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Gross alpha and beta radioactivity in food crops and surface soil from Ho Chi Minh City, Vietnam

Van Thang Nguyen[1] · **Ngoc Ba Vu**[1] · **Nguyen Phong Thu Huynh**[1]

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Abstract In this study, gross alpha and beta radioactivity in food crops and surface soil collected from Ho Chi Minh City, Vietnam were measured. Based on the annual effective dose from ingestion of food crops, the degree of risk to human health was estimated. We found out that the obtained values of the dose do not exceed the WHO recommended level (290 µSv year^{-1}). The estimated soil-to-plant transfer factors for gross alpha (TF_α) and beta (TF_β) for food crops were also presented. It was found that TF_α varied in the range from 0.009 ± 0.005 to 0.99 ± 0.06, TF_β varied in the range from 2.26 ± 0.10 to 10.87 ± 0.53 and the maximum values of transfer factors were found in the root of ipomoea batatas.

Keywords Gross alpha activity · Gross beta activity · Food crops · Annual committed effective dose · LB4200 · Soil-to-plant transfer factors

Introduction

In surface soil, the terrestrial long-lived radionuclides ^{238}U, ^{232}Th and their progeny and ^{40}K exist at trace levels [1]. The variation in concentrations of radionuclides on surface soil depends mainly on the mineralogical composition of that soil, as well as its chemical and physical properties, meteorological conditions and the possible transfer of material to deeper soil layers [2–4]. During the cultivation, adding amount of fertilizer and water also makes the change of radioactive concentration level in the surface soil [5, 6]. In general, the radionuclides are transferred to plant by various possible pathways, as for example through the atmosphere, aquatic systems and soil sub-compartments. Radionuclides appear in plants, either through uptake of radionuclides via the root system, or through direct atmospheric interception onto external plant surfaces, indirectly from re-suspended material [2, 7]. The previous studies show that surface soil is the largest radioactive source providing to the plants [7, 8].

Naturally occurring radionuclides of are significant contributors of ingestion dose and are present in the biotic system of plants, animals, soil, water and air. Studies on the radioactivity of the consumable parts of a vegetable assume importance as it is necessary to estimate the ingestion dose to the public. Therefore, the contents of naturally-occurring radionuclides in difference plants and vegetables and radiological assessment have been investigated all over the world [2, 7–11]. In many studies, gross alpha and beta activity and total annual committed effective dose due to natural radionuclides were used for radiological assessment [2, 8, 12–14]. For public health, the dose must not exceed the criteria of 290 µSv year^{-1} [15].

Soil-to-plant transfer factors (TF_s) of radionuclides have been studied extensively for various components of the food chains, common to European and American countries [2, 7–11]. It is one of the important factors for studying environmental radioactivity. TF_s is a key in calculation of radionuclide concentration in food crops, also allowing estimation of internal radiation dose as a result of food ingestion. Distribution of radionuclides in different parts of the plant is different and depends on the chemical characteristics and several parameters of the plant and soil [4]. It makes the variation of TF_s among many components of

✉ Van Thang Nguyen
nvthang@hcmus.edu.vn

1 Nuclear Technique Laboratory, VNUHCM-University of Science, 227 Nguyen Van Cu Street, District 5, Ho Chi Minh City, Vietnam

the plant. IAEA have reported data on the transfer factors for different plants in IAEA-TRS-472 [16]. Following that, TF_s is different from plant to plant and is influenced by soil properties, climate conditions and element properties. In Vietnam, the studies on soil-to-plant transfer factors have not been carried out popularly. In this study, the estimated soil-to-plant transfer factors for gross alpha and beta for food crops were also presented. The transfer factors for gross alpha and beta have been proposed and calculated for water spinach (ipomoea aquatica Forssk) in our previous study [8].

Experimental

Description of the site

Figure 1 shows the location map of the study site in Ho Chi Minh City (hereafter HCMC). HCMC locates in the south of Vietnam, and is the biggest city in Vietnam. The city has a tropical climate, specifically a tropical wet and dry climate, with an average humidity of 78–82%. The year is divided into two distinct seasons. The rainy season usually begins in May and ends in late October. The dry season lasts from December to April. The average temperature is 28 °C, with little variation throughout the year. There is more than 1000 km far from HCMC to the nearest nuclear power plant. The concentration levels of radionuclides in soil, water and air are normally, and radionuclides are originated from the natural [5, 8, 17]. The study site (Latitude: 10.9°N and Longitude: 106.6°E) is belong to Hoc Mon district. It is one of the suburban district where foods crops are cultivated popularly.

Sample collection and preparation

In this study, 18 food crops samples ready for harvest were collected random from the farm and carefully separated from the soil. At each sampling area, five topsoil layer (20 cm) samples were collected and mixed to obtain a representative sample lead to a total of 12 surface soil samples was recorded. All the samples were place in polythene bag, labelled and transported to the laboratory sample processing room for subsequent investigation. Food crops and soil samples were prepared as the procedure using for previous study [8].

At the laboratory sample processing room, food crops samples were washed with ultrapure water to remove impurities and any soil particles present in all plant structures, air-dried and separated into leaf, stem and root parts. After these processes, the food crops samples and were oven dried at 105 °C to constant weight then stone, gravel, leaf and root were removed from the samples. These food crops samples were then ashed in a muffle furnace at 450 °C for 8 h. The ash obtained from each sample was homogenized again by filtering through a 0.1 mm sieve. Soil samples were prepared by drying at 105 °C to constant weight, ashing in a muffle furnace at 450 °C for 8 h. The samples are next crushed into fine powder and homogenized by filtering through a 0.1 mm sieve. Final food crops and soil samples were afterwards used for analysis.

Fig. 1 Map of Vietnam shows Ho Chi Minh City and the sampling locations in the inset ▶

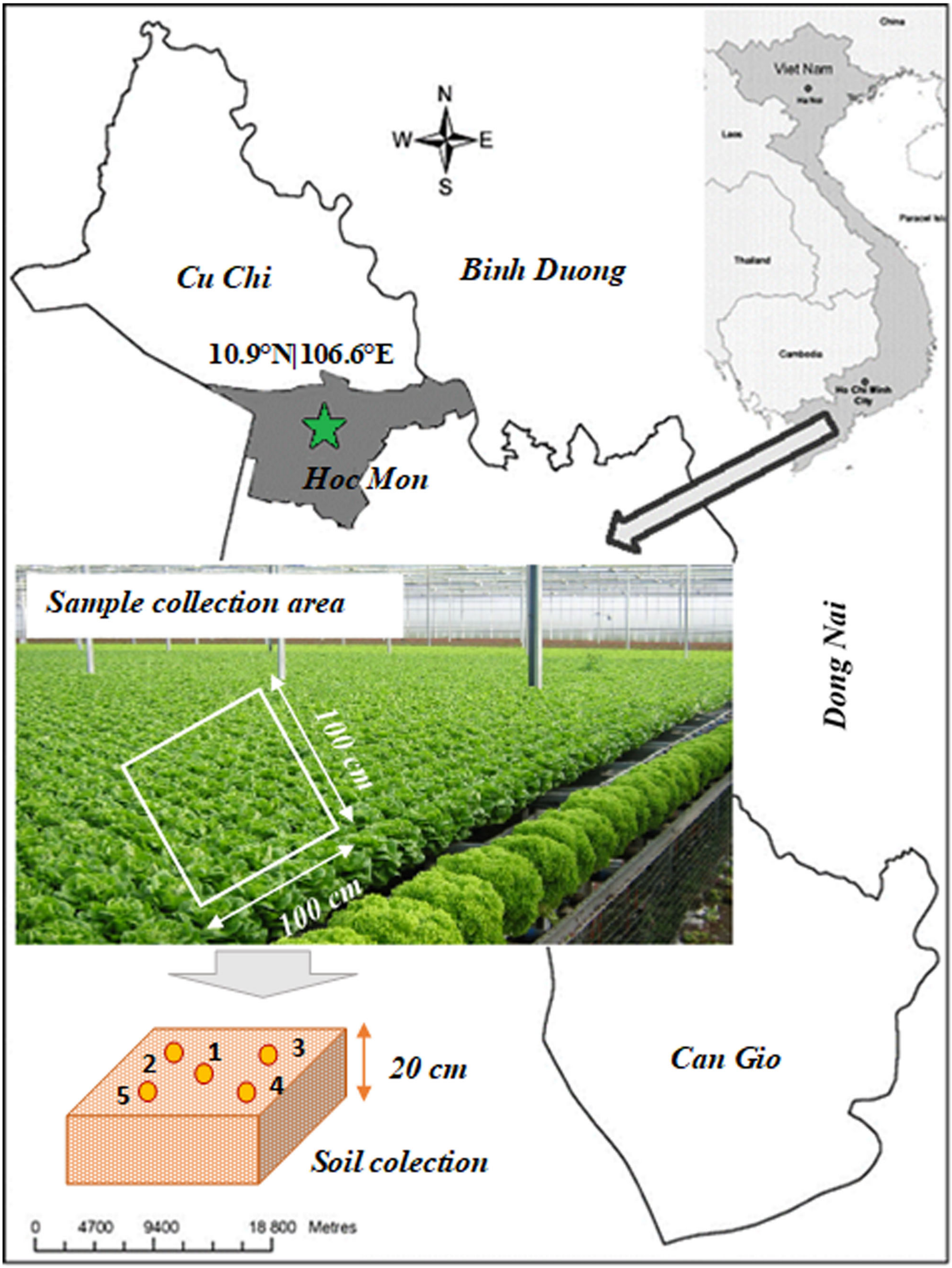
According EPA method, the largest amount of sample that should be counted for gross alpha activity is that size amount of sample which gives a solids density thickness of 5 mg cm^{-1} in the counting planchet [18]. For the counting of gross beta activity, the total dissolved solids is not as limiting as for gross alpha activity because beta particles are not stopped in solids as easily as are alpha particles. For a 2-inch diameter counting planchet (20 cm^2) (planchet used in our laboratory), about 0.1 g from each sample was weighted in stainless steel planchet. The sample was spread in a planchet using a glass rod until evenly spread then a few drops of the diluted acetone was spread on the surface samples and was put to dry under an infrared lamp with heating control so that the sample did not spatter.

Three standard samples were prepared for self-absorption correction. A ^{241}Am radiotracer (NIST) was used for alpha activity measurement while KCl standard and IAEA-156 standard were prepared for beta activity measurement. Similar sample preparation procedure was applied as mention above before counting.

Measurement of radioactivity

A LB4200 Multi-Detector Low Background Alpha/Beta counting system manufactured by Canberra Company, USA was used to make direct measurement of the alpha and beta activity in the samples. This counting system has 2π geometry gas flow proportional counter and incorporates anti-coincidence gating to further reduce the system background count rate due to external cosmic interactions with the sample detector. The guard detector has a thick metal plate on both sides that maximizes the interaction of cosmic rays and gamma ray with the gas. The passive lead shielding surrounding the detector effectively blocks all alpha and beta particles from reaching the detector unless it originates in the sample [19].

The LB4200 has high performance gas-flow detectors with ultra-thin 80 μg/cm^2 window and lowest warranted 5.7 cm diameter gas flow proportional detector background. The counting gas used in the proportional counter is P-10 gas (10% CH_4, 90% Ar). The normal operational



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gas flow rate is set at 50 SCCM (standard cubic centimetres per minute). The gas pressure should be set to 10 ± 1 PSI for normal operation. The LB4200 includes the Gas Stat Gas Conservation system which dramatically reduces P-10 consumption by as much as 50% compared with past multi-detector alpha/beta systems. The LB4200 has also an electronic gas monitoring system that automatically delivers optimal gas pressure to the detectors without manual flow valves. In this study, the food crops and soil samples were counted for 86,400 s and 43,200 s, respectively. ^{241}Am and $^{90}Sr/^{90}Y$ standard sources were used as the efficient calibration sources for gross alpha and gross beta counting.

Dose assessment

For food crops, the radiation dose of particular radionuclide is used for assessment of the degree of risk by intake this radionuclide. The annual effective ingestion dose due to a particular radionuclide is calculated using Eq. (1) [2].

$$D_i = A_i \times I \times DCF_i \quad (1)$$

where, D_i (Sv year^{-1}) is the annual individual effective dose, A_i activity concentration of radionuclide i, I (kg year^{-1}) is the consumption intake rate of food crops and DCF_i is the dose conversion factor for ingestion of the radionuclide i taken from ICRP [20].

However, the total dose is contributed by many radionuclides and the risk to human health may come from these radionuclides. The total annual committed effective dose due to natural radionuclides were studied and applied to evaluate the radiological hazard [2, 8, 12–14]. The total annual committed effective dose to an individual due to the intake of natural radionuclides from food crops were calculated using Eq. (2) [12].

$$D_{tot} = D_\alpha + D_\beta \quad (2)$$

where, D_{tot} (Sv year^{-1}) is total annual committed effective dose, D_α (Sv year^{-1}) is the average alpha effective dose and D_β (Sv year^{-1}) is the average beta effective dose. D_α and D_β are calculated by averaging the individual annual committed effective doses contributed by the major alpha and beta emitters in the ^{238}U and ^{232}Th series of the naturally occurring radionuclides and ^{40}K as shown in Eqs. (3) and (4) [12].

$$D_\alpha = \frac{I}{N_\alpha} \sum_{R_\alpha} A_\alpha DCF_\alpha \quad (3)$$

$$D_\beta = \frac{I}{N_\beta} \sum_{R_\beta} A_\beta DCF_\beta \quad (4)$$

where, I (kg year^{-1}) is the consumption intake rate, A_α (Bq kg$^{-1}_{fresh}$) is the gross alpha radioactivity of the sample, A_β (Bq kg$^{-1}_{fresh}$) is the gross beta radioactivity of the sample, N_α is the number of radionuclides considered as major alpha (^{234}U, ^{238}U, ^{232}Th, ^{226}Ra, ^{210}Po, ^{230}Th and ^{228}Th) emitters, N_β is the number of radionuclides considered as major beta (^{40}K, ^{210}Pb and ^{228}Ra) emitters, DCF_α and DCF_β (Sv Bq^{-1}) are the dose conversion factors for ingestion of the radionuclides for an adult taken from ICRP [20].

Although a lot of natural radionuclides exist in food crops, it was assumed that only the major radionuclides of ^{238}U decay series (^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Po and ^{210}Pb), major radionuclides of ^{232}Th decay series (^{232}Th, ^{228}Th and ^{228}Ra) and ^{40}K contribute to the total annual committed effective dose. These radionuclides are also the major alpha and beta emitting radionuclides which are of importance to internal irradiation [14]. In this study, the consumption intake rate was an average values of Vietnamese adults (1.2 kg year^{-1}) and it was assumed that the activity concentrations of radionuclides contributing to the effective dose are the same.

The world average value of total annual committed effective dose for ingestion of food and drinking water is in the range from 0.2 to 1 mSv year^{-1} [1], and 290 μSv year^{-1} is the limitation value of World Health Organization (WHO) [15].

Transfer factor (TF)

The ratio of activity concentration of any radionuclide in a plant to its activity in the soil is termed as transfer factor (TF_s) [2, 7, 11, 21, 22]. In this study, we have estimated the transfer factor for gross alpha (TF_α) and beta (TF_β) for food crop samples using the following Eq. (5) as the previous study [8].

$$TF_{(\alpha/\beta)} = \frac{A_{food\ crops}}{A_{soil}} \quad (5)$$

where $A_{food\ crops}$ and A_{soil} are gross alpha/beta activity in food crops (root, aerial, leaf) (Bq kg$^{-1}_{dry}$) and soil (Bq kg$^{-1}_{dry}$), respectively.

Results and discussion

Table 1 summaries the results of gross alpha and beta radioactivity measurement in 18 types of food crops (root, stem and leaf) from Hoc Mon district, Ho Chi Minh City. They include 12 samples of leafy vegetables, three samples of tubers and three samples of fruits. Gross alpha activity was found in the range from 0.25 ± 0.09 Bq kg$^{-1}_{fresh}$ to 23.75 ± 0.61 Bq kg$^{-1}_{fresh}$ while gross beta activity was found in the range from 78 ± 1 to 254 ± 4 Bq kg$^{-1}_{fresh}$. The highest gross alpha activity concentration was measured in the stem of orchorus capsularis to be 23.75 ± 0.61 Bq

Table 1 Gross alpha, gross beta radioactivity of food crops samples and the total annual effective doses

Food crops types	Food crops names	Food crops parts	Gross alpha (Bq kg^{-1}_{fresh})	Gross beta (Bq kg^{-1}_{fresh})	Total annual effective dose due to ingestion (μSv y^{-1})
Fruits	Momordica charantia	Fruit	2.3 ± 0.2	78 ± 1	44 ± 1
	Zea mays	Fruit	0.25 ± 0.09	135 ± 2	75 ± 1
	Luffa aegyptiaca	Fruit	1.7 ± 0.2	81 ± 1	45 ± 1
Tubers	Ipomoea batatas	Root	16.43 ± 0.50	239 ± 4	135 ± 2
		Stem	2.59 ± 0.21	209 ± 4	Not used
		Leaf	2.97 ± 0.20	139 ± 2	78 ± 1
	Raphanus sativus	Root	3.3 ± 0.2	159 ± 3	89 ± 2
		Leaf	1.29 ± 0.12	106 ± 2	Not used
	Anihot esculenta	Root	3.78 ± 0.23	223 ± 4	124 ± 2
Leafy vegetables	Brassica integrifolia	Stem	2.9 ± 0.2	106 ± 2	Not used
		Leaf	1.29 ± 0.12	106 ± 2	59 ± 1
	Ocimum basilicum	All plant	8.14 ± 0.37	247 ± 4	Not used
		Leaf	0.61 ± 0.15	186 ± 3	103 ± 2
	Brassica juncea	Stem	5.07 ± 0.23	143 ± 2	Not used
		Leaf	2.04 ± 0.14	123 ± 2	74 ± 1
	Orchorus capsularis	Stem	23.75 ± 0.61	135 ± 3	Not used
		Leaf	6.87 ± 0.29	150 ± 3	84 ± 2
	Ipomoea aquatica	All plant	8.81 ± 0.23	116 ± 2	66 ± 1
	Basella alba	Leaf	1.84 ± 0.15	117 ± 2	65 ± 1
	Piper sarmentosum	Stem	2.25 ± 0.23	142 ± 2	Not used
		Leaf	2.48 ± 0.24	249 ± 4	139 ± 2
	Polyscias fruticosa	Leaf	14.8 ± 0.44	149 ± 3	85 ± 2
	Red amaranthus	Stem	8.24 ± 0.30	175 ± 3	Not used
		Leaf	0.27 ± 0.14	211 ± 4	89 ± 2
		All plant	1.2 ± 0.2	161 ± 3	Not used
	White amaranthus	Leaf	3.22 ± 0.21	254 ± 4	116 ± 2
		Stem	4.9 ± 0.3	162 ± 3	Not used
	Houttuynia cordata	Leaf	6.95 ± 0.31	139 ± 2	100 ± 2
		Stem	5.20 ± 0.31	219 ± 4	Not used
	Sauropus androgynus	Leaf	1.9 ± 0.2	173 ± 3	96 ± 2

kg^{-1}_{fresh}. Following that, the highest gross beta activity concentration was also found to be 254 ± 4 Bq kg^{-1}_{fresh} in the leaf of white amaranthus. In the same of food crops, gross alpha and beta activity are quite different between various plant parts. It is belong to the biological characteristic of the plants and the present radionuclides as the report in IAEA-TRS-472 [16]. For most of leafy vegetables, the gross alpha activity of stem part is higher than leaf part, except ipomoea batatas and piper sarmentosum as shown in Fig. 2. In the contrast, the gross beta activity does not follow the rule and was showed in Fig. 3. For tubers types (ipomoea batatas, raphanus sativus and anihot esculenta), gross alpha and beta activity of the root part are higher than the other part.

Due to the lack of a consumption intake rate for food crops in report, a consumption intake rate of 1.2 kg_{fresh} $year^{-1}$ was assumed for this study. The total annual effective dose contributions from natural radionuclides in food crops samples are also given in Table 1. It was found that the total annual committed effective doses ranged from 45 ± 1 to 139 ± 2 μSv $year^{-1}$. The highest dose rate was found in the root of ipomoea batatas sample. High total annual committed effective doses was found in the root of three food crops of tubers type while the low values was found in fruit of two food crops of fruit type. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has provided the worldwide average annual effective dose (290 μSv $year^{-1}$) and typical

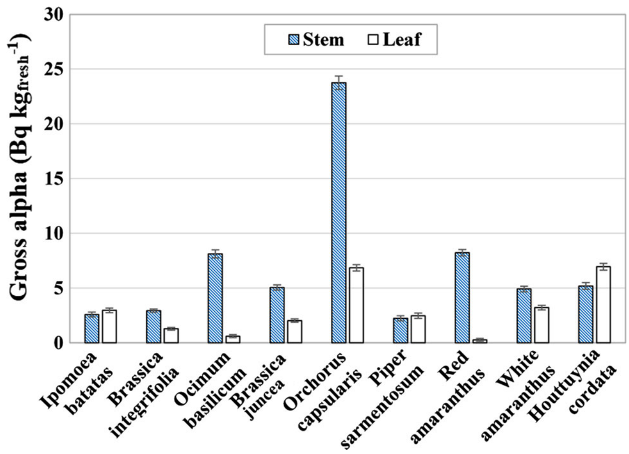

Fig. 2 Comparison between gross alpha activity of stem and leaf parts for leafy vegetables

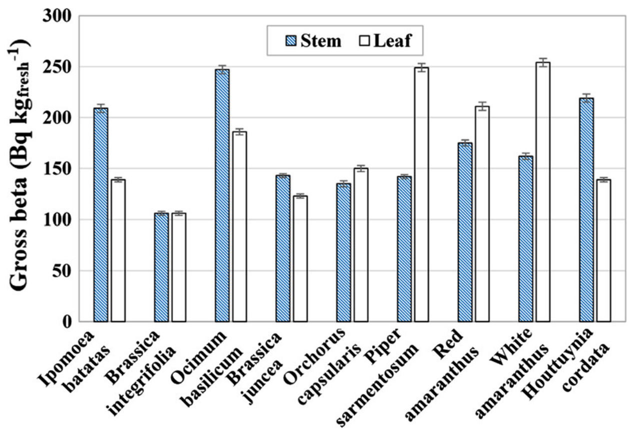

Fig. 3 Comparison between gross beta activity of stem and leaf parts for leafy vegetables

annual effective dose range (0.2–1 mSv year^{-1}) from ingestion (food and drinking water) [1, 15]. When comparing with typical annual effective dose range from ingestion, our ranges are lying within the limit of annual radiation dose from natural sources. It is found that our effective dose due to ingestion is well below the reference level values of UNSCEAR. Therefore, the radiological hazard associated with intake of the natural radionuclides in food crops is insignificant in the study area. The change of consumption intake rate makes the significant change of the total annual committed effective dose [8]. In Vietnam, rice is a type of food crops which is used most popularly with the high intake rate. In this study, most of food crops are vegetables. Therefore, 1.2 kg$_{fresh}$ year^{-1} of consumption intake rate is the good value. It was also found that 3 kg$_{fresh}$ year^{-1} of consumption intake rate makes the dose of ipomoea batatas root exceed the exemption mean dose criterion of 290 μSv year^{-1}.

Table 2 summaries the results of gross alpha and beta radioactivity measurement in 12 surface soil samples corresponding with 12 food crops samples. Gross alpha activity was found in the range from 207 ± 10 to 509 ± 21 Bq kg$_{dry}^{-1}$ while gross beta activity was found in the range from 275 ± 12 to 529 ± 20 Bq kg$_{dry}^{-1}$. The highest value of gross alpha and beta activity was found in the soil sample of anihot esculenta. It was also found that the average values of gross alpha and gross beta activity are 385 ± 18 and 442 ± 18 Bq kg$_{dry}^{-1}$, respectively. The average ratio of gross alpha activity and gross beta activity of surface soil samples is 0.87 ± 0.05 and significant larger than the ratio of food crops samples. It was explained by the present of beta emitter radionuclides including radionuclides from the atmosphere within the plant structures and the easier transfer ability of beta emitter radionuclides from soil to plant [8]. Despite different sites of surface soil samples, the average of gross alpha and beta activity between this study and previous study are in the same [8].

Table 3 summaries the obtained transfer factor for gross alpha (TF$_\alpha$) and beta (TF$_\beta$) for food crops samples. TF$_\alpha$ was found in the range from 0.009 ± 0.005 to 0.99 ± 0.06

Table 2 Gross alpha, gross beta radioactivity of surface soil samples

Soil of plant types	Gross alpha (Bq kg$_{dry}^{-1}$)	Gross beta (Bq kg$_{dry}^{-1}$)
Momordica charantia	250 ± 11	454 ± 14
Ipomoea batatas	207 ± 10	275 ± 12
Raphanus sativus	373 ± 18	423 ± 18
Anihot esculenta	509 ± 21	529 ± 20
Brassica integrifolia	428 ± 19	489 ± 19
Brassica juncea	337 ± 17	408 ± 18
Ipomoea aquatic	413 ± 19	456 ± 19
Basella alba	412 ± 19	490 ± 19
Piper sarmentosum	432 ± 20	494 ± 19
Polyscias fruticosa	405 ± 19	450 ± 19
Red amaranthus	434 ± 20	458 ± 18
White amaranthus	418 ± 19	383 ± 18
Average values	385 ± 18	442 ± 18

Table 3 Transfer factor soil-to-plant for gross alpha and gross beta for food crops samples

Food crops types	Food crops names	Food crops parts	TF_α	TF_β
Fruits	Momordica charantia	Fruit	0.123 ± 0.010	2.26 ± 0.10
Tubers	Ipomoea batatas	Root	0.99 ± 0.06	10.87 ± 0.53
		Stem	0.16 ± 0.02	9.7 ± 0.5
		Leaf	0.143 ± 0.012	5.04 ± 0.24
	Raphanus sativus	Root	0.116 ± 0.009	4.99 ± 0.23
		Leaf	0.043 ± 0.005	3.13 ± 0.14
	Anihot esculenta	Root	0.11 ± 0.01	6.3 ± 0.3
Leafy vegetables	Brassica integrifolia	Stem	0.09 ± 0.01	2.71 ± 0.12
		Leaf	0.038 ± 0.004	2.71 ± 0.12
	Brassica juncea	Stem	0.200 ± 0.014	4.67 ± 0.22
		Leaf	0.076 ± 0.007	3.8 ± 0.2
	Ipomoea aquatica	All plant	0.27 ± 0.02	2.96 ± 0.13
	Basella alba	Leaf	0.06 ± 0.01	3.16 ± 0.13
	Piper sarmentosum	Stem	0.039 ± 0.004	2.26 ± 0.10
		Leaf	0.037 ± 0.004	3.4 ± 0.2
	Polyscias fruticosa	Leaf	0.548 ± 0.030	4.97 ± 0.23
	Red amaranthus	Stem	0.336 ± 0.021	6.77 ± 0.30
		Leaf	0.009 ± 0.005	6.55 ± 0.29
		All plant	0.040 ± 0.005	5.29 ± 0.23
	White amaranthus	Leaf	0.07 ± 0.01	6.20 ± 0.31
		Stem	0.136 ± 0.010	4.9 ± 0.3

and TF_β was found in the range from 2.26 ± 0.10 to 10.87 ± 0.53. The highest TF_α and TF_β were found in the ipomoea batatas root sample. TF_α is contributed by transfer factor soil-to-plant (TF_s) of all alpha emitting radionuclides existing in the plant, whereas TF_β is contributed by TF_s of all beta emitting radionuclides existing in the plant. Therefore, they depend on the TF_s of particular radionuclides that ^{238}U, ^{232}Th, their progeny and ^{40}K occupy the majority. Because the value of TF_s is very different among radionuclides [16], TF_α and TF_β of different plants are various, and they depend on the type of radionuclide existing in plants. The climate regions and soil types make a significant variation of TF_s as the report of IAEA-TRS-472 [16]. The TF_s also depends to the physico-chemical properties of the soil (pH, electrical conductivity, sand, silt, clay, organic content, and total cation exchange capacity) and the competition elements (K and Ca) [3, 21–23]. The biological features of plants such as harvest time, plant types (leafy vegetables, non-leafy vegetables, grasses, tubers, maize, fruits, pastures, herbs, leguminous vegetables and root crops) and plant components also influence to TF_s [2, 16, 21]. These affection factors makes the

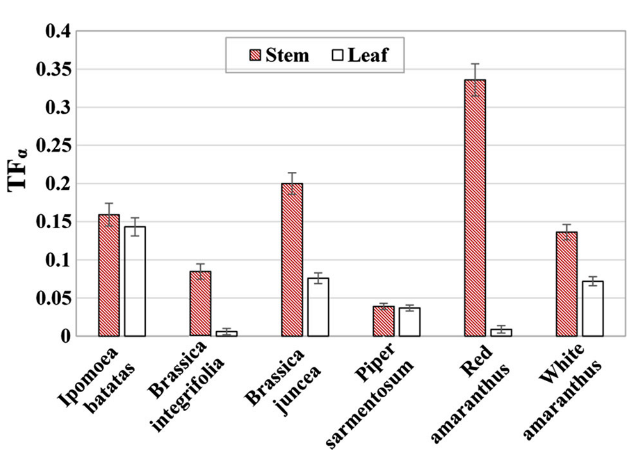

Fig. 4 Comparison between TF_α of stem and TF_α of leaf parts for leafy vegetables

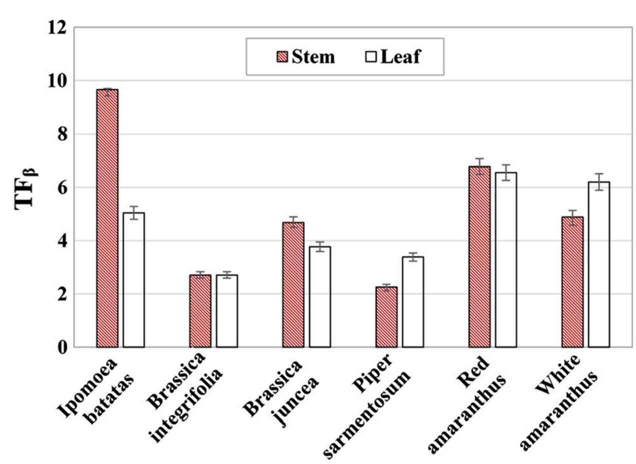

Fig. 5 Comparison between TF_β of stem and TF_β of leaf parts for leafy vegetables

Table 4 ^{238}U and ^{40}K activity concentration in the leaf of basella alba and white amaranthus

Food crops names	^{238}U		^{40}K	
	Activity concentration (Bq kg^{-1}_{fresh})	TF_s	Activity concentration (Bq kg^{-1}_{fresh})	TF_s
Basella alba	0.46 ± 0.04	0.08 ± 0.01	78 ± 2	2.6 ± 0.2
White amaranthus	1.09 ± 0.08	0.015 ± 0.002	155 ± 5	4.4 ± 0.3

differences of TF_s among food crops types and also the differences of TF_α and TF_β. Following the results of Table 3, TF_α and TF_β of the root part are higher than these values of other parts for the tuber types (ipomoea batatas and raphanus sativus). For all the leafy vegetables, TF_α of stem part are higher than these values of leaf part as shown in Fig. 4. In the contrast, TF_β of two parts are also different, and not follow the rule as shown in Fig. 5. It caused by the flexible probability of beta emitter radionuclides within the plant structure. For the impomoea aquatica sample, TF_β was found in the same with the previous study [4], but TF_α was found in significant higher than. It was explained by the differences of the growth time, the characteristics of surface soil and climate conditions [3].

The activity concentrations of two main radionuclides (^{238}U and ^{40}K) in leaf of basella alba and white amaranthus are shown in Table 4. The measurements were carried out using gamma spectroscopy equipped with a high purity germanium detector (HPGe). ^{238}U is an alpha emitting radionuclide while ^{40}K is a beta emitting radionuclide, and they are two of the most popular radionuclides existing in the environment. The results show that ^{238}U activity concentrations occupy 25 and 33.9% in gross alpha for basella alba and white amaranthus, respectively. ^{40}K activity concentrations occupy 66.7 and 61% in gross beta for basella alba and white amaranthus, respectively. Therefore, $TF_s(^{40}K)$ can contribute a significant fraction to TF_β. For the leaf of basella alba, it was found that $TF_s(^{40}K)$ and TF_β are 2.6 ± 0.2 and 3.16 ± 0.13, respectively. For the leaf of white amaranthus, the values of $TF_s(^{40}K)$ and TF_β are 4.4 ± 0.3 and 6.20 ± 0.31, respectively. The similar relation was found for $TF_s(^{238}U)$ and TF_α due to the high activity concentration of ^{238}U in the comparison with others alpha emitting radionuclides.

For leafy vegetables, the average values of TF_α are 0.16 ± 0.05 and 0.054 ± 0.006 for stem part and leaf part, respectively. It was also found that the average values of TF_β are 5.2 ± 0.2 and 4.6 ± 0.2 for stem part and leaf part, respectively. As no reference values for TF_α and TF_β are available, the alpha activity in leafy vegetables considered in the present study was assumed to be caused by the radionuclides uranium, thorium and radium along with their decay products. Due to the mobility of uranium and thorium is lower than that of radium and the ^{226}Ra content of the plants origin from soil [9], the results were compared with Ra transfer factor range (0.003–0.43) for leafy vegetables (tropical environment) reported in IAEA-TRS-472 [16]. Similarly, in case of beta emitting radionuclides, the radionuclides ^{40}K, ^{210}Pb and ^{228}Ra were assumed to be used to evaluate TF_β. However, due to the ^{40}K content is much higher than the concentration of the other radionuclides, the results were compared with K transfer factor range (0.49–5.6) for other crops. Our ranges are lying within the IAEA report.

Conclusions

Gross alpha and gross beta radioactivity of 18 food crops including leafy vegetables, tubers and fruits were measured by a low-background proportional counters LB4200 manufactured by Canberra Company. For a particular food crops, gross alpha activity was found various in order root part > stem part > leaf parts while gross beta activity did not follow the rule. The total annual committed effective dose due to natural radionuclides in food crops samples was calculated. The high radiation dose and low radiation dose were found in the root parts and the fruit parts, respectively. From the results of gross alpha and beta radioactivity measurement in food crops samples and the total annual effective dose contributions, it can be concluded that the radiological hazard associated with intake of the natural radionuclides in the food crops is insignificant in the study area. All of food crops samples have the total annual effective not exceed the exemption dose criterion of 290 μSv $year^{-1}$ with 1.2 kg $year^{-1}$ of the consumption intake rate.

Gross alpha and gross beta activity of 12 surface soil samples corresponding with food crops samples were determined for the transfer factor estimation. The radioactivity levels of the soil samples were found in the same with the values of previous study in Ho Chi Minh City. The transfer factors of gross alpha and beta activity for 12 food crops samples were obtained in this study. The high values of TF_α and TF_β transfer factors were found in the ipomoea batatas root sample. We also found that the

TF_α of leafy vegetables varies in the order stem part > leaf part while TF_β did not follow the rule. It is explained by the flexible probability of beta emitter radionuclides. The transfer factors obtained in this study is useful for the selection of the food crops types. Following that, leafy vegetables are suggested for high radiation soil areas.

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