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Original Article

Accumulation and distribution of nutrients, radionuclides and metals by roots, stems and leaves of plants

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ABSTRACT

In the process of growth and development, plants not only absorb essential nutritional elements, but also absorb radioactive and non-essential elements from the environment, and their distribution varies in different parts of the plant. In this study, neutron activation analysis and gamma spectrometry were performed on stems, roots, and leaves of vegetables. The results indicate that the accumulation of radionuclides and multi-elements depends on the plant type and plant parts. Activity concentrations of ^{226}Ra and ^{232}Th in plants were accumulated in the following order: Roots > Stems > Leaves. The highest concentrations of ^{40}K and ^{210}Pb were observed in the stems and leaves of plants, respectively. Essential nutrient requirements of plants are in the following order: K > Ca > Mg > Fe > Zn > Mn. Among the non-essential metals, the concentration of Na in the vegetable sample was much greater than those of the other elements. The K/Na ratio in the plant depends on the type of plant and the translocation within the plant.

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1. Introduction

Plants absorb nutrients mainly from the soil environment during growth and development processes. During absorption, plants not only absorb essential nutrients but also absorb trace amounts of non-essential elements and radioactive elements from the environment [1–3]. The accumulation of elements in plants is influenced by plant type, region, and environmental characteristics [1,3–5]. Moreover, the accumulation also depends on different parts of plants (roots, stems and leaves) [2,6]. Therefore, studying the accumulation and translocation of essential and non-essential elements makes it possible to know the requirements and tolerance limits of plants for each element. The translocation of toxic elements and radionuclides in plants helps us to choose the appropriate and safe parts for human consumption. In addition, it also helps us choose plants capable of absorbing radionuclides and heavy metals to improve the environment.

Contamination of heavy metals and radioisotopes in plants has become a major problem in recent years because of their potential accumulation in plants from soil and air environments. Although plants contain only a small amount of heavy metals and radioactive elements under normal conditions, it is extremely important because it directly affects many sensitive organs and has certain effects on the living organisms and human body [3,7–11]. [3] studied the accumulation of radioactivity in different leafy vegetables and evaluated their effects on different organs. Extensive exposure to Cr can lead to liver, kidney and lung organ damage [9]. Lead compounds are not considered to be directly genotoxic but can be genotoxic indirectly through generation of reactive oxygen species [12], through inhibition of repair enzymes DNA [13]. Most of these studies concluded that essential metals can also produce toxic effects at high concentrations of absorbed metals, while non-essential metals are toxic for human health even at trace amounts.

Analysis of the ability to accumulate and translocation metallic and radioactive elements in plants helps us to evaluate their characteristics, distribution and tolerances in plants. In recent times, many researchers have calculated the transfer factor of metal and radioactive elements of plants from soil to plants [1,3,14,15] and the influence of environment: fertilizer, pH, fertilizer, soil type and organic content on absorption capacity in plants [16,17]. [18] summarize the present knowledge of Na^+ influx, efflux and compartmentalization in plants in response to salt stress. The main

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effects of salinity on plants are: (1) osmotic effect leading to water shortage due to high concentration of soil solutes; (2) on-specific stresses leading to K+ deficiency [19].

In this study, vegetable samples commonly used in daily meals in Ho Chi Minh City was collected at the farm. As Ho Chi Minh is an area containing many large industrial parks, radionuclides and metals monitoring must be conducted. We used gamma spectrometry analysis and neutron activation analysis to determine the activity concentration, metal concentration, transfer factor in different plant parts. The results help evaluate the distribution of essential nutrients in the composition of the plant, the distribution of heavy and radioactive elements to choose the appropriate food for consumers.

2. Material and methods

2.1. The sample preparation

Soil and vegetable samples were taken from a vegetable farm in Xuan Thoi Commune, Hoc Mon District, Ho Chi Minh City. About 5 kg of water spinach, white jute, and malabar spinach were collected. These vegetable samples are widely used in daily meals. Soil samples were collected at the respective planting sites and it has a weight of about 2 kg. The collected samples were stored in polymer bags, labeled and transported to the laboratory for sample preparation. After removing soil, the plant samples were divided into three sections: roots, stems and leaves. Then, vegetables samples were washed by using distilled water and dried to determine fresh weight. The samples were then allowed to dry at 60 °C, and then placed in an oven at 105 °C for 12 h and weighed. Dried plant samples were burned and then ashed to white ash at 425 °C in an electric furnace where the temperature was gradually increased, and the ash mass was weighed. The ash sample was divided into two parts, one part was used for gamma radioactivity analysis, the other part was used for neutron activation analysis.

2.2. Activity concentration analysis

Sample was placed in a cylindrical plastic box with a diameter of 76.6 cm and a sample height of 1 cm to minimize self-absorption in the sample. Samples were kept for 40 days and then measured for 36 h using the HPGe gamma spectrometer. Activity concentration of ^{226}Ra, ^{232}Th, ^{40}K and ^{210}Pb from these samples were measured by gamma spectrometry with a HPGe detector of GMX35 of Ortec. The n-type HPGe detector of GMX35 has its 35% relative efficiency at the 1332.5 keV. The gamma radiation spectrum was analyzed by Genie2k software and the gamma energy peak efficiency was determined by ANGLE software. The radioactivity of ^{226}Ra were determined over nucleus of ^{214}Pb (241.9 keV; 295.2 and 351.9 keV) and ^{214}Bi (609.3; 1120.5 and 1764.5 keV). ^{232}Th concentrations were determined over ^{212}Pb (238.6 keV), ^{228}Ac (338.3 and 911.2 keV) and ^{208}Tl (583.2 and 2614.5 keV). The concentrations of ^{40}K and ^{210}Pb were determined through peaks of 1460.8 keV and 46.6 keV, respectively. Minimum detection activity was calculated based on the work of [20]. Detailed analytical methods can be found in the study of [21].

2.3. Multi-elements concentrations analysis

In this work, the k0 instrumental neutron activation analysis method (k0-INAA) on the 500 kW Da Lat Research Reactor in Vietnam was used. Vegetables and soil samples are packed in a dedicated sampler and the sample weight is 50 mg and 100 mg for short irradiation and long irradiation, respectively. Vegetable and soil samples were irradiated at Channel 7-1 (for short irradiation) and at the Rotary Rack (for long irradiation). Short-irradiated samples were measured for 120 s and 600 s after a decay period of about 420 s and 5400 s, respectively, to determine the concentration of Mg, Ca and Mn. Long-irradiated samples were measured for 3600 s and 10800 s after a decay period of 5 days and 20 days, respectively, to determine the concentration of K, Fe and Zn. The gamma-ray spectral determination used for this study was based on the GMX-30190 detector (ORTEC) and the relative efficiency was 30%. The data processing of k0-INAA and limit of detection is performed by the k0-IAEA software. Details of the experimental k0-INAA method are presented in Refs. [22,23].

2.4. Transfer factor

Characteristic for the uptake capacity of plants, the soil-to-plant transfer factor (TF) is determined by the ratio of the activity concentration in the plant and the activity concentration in the soil. The transfer factor is determined according to the formula number 5 [1,3].

$$TF = \frac{C_{plant,i}}{C_{Soil,i}} \tag{5}$$

3. Results and discussion

3.1. Activity concentration

Activity concentration in soil and plant samples determined by the HPGe gamma spectrometer system were presented in Table 1. Activity concentrations of soil samples in vegetable growing areas are quite diverse. The activity concentrations of ^{226}Ra, ^{40}K, ^{232}Th, and ^{210}Pb in soil samples ranged from 17.8 Bq kg^{-1} to 37.7 Bq kg^{-1}; 19.4 Bq kg^{-1} to 39.1 Bq kg^{-1}; 14.8 Bq kg^{-1} to 39.0 Bq kg^{-1}; 11.9 Bq kg^{-1} to 19.6 Bq kg^{-1}, respectively. Activity concentrations of ^{226}Ra and ^{232}Th in soil samples are in the reference values proposed by UNSCEAR (2000) (30 and 35 Bq kg^{-1}, respectively). The results showed that the radioactive concentration of ^{40}K in the soil sample was much lower than the ^{40}K concentration previously studied in Vietnam (312 Bq kg^{-1}) [24] and world average value (400 Bq kg^{-1}) (UNSCEAR, 2000). It could be explained as the agricultural land in this study has been cultivated in the long-term, so plants have absorbed a large amount of ^{40}K in the soil, causing the activity concentration to be reduced. In addition, this vegetable sample is grown with organic fertilizer (Chicken manure 30% + 70% Rice husk) and applied to the soil environment at the beginning of planting time. Organic manure samples had low levels of radioactivity and metals. However, organic fertilizers help improve the soil, add a large amount of humus, useful microorganisms, and nutrients to help the soil to be loose, aerated, and increase fertility. The results of radiation concentrations of this study are similar to those of other studies in Ho Chi Minh City [25]; Huy et al., 2012, [3]. The results show that the differences between studies are due to differences in geographical location, climate-weather conditions, plant absorption, fertilizers application, and farming methods.

The results in Table 1 indicate that the activity concentrations varied in different parts of the plant. The accumulation of ^{226}Ra and ^{232}Th in most plant samples is in the following order: Root > Leaves > Stem. The absorption of radionuclides at different parts of plant can be influenced by many physical, chemical and biological effects of the soil. The results of the highest accumulation of ^{226}Ra and ^{232}Th in roots were also found in the study of [2]. This is because the radionuclides in the soil are directly absorbed by plants through their root systems, and these radionuclides travel to

Table 1
Activity concentration in soil and plant samples (dried weight).

Radionuclide	Soil		Roots		Steams		Leaves		Transfer factor		
	Activity	error	Activity	Error	Activity	Error	Activity	Error	Roots	Stems	Leaves
Water spinach											
^{226}Ra	17.8	1.9	3.6	0.1	2.0	0.1	3.1	0.1	0.20	0.11	0.17
^{40}K	19.4	1.1	1065.4	0.3	1497.2	0.2	934.3	0.3	54.85	77.09	48.10
^{232}Th	14.8	2.0	5.6	0.1	2.5	0.1	3.6	0.1	0.38	0.17	0.24
^{210}Pb	17.1	0.6	0.1	0.1	3.5	0.1	3.9	0.1	0.01	0.20	0.23
White jute											
^{226}Ra	30.0	4.6	4.5	0.1	1.7	0.1	3.0	0.1	0.15	0.06	0.10
^{40}K	34.6	3.1	1665.2	6.8	3215.5	6.6	2163.6	7.1	48.11	92.89	62.50
^{232}Th	29.9	3.5	3.5	0.1	0.6	0.1	1.7	0.1	0.12	0.02	0.06
^{210}Pb	19.6	1.8	0.4	0.1	<0.1[a]		1.3	0.1	0.02	<0.1[a]	0.06
Malabar spinach											
^{226}Ra	36.7	1.7	7.2	0.1	3.0	0.1	3.3	0.1	0.20	0.08	0.09
^{40}K	39.1	1.2	2935.6	10.0	7442.0	7.9	3480.4	5.2	75.03	190.21	88.95
^{232}Th	39.0	1.5	5.3	0.1	2.1	0.1	4.5	0.1	0.14	0.05	0.12
^{210}Pb	11.9	0.4	0.8	0.1	<0.1[a]		1.5	0.1	0.06	<0.1[a]	0.13

Note:
[a] < MDA minimum detectable activity.

different parts of the plant and depending on the reaction and requirements of plants for radionuclides. Once the non-nutritive radioactive trace elements are dissolved in water, plant roots actively accumulate them depending on the chemical activity of the element in the soil solution, the presence of competing ions, redox potential and root absorptive capacity [15]. The uptake of radionuclides from the soil onto plants under favorable conditions has similarities to the plant's essential nutrients [26].

The accumulation of ^{40}K in different parts of plant is higher than those of ^{226}Ra and ^{232}Th. This result is also found in previous studies [1,3,14]. Because potassium is a macronutrient, it can account for 2%–10% of the dry weight of plants [27]. It is a major inorganic cation in the cytoplasm of plants, required for the activity of various enzymes, including those involved in primary metabolism [][] [28]). The results also show that there is a difference in potassium concentration in the plant parts and plant types, which may be due to the characteristics and requirements of each plant type for potassium, the influence of potassium concentration in the soil sample (Table 1). The transfer factor of ^{40}K is found to be highest in stems, and the following order: Malabar spinach > white jute > water spinach. The accumulation of ^{40}K depends on the type of plant on different locations and growth characteristics of each plant. It could be explained as the activation of enzymes by potassium is important to maintain the turgidity of the cells [29]. The potassium concentrations in the roots and leaves of plants are affected by the potassium concentration and water in the environment [30]. The transport coefficient of k40 is similar to the study of [3] but higher than that of the [1] (1.4) and [31] studies (0.32–8.04). The differences between studies are due to differences in geographical location, environment, plant types, and farming practices.

In the case of ^{210}Pb, the highest concentration of ^{210}Pb was found in the leaves. The cause may be the presence of a pre-existing concentration of ^{210}Pb in the environment and the decay product of the isotope in the ^{238}U series, resulting in an increase in the ^{210}Pb concentration in the plant sample. In addition to the ability of plants to absorb nutrients from the soil through their roots, plants can absorb nutrients through leaves. ^{210}Pb is a decay product of ^{222}Rn (^{226}Ra), which exists in the air with a short half life [32] and can be carried away by aerosol particles and removed from the atmosphere through deposition [33]. ^{210}Pb is deposited on leaves and absorbed in a passive manner similar to passive absorption through the roots. The epidermal features of plant foliage can exert an effect when the leaves retain seeds and subsequently absorb radionuclides from the surface. The transport of radionuclides across the epidermis and dermis of leaves is partly determined by leaf conformation and physiological factors [34]. The absorption of ^{210}Pb in plants depends on the type of plant, weather, humidity, plant health will directly affect the absorption capacity.

3.2. *Essential elements concentrations*

Mineral nutrition includes the supply, absorption, and utilization of nutrients necessary for plant growth and yield. All nutrients are equally important in terms of growth. If any nutrient is lacking, it will adversely affect plant growth. Analysis of soil and plants to determine metal concentrations in crops is presented in Table 2. The results show that metal concentrations in vegetable samples depend on the nutrient requirements of each plant and different parts in each plant. Essential nutrient requirements of plants for elements are in the following order: K > Ca > Mg > Fe > Zn > Mn. The highest concentration of potassium was found in spinach. The concentration of essential metals (except for potassium) in water spinach was higher than in jute and spinach. Concentrations of K, Ca and Mg in plants are much higher than that of other elements. Because these are the quantitative elements (accounting for >100mg/1 kg dry weight of the plant) participating in the composition of living substances and regulating the vital activities of the plant.

The metals in these plants are introduced into the human body directly or indirectly in large amounts, which will affect the health of the user. From the data in Table 1 and 3, metal concentrations in fresh vegetable samples were calculated and compared with the world. The maximum concentration of elemental Mg (fresh weight) in white jute leaf samples was 569.9 ppm, much higher than the 200 ppm allowed level set forth by Ref. [35]. The high concentration of Mg in the samples were similarities with previous studies [6,36]. Concentrations of elemental Zn (fresh weight) in vegetable samples (except water spinach leaves) were within the limits set forth by Ref. [35] for edible leafy plants of 27.4 ppm. The maximum allowable limit of Zn in fresh vegetable products is required not to exceed 10 ppm [37]. However, roots (17.3 ppm) and stems of water spinach

Table 2
Metal concentrations in soil and plant samples (ppm dried weight).

	Element	Water spinach				White jute				Malabar spinach			
		Soil	Roots	Stems	Leaves	Soil	Roots	Stems	Leaves	Soil	Roots	Stems	Leaves
Essential	K	<[a]	34790.3	33570.6	31281	856.5	26576.6	54625.7	49495.7	[a]	92298	146183	71165
	Fe	3232	807.3	201.7	849.9	3973	192.5	113.4	400.2	4095	384.2	244.1	277
	Zn	49	340.8	113	453.1	81.7	124.2	114.2	126.3	62.8	131.1	126.6	162
	Mn	38.6	267.6	168.4	376.7	49.7	62.1	11.5	420.7	68.9	[a]	25.2	118.2
	Ca	[a]	16729.6	12267.1	7261.3	[a]	3494.6	7152.4	11369	[a]	3450	4826.7	12726
	Mg	[a]	3664.6	2691.5	3405.5	[a]	2221.1	3052.8	5204.2	[a]	4365.4	5264.5	10423
Non-essential	Na	172.8	14714.8	2828.4	13824.8	207.4	5156.1	2421.8	1050	205.4	2109.9	4477.7	6492.9
	Co	0.8	1.1	0.1	0.4	0.9	0.2	0.2	0.2	1.0	0.4	0.2	0.4
	La	6.5	1.9	0.8	0.9	7.0	0.8	0.6	0.6	7.8	3.1	0.8	0.4
	Ce	10.8	2.6	1.2	1.6	[a]	1.4	1.0	1.0	14.4	4.5	1.3	0.6
	Cr	26.2	43.9	10.4	8.1	31.7	2.2	1.3	20.4	29.5	24.5	9.1	7.1
	Cs	1.6	0.5	0.3	0.6	1.6	0.1	0.1	0.3	1.8	0.1	0.2	0.2
	Br	2.0	27.4	27.9	22.4	2.4	9.1	21.8	29.3	2.6	6.1	13.4	9.4
	Rb	5.6	30.2	24.2	28.5	7.9	18.2	35.7	37.4	[a]	35	60.3	48.1

Note:
[a] < MDA minimum detactable activity.

(35.0 ppm) as well as roots (16.9 ppm) and stems (13.8 ppm) of jute vegetables exceeded the allowable limit. The potassium concentrations in the vegetable samples were found to be the highest among analyzed elements. Potassium supports the proper function of the brain and nerves, consequently prevent strokes. It regulates acid-base and water balance in blood and tissues. It is necessary for bone and in the prevention of osteogenic disease [38]. However, when the vegetable samples were cooked, radioactive and metal content in the vegetable samples were reduced [39]. The use of vegetables in this study as food can provide a daily amount of metal for human consumption. However, excessive consumption could adversely affect human health. Data on the effects of chromium, iron, manganese, molybdenum, selenium and zinc on the human body were covered in the study by [7].

For the nutritional elements in Table 2, the results show that the concentration of potassium in this study vegetable sample accumulates mostly in the stem. Because potassium has a major role in energy metabolism in the process of assimilation of substances in plants. Functions as cofactor or activator for many enzymes in carbohydrate and protein metabolism. Potassium increases the plant's resistance to adverse effects from the outside, making the tree more branched, more leafy, strong and less prone to falling [40,41].

Micronutrients such as Mn, Fe, Zn, and Mn are accumulated and translocated into different parts of plant in the following order: Leaves > Roots > Stems. The accumulation of micronutrients occurs mostly in leaves because these elements are involved in the construction of living substances and in the regulation of vital activities of the plant. For example, Iron is the catalyst for the formation of Chlorophyll and acts as an Oxygen carrier. It also helps form several respiratory enzyme systems [42]. Manganese is a component of enzyme systems in plants. It activates several important metabolic reactions in plants and has a direct role in photosynthesis, by aiding in chlorophyll synthesis [42,43]. Zn participates in activating about 70 enzymes of many physiological and biochemical activities of plants. It is required for the production of Chlorophyll and other hydrates [42,44]. The greater accumulation in roots than in stems may be due to the fact that the roots are the organs that directly absorb minerals from the soil into the plant. Minerals absorbed by plant roots from the soil must undergo reduction and metabolism in the roots to form a stream going up the leaf stem (the above-ground parts).

3.3. *Non-essential elements concentrations*

Some elements can stimulate plant growth, especially by playing a role in symbiosis and abiotic-biotic stress resistance, even though they are not essential nutrients, or only required for specific plant species. The results of concentrations of non-essential elements for plants are presented in Table 2. The results show that metal concentrations in vegetable samples depend on the type of plant and different parts of the plants. Metal concentrations of Co, La and Ce were most concentrated in plant roots. The highest concentrations of Cs and Rb in the plants in this study were found in the leaves. Br concentrations are found in the highest concentrations in the stems of plants. Concentrations of Na and Cr varied on different plant parts, it depends on the characteristics of each plant. Heavy metals are absorbed mainly through plant roots and remain there or are transferred into shoots and into cells [45]. For most plants, roots represent a barrier to metals. Therefore, heavy metal content in roots is usually higher than in stems and leaves [46,47].

The results of elemental analysis of parts of vegetables for Co showed that the highest Co concentration of 0.1 ppm (fresh weight) of water spinach root samples were below the allowable limit of cobalt in plants of 0.2 ppm according to WHO regulations (2005). Excess Co causes plant toxicity symptoms ranging from leaf wilt and necrosis in tomatoes [48], to reduced biomass accumulation and nutrient absorption. in cauliflower [49]. The range of Cr concentrations in (fresh) vegetable samples ranged from 0.1 ppm in jute stem samples to 2.2 ppm in jute leaf samples. Comparing the limit set by Ref. [35] for edible plants of 0.02 ppm, all samples in this study exceeded the limit. The results were within the allowable range for Cr by the Canadian government (2 ppm) [50]. The results of this study are smaller than those of Jabeen et al. al. (2010) (1.2–29.5 ppm). We need to pay attention to Cr in vegetable samples because this is one of the toxic heavy elements, which when exposed can lead to liver, kidney and lung damage [9].

Among non-essential metals, the concentration of Na in vegetable samples was much higher than those of other elements (Table 2), Na concentrations ranged from 1050 ppm in jute leaves to 14714.8 ppm in water spinach roots. The reason may be due to the concentration of Na, which accounts for 3% of the weight of the Earth's crust, leading to high soil solubility. Na is chemically similar to K, and might nonselectively enter cells through the potassium channel, although several Na transporters have also been detected [51]. Na deficiency in some plants inhibits the conversion of pyruvate to phosphorenolpyruvate in mesophyll cells, and reduces the amount of Na+/H+ of pyruvate across the membrane [52]. The migration behavior of Na in cells is similar to that of K in terrestrial ecosystems. K^+ moves from tissue to growing tissues if K is in deficit. If Na^+ mimics the movement of K^+ within the plant, then Na can also accumulate in newer tissues when the plant lacks K [][] [53]). The change in K^+/Na^+ ratio is due to an increase in Na+ content. The ionic radius of Na^+ and K^+ in their hydrated forms are similar, making the distinction between the two ions difficult [18].

One of the important physiological changes during the early evolution of plant cells was their ability to adapt to low levels of the Na^+ and K^+ mediators. The effects of salinity are varied, but Na^+ toxicity is one of the main mechanisms of cell injury in most salt-sensitive plants, while K^+ is an essential ion [54]. In order to characterize the plant's tolerance to salinity, the K/Na ratio has been calculated and presented in Fig. 1. The results show that the K/Na ratio depends on different parts (roots, stems, leaves) in plants, and depends on different types of plants. In comparison, the K/Na ratios in the roots and stems of vegetables in this study in descending order are Malabar spinach > White jute > Water spinach. In leaves, K/Na ratio is in the order of White jute > Malabar spinach > Water spinach. K/Na ratio differ in plants because of their dependence on the high-affinity K^+ transporter, which plays a key role in regulating Na + homeostasis [55]. For water spinach sample, the K/Na ratio is the highest in the stem. For white jute sample, this ratio is the highest in the leaves. Whereas, this ratio reached the highest value in the roots of malabar spinach sample. The difference between the K/Na ratios in different plant components is due to the role and properties of each element for different parts of plant. For example, Na+ is absorbed by the roots then moves to the xylem with the help of other transporters and channels and is carried to the shoot, especially the leaf blade, where its effects are most pronounced [19].

The uptake capacity of plants for metals and radioactivity depends on many different factors and has been suggested by many previous studies: elemental concentration, soil type, climate zone and plant species [1] and soil type, soil formation including texture, clay content, cation exchange capacity, cation exchanger, pH and organic matter content [4,5]. The use of fertilizers in agriculture also affects the absorption of elements [15]. The extent of mineral uptake and its distribution in plants depends on the bioavailability of the minerals in the soil, and the structure of the shoot and root systems [56].

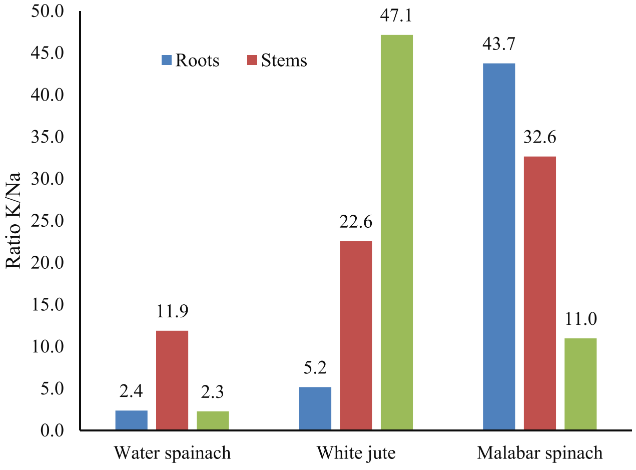

Fig. 1. K/Na ratio comparison.

4. Conclusion

Nutrient metal, metal and radioactivity concentrations in soil and plants were determined. The results showed that the radioactive concentration in the soil was within the radioactive safe limits set forth by UNSCEAR (2000) and that the soil sampled area on the farm had a low concentration of ^{40}K radiation. The distribution of radioactivity in the rhizomes and leaves depends on the isotope and the type of plant. The accumulation of ^{226}Ra and ^{232}Th in most plant samples is in the following order: Root > Leaves > Stem. The accumulation of ^{40}K is found to be highest in stems, and the following order: Malabar spinach > white jute > water spinach. The highest concentration of ^{210}Pb was found in the leaves. Essential nutrient requirements of plants for elements are in the following order: K > Ca > Mg > Fe > Zn > Mn. Micronutrients such as Mn, Fe, Zn, and Mn are accumulated and translocated into different parts of plant in the following order: Leaves > Roots > Stems. Non-essential elements concentrations in vegetable samples depend on the type of plant and different parts of the plants. The K/Na ratio is in the order of White jute > Malabar spinach > Water spinach.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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