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A Comparison of the Concentration of Naturally Occurring Radionuclides in Organic and Conventional Staple Food

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Fertilizers based on NPK are reported to have large concentrations of naturally occurring radionuclides. Hence, fertilizers usage can elevate the concentration of natural radioisotopes in soil and groundwater leading to a higher concentration of ^{40}K, ^{238}U and ^{232}Th in crops grown in these fields. In the last few years, a surge is witnessed in organic farming methods due to consumer demand. In this study, the concentrations of ^{40}K,^{232}Th and ^{226}Ra are compared between organic and conventionally grown food crops. In total, 25 samples of organic and conventionally grown pulses and cereals were collected. The NaI(Tl) gamma-ray spectrometer was used for measuring naturally occurring radioisotopes in samples. The activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th are almost same for both categories. The values of activity concentration of ^{226}Ra and ^{232}Th are well within the recommended limits but ^{40}K activity concentration is higher than 400 Bq/kg in all the samples. The radium equivalent for all organic and conventional samples is below the reference value of 370 Bq/kg. The annual effective dose of children for ^{226}Ra is higher than other age groups for wheat and rice samples but lower than the reference value of 2.4 mSv/year. The internal hazard index for all samples is less than 1 for both categories. All samples of both categories are safe for consumption as far as radionuclide concentrations are concerned. An elaborate investigation is advised for different food and drinking items to broaden the horizons.

Keywords: Organic food; Comparison; Natural radioactivity; Conventional food

1 Introduction

Organic and conventional ways of agricultural produce are extensively practiced commercial farming techniques. Organic farming preserves the soil and plant nutrients by maintaining the salt ratio, thus impeding desertification by retaining moisture[1]. Organic farming is based on an environment-friendly approach using bovine, guano manure or vermicompost whereas, conventional farming is done using chemical fertilizers and pesticides to increase the yield. Uranium (^{238}U), thorium (^{232}Th) and potassium (^{40}K) are primordial radionuclides and are found in rocks, water and soil[2]. The phosphate ores (rock phosphate) are present in sedimentary rocks, consequently accumulating elevated levels of uranium, thorium and their progenies[3,4]. In various fertilizers, the amount of phosphoric anhydride (P_2O_5) and uranium are proportional to one another[5]. The ternary fertilizers which include nitrogen, phosphorous and potassium (NPK) contain a higher concentration of uranium[6]. Hence, the usage of these fertilizers impacts the radioactivity levels in the soil which further affects the crops cultivated in the region. The soil composition, presence of radionuclides in chemical and physical form in the soil, climate along with the uptake by a specific plant impact the radioactivity of the edibles[7–9]. Therefore, routes followed by radionuclides in food vary in different regions of the globe depending on diet intake and agricultural practices[10].

The plants absorb radionuclides either through leaves from surroundings or roots via soil[11]. Various plant species also adsorb uranium from polluted water[12,13]. The plants are reliant only on the chemical characteristics of an element for the uptake of essential nutrients. They cannot differentiate uptake on the basis of radioactive properties therefore, take radionuclides as well[14,15].

The consumption of staple food that have high phosphate fertilizers scan result in higher internal exposure to radiation[5]. The uranium ingestion through vegetables is 33% of the total adult ingestion and different studies have confirmed the presence of uranium in plants[10,16,17]. The ingestion of natural radionuclides can cause severe health effects. The elevated levels of uranium intake can harm proximal

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tubes engendering renal failure as well as deposition on bones[18,19]. Uranium intake can lead to diarrhoea and paralytic ileus[20]. The liver, lungs and skeleton are impacted by thorium ingestion[21] and ^{228}Ra, a thorium progeny, accumulates in soft tissues[22]. Potassium gets evenly distributed in the body and gets deposited in cardiac rhythm and muscles[23].

Lindahl *et al.*[24] did not find any variation in activity concentrations of the radionuclides evaluated in wheat grains (*i.e.* ^{40}K, ^{226}Ra, ^{228}Ra and ^{228}Th) between conventional and organic cultivation. Similarly, Lauria *et al.*[25] observed no difference for uranium and radium in vegetables that were grown with organic and conventional farming methods. However, the results by Mehmet *et al.*[1] indicated that the activity concentrations of ^{210}Po, ^{210}Pb, ^{226}Ra, ^{228}Ra and ^{40}K of soil and plant samples from the conventional farming areas were elevated than that of organic farming areas. There can be a difference in the concentration of radionuclides in conventional and organic food due to the usage of chemical and natural fertilizers, respectively. Therefore, a comparison of natural radionuclides between organic and conventional food items is done in this paper.

2 Materials and Methods

2.1 Sample collection and preparation

Different samples of regular staple food which includes wheat, rice and pulses were collected from the organic brands and local markets in Patiala, a city in the Punjab region (India). The samples of organic and conventional food were air-dried and weighed for examining the fresh mass followed by oven-drying the samples at 110 °C for 4 hours and weighing them again to measure dry mass. The samples were ground finely and sieved with a 150 µm scientific sieve. Finally, the samples were sealed hermetically for a month to attain radioactive equilibrium and were marked with sample ID and date of preparation.

2.2 NaI(Tl) Gamma Ray Spectroscopy

Gamma spectrometry is a method of qualitative and quantitative estimation of radioisotopes by measuring the energies of gamma radiations emitted by radioactive nuclei. NaI(Tl) detector is ideal for gross-gamma counting because of its high efficiency and room temperature operation. An Atomtex Gamma–Beta spectrometer with cylindrical dimensions 63×63 mm, having energy resolution <7.5% and efficiency of about 20% was used to determine the activity concentration of natural radionuclides in the food samples. This spectrometer is suitable for gamma radiation energy ranging from 50 to 3000 KeV. The assessment of ^{238}U depends on the radionuclide decay of daughter nuclei ^{226}Ra which emanate an adequate amount of gamma radiation for detection. The gamma rays used for the estimation of ^{40}K, ^{226}Ra and ^{232}Th activity concentrations were 1461 keV (^{40}K), 1765 keV (^{214}Bi) and 2615 keV(^{208}Tl), respectively. The energy scale stabilization of the gamma radiation line with the energy of 661.6 keV from the reference source of ^{137}Cs, 1170 keV and 1330 keV from ^{60}Co were carried out. ^{137}Cs was used as the reference source for detector efficiency. Each sample's counting time was set to 21,600 s to produce sufficient statistics and small counting errors. The background spectra were also computed under identical conditions as the reference materials and the samples. The specific activity is calculated using

$$C_n = N_n/(\gamma_d.\eta_E.T.W)$$

where C_n is the specific activity in Bq/kg, N_n is the net counts, γ_d is γ ray emission probability, η_E is the detection efficiency, T is counting time (sec) and W is the dry mass of the sample (kg).

3 Results and Discussion

3.1 Activity concentrations

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K for different samples of organic and regular food taken from the market are slightly different as given in Table 1. The average activity of ^{226}Ra, ^{232}Th and ^{40}K for organic wheat samples are found to be 17.70 Bq/kg, 4.64 Bq/kg and 450.25 Bq/kg, respectively, whereas for conventional samples, the values are 21.52 Bq/kg, 5.85 Bq/kg and 448.55 Bq/kg, respectively. For organic rice, the average activities of ^{226}Ra, ^{232}Th and ^{40}K are 19.19 Bq/kg, 6.64 Bq/kg and 471.61 Bq/kg, respectively. The average activities of ^{226}Ra, ^{232}Th and ^{40}K for conventional samples of rice are 19.62 Bq/kg, 7.30 Bq/kg and 469.12 Bq/kg, respectively. For pulses, the ^{226}Ra, ^{232}Th and ^{40}K activity concentrations for organic rajma are 17.78 Bq/kg, 6.43 Bq/kg and 471.82 Bq/kg, respectively. For conventional market bought rajma, the activity concentrations for ^{226}Ra, ^{232}Th and ^{40}K are 17.06 Bq/kg, 6.52 Bq/kg and 437.86 Bq/kg, respectively. For organic channa dal, the average activity concentrations for ^{226}Ra, ^{232}Th and ^{40}K are 13.77 Bq/kg, 7.84 Bq/kg and 462.70 Bq/kg, respectively. Similarly, for the conventional samples, the average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K for

Table 1 — Activity concentration in various food samples.

Sample type	Type	^{226}Ra activity Bq/kg	^{232}Th activity Bq/kg	^{40}K activity Bq/kg
Wheat	Organic 1	17.86±3.23	6.37±1.01	465.25±32.42
	Organic 2	20.13±3.2	4.34±0.85	453.21±38.23
	Organic 3	15.13±2.85	3.22±0.36	432.29±38.09
	Conventional 1	20.83±3.01	6.39±0.96	469.28±36.23
	Conventional 2	22.21±3.89	5.32±0.89	427.82±37.36
Rice	Organic 1	19.43±4.21	6.89±0.95	473.22±28.34
	Organic 2	19.41±3.08	6.97±1.01	485.82±38.09
	Organic 3	18.73±3.25	6.06±0.98	455.81±36.23
	Conventional 1	19.72±3.45	7.01±0.87	472.82±31.28
	Conventional 2	19.52±3.28	7.60±0.66	465.42±32.21
Rajma	Organic 1	16.83±1.96	6.3±0.63	450.81±30.21
	Organic 2	18.81±2.09	5.59±0.12	470.82±32.25
	Organic 3	17.72±2.63	7.41±1.02	493.84±31.28
	Conventional 1	14.72±2.52	5.93±0.96	452.83±28.39
	Conventional 2	19.41±3.25	7.11±0.65	422.89±32.25
Chana Dal	Organic 1	15.62±2.58	8.13±1.02	479.82±31.25
	Organic 2	14.31±1.97	7.22±0.54	472.89±39.21
	Organic 3	11.39±2.32	8.19±0.96	435.4±31.24
	Conventional 1	16.32±3.01	9.13±0.56	480.81±34.12
	Conventional 2	14.32±3.25	8.28±0.85	489.29±31.28
Masoor Dal	Organic 1	13.42±3.65	7.82±0.78	480.22±28.39
	Organic 2	14.83±2.07	6.89±1.03	490.22±32.25
	Organic 3	16.82±2.92	7.93±1.01	432.29±37.24
	Conventional 1	16.89±2.98	8.08±0.98	472.21±38.09
	Conventional 2	19.83±3.52	8.92±0.91	481.89±36.23

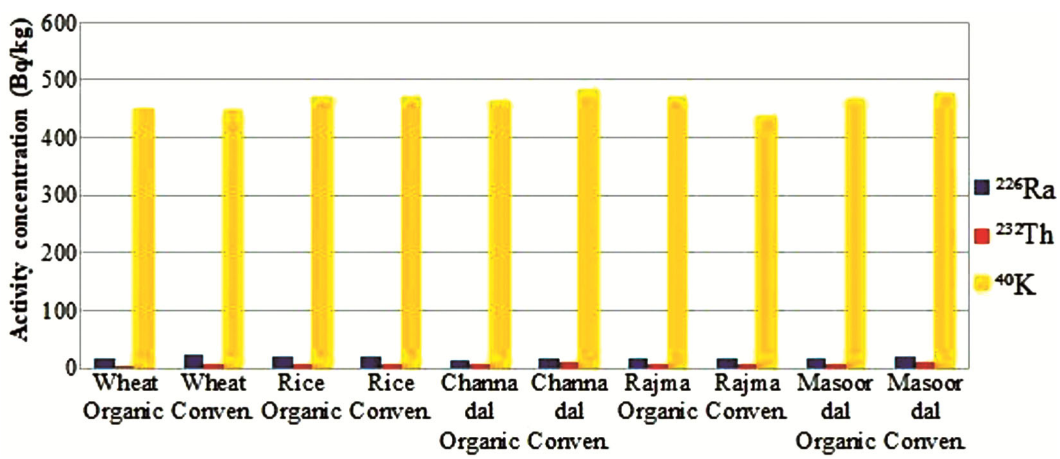

Fig. 1 — Activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in different organic and conventional market bought samples.

channa dal are 15.32 Bq/kg, 8.70 Bq/kg and 485.05 Bq/kg, respectively. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K for organic masoor dal are 15.02 Bq/kg, 7.54 Bq/kg and 467.57 Bq/kg, respectively. The average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K for conventional market samples of masoor dal are 18.36 Bq/kg, 8.5 Bq/kg and 477.05 Bq/kg, respectively. The bar graph in Fig. 1 shows the activity concentration for different samples. Although the values of ^{40}K are higher than the reference value of 400 Bq/kg, but the hemostatic balance of the human body keeps the concentration of ^{40}K in control despite the intake variations[26].

3.2 Radium equivalent activity

The radium equivalent activity is calculated for materials having an amalgamation of ^{232}Th, ^{226}Ra and ^{40}K as it deduces similar index of the gamma yield. The activity concentration of 259 Bq/kg of ^{232}Th or 370 Bq/kg of ^{238}U or 4810 Bq/kg of ^{40}K gives the same gamma dose rate[27]. The radium equivalent activity is given as

$$Ra_{eq}(Bq/kg) = U_C(Bq/kg) + Th_C 1.43\,(Bq/kg) + K_C 0.077\,(Bq/kg)$$

where U_C, Th_C and K_C represent the concentration of uranium, thorium and potassium, respectively. There is not much difference in the radium equivalent activity of different samples as given in Table 2. The least value of radium equivalent activity is of organic wheat 59.01 Bq/kg and the highest is for conventional market-bought masoor dal 67.24 Bq/kg which are well below the limit of 370Bq/kg[28].

3.3 Internal hazard index

The internal hazard index (H_{in}) determines the internal exposure of living cells to radon (^{222,220})Rn and its daughter nuclei. The results are considered insignificant if the value of H_{in} is less than 1[29].

$$H_{in} = S_{Ra}/185 + S_{Th}/259 + S_K/4810$$

where H_{in} is the internal hazard index. S_{Ra}, S_{Th} and S_K are the specific activity concentrations of ^{238}U, ^{232}Th and ^{40}K, respectively.

The values of the internal hazard index vary between 0.20 and 0.24 which is listed in Table 2. The values are inconsequential therefore, cause no effect on human health.

3.4 Annual effective dose

The annual effective dose is the susceptibility of the organs to radiation on the body as a whole.

It is calculated as

$$AD = S_a.DCF.I$$

Table 2 — Average hazard indices for different samples.

Sample type	Radium equivalent Bq/kg	Internal Hazard Index
Wheat Organic	59.01	0.20
Wheat Conventional	64.43	0.23
Rice Organic	64.99	0.22
Rice Conventional	66.18	0.23
Rajma Organic	63.31	0.21
Rajma Conventional	60.10	0.20
Channa Dal Organic	60.62	0.20
Channa Dal Conventional	65.11	0.21
Masoor Dal Organic	61.81	0.20
Masoor Dal Conventional	67.24	0.23

where AD is the annual effective dose in mSv/year, S_a is the specific activity in Bq/kg, DCF is the dose conversion factor in mSv/Bq and I is the annual intake (kg/year). The dose conversion factors (DCF) for different age groups given by ICRP[30] are listed in Table 3. The yearly intake of cereals given by UNSCEAR for infants is 45 kg/year, for children is 90 kg/year and for adults is 140 kg/year[29].The annual intake of cereals based on Indian standards[31] is divided into infants, children and adults (male) with average consumption of 43.07 kg/year, 92.16 kg/year and 141.62 kg/year, respectively.

The pulses intake based on Indian standards is divided into infants, children, adults (male and female) with average consumption of 5.47 kg/year, 9.12 kg/year, 12.41 kg/year and 11.31 kg/year, respectively. The age group of children is average values of two age groups 7-9 years and 10-12 years mentioned in NNMB. The calculated ^{226}Ra average annual effective dose of organic and conventional wheat and rice for children is the highest among all age groups ranging between 1.30 and 1.58 mSv/year. For all age groups, the values are below the reference value of 2.4 mSv/year given by UNSEAR[29]. The rice samples having the highest annual effective dose among all samples can be contributed to their high transfer coefficient and leaching of water into soil[32]. The pulses have lower annual effective dose due to less consumption as compared to cereals in India. The calculated values are listed in Table 4 and 5.

Table 3 — Dose conversion factors for annual effective dose given by ICRP in mSv/Bq[30].

Element	Infants	Children	Adult
^{226}Ra	9.60E-04	8.00E-04	2.80E-04
^{232}Th	4.50E-04	2.90E-04	2.30E-04
^{40}K	4.20E-05	1.30E-05	6.20E-05

Table 4 — Comparison of average annual effective dose of cereals for different age groups for Indian and the world population in mSv/year.

Sample type	Age group	^{226}Ra		^{232}Th		^{40}K	
		India	World	India	World	India	World
Wheat Organic	Infant	0.73	0.76	0.08	0.09	0.81	0.85
	Children	1.30	1.27	0.12	0.12	0.53	0.52
	Adults	0.70	0.69	0.15	0.14	3.95	3.90
Wheat Conventional	Infants	0.88	0.92	0.11	0.11	0.81	0.84
	Children	1.58	1.54	0.15	0.15	0.53	0.52
	Adults	0.85	0.84	0.19	0.18	3.93	3.89
Rice Organic	Infants	0.79	0.82	0.12	0.13	0.85	0.89
	Children	1.41	1.38	0.17	0.17	0.56	0.55
	Adults	0.76	0.75	0.21	0.21	4.14	4.09
Rice Conventional	Infants	0.81	0.84	0.14	0.14	0.84	0.88
	Children	1.44	1.41	0.19	0.19	0.56	0.54
	Adults	0.77	0.76	0.23	0.03	4.11	4.07

Table 5 — Average annual effective dose of pulses for different age groups in mSv/year for Indian population[31].

Sample type	Age group	^{226}Ra	^{232}Th	^{40}K
Channa Dal Organic	Infant	0.07	0.01	0.10
	Children	0.10	0.02	0.05
	Adult (Male)	0.04	0.02	0.03
	Adult (Female)	0.04	0.02	0.03
Channa Dal Conventional	Infant	0.08	0.02	0.11
	Children	0.11	0.02	0.05
	Adult (Male)	0.05	0.02	0.03
	Adult (Female)	0.04	0.02	0.03
Rajma Organic	Infants	0.09	0.01	0.10
	Children	0.13	0.01	0.05
	Adult (Male)	0.06	0.01	0.03
	Adult (Female)	0.05	0.01	0.03
Rajma Conventional	Infants	0.08	0.01	0.10
	Children	0.12	0.01	0.05
	Adult (Male)	0.05	0.01	0.03
	Adult (Female)	0.05	0.01	0.03
Masoor Dal Organic	Infant	0.07	0.01	0.10
	Children	0.11	0.02	0.05
	Adult (Male)	0.05	0.02	0.03
	Adult (Female)	0.04	0.01	0.03
Masoor Dal Conventional	Infant	0.09	0.02	0.10
	Children	0.13	0.02	0.05
	Adult (Male)	0.06	0.02	0.03
	Adult (Female)	0.05	0.02	0.03

Both the UNSCEAR and Indian standards gave similar values for cereals.

4 Conclusions

In this paper, the risk and dosimetric analysis is done for different samples of organic and regular market food. The activity concentration for all the samples is well below 35 Bq/kg and 30 Bq/kg for ^{226}Ra and ^{232}Th, respectively. The ^{40}K activity concentration is higher than 400 Bq/kg. The internal hazard index is less than unity for all samples. The organic food shows low activity concentration as compared to conventional food samples. Moreover, there is a need to estimate the effects of fertilizers as the concentration is moderately higher in that case. Although organic food is much costlier than regular market food, there is not a huge difference in naturally occurring radionuclides concentration of organic and regular market samples. From the samples collected, both categories are safe for consumption as far as radionuclide concentrations are taken into account. For more accurate data, the study can be broadened to different food and drinking items along with the measurement of heavy metals.

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