

Radiological assessment of different varieties of pistachios produced in Iran

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HIGHLIGHTS

- Measurement of natural radionuclides in some popular variety of pistachios.
- Calculation of radiometric parameters for these varieties.
- Comparison of them contains with other reported work from other countries.
- Provided discussion about of radiological indices.
- Comparing of radionuclides absorption in point of varieties

ABSTRACT

Nuclear radiations are harmful to the human body. The main sources of nuclear radiation are the decay chains of U-238, U-235, and Th-232 and also some radionuclides as K-40, which are present in small amounts in the materials of the earth's crust, including plants, rocks, soil and water. Radioactive substances are transferred to the human body in a variety of ways, including plant and animal products. Therefore, it is very important to determine the amount of radioactive substances in food products. In this research, seven samples of pistachios with different types were collected from Tehran markets in Iran. In this project, ultra-pure germanium spectroscopy system model GCD30195 was used. The specific activities of Ra-226, Th-232 and K-40 varied from < 1.96 to 9.86 , from 1.21 to 1.95 , and from 317.22 to 382.80 Bq.kg⁻¹. The artificial radionuclide of Cs-137 in all samples was lower than minimum detectable value (MDA). Calculations of the radiological impact showed that consumption of pistachios would endanger human health. The results of this study also showed that the amount of natural radionuclides in pistachio cores is higher than pistachio shells.

KEYWORDS

Pistachio
HPGe
Ra-226
Th-232
Radiation
Radionuclide

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1 Introduction

Radioactive materials are naturally present in the earth's crust. The main sources of nuclear radiation are the decay chains of U-238, Th-232 and U-235 and some individual radionuclides such K-40. This radiation is harmful to living tissue and can cause cancer or genetic abnormalities (Abojassim and Hashem, 2019). In recent years many research were done in foods stuff containing radionuclides (Pourimani and Anoosheh, 2015; Pourimani and Asadpour, 2016; Pourimani and Mortazavi Shahroudi, 2018; Pourimani and Mohebian, 2021). Many researchers have measured the radiation levels of nuts in other countries such as Iraq, Ukraine, and Italy (Abojassim and Hashem, 2019; Abda et al., 2020; Ezzulddin et al., 2017). pistachios are one of the oilseeds your body needs, rich in nutrients

such as potassium, phosphorus, vitamins B6 and B1, and full of antioxidants. Antioxidants play a vital role in the health of the body. These substances reduce the risk of cancer and other diseases by preventing damage to the body's cells. Pistachios are essential for eye health due to their antioxidants lutein and zagratin. Pistachios contain fiber and are good for digestive health. On the other hand, 21% of the total weight of pistachios is protein and it is important for people who have a vegetarian diet. Pistachio shell is also used to produce activated carbon and tar extraction in industry (Raw, 2012). Considering the importance of pistachios in the diet and its shell in industry, it is important to know the specific amount of different radioactive nuclei in it, pistachio and sunflower seeds have been done in different parts of the world, including Iran (Ezzulddin et al., 2017).

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2 Materials and Methods

In this project, seven samples of pistachios with different types of Ahmad Aghaei, Akbari, Fandoughi and Koleghoochi Rafsanjan and Damghan were collected from Tehran markets in Iran. Sampling was done randomly. For each type of pistachio, pistachio shell was homogeneous and homogeneous powder after separation from the kernel by mill (Mohebian and Pourimani, 2020; IAEA, 2004). 300 g of each pistachio sample was transferred to small cylindrical containers and then each container was coded according to the type of sample. Coding was done according to the type of sample. Type Ahmad Aghaei Rafsanjan with AMR code, Ahmad Aghaei Damghan with AMD code, Akbari Rafsanjan with AKR code, Akbari Damghan with AKD code, Rafsanjan fandoghi with FDR code, Damghan fandoghi with FDD code, Rafsanjan Kalle Ghoochi with KGR code. Containers of pistachio samples were sealed with aquarium glue. The reason for sealing is to prevent the leakage of radon gas from the container, which is necessary to maintain the equilibrium of radionuclide activity in the chain (Gilmore and Hemingway, 2008). Detector energy calibration and efficiency were determined by the standard RGU and Cs-137 source with specified activity. The energy-channel relationship is presented in Eq. (1) (Linear Energy Calibration Equation):

$$\text{Energy} = 7.52 + (0.33 \times \text{Channel}) \quad (1)$$

In this project, ultra-pure germanium spectroscopy system model GCD30195 was used. The detector has a voltage of 1.95 keV with a voltage of v3000 and an efficiency of 30%.

2.1 The efficiency of detector

Using the efficiency calibration curve, the efficiency of gamma lines was determined to be 295.22, 351.93, 609.31 related to decay products Ra-226, 338.32, 583.19, 911.25 related to decay products Th-232 and 1460.83 related to K-40 radionuclide (Firestone et al., 1997):

$$\varepsilon(\%) = \frac{\text{NetArea}}{A \times \text{BR}(\%) \times T} \times 100 \quad (2)$$

where *NetArea* is the net count below the peak of all energy corresponding to E_i energy, A is the specific radionuclide activity, $\text{BR}(\%)$ is the probability of emitting photons with E_i energy, and T is the count time. The gamma ray spectrum of each sample was recorded for 86400 seconds. Spectra were recorded using Lsrmbisi software and spectra analysis was performed using Gammavision 32 software (Mohebian and Pourimani, 2020). Background radiation measured under the same conditions for a container filled with double-distilled water and subtracted from the spectra of the samples (Pourimani and Mohebian, 2021).

2.2 The specific activity of radioactive nuclei

Using the net level below the full energy peak, the efficiency of the detector-sample system, the mass of the

sample and the probability of gamma emission, the specific activity of Ra-226, Th-232, K-40 and Cs-137 in the samples can be calculated (UNSCEAR, 1988):

$$A = \frac{\text{NetArea}}{\varepsilon(\%) \times \text{BR}(\%) \times T \times M} \times 100 \quad (3)$$

where A is the specific radionuclide activity in the sample in terms of Bq.kg^{-1} , ε is the detector efficiency, and M is the mass of the sample in kg. *NetArea*, T , and $\text{BR}(\%)$ are defined according to Eq. (1).

If the activity of a radioactive nucleus in a sample is less than the minimum measurable activity (MDA) of that nucleus by the detector, then the activity of that specific nucleus is less than MDA (Mohebian and Pourimani, 2020).

3 Measurements of the radiological parameters

3.1 Radium Activity equivalent (Ra_{eq})

The total radioactivity of natural radionuclides, including Ra-226, Th-232, and K-40 in the samples can be defined as the equivalent of Ra-226 radioactivity, which is calculated using Eq. (4) (UNSCEAR, 1988):

$$Ra_{(eq)} = A_{Ra} + 1.43 A_{Th} + 0.077 A_K \quad (4)$$

3.2 Absorbed dose rate (ADR)

The dose of gamma radiation absorbed (D) in the air at an altitude of 1 m above the ground (average height of the gonads) for natural radionuclides is obtained from Eq. (5) (UNSCEAR, 1988):

$$D \text{ (nGy.h}^{-1}\text{)} = 0.427 A_{Ra} + 0.662 A_{Th} + 0.0432 A_K \quad (5)$$

The Scientific Committee on the Effects of Atomic Radiation Sources reports the global average of the absorption dose rate in air from ground materials at nGy.h^{-1} (59.29) (UNSCEAR, 1988).

3.3 Calculation of alpha, gamma indexes and internal risk index (H_{in}) and external risk index (H_{ex})

External gamma and gamma radiation indices are used to evaluate the excess gamma radiation of pistachio samples. In addition to radon gas decay in samples, alpha radiation measurements are performed using internal and alpha risk indices. Equations (6) to (9) show the alpha, gamma index, internal and external risk index, respectively (EC, 1999; Inuyomi et al., 2019). To ensure the safety of pistachio samples the value of the mentioned equations must be less than one.

$$I_\alpha = \frac{A_{Ra}}{200} \quad (6)$$

$$I_\gamma = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \quad (7)$$

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (8)$$

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (9)$$

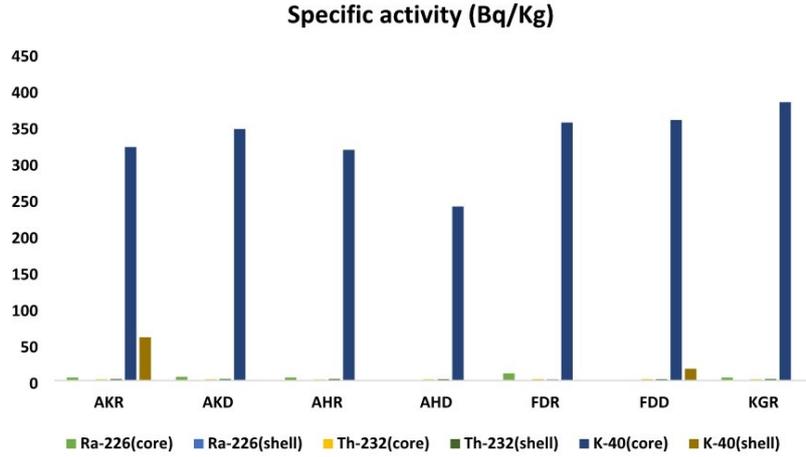


Figure 1: Specific activity (Bq.kg^{-1}) for the sample.

3.4 Calculating annual gonads equivalent dose

The dose absorbed by some important organs of the body such as the thyroid gland, lungs, gonads can be calculated using Eq. (10) by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (UNSCEAR, 2008).

$$AGDE (\mu\text{Sv.y}^{-1}) = 3.09 A_{Ra} + 4.18 A_{Th} + 0.314 A_K \quad (10)$$

3.5 calculating the effective annual dose

The effective annual dose for each individual resulting from the intake of natural radionuclides and Cs-137 is obtained using Eq. (11) (UNSCEAR, 2008):

$$D_w = \sum A_i \times DCF_i \times Cr \quad (11)$$

where A_i is the specific activity of the radionuclides of Ra-226, Th-232, K-40, and Cs-137 in Bq.kg^{-1} . DCF_i is the conversion factor in terms of Sievert per Becquerel, which is equal to 2.8×10^{-7} , 6.9×10^{-7} , 6.2×10^{-9} , and 1.3×10^{-8} , respectively (Pawel et al., 2007).

Cr is the annual consumption of pistachios which is 600 g in Iran (MAJ, 2019). The conversion factor depends on two factors, the main type of radioisotope being in the pistachio sample.

3.6 Excessive risk of lifelong cancer (ELCR)

The calculation of the additional cancer risk due to environmental gamma radiation is calculated using Eq. (12) (UNSCEAR, 2008).

$$ELCR = AED \times AL \times RF \quad (12)$$

where AED , AL , and RF are effective annual dose, Average lifespan, and risk factor, respectively. The International Committee for Radiation Protection set the risk conversion factor at 0.05 Sv^{-1} (Pawel et al., 2007). According to the World Health Organization for Iranians,

the AL was 71.15 years (DOC, 2017). The global average of $ELCR$ is 0.29×10^{-3} and the maximum allowable limit is 10^{-3} (Abojassim and Hashem, 2019; IAEA, 2011).

4 Results

The specific activity values of radioactive nuclei of Ra-226, Th-232, K-40, and Cs-137 in seven samples of pistachio core and seven samples of pistachio shell are given in Table 1. Data on radium equivalent activity (Ra_{eq}), annual effective dose (AED) and excess lifetime cancer risk (ELCR) calculated in Tables 2 and 4 for pistachio core and their shell samples, respectively. Also data on air dose rate (D), internal and external risk indices (H_{in} and H_{ex}), alpha-gamma index (I_α and I_γ) and effective annual gonadal dose (AGDE) in Tables 3 and 5. It is given for pistachio and their shell samples, respectively.

5 Discussion and conclusion

Based on the data in Table 1 and Fig. 1 the highest specific activity of radium nucleus in the FDR sample (9.86 ± 1.176) and the lowest activity in the FDD, AHD samples was obtained. The highest and lowest specific activity of thorium nucleus are in FDR and AHR samples (1.95 ± 0.30 , 1.21 ± 0.37), respectively. The highest specific activity of potassium radioactive nucleus was obtained in KGR sample (382.80 ± 11.85) and the lowest amount of activity was obtained in AHR sample (317.22 ± 10.32). The specific activity level of cesium radioactive nuclei in pistachio cores and pistachio shells and the specific activity level of radium radioactive nuclei in the shell of all samples is less than the level of MDA. The highest specific activity of thorium and potassium radioactive nuclei is in AHR and AKR sample shell (2.27 ± 0.30 , 59.39 ± 3.34), respectively. The amount of activity due to the specific nuclei of radium, thorium and potassium is less than the allowable average (35, 40, and 400 Bq.kg^{-1}). Based on the data in Tables 2 and 4, the average activity of radium equivalent for pistachios and pistachio shells was 31.54 and 3.57

Table 1: Specific activities of Ra-226, Th-232, and K-40 radionuclides in pistachio core samples.

	Sample	Activity (Bq.kg ⁻¹)				
		Ra-226	Th-232	CS-137	MDA	K-40
Pistachio core	AKD	5.05 ± 0.83	1.37 ± 0.30	<MDA	0.71	345.94 ± 10.76
	FDD	<1.96	1.84 ± 0.30	<MDA	0.59	358.05 ± 10.51
	AKR	3.93 ± 0.96	1.38 ± 0.26	<MDA	0.48	321.07 ± 10.32
	FDR	9.86 ± 1.176	1.95 ± 0.30	<MDA	0.48	354.70 ± 11.3
	KGR	4.06 ± 1.02	1.48 ± 0.28	<MDA	0.67	382.80 ± 11.85
	AHD	<2.38	1.52 ± 0.42	<MDA	0.80	239.10 ± 7.90
	AHR	4.01 ± 0.89	1.21 ± 0.37	<MDA	0.80	317.22 ± 10.32
	Average	3.84	1.53	<MDA	0.62	331.26
Pistachio shell	AKD	<2.95	2.06 ± 0.28	<MDA	1.01	<13.88
	FDD	<2.98	1.69 ± 0.28	<MDA	0.97	16.06 ± 3.61
	AKR	<2.76	2.17 ± 0.32	<MDA	0.94	59.39 ± 3.34
	FDR	<2.93	1.28 ± 0.30	<MDA	0.96	<14.61
	KGR	<2.92	2.09 ± 0.29	<MDA	0.97	<14.59
	AHD	<2.93	1.88 ± 0.30	<MDA	0.97	<14.71
	AHR	<2.94	2.27 ± 0.30	<MDA	1.02	<9.13
	Average	<2.91	1.92	<MDA	0.97	10.77

Table 2: Radium equivalent activity, effective annual dose and cancer risk in pistachio samples.

Sample	Ra _{eq} (Bq.kg ⁻¹)	AED (μSv.y ⁻¹)			Total AED (mSv.y ⁻¹)	Cr (kg.y ⁻¹)	ELCR (×10 ⁻³)
		Ra-226	Th-232	K-40			
AKR	30.62	2.2	0.77	179.8	0.18	0.016	0.53
AKD	33.64	2.82	0.76	193.7	0.20	0.014	0.57
AHR	30.16	2.24	0.67	177.6	0.18	0.016	0.52
AHD	20.58	0	0.85	133.9	0.13	0.021	0.39
FDR	39.96	5.52	1.09	198.6	0.21	0.014	0.59
FDD	30.2	0	1.03	200.5	0.20	0.014	0.58
KGR	35.65	2.27	0.82	214.4	0.22	0.013	0.63
min	20.58	0	0.67	133.9	0.13	0.013	0.39
max	39.96	5.52	1.09	214.4	0.22	0.021	0.63
mean	31.54	2.15	0.86	185.50	0.19	0.015	0.54

Table 3: The Radiological hazard indicators of pistachio core samples.

Sample	ADR (nGy.hr ⁻¹)	H _{in}	H _{ex}	Gamma and Alpha indices		AGDE (μSv.y ⁻¹)
				I _α	I _γ	
AKR	16.04	0.09	0.08	0.01	0.25	118.72
AKD	17.59	0.1	0.09	0.02	0.27	129.95
AHR	15.82	0.09	0.08	0.02	0.25	117.05
AHD	10.89	0.05	0.05	0	0.17	81.43
FDR	20.53	0.13	0.1	0.04	0.32	149.99
FDD	16.05	0.08	0.08	0	0.25	120.11
KGR	18.73	0.1	0.09	0.02	0.29	138.93
min	10.89	0.05	0.05	0	0.17	81.43
max	20.53	0.13	0.1	0.04	0.32	149.99
mean	16.52	0.09	0.08	0.02	0.26	122.31

Table 4: Radium equivalent activity, effective annual dose and cancer risk in pistachio shell samples.

Sample	Ra _{eq} (Bq.kg ⁻¹)	AED (μSv.y ⁻¹)			Total AED (μSv.y ⁻¹)	ELCR (×10 ⁻⁶)
		Ra-226	Th-232	K-40		
AKR	7.67	0	0.99	0.73	1.72	5.01
AKD	2.94	0	0.94	0	0.94	2.74
AHR	3.24	0	1.04	0	1.04	3.03
AHD	2.68	0	0.86	0	0.86	2.51
FDR	1.82	0	0.58	0	0.58	1.69
FDD	3.65	0	0.77	0.19	0.96	2.8
KGR	2.98	0	0.96	0	0.96	2.8
min	1.82	0.00	0.58	0.00	0.58	1.69
max	7.67	0.00	1.04	0.73	1.72	5.01
mean	3.57	0.00	0.88	0.13	1.01	2.94

Table 5: Radiological hazard indices of pistachio shell samples.

Sample	Ra _{eq} (Bq.kg ⁻¹)	AED (μSv.y ⁻¹)			Total AED (μSv.y ⁻¹)	AGDE (×10 ⁻⁶)
		Ra-226	Th-232	K-40		
AKR	3.78	0.02	0.02	0.00	0.06	27.71
AKD	1.24	0.01	0.01	0.00	0.02	8.61
AHR	1.37	0.01	0.01	0.00	0.02	9.48
AHD	1.13	0.01	0.01	0.00	0.02	7.85
FDR	0.77	0.00	0.00	0.00	0.01	5.32
FDD	1.69	0.01	0.01	0.00	0.03	12.10
KGR	1.26	0.01	0.01	0.00	0.02	8.73
min	0.77	0.00	0.00	0.00	0.01	5.32
max	3.78	0.02	0.02	0.00	0.06	27.71
mean	1.61	0.01	0.01	0.00	0.03	11.40

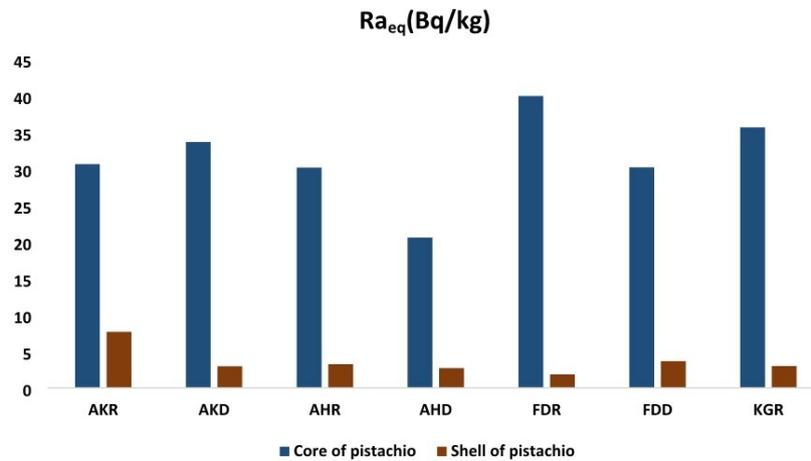


Figure 2: Comparison of radium equivalent activity between pistachio core samples and pistachio shell.

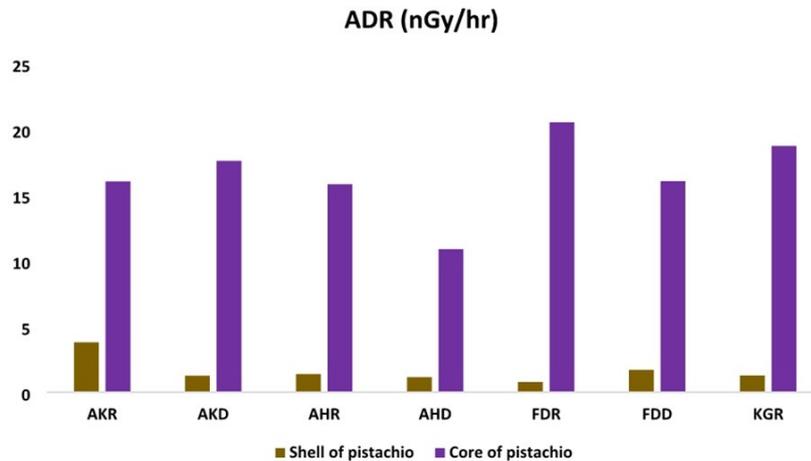


Figure 3: The absorbed dose rate of gamma radiation for samples.

Bq.kg⁻¹, respectively. Table 2 shows a higher absorption dose rate in the FDR pistachio core sample. Also, Figs. 2 and 3 show that the radium activity equivalent and the absorbed dose of pistachio samples are higher than pistachio shells samples, which indicates high radioactivity of pistachio cores compared to pistachio shells. In all samples, the total concentration of measured radionuclides did not exceed the IAEA limit of 1000 Bq.kg⁻¹ for food gamma emitters. Consequently, the pistachios analyzed in this ar-

ticle are considered safe for human consumption (IAEA, 2016). The absorption dose rate due to gamma radiation specific of natural radioactive nuclei is lower than the average amount in all samples (59.29 nGy.h⁻¹). In Fig. 4, the absorbed dose rate in the air at a height of one meter above the ground surface of the studied pistachio shell is compared with other countries. This figure shows well that the Iranian pistachio shell is healthier in terms of quality. The results show that the average dose of in-

Table 6: Comparison of activity, radium equivalent activity, absorbed dose rate, gamma index and internal risk index of this study with other parts of the world.

sample	Activity (Bq.kg ⁻¹)			Ra _{eq} (Bq.kg ⁻¹)	ADR (nGy.hr ⁻¹)	I _γ	H _{in}	Reference
	Ra-226	Th-232	K-40					
Almonds (Iraq)	4.90	2.43	256.50	28.13	14.42	0.23	0.09	(Abojassim and Hashem, 2019)
Pistachio (Erbil)	0.05	0.35	268.93	21.26	11.45	0.18	0.06	(Ezzulddin et al., 2017)
Hazelnut(Erbil)	0.05	0.28	258.84	20.39	10.98	0.18	0.05	(Ezzulddin et al., 2017)
Core Walnut (Ukraine)	5.11	16.05	124.30	37.63	17.23	0.28	0.11	(Abda et al., 2020)
Core Walnut (Romania)	2.81	ND	135.70	13.26	1.85	0.11	0.04	(Abda et al., 2020)
AKR	3.93	1.38	321.07	30.63	16.04	0.25	0.09	This work
AHR	4.01	1.21	317.22	30.17	15.82	0.25	0.09	This work
FDR	9.86	1.95	354.70	39.96	20.53	0.32	0.13	This work

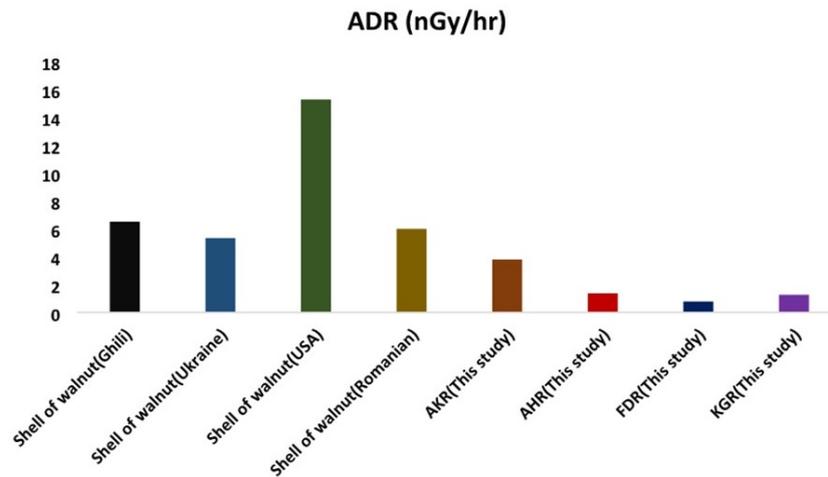


Figure 4: The absorbed dose rate (ADR) of gamma radiation for different samples between countries.

gestion due to pistachio core consumption is lower than the Global average annual effective dose (0.30 mSv.y⁻¹) (Higley, 2006).

Internal and external risk indices in pistachio core samples vary from 0.05 to 0.013 and 0.05 to 0.10, respectively. Internal and external risk indices in pistachio shell samples vary from 0 to 0.02. Alpha and gamma index for pistachio core samples ranged from 0 to 0.04 and 0.17 to 0.32. Alpha and gamma index for pistachio shell samples was calculated from 0 to 0.02. The average internal risk index and gamma index of pistachio samples were calculated with 0.09 and 0.26, respectively, which is higher than the sample of pistachio shell. Comparison of radioactivity of pistachio core samples with other parts of the world shows that the measured thorium is lower than Ukrainian walnut and Iraqi almond core. According to the data in Table 6. The amount of radium and potassium activity in the FDR sample is higher than the data. Radium equivalent activity and absorption dose in FDR sample show higher value than Erbil pistachio.

6 Conclusions

The results of this study show that the amount of radiation from the radioactive nuclei of radium, thorium, potassium and cesium in samples of pistachio cores is higher than pistachio shells and also the radiation of the studied samples

is higher than the radiation of some other countries. Using the results and comparing them, it can be seen that the use of pistachios in the diet and pistachio skin in the process of producing activated carbon is safe.

Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work.

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