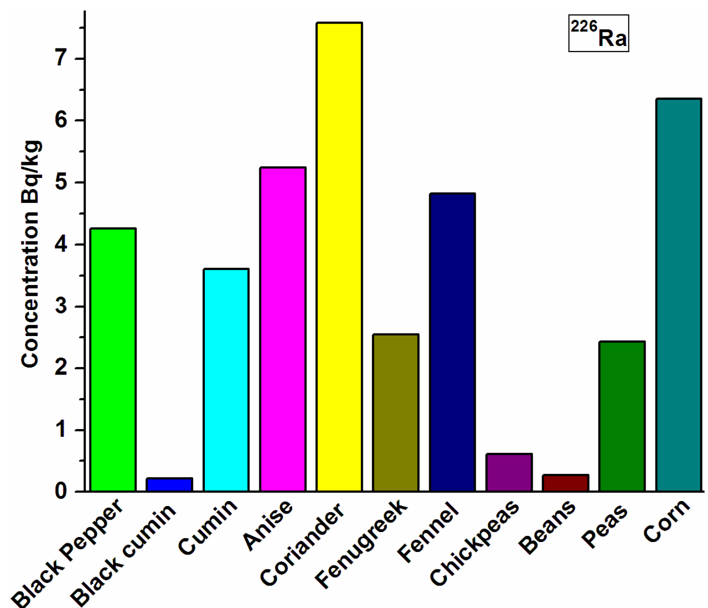

FIG. 1. The concentrations of ^{226}Ra in the selected plant seeds in (Bq/kg_{dry}).

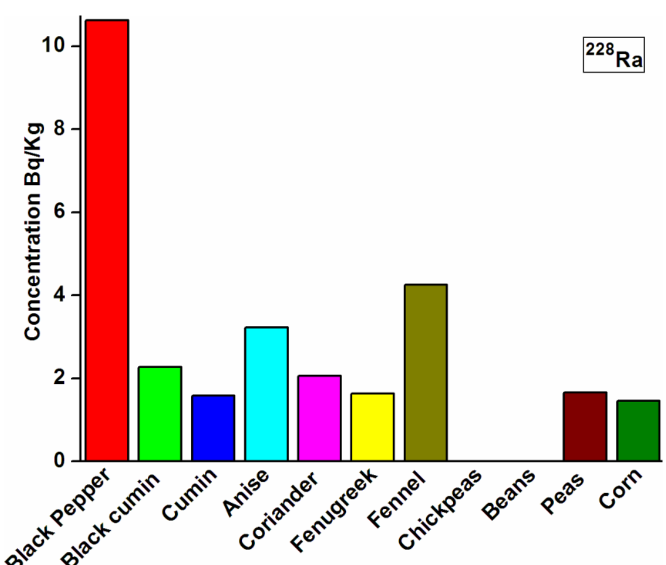

FIG. 2. The concentrations of ^{228}Ra in the selected plant seeds in (Bq/kg_{dry}).

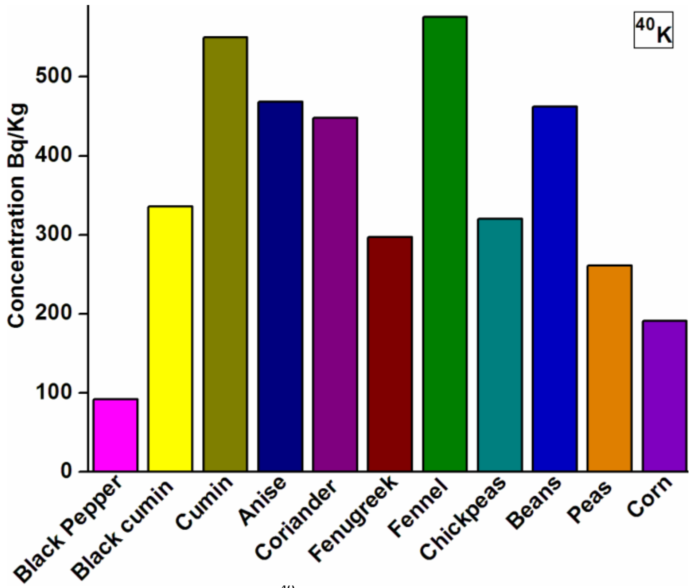

FIG. 3. The concentrations of ^{40}K in the selected plant seeds in (Bq/kg_{dry}).

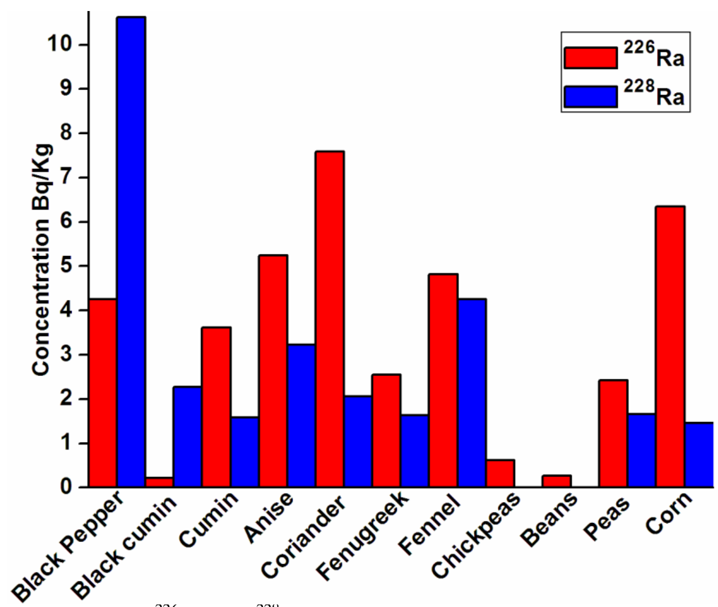

FIG. 4. Comparison between ^{226}Ra and ^{228}Ra concentrations in the selected plant seeds in (Bq/kg_{dry}).

It is worth to mention that the present results are comparable with other local and international results. A study in Saudi Arabia reported that the concentrations of ^{226}Ra in black pepper, black cumin, anise, coriander and fennel were 21.71, 5.9, 38.2, 69 and 16.5 Bq/kg_{dry} respectively [12]. For comparison, the concentrations of ^{226}Ra in the present study were 4.3, 0.21, 5.2, 7.5 and 4.8 Bq/kg_{dry} for black pepper, black cumin, anise, coriander and fennel, respectively. It can be seen that all concentrations in the present study were less than those in Saudi Arabia. However, in Pakistan, for instance, the concentration of ^{226}Ra in black pepper and peas was 1.2 Bq/kg_{dry} [15], which means less than in our study.

Furthermore, in Spain [16], the concentrations of ^{226}Ra in such seeds were comparable with those in our study, except in coriander which was higher in our study. Moreover, in Tanzania, the concentrations of ^{226}Ra in beans and corn were 21 and 25.6 Bq/kg [17] and 34 Bq/kg for corn in Nigeria [18], while in Iraq, the ^{226}Ra concentration was 0.41 Bq/kg in corn [19]. In the present study, the concentrations of ^{226}Ra were much less than those in Tanzania and Nigeria, yet, they are comparable with the results in Iraq. Additionally, the concentrations of ^{228}Ra in coriander, chickpeas and beans were < 0.11 *Bq/kg*, < 0.39 *Bq/kg* and < 0.34 *Bq/kg*, respectively in Spain [16], which are close to our results for both chickpeas and beans, yet ^{228}Ra was not detectable in both chickpeas and beans. However, in our study, higher concentrations of ^{228}Ra in coriander were present.

As a final comparison, the concentrations of ^{40}K in Saudi Arabia, as Al-Ghamdi reported, were 446, 1039, 589, 964 and 786 *Bq/kg* for black pepper, black cumin, coriander, anise and fennel, respectively [12]. On the other hand, our investigations reveal lower ^{40}K concentrations for the same seeds, respectively (refer to Table 1). Moreover, in Egypt, ^{40}K concentrations were 507, 900, 611 and 596 *Bq/kg* in black pepper, cumin, coriander and beans, respectively, which are greater than the concentrations of ^{40}K in our study [20]. In a Nigerian study, Jibiri and others reported that the concentrations of ^{40}K in beans and corn were 453 and 243 *Bq/kg*, respectively compared with the concentrations of ^{40}K in beans and corn in the present study [18]. In Spain, ^{40}K concentrations were 380 and 370 *Bq/kg* in chickpeas and corn, respectively [16], while those concentrations were 130 and 419 *Bq/kg* for black cumin and chickpeas in Iraq [19]. Both annual effective dose and cancer risk were calculated and presented in Table 2.

TABLE 2. Annual effective doses in μSv/year and cancer risk values for ^{226}Ra, ^{228}Ra and ^{40}K radionuclides.

Generally	Annual consumption	Annual effective dose			Total annual effective dose	Cancer risk μSv/year
Plant seed	kg/y	^{226}Ra	^{228}Ra	^{40}K		
Black Pepper	0.14	0.17	1	0.08	1.25	3.13
Black cumin	0.23	0.01	0.35	0.48	0.84	2.1
Cumin	0.18	0.18	0.19	0.61	0.98	2.45
Anise	0.22	0.32	0.47	0.64	1.43	3.58
Coriander	0.37	0.79	0.51	1.03	2.33	5.83
Fenugreek	0.42	0.3	0.46	0.77	1.53	3.83
Fennel	0.15	0.2	0.43	1.11	1.74	1.58
Chickpeas	3.5	0.24	0	0.53	0.77	1.93
Beans	3.2	0.24	0	9.17	9.41	23.53
Peas	2.4	1.63	2.68	3.88	8.19	20.48
Corn	1.7	3.02	1.67	2.01	6.7	16.75
Total	12.51	7.10	7.76	20.31	35.17	102.56

From Table 2, it can be seen that the annual effective dose for ^{226}Ra was maximum for corn (3.02 *μSv/year*) and minimum for black cumin (0.01 *μSv/year*). In addition, for ^{228}Ra, the maximum annual effective dose was recorded for peas with 2.68 *μSv/year*, followed by corn with 1.67 *μSv/year*, while ^{228}Ra was not detected in both beans and chickpeas. Finally, the maximum annual effective dose of ^{40}K was recorded for beans with 9.17 *μSv/year*, followed by peas with 3.88 *μSv/year*. Black pepper has the minimum dose of 0.08 *μSv/year*. Apparently, the annual effective dose depends not only on the concentration of radionuclide in the individual seed (*Bq/kg*), but also on the annual consumption (*kg/year*). This can explain the variations in the above calculated annual effective doses. In general, beans have the maximum total annual effective dose of 9.41 *μSv/year*, followed by peas with 8.19 *μSv/year* and corn with 6.7 *μSv/year*, with the minimum dose of 0.77 *μSv/year* in chickpeas.

Clearly, about 58% of the total annual dose resulting from the studied radionuclide was for ^{40}K with 20.31 *μSv/year*, while ^{228}Ra and ^{226}Ra are forming 22% and 20%, respectively. Additionally, the total annual effective dose for all seeds was 35.17 *μSv/year*, which is quite below the upper limit of 3 mSv as specified by ICRP recommendations [13].

Furthermore, beans have the maximum cancer risk of 23.53×10^{-6}, followed by peas and corn with 20.48×10^{-6} and 16.75×10^{-6}, respectively, while the cancer risk is minimum for fennel with 1.58×10^{-6} (refer to Table 2). In addition, the total cancer risk for seeds under study is 102.56×10-^{6}. However, the average risk value is 7.74×10^{-6}, which could be less than those reported in other studies of 58×10^{-6} [12]

and 48×10^{-6} [10]. Compared to the world average risk of 290×10^{-6}, the present study shows a lower cancer risk.

Conclusion

The concentrations of ^{226}Ra, ^{228}Ra and ^{40}K in selected food seeds in Jordan were measured and compared with those reported in other international studies. The concentrations range from 0.214 Bq/kg_{dry} in black cumin to 7.54 Bq/kg_{dry} in coriander for ^{226}Ra. While ^{228}Ra concentrations were not detectable in chickpeas and beans, ^{228}Ra concentration was 10.62 Bq/kg_{dry} in black pepper. Furthermore, ^{40}K concentrations in black pepper and fennel were 92 Bq/kg_{dry} and 576 Bq/kg_{dry}, respectively. The annual effective dose ranges from 0.77 $\mu Sv/year$ in chickpeas to 9.41 $\mu Sv/year$ in beans, which is less than the upper limit 3mSv according to ICRP [13]. On the other hand, the average cancer risk was 7.4×10^{-6}, which is less than the world average risk [12]. Our investigations suggest that consuming the selected seeds by Jordanian people has no significant health risk. However, other consumed foods by Jordanians require further investigations.

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