Research article

Measurement and Analysis of Specific Activities of Natural and Anthropogenic Radionuclides in Fresh Turmeric (*Curcuma longa* L.) from Lan Khoi Sub-district, Pa Phayom District, Phatthalung

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Received: 11 August 2021, Revised: 20 December 2021, Accepted: 11 January 2022

DOI: 10.55003/cast.2022.05.22.008

Abstract

Keywords

Turmeric;

Curcuma longa L.;

high purity germanium detector;

HPGe;

radiological hazard index;

lifetime cancer risk

Turmeric (*Curcuma longa* L.) is one of the popular medicinal plants that is widely used and consumed in Thailand. In particular, it is taken to mix with curry and used as an herbal medicine for the general public. In this study, the specific activities of natural (^{226}Ra, ^{232}Th and ^{40}K) and anthropogenic (^{137}Cs) radionuclides that had accumulated in the rhizomes of fresh turmeric plants were measured and analyzed using a high purity germanium detector (HPGe) and gamma spectrometric analysis system. A total of 20 samples of fresh turmeric were collected from Lan Khoi Sub-district, Pa Phayom District, Phatthalung Province and were then prepared according to the standard method described in the IAEA manual. It was found that the range of values of ^{226}Ra,^{232}Th, ^{40}K and ^{137}Cs were <1.48-4.36, 7.78 - 17.65, 719.52 - 974.43, and < 1.40 - < 2.31 Bq/kg, respectively. The average values of those ranges were 1.99±0.07, 10.30±0.40, 818.03 ±22.85, and <1.82±0.25 Bq/kg, respectively. According to the asymmetrical distribution of specific activities of all required radionuclides, the median values of ^{226}Ra, ^{232}Th and ^{40}K were used to evaluate some related radiological hazard indices which were annual radionuclide intake (D_a), annual effective dose (D_{eff}), total annual effective dose (D^{total}), and Lifetime Cancer Risk (LCR). Furthermore, the results were presented and compared to national and international recommended data. Moreover, the measured and evaluated values fell under the recommended limits of the UNSCEAR and IAEA.

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1. Introduction

The use of medicinal plants for treating diseases is probably the oldest existing method that humanity has used to cope with illnesses. Medicinal plants have been used therapeutically all around the world and such plants has been an important part of various customary medicine systems. It is notable that there are many remains and contaminants that may injure the consumers of herbal medicines, and naturally occurring radionuclides are one kind of contaminant that surrounds them [1]. In most places on earth, natural radioactivity varies only within relatively narrow limits, whereas in some other localities important differences have been noticed. In addition, anthropogenic radionuclides created from human activities such as atomic bomb testing and nuclear power plant accidents have been accumulated and distributed on the earth's surface at the same time. The presences of natural radionuclides such as ^{228}Ac, ^{226}Ra, ^{214}Pb, ^{214}Bi, ^{210}Po, ^{210}Pb, ^{40}K, and anthropogenic (^{137}Cs) radionuclides in the soil are metabolically incorporated into plants and ultimately find their way into the food chain. The presence of radionuclides in many concentrations in various parts of the plants may end up in human beings, since the plant parts are used as ingredients in producing the medicines [2-6]. An evaluation of the hazard to humans from medicinal plants through ingestion requires a quantitative understanding of the interrelated means by which the radionuclides are finally consumed by humans [7-9]. Therefore, it is important to investigate the absorption and activity distribution of radionuclides and the suitable effective radiation dose to humans through the use of medicinal plants.

Turmeric (*Curcuma longa* L.) is a popular medicinal plant that has been used as an alternative medicine for treating various diseases in Thailand. Generally, turmeric has been used for 4,000 years to treat a variety of ailments. Some research studies have discovered that turmeric may actually help treat a number of illnesses [10-13]. However, there have been few studies of the natural radioactivity levels in medicinal plants including turmeric plant in Thailand. For example, the natural radionuclide activity concentrations and annual committed effective doses in selected Thai medicinal plants using gamma spectroscopy technique were studied and evaluated by Saenboonruang *et al*. in 2017 [14]. Furthermore, some scientists and researchers from Chulalongkorn and Chiang Mai Universities, and from the Office of Atoms for Peace (OAP) studied, measured, and evaluated the concentration of natural radioactivity in 99 kinds of popular Thai medicinal herb plants (total 212 samples) [15]. In addition, the concentrations of ^{238}U in selected Thai spices and the related dose assessment were also studied and presented by Nochit *et al.* in 2021 [16].

In the present study, we were interested in the assessment of contamination of radioactivity in fresh turmeric plant roots. The objectives were to measure and analyze the specific activities of natural (^{226}Ra, ^{232}Th, and ^{40}K) and anthropogenic (^{137}Cs) radionuclides in 20 fresh samples of turmeric plant root collected from Lan Khoi Sub-district, Pa Phayom District, Phatthalung Province in the south of Thailand. The frequency distributions of all measured specific activities were studied and evaluated. Then, some related radiological hazard indices and the excess lifetime cancer risk values were also evaluated and compared with data from some previous studies that were undertaken at both national and worldwide levels.

2. Materials and Methods

2.1. Study area

Lan Khoi Sub-district is one of four Sub-districts (*tambons*) of Pa Phayom District in Phatthalung Province. The Lan Khoi Sub-district is divided into nine villages (*mubans*). There are some groups of rubber plant farmers who changed to growing turmeric plant in the study area. The population of Lan Khoi Sub-district was 7,594 in 2019. The 9th village in Lan Khoi Sub-district was chosen to be our sampling locations in this study. Lan Khoi Sub-district location coordinates are 7° 50’ 49” N and 99° 50’19” E.

2.2 Sample collection and processing

Twenty fresh turmeric plant samples were collected from a cultivated area in Lan Khoi Sub-district in Pa Phayom District in Phatthalung Province, Thailand. Each sample was randomly selected and prepared following the IAEA sampling and preparation of vegetable sample method [17]. Turmeric samples collected from the cultivated fields were cleaned up. Next, their roots and bark were removed and cut into thin slices. The samples were then spread onto aluminum trays and allowed to dry at room temperature for a few days. Consequently, a grinding machine was employed to grind the dry turmeric slices into a fine powder. In addition, the turmeric powder was sieved through a 2 mm mesh-sized sieve to remove course parts. A slow-airflow drying closet set at a temperature of 60°C and drying time of 5 h was used to accelerate the drying process without loss of radionuclides from the turmeric samples. Each sample (about 310 cm^3) was placed in a PVC cylindrical container of diameter 7.5 cm and height 8.0 cm. The containers were sealed tightly with thick cellophane tape around their necks to prevent any gas escape, and then stored for a minimum period of 4 weeks to ensure equilibrium between ^{222}Rn and its daughter products.

2.3 Gamma-ray spectrometry with high-purity germanium (HPGe) detector

In the present work, the specific activities of natural (^{40}K, ^{226}Ra and ^{232}Th) and anthropogenic (^{137}Cs) radionuclides in 20 turmeric samples were evaluated using a gamma spectrometry analysis system with a high-purity germanium detector (HPGe, EG&G ORTEC Model GEM 20 P4) at an advanced laboratory, Thailand Institute of Nuclear Technology (Public Organization) (TINT). The detector was enclosed in a massive 10 cm thick lead shielding. The gamma-ray background spectra were measured frequently to check the stability of the background and to correct the net count rate of the selected gamma-ray photopeaks of the samples. The measuring time was 10,800s. The IAEA-330 (Spinach) reference material (International Atomic Energy Agency (IAEA), Vienna, Austria) was employed to determine the geometric efficiency for fresh turmeric matrices in the container.

2.4. Frequency distribution of specific activities

By using the SPSS computer program, the frequency distribution of the specific activities of natural (^{40}K, ^{226}Ra and ^{232}Th) and anthropogenic (^{137}Cs) radionuclides in 20 fresh turmeric samples from the studied area were calculated and analyzed. The result will be presented in Section 3.

2.5. Calculation of related radiological hazard indices and the excess lifetime cancer risk

The Specific Activity (S.A.) in Bq/kg for each of the four required radionuclides was evaluated for each sample using formula [18]:

$$\text{S.A.} = \frac{\text{Area}}{\varepsilon P_{\gamma} M t} \tag{1}$$

where Area was the net number of counts of the corresponding full-energy-peak, ε was the detector's efficiency at the specific full-energy-peak, P_γ was the emission probability per disintegration, M was the weight of the sample in kg, and t was the counting time in seconds.

The first related radiological hazard index was the annual intake of radioactivity (D_a) [19]. This quantity, which was assumed to be due to the accumulation of the required radionuclides, was calculated using the formula:

$$D_a = AI \quad (2)$$

where D_a was the annual radionuclide intake (Bq/yr), A was the specific activity of the radionuclide (Bq/kg) and I was the annual consumption of turmeric plant (kg/yr). Owing to the lack of reliable statistics for the consumption of turmeric plant in Thailand, the quantity I was taken to be 2.92 kg/yr [20].

The annual effective dose (D_{eff}) [19] from the consumption of turmeric plant was calculated as well. This quantity was considered to be among the most important due to the proportional relationship between its value and the induced health effects from the intake of radionuclides.

$$D_{eff} = D_a D_{cf} \quad (3)$$

where D_{cf} was the ingestion dose conversion factor (2.8×10^{-7} Sv/Bq for ^{226}Ra, 2.3×10^{-7} Sv/Bq for ^{232}Th, and 6.2×10^{-9} Sv/Bq for ^{40}K) [21]. The total dose was simply calculated by summing the contributions associated with the individual radionuclides.

$$D_{eff}^{total} = D_{eff}(^{226}Ra) + D_{eff}(^{232}Th) + D_{eff}(^{40}K) \quad (4)$$

The lifetime cancer risk (LCR) [19] was calculated to assess the carcinogenic effects that were induced from the consumption of turmeric plant, owing to the presence of the targeted radionuclides. This calculation was performed using the formula:

$$LCR = D_a A_L R_C \quad (5)$$

where A_L was the lifetime span (75 years) [22], and R_C was the mortality risk coefficient taken as 9.56×10^{-9}, 2.45×10^{-9}, and 5.89×10^{-10} for ^{226}Ra, ^{232}Th, and ^{40}K, respectively [23].

3. Results and Discussion

3.1 Gamma-ray energy spectrum

The gamma-ray energy spectrum of fresh turmeric samples in the studied area showed the existence of natural (^{226}Ra, ^{232}Th, and ^{40}K) and anthropogenic (^{137}Cs) radionuclides (Figure 1). The gamma-ray energy spectra of all turmeric samples were carried out and all had the characteristic peaks with difference quantity (high or low). Hence, the specific activities of all required

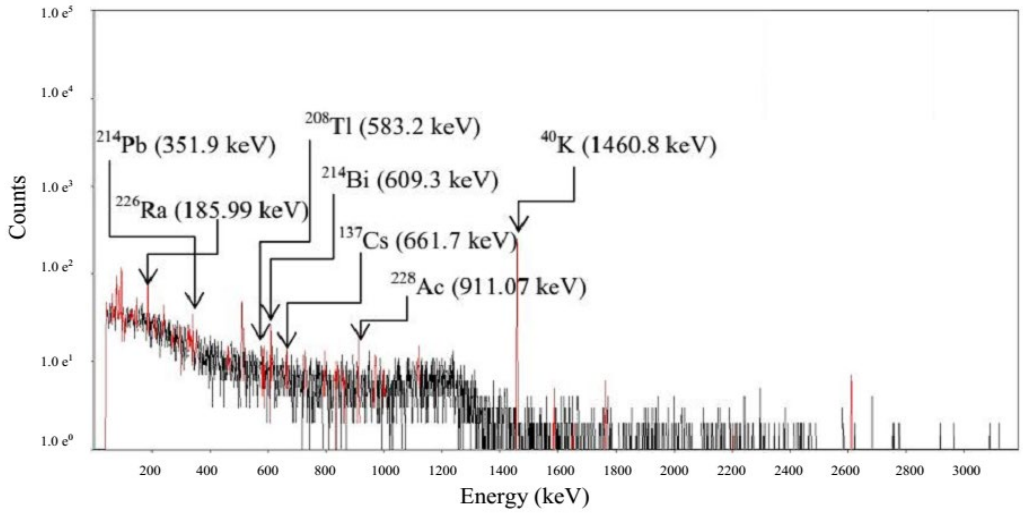

Figure 1. The gamma-ray energy spectrum of fresh turmeric plant root sample collected from Lan Khoi Sub-district, Pa Phayom District in Phatthalung Province

radionuclides were evaluated, analyzed and compared in the Sections 3.2 and 3.3 using the selected reference material and equation (1).

3.2. Ranges and mean values of specific activities of natural and anthropogenic radionuclides

The ranges and mean values of specific activities of ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs radionuclides in 20 fresh turmeric plant samples collected from the studied area were measured, calculated and are shown in Table 1. It was found that the specific activity of ^{40}K was the highest value and the specific activity of ^{137}Cs was the lowest value and lower than the limit of detection of the measurement system.

Table 1. Mean values and ranges of specific activities of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in Bq/kg as evaluated from 20 fresh turmeric plant samples collected from Pa Phayom District in Phatthalung Province

Fresh turmeric plant sample collected from Pa Phayom District in Phatthalung Province (20 samples)	Specific Activities (Bq/kg)			
	^{226}Ra	^{232}Th	^{40}K	^{137}Cs
Ranges	<1.48–4.36	7.78–17.65	719.52–974.43	< 1.40–< 2.31
Mean values	1.99±0.07	10.30±0.40	818.03±22.85	< 1.82±0.25

3.3 Frequency distribution of specific activities and statistical values

The frequency distributions of calculated specific activities of ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs in 20 fresh turmeric plant root samples collected from the investigated area were analyzed using the SPSS computer program (Figure 2). In addition, some important statistical values were calculated and are shown in Table 2. It was found that the frequency distributions of the specific activities of ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs in 20 fresh turmeric plant samples were asymmetrical distributions with skewness of 2.72, 1.58, 0.74 and 0.13, respectively.

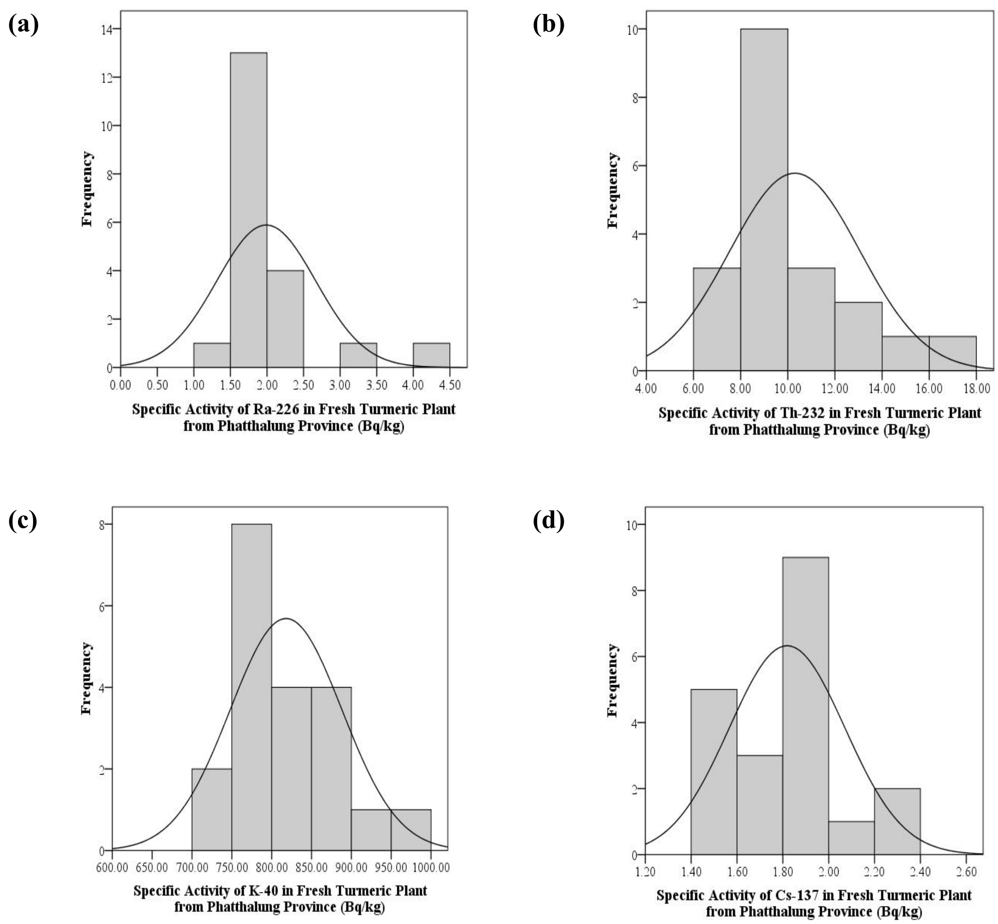

Figure 2. Frequency distributions of specific activities of (a) ^{226}Ra; (b) ^{232}Th; (c) ^{40}K and (d) ^{137}Cs in 20 fresh turmeric plant samples collected from Lan Khoi Sub-district, Pa Phayom District in Phatthalung Province

Table 2. Statistical values of the frequency distributions of specific activities of ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs in 20 fresh turmeric plant samples collected from Phatthalung Province in Thailand

Statistic values	Analyzed values			
	^{226}Ra	**^{232}Th**	**^{40}K**	**^{137}Cs**
Mean (Bq/kg)	1.99	10.30	818.03	<1.82
Median (Bq/kg)	1.74	9.69	802.40	<1.88
Mode (Bq/kg)	1.65	9.69	781.05	<1.93
Std deviation	0.68	2.76	70.16	0.25
Skewness	2.72	1.58	0.74	0.13
Kurtosis	8.05	1.88	-0.29	-0.53
Minimum value (Bq/kg)	1.48	7.78	719.52	<1.40
Maximum value (Bq/kg)	4.36	17.65	974.43	<2.31

3.4. Radiological hazard indices values and comparison

According to the frequency asymmetrical distribution of all required radionuclides in all turmeric plant samples as discussed in Section 3.3, the median values of ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs which were 1.74±0.04, 9.69±0.24, 802.40±22.60, and <1.88±0.25 Bq/kg for the present study, are the appropriate medium value and should be chosen for calculation of the four radiological hazard indices and the LCR value in this study. Moreover, the results and their average values were evaluated and compared with some research data in Thailand, foreign countries and the recommended values reported by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and IAEA as shown in Table 3.

Table 3. Related radiological hazard indices and LCR values for the present investigation and compare to some research studies in Thailand, foreign counties, UNSCEAR and IAEA

Literatures	D_a (kBq/yr)	D_{eff} (Sv/yr) × 10^{-5}			D^{total} (Sv/yr) × 10^{-5}	LCR × 10^{-3}
		$D_{eff}(^{226}Ra)$	$D_{eff}(^{232}Th)$	$D_{eff}(^{40}K)$		
Turmeric in Thailand [24]	2.21±0.03	0.16±0.05	0.26±0.02	1.36±0.02	1.78±0.09	0.10±0.00
Medicinal herb plants in Thailand [25]	0.30±0.02	0.15±0.03	0.20±0.02	0.23±0.01	0.58±0.07	0.02±0.00
Phlai in Thailand [14]	1.01±0.09	0.30±0.03	0.09±0.01	0.61±0.06	1.01±0.09	0.05±0.00
Turmeric in Prachin Buri [15]	1.97±0.13	0.23±0.08	0.22±0.06	1.21±0.08	1.66±0.21	0.09±0.01
Turmeric in Chiang Mai [15]	3.18±0.10	0.34±0.06	0.40±0.10	1.95±0.06	2.69±0.22	0.15±0.01
Turmeric in Kalasin [15]	4.81±0.22	1.41±0.31	0.64±0.11	2.93±0.13	4.98±0.55	0.25±0.02
Turmeric in Ratchaburi [15]	5.34±0.22	0.72±0.19	0.01±0.00	3.30±0.13	4.02±0.33	0.25±0.01
Turmeric in Phayao [15]	3.35±1.75	0.24±0.15	0.26±0.11	2.07±1.08	2.56±1.34	0.16±0.08
Turmeric in Bangladesh [6]	1.74±0.23	1.01±0.26	0.83±0.52	1.03±0.12	2.87±0.90	0.11±0.02
Medicinal Plants in Italy [26]	10.51	0.60	0.72	6.48	7.80	0.48
Medicinal Plants in Serbia [27]	36.38	0.67	1.01	22.52	24.20	1.63
Medicinal Plants in Ghana [28]	2.63±0.05	0.26±0.23	3.77±0.15	1.52±0.02	5.55±0.40	0.15±0.01
Medicinal Plants in Jordan[29]	6.03±0.17	1.28±0.04	1.03±0.01	3.68±0.10	5.99±0.15	0.30±0.01
Medicinal Plants in India [30]	9.98	0.78	0.43	6.16	7.37	0.46
Medicinal Plants in South India [2]	20.23	7.12	0.59	12.37	20.07	1.07
Medicinal Plants in Iraq [31]	0.66±0.01	0.40±0.03	0.20±0.01	0.40±0.00	1.00±0.04	0.04±0.00
Turmeric in Phatthalung*	**2.38±0.07**	**0.14±0.00**	**0.65±0.02**	**1.45±0.04**	**2.25±0.06**	**0.11±0.00**
UNSCEAR [32-34]	1.14	5.48	0.81	0.56	6.85	0.19
IAEA [35]	-	-	-	-	100	-

*Present study

From Table 3, the D_a values from the present study were higher than those in previous research data on turmeric, medicinal herb plants and Phlai samples from Thailand, turmeric in Prachin Buri Province, Bangladesh, medicinal plants in Iraq and the recommended value (1.14 kBq/yr) as reported by UNSCEAR. In addition, the D_a values were lower than turmeric in Chiang Mai, Kalasin, Ratchaburi, Phayao Provinces and all of international research data of medicinal plants (excepted in Iraq). The D^{total} value from this investigation, which was combined with D_{eff} (^{40}K), D_{eff} (^{226}Ra) and D_{eff} (^{232}Th), was higher than some research on turmeric, medicinal herb plants and Phlai samples from Thailand, turmeric in Prachin Buri Province and medicinal plants in Iraq. In addition, the D^{total} value was lower than 6.85×10^{-5} Sv/yr, which was reported by UNSCEAR, turmeric in Chiang Mai, Kalasin, Ratchaburi, Phayao Provinces and all of international research data of medicinal plants (excepted in Iraq). Furthermore, the D^{total} value was approximately 0.98 times lower than the IAEA dose constraints for public exposure in planned exposure situations and reference levels for public exposure in specific existing exposure situations, e.g., exposure due to radionuclides in commodities such as food, drinking water or construction materials (< 1 mSv/yr or 100×10^{-5} Sv/yr). Moreover, the LCR value was also calculated and was found to be higher than turmeric, medicinal herb plants and Phlai samples from Thailand, turmeric in Prachin Buri Province, Bangladesh and medicinal plants in Iraq but lower than 0.19×10^{-3}, which are the recommended values by UNSCEAR, turmeric in Chiang Mai, Kalasin, Ratchaburi, Phayao Provinces and all of international research data of medicinal plants (excepted in Iraq). In addition, we can see that the specific activity of ^{40}K in this investigation, which was equal to 802.40±22.60 Bq/kg, should be the main factor behind the high values of evaluated related radiological hazard indices and LCR value for this present study. These high values of the concentration of ^{40}K might have been caused by the regular use of fertilizers by some farmers in Thailand. A similar study should be undertaken with an increased turmeric plant samples collected from different regions of Thailand. Consequently, the concentration of natural and anthropogenic radionuclides in some important medicinal plants that are necessary for the treatment of patients should be randomly measured and monitored in every year of production. Moreover, this study can be used as a guide for studies and research on the measurement of the background radiation level in other medicinal plants and fresh vegetables consumed by Thai people.

4. Conclusions

The evaluated median values of specific activity of natural (^{226}Ra, ^{232}Th and ^{40}K) and anthropogenic (^{137}Cs) radionuclides in 20 fresh turmeric plant root samples collected randomly from Lan Khoi Sub-district, Pa Phayom District in Phatthalung Province were 1.74±0.04, 9.69±0.24, 802.40±22.60, and <1.88±0.25 Bq/kg, respectively. The median values of specific activity of ^{40}K, ^{226}Ra and ^{232}Th were chosen to assess three related radiological hazard indices (D_a, D_{eff}, and D^{total}) and the ELCR value. The results obtained in this study fall within the range of values reported in similar studies conducted nationwide and worldwide. The D_a value and the D_{eff} (^{40}K) were higher than the recommended values of 1.14 kBq/yr and 0.56×10^{-5} Sv/yr as reported by UNSCEAR. The D_{eff} (^{226}Ra) and D_{eff} (^{232}Th) values were lower than the recommended values of 5.48 and 0.81×10^{-5} Sv/yr as presented by UNSCEAR. Furthermore, the D^{total} value, which was evaluated from all three of D_{eff} values, was lower than the recommended values of 6.85×10^{-5} Sv/yr as announced by UNSCEAR and lower than the IAEA dose constraints and reference levels for public exposure (< 1 mSv/yr). In addition, the LCR values were found to be below the recommended values of 0.19×10^{-3} as specified by UNSCEAR. It can be seen that Thai people and consumers of turmeric plants receive an effective annual dose due to some radioactive substances present in turmeric plant, that is within the safe range. However, the results of this study show directly the effects of the specific activities of ^{40}K to the LCR value. The specific activities of ^{40}K might be the result of accumulation in the original cultivated soil, water and fertilizers used by farmers that was transferred to the stems, leaves and seeds of turmeric plant. In addition, we would like to mention that the results from this research are the first systematic data set in the studied area. According to the present study results, we recommend the monitoring, measurement and assessment of the concentration of natural radionuclides, especially ^{40}K in all kinds of medicinal plants which are usually used as alternative medicines for Thai people every harvesting year. Hence, this data may provide a general background level for the turmeric plant and may also serve as a guideline for future measurement and assessment of possible radiological risks to the health of Thai people. Therefore, we should further study, measure and assess the specific activities of natural and anthropogenic radionuclides in all kinds of medicinal plants samples collected from cultivated area around the Thailand Kingdom, and also further study the transfer factor of those radionuclides from the soil to the medicinal plants.

5. Acknowledgements

This work was partly supported by Department of Basic Science and Mathematics, Faculty of Science, Thaksin University, Songkhla Campus. We are grateful for facility support and technical cooperation provided by TINT. The authors are particularly indebted to undergraduate students for their works and patience in sample collection, measurement and analysis of the data.

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