EVALUATION OF RADIATION HAZARDS AND RISK ASSESSMENT IN AGRICULTURAL SOIL AND COMMONLY CONSUMED VEGETABLES IN THE DISTRICT OF KLANG, MALAYSIA

by

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Commonly consumed vegetables and their surrounding soil samples are gathered from a farm located in Klang, Selangor. Gamma spectrometry has been utilized to analyze the activity concentration of the natural radionuclides, ^{226}Ra, ^{232}Th, and ^{40}K in nine vegetables and soil samples collected. These data are used to evaluate the hazard indices in the soil samples and their radiological exposure to humans. It is found that the external hazard index H_{ex} ranged from 0.05 to 0.44 with a mean value of 0.14. The internal hazard index H_{in} of the soil samples ranged from 0.05 to 0.56 with a mean value of 0.17. Both H_{ex} and H_{in} average values are lower than the limit established by the European Commission for Radiation Protection. The absorbed dose rate D_N, The annual ingestion dose A_{eff}, annual effective dose equivalent *AEDE*, and excess life-time cancer risk, are used to learn the potential risk on the general public consuming these vegetables. For the vegetable sample, it is found that the average value for the D_N is 6.70 nGyh^{-1} and ranged between 1.75 to 16.94 nGyh^{-1}. The average value of A_{eff} is 10.17 Sv, and it ranges from 2.54 Sv to 22.89 Sv. The range of *AEDE* is between 2.15 Sv and 20.78 S, with an average value of 8.21 Sv. Excess life-time cancer risk *ELCR* is used to determine the likelihood of cancer development due to the radiological exposure of consuming these vegetables. It is found that the average value of *ELCR* is 2.87 10^{-5}, and the range is from 0.75 10^{-5} to 7.27 10^{-5}. Both the A_{eff} and *AEDE* are found to be lower than the average world value recommended by UNSCEAR.

Key words: annual ingestion dose, radiation hazard, naturally occurring radionuclide, hazard index, absorbed dose rate

INTRODUCTION

Radioactive substances can be found in the environment. They can enter the body through various sources and paths. The consumption of radionuclide-containing plants is the most common route of human radiation ingestion. It leads to internal radiation exposure over time, particularly to critical organs.

Ionizing radiation has the potential to induce tissue injury. Radiation-induced changes in the chemical properties of molecules in the tissue are the primary cause of tissue damage after being exposed to radiation. The most significant source of radiation-induced damage is the creation of so called *free radicals*. Given that free radicals are chemically extremely active, they have the potential to react with genetic components inside the cell (*i. e.*, the DNA). This has the potential to cause DNA damage, the majority of which is easily repaired by the cell. If this is not the case, cell death may occur. Alternatively, if the DNA damage is repaired incorrectly, it may result in a modification of the genetic encoding, which can result in hereditary alterations or the development of cancer.

Since radiation has been a part of our lives, our bodies have evolved to handle the low levels of radiation that we are exposed to. In contrast, excessive exposure to radiation may result in tissue damage by changing the structure of cells and damaging DNA in the body. The consequence of this may be a variety of health problems, including cancer. Inhaling or ingesting a radionuclide can expose the body to ionizing ra-

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diation. This type of exposure usually lasts for a long time and can be initiated by various means, such as injection or through wounds.

According to the Ministry of Health (MOH) report, Malaysia, the most frequently consumed item are bananas, apples, oranges, green leafy vegetables, bean type vegetables, and cabbages. Nearly 40 % of the adult population eat green leafy vegetables daily. The MOH recommends taking fruits and vegetables at least five servings a day (approximately 400 gram per day) since vegetables and fruits are categorized as the second most crucial food after rice and grains [1].

The present work aims to evaluate the radiological hazards both in the soil and the commonly consumed vegetables by adults living in Selangor, Malaysia [2]. A total of 9 types of vegetables are collected from the farms located in these areas. These vegetables are grouped into three main types of vegetables. They are leaf-type vegetables where Japanese mustard (*Brassicas junceea*), spinach (*Spinnacia oleracea*), and water spinach (*Ipomoeea aquatic*). The fruit species are bitter gourd (*Momordica charantia*), cucumber (*Cucumis sativus*), and round brinjal (*Solanum melongena*). Bean's type of vegetables is long beans (*Vigna sesquipedolis*), lady's finger or okra (*Hibiscus esculentus*), and four angles bean (*Psophocarpus tetragonolobus*). These vegetables are grown in a peat soil farm located in the district of Klang, where farming has been going on for more than 20 years, where once it was oil palm estates. In this study, the H_{ex} and the H_{in} were determined for the soil surrounding and the selected vegetables. As for the vegetable samples, the A_{eff}, D_N, and *AEDE*, was determined. At the end of the process, these values are used to evaluate the *ELCR* to humans, which was compared to the world average values for cancer risk.

MATERIALS AND METHODS

Sampling technique

In this study, nine types of vegetables were identified, and 5 kg of each vegetable sample were collected. These vegetables were freshly harvested from the farm with the help of the farmers. The location of these farms, at the following co-ordinates: 2º57'03.5"N, 101°28'30.0"E, is shown in fig. 1. Everything from dirt to dust, to surface contaminants, was removed from all of the vegetable samples before they were used. In the next step, the edible portion of the vegetable was cut into tiny pieces and dried out using an electric furnace at 65 °C for 24 hours, until the sample achieved a dry weight. The dry samples were ground and sieved to get a fine powder. Soil samples from the area where the respective vegetables were grown, was collected at the same time. The surface soil 10 cm deep was removed, and a soil sample was taken from a depth of 10-30 cm, to determine its composition. Rocks, dry leaves and twigs and other debris were cleared from the soil sample before crushing it into a fine grain. The samples of soils were then dried in an electric oven at 110 °C for 24 hours to fully eliminate the humidity. For four weeks, dried vegetable and soil samples were sealed in a Marenilli beakers to achieve radioactive equilibrium among ^{226}Ra and its progenies [3, 4].

Measurement of radioactivity

Gamma spectroscopy analysis was performed using a closed-end coaxial HPGe gamma-ray detector (Canberra; Model GC3018, serial no. 04089401; 59 mm

Figure 1. Location of Klang district in the state of Selangor

crystal diameter; 50 mm long; 2500V working voltage) with an efficiency of 30 % and resolution of 1.8 keV-FWHM at the 1332.5 keV peak of ^{60}Co. The detector was placed inside a cylinder-shaped lead cover to lessen the background radiation. The HPGe gamma-ray detector was linked to a 16k MCA2 for data measurement. The spectra were analyzed using Genie 2000 software, which was developed in Canberra.

As shown in fig. 2, the spectrometer's energy efficiency calibration is performed. The standard materials and samples were taken using containers of the same size (having a diameter of 6.5 cm and a height of 7.5 cm) so that the detector geometry remained identical. The counting time of the sample was kept enough to minimize the counting error. This energy efficiency calibration of the detector was made using Marinelli calibration sources comprising the following: ^{109}Cd (88 keV), ^{57}Co (122 keV), ^{139}Ce (167 keV), ^{203}Hg (279 keV), ^{113}Sn (392 keV), ^{85}Sr (514 keV), ^{137}Cs (662 keV), ^{88}Y (898 and 1836 keV), and ^{60}Co (1173 and 1332 keV). The calibration source with an initial activity of 5.08 Ci (1 Ci = 3.7 10^{10} Bq) was acquired from Eckert & Ziegler, Isotope Products Laboratories (Valencia, Cal., US).

The soil and vegetable samples were measured for a total of 86400 seconds to minimize the counting uncertainty and background readings in the measurements. To measure the activities of ^{238}U, ^{232}Th, and ^{40}K, gamma spectroscopy was used. The ^{226}Ra activity concentration was evaluated using the gamma-ray lines at 352 keV (35.8 %) from ^{214}Pb decay, and at 609 keV (44.8 %), 1120 keV (14.8 %), and 1764 keV (15.36 %) from ^{214}Bi decay. The ^{232}Th activity concentration was measured utilizing the gamma-ray lines at 239 keV (43 %) from ^{212}Pb decay, 583 keV (84.5 %) and 2614 keV (99.16 %) from ^{208}Tl decay, and 911 keV (26.6 %) from ^{228}Ac decay. The activity concentration of ^{40}K was directly analyzed using the gamma-ray line at 1461 keV (10.7 %) represented in tab. 1 [5, 6]

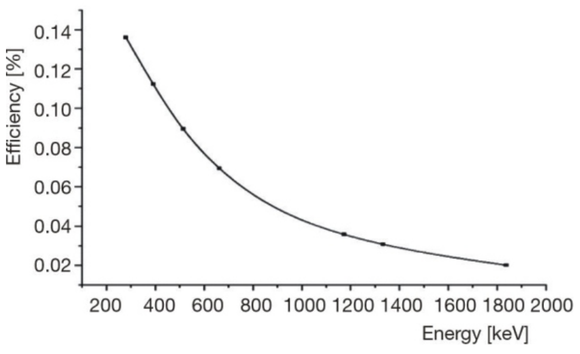

Figure 2. Energy efficiency curve of the detector

Determination of the activity concentration

The activity concentrations of these radionuclides A_{Ei} [Bqkg^{-1}], were determined using the equation below

$$A_{Ei} \quad \frac{N_{Ei}}{C_{\text{eff}}\, tm\gamma} \tag{1}$$

where N_{Ei} is the net count of a peak at energy E, C_{eff} – the detection efficiency at energy E, γ – the proportion of the radionuclide i's gamma emission probability for an energy transition E, m – the mass in kg of the calculated sample, and t – the count period [7].

External hazard index H_{ex}

External hazard index H_{ex} is another approach that has been generally used to set a maximum of exposure to humans. The limit of the H_{ex} is 1.00 and H_{ex} is calculated by [8, 9]

$$H_{\text{ex}} \quad \frac{C_{\text{Ra}}}{370} \quad \frac{C_{\text{Th}}}{259} \quad \frac{C_{\text{K}}}{4810} \tag{2}$$

Internal hazard index H_{in}

The internal hazard index H_{in} measures the Radon amount and its' harmful progeny that has been introduced into the body *via* inhalation or food consumption. The H_{in} is given by

$$H_{\text{in}} \quad \frac{C_{\text{Ra}}}{185} \quad \frac{C_{\text{Th}}}{259} \quad \frac{C_{\text{K}}}{4810} \tag{3}$$

where C_{Ra}, C_{Th}, and C_{K} are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively, in Bqkg^{-1} [10].

Annual effective ingestion dose A_{eff}

The A_{eff} to humans, due to consumption of vegetables, is assessed using the following equation [11].

$$A_{\text{eff}}(\ \text{Sv}) \quad \text{Activity Concentration (Bqkg}^{\ 1}) \quad \text{Annual intake (kg)}\ DCF\ (\ \text{SvBq}^{\ 1}) \tag{4}$$

where *DCF* is the dose conversion factor for ingestion, 0.28 μSvBq^{-1} for ^{226}Ra, 0.23 μSv B^{-1} for ^{232}Th, and 0.0062 μSvBq^{-1} for ^{40}K [12].

The annual intake of vegetable type is 12.4 kgy^{-1} for leaf, 14.04 kgy^{-1} for beans and 11.68 kgy^{-1} for fruit. Based on the consumption of vegetables by adults in Selangor, Malaysia, it is possible to determine the total yearly intake of vegetables [2]. The average worldwide annual effective ingestion dose A_{eff} of ^{226}Ra and ^{232}Th is 120 μSv and for ^{40}K is 170 μSv, with a total annual dose of 290 μSv [13].

Table 1. Gamma-ray energy and percentage abundance for ^{238}U, ^{232}Th, and ^{40}K radionuclides

Element	Nuclide	Half-life	Energy of gamma ray [keV]	Abundance [%]	Sources
^{238}U	^{214}Pb	26.8 minutes	351	35.8	^{238}U (^{226}Ra) series
	^{214}Bi	19.9 minutes	609.3 1764.5	45.4 15.3	
^{232}Th	^{228}Ac	6.15 hours	338.4 911.1 968.9	11.4 25.8 17.4	^{232}Th series
	^{212}Pb		238.63	46.6	
	^{208}Tl		583.19	85.0	
^{40}K	^{40}K	1.28 10^9 years	1460.8	10.7	Primordial

Absorbed dose rate D_N

The effect of naturally occurring radionuclides on the rate at which radiation is absorbed is dependent on the active concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the environment. It is a total ionizing dose, and it is divided by the time it takes to deliver the dose. The higher dose – the greater is the harm and damages to the human body. The worldwide suggested values of the absorbed dose rate recommended are 55 nGyh^{-1} [13]. Therefore, the absorbed dose rate D_N (nGyh^{-1}) is calculated with [14, 15]

$$D_N \quad 0.461C_{Ra} \quad 0.623C_{Th} \quad 0.0414C_K \tag{5}$$

Annual effective dose equivalent *AEDE*

In order to convert the absorbed dose rate into the effective dose rate *AEDE*, owing to natural radionuclides, was calculated using the constant of 0.2 and the dose transfer coefficient of 0.7 SvGy^{-1}, which were both used in the calculation [13]. It is possible to calculate the yearly effective dosage for the population by [16].

$$AEDE \quad D_N\,(\text{nGyh}^{\ 1})\ 8760\,(\text{h})\ 0.2\ 0.7(\text{SvGy}^{\ 1}) \tag{6}$$

Excess life-time cancer risk *ELCR*

When the human body is subjected to different radiation doses, it may have both short- and long-term negative effects on the health, including the development of cancer and tumors, among other things. By taking into consideration the number of cancer patients who have been exposed to the radiation dose, it is possible to determine the cancer risk per unit dose. Risk factor R*F* is defined as the increased threat of the cancer per unit dose, whereas the lifetime risk of fatality due to cancer linked to the probability of developing life-long cancer due to the exposure of radiation. The *ELCR* can be assessed using the following equation [17]

$$ELCR \quad AEDR\ DL\ RF \tag{7}$$

where *AEDR* is the annual effective dose rate, DL – average Malaysian lifespan, 75 years [18], and RF is the risk factor that is 0.05 for the public according to International Commission on Radiological Protection ICRP [19, 20]. The worldwide documented ELCR value is 0.29 10^{-3} [13].

RESULTS AND DISCUSSION

The samples have been tested using HPGe gamma spectroscopy and the important performance properties have been calculated using the equations illustrated in the previous section. These data were used to evaluate the radiological hazards from both the soil and vegetables. According to the activity concentrations (AC) in vegetable and soil samples, the minimum and maximum AC of ^{226}Ra, ^{232}Th, and ^{40}K in the vegetable samples were found from 0.4 0.3 Bqkg^{-1} to 3.4 0.3 Bqkg^{-1}, 0.02 0.01 to 3.6 0.3 Bqkg^{-1}, and 16.2 0.4 to 318 8 Bqkg^{-1}, respectively. The minimum and maximum AC of ^{226}Ra, ^{232}Th, and ^{40}K in the soil samples, were found to be from 2.7 0.6 Bqkg^{-1} to 46.5 0.2 Bqkg^{-1}, 9.0 0.3 to 54.8 0.4 Bqkg^{-1}, and 19.2 0.2 to 478 6 Bqkg^{-1}, respectively. The average value AC of ^{226}Ra, ^{232}Th, and ^{40}K in the vegetable samples are 1.58 0.06 Bqkg^{-1}, 1.41 0.02 Bqkg^{-1}, and 128 5 Bqkg^{-1}, respectively, while the average value AC of ^{226}Ra, ^{232}Th, and ^{40}K in the soil samples are 11.1 0.2 Bqkg^{-1}, 22.6 0.4 Bqkg^{-1}, and 119 3 Bqkg^{-1}, respectively. The AC of ^{226}Ra, ^{232}Th, and ^{40}K in the four angled beans soil sample were found to be 46.5 0.2 Bqkg^{-1}, 54.8 0.4 Bqkg^{-1}, and 478 6 Bqkg^{-1}, respectively, which are higher than the global average values suggested by UNSCEAR (2008) [21], which are 35 Bqkg^{-1}, 30 Bqkg^{-1}, and 400 Bqkg^{-1}, respectively, and this has been discussed by Hari *et al.* [22].

Radiological hazard in soil samples

A comparison of the radiological hazard is shown in tab. 2 and tab. 3. As a result of this study, it has been discovered that the average external hazard index H_{ex} values are greater than the amount found in

Table 2. External hazard index H_{ex} and Internal hazard index H_{in} for soil surrounding the respective vegetable samples

Soil samples surrounding vegetables	H_{ex}	H_{in}
Spinach	0.13	0.16
Japanese mustard	0.05	0.05
Water spinach	0.14	0.16
Okra	0.08	0.09
Long beans	0.11	0.12
Four angles bean	0.44	0.56
Cucumber	0.13	0.14
Round brinjal	0.11	0.14
Bitter gourd	0.10	0.12
Average	0.14	0.17

Table 3. Radiological hazard comparison with the values of some other countries of the world

Countries	H_{ex}	H_{in}	References
Pakistan	0.26	0.28	[23]
India	0.08	–	[24]
Turkey	–	0.46	[25]
Brazil	0.03	–	[26]
Serbia	0.12	–	[26]
Libya	0.05	–	[26]
USA	0.18		[26]
Montenegro	0.18	–	[26]
Current study	0.14	0.17	

India, Brazil, and Libya, but lesser than the values found in Pakistan, the USA, and Montenegro. The internal hazard index H_{in} is lower compared to the value in Pakistan and Libya.

Annual ingestion dose A_{eff}

With reference to tab. 4, the highest annual ingestion dose is for water spinach which is 22.89 μSv and the lowest is in the bitter gourd, which is 2.54 μSv. The standard global annual ingestion dose from ^{226}Ra and ^{232}Th is 120 μSv and 170 μSv, respectively. The

Table 5. Comparing the total yearly intake of vegetable samples to other nations' research and the global permissible limit

Countries	A_{eff} [μSv]	References
Turkey	227	[28]
Nigeria	270	[29]
Korea	110	[30]
Spain	360	[31]
Brazil	500	[32]
Vietnam	387	[33]
WHO	250-400	[27]
Current study	91.52	

nine vegetable samples that were taken from this study area are found to have smaller annual ingestion dose than the average world value [27]. The annual ingestion dose calculated in this study is compared with the values from other countries, as represented in tab. 5. The total annual ingestion dose in this study is noted to be lesser than the recommended dose in the range of 250-400 μSv, as the report by WHO [27]. The yearly absorption dosage in this research is lower than the amounts recorded in Turkey, Nigeria, Spain, Brazil, and Vietnam but, it is nearly the same as the dose reported in Korea, according to the findings. Differences in the frequency and manner of vegetable consumption in various countries have been attributed to differences in the environment and natural resources. Despite these factors, the researchers concluded that the consumption of vegetables in most countries is not hazardous to the overall population.

Absorbed dose rate D_n and excess life-time cancer risk *ELCR*

According to the determined absorbed dose rate D_n in tab. 4, it is found that the highest D_n value is 16.94 nGyh^{-1} for water spinach, and the lowest is 1.75 nGyh^{-1} for Japanese mustard. The absorbed dose rate for all the vegetable samples, however, was deter-

Table 4. Annual ingestion dose A_{eff}, absorbed dose rate D_n, annual effective dose equivalent *AEDE*, and excess life-time cancer risk

Vegetable type	Vegetables	Samples	A_{eff} [μSv]				D_n [nGyh^{-1}]	*AEDE* [μSv]	*ELCR* 10^{-5}
			^{226}Ra	^{232}Th	^{40}K	Total			
Leaf	Spinach	V1	3.32	3.05	0.26	6.63	2.53	3.10	1.16
	Japanese mustard	V2	6.32	0.29	0.49	7.10	1.75	2.15	0.80
	Water spinach	V3	11.83	10.15	0.91	22.89	16.94	20.8	7.79
Beans	Okra	V4	4.96	2.75	0.38	8.09	1.79	2.20	0.82
	Long beans	V5	6.28	10.59	0.48	17.35	8.14	9.98	3.74
	Four	V6	1.63	2.70	0.13	4.45	5.80	7.11	2.66
	Angles bean								
Fruit	Cucumber	V7	4.71	0.11	0.36	5.19	6.46	7.92	2.97
	Round brinjal	V8	8.67	7.92	0.67	17.27	8.45	10.36	3.88
	Bitter gourd	V9	2.31	0.05	0.18	2.54	8.39	10.29	3.86
		Average	5.56	4.18	0.43	0.17	6.69	8.21	3.08

mined to be lower than UNSCEAR's suggested value, which is 55 $nGyh^{-1}$ [13].

According to the statistic by Global Cancer Observatory, WHO, 9.1 % of the total of Malaysian population has a probability of dying from cancer before reaching 75 [34]. Thus, it is critical to evaluate the cancer risk related with the intake of vegetables in this geographical region.

As for the *ELCR*, it is noticeable from tab. 4 that the highest *ELCR* value is 7.79 10^{-5} for water spinach, and the lowest value is 0.80 10^{-5} for Japanese mustard. However, the *ELCR* for all the samples of vegetable are lesser than 0.29 10^{-5}, the suggested amount by UNSCEAR [13]. This implies that vegetable grown in this area has a very low cancer risk. Consumption of fruits and vegetables in our daily life can help to reduce the chances of getting cancer. According to the studies by the American Cancer Society, consuming vegetables and fruits can lessen the obesity which causes to the lowering the chance of cancer development [35]. The assessment of excess life-time cancer risk from consumption of vegetable in this study can help to encourage Malaysians to consume more vegetables for a healthier lifestyle.

CONCLUSION

This experimental study on radionuclides ^{226}Ra, ^{232}Th, and ^{40}K allow evaluating the soils' and highly consumed vegetables in the Klang, Selangor, radiological hazards. Both External and internal hazards show insignificant exposure to the farmers and the general public living in this area. Data analysis of the radiological hazards, due to the consumption of the vegetables grown in this area, shows that the absorbed dose rate, annual effective dose equivalent, annual ingestion dose have an insignificant impact on the consumers and the general public. As a result of the data collected and analyzed in this research, we can infer that the soil and vegetables grown on these farms pose a minimal risk of developing cancer as a result of exposure to naturally existing radiation to the public.

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AUTHORS' CONTRIBUTIONS

The idea of the research on the evaluation of radiation hazards and risk assessment in agricultural soil and commonly consumed vegetables in the District of Klang, Malaysia was from H. Muthu. R. Kasi, and R. T. Subramaniam. The conceptualization, methodology, and formal analysis were made by all the authors. H. Muthu collected the samples, did the analyses, and collected the data. He wrote first original manuscript draft under the guidance of R. Kasi, and R. T. Subramaniam. R. Kasi, and R. T. Subramaniam did the editing and revised the original manuscript draft. S. BASHIR participated in the results and discussion and made the original draft.

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ЕВАЛУАЦИЈА ОПАСНОСТИ ОД ЗРАЧЕЊА И ПРОЦЕНА РИЗИКА У ПОЉОПРИВРЕДНОМ ЗЕМЉИШТУ И УОБИЧАЈЕНО КОНЗУМИРАНОМ ПОВРЋУ У ОКРУГУ КЛАНГ, МАЛЕЗИЈА

Поврће које се обично конзумира и узорци земљишта који га окружују прикупљени су са фарме која се налази у Клангу, Селангор. Гама спектрометрија коришћена је за анализу концентрације активности природних радионуклида ^{226}Ra, ^{232}Th и ^{40}K у девет сакупљених узорака поврћа и земљишта. Ови подаци коришћени су за процену индекса хазарда у узорцима земљишта и радиолошке изложености људи. Утврђено је да се екстерни индекс хазарда, кретао од 0.05 до 0.44 са средњом вредношћу од 0.14. Интерни индекс хазарда узорака земљишта кретао се од 0.05 до 0.56 са средњом вредношћу од 0.17. Обе просечне вредности индекса ниже су од границе коју је утврдила Европска комисија за заштиту од зрачења. Јачина апсорбоване дозе, годишња доза ингестије, годишњи еквивалент ефективне дозе и додатни животни ризик од рака, коришћени су да би се сазнао потенцијални ризик за општу популацију која конзумира ово поврће. За узорак поврћа утврђено је да је просечна вредност за јачину апсорбоване дозе 6.70 nGy h^{-1} и да се кретала између 1.75 и 16.94 $nGyh^{-1}$. Просечна вредност годишње дозе ингестије је 10.17 Sv, а креће се од 2.54 Sv до 22.89 Sv. Опсег годишњег еквивалента ефективне дозе је између 2.15 Sv и 20.78 Sv, са просечном вредношћу од 8.21 Sv. Додатни животни ризик од рака коришћен је за одређивање вероватноће развоја рака услед радиолошке изложености конзумирањем овог поврћа. Утврђено је да је његова просечна вредност 2.87 10^{-5}, а опсег од 0.75 10^{-5} до 7.27 10^{-5}. Такође, утврђено је да су и годишња доза ингестије и годишњи еквивалент ефективне дозе нижи од просечне светске вредности коју препоручује UNSCEAR.

Кључне речи: годишња доза ингестије, опасност од зрачења, природни радионуклид, индекс хазарда, јачина апсорбоване дозе