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Study on Radionuclides from Soil to Onion at Johor and Perak, Malaysia

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

In this report, the radiological survey of radioactivity measurements in soil and onion and their mobility is carried out which is very important in the environment and several scientific fields. The measurements about the concentrations of activity in soil, leaves and bulbs for onion in the location of Johor and Perak, Malaysia have been carried out using neutron activation analysis (NAA) of TRIGA MARK II research reactor facilities at Nuclear Agency, Bangi, Malaysia. The transfer factors (TFs) of ^{238}U, ^{232}Th and ^{40}K from 6 different natural background soils are studied from soil to onion under natural field conditions. The TFs for onion leaves and bulb are in the range of (6.01-79.2) x 10^{-3}, (1.21-61.4) x 10^{-3}, (1.012-4.265) x 10^{-1} and 0.028-0.334, 0.017-0.293 and (0.908 -3.685) x$10^{-1}$for ^{238}U, ^{232}Th, and ^{40}K respectively. There exists a linearity correlation between the dose rate as well as activity concentration of the soils. The observed transfer factor of onion bulbs was usually higher than in leaves.

Keywords: Soil; onion; 238U; 232Th; 40K; transfer factor.

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1. INTRODUCTION

The radiation exposure to the community arises from two main sources; natural and artificial sources. The radioactivity from terrestrial (soil) is owing to gamma-emitting radionuclides that existing in trace amounts, particularly of ^{232}Th, ^{238}U and ^{40}K. Naturally, primordial radionuclides are widely spread during the earths crust and they can enter to the human body [1-3]. Consequently, humans are continuously exposed to the gamma rays from these sources. Actually, in some inhabited areas of the world, the background radiation is significantly raised owing to radiation in soil and construction solid. There is a lot of research work on radionuclides that are found in soil and plants [4-8].

Soil sources are important for Malaysians in industry, agriculture, construction, engineering, forestry and environmental survey for land use policy. The research on activity and the mobility of natural radionuclide in the environment is very important in several scientific fields. In Malaysia, only a little record of radioactive contamination of the environment has been reported [9-11]. Recently, the transfer of natural radionuclides from soil to groundnut crops has been investigated [12]. According to our literature survey and the authors knowledge, no research was carried out on radionuclides from soil to onion in Malaysia. Onion is very useful food for the human being. Consumed onions are low in fat and reduce the risk of cancer, stroke, heart attack, inflammation, heal infections and assist in regular blood sugar. Onions are rich in potassium, calcium, fibers, vitamin B and C [13]. It is very important to study natural radionuclides in soil and onion to measure the level of radioactivity and TFs from soils to onion (*Allium cepa*) with different levels of background radiation. This study attempts to determine the level of radioactivity in onion that is commonly consumed by people in Malaysia. For this, a radiological survey of radioactivity measurements in soil and onion at different locations of Perak and Johor has been measured by instrument neutron activation analyses (INAA) [12]. The method of INAA can analyze very small sample sizes, low detection limits, no chemical preparation, no-destructive and a large number of elements simultaneously.

2. MATERIALS AND METHODS

Six soil samples were selected based on normal and high natural background radioactivity at different locations in Johor and park, Malaysia. Three high natural background samples S1 (surrounded by palm tree) and S2 (surrounded by rubber) were located at Palong, Segamat, and S6 was located at Kg Sg Durian, Perak. The rest of the three was randomly selected with low natural background indicated by sample S3 at Kg Tg Langsat, Pasir Gudang, S4 at Kg Perigi Acheh, Pasir Gudang and S5 at Kg Rahmat, Kulai. All samples were prepared according to the instruction of the International Atomic Energy Agency (IAEA) for the neutron activation analysis (NAA) [9]. The topsoil of each area obtained a sample of mass 2 kg at ~5cm depth. The sample of location is recorded as accurately as possible, preferably using a handheld GPS. Tasters were heated by a stove at 100°C for twenty-four-hour. The samples were made to powder form. Finally, 1.5 gm of the sample was placed in a polyethylene vial and stored for 30 days to achieve secular equilibrium of Thorium and Uranium and their decay goods before preparation for neutron irradiation.

The detailed sample preparations of plants are presented in Ref. [12]. The soil samples were separately placed in a polybag of size 5 x 9. Each crop was planted for 3 onions using a different type of soil in a different polybag. We used tap water periodically. The onions are harvested after 7 days of cultivation. The procedure of washing, dried, weighed, ground to fine powder, homogenized and sealed samples of onion in 1 mL polyethylene vial are presented [12]. Finally, the samples were left for 30 days before preparation for irradiation. The detailed method of preparation of soil samples for measurement of U^{238}, Th^{232}, K^{40} and certified reference materials, i.e. IAEA-312, NBS-1633 and NBS-1573 explained in ref. [12,14].

The analytical procedure is based on four steps; sample preparation, irradiation of samples with a neutron, gamma-ray measurement and analysis. The experiments were performed using TRIGA MARK II research reactor at Malaysia Nuclear Agency, Bangi, Selangor employing the thermal neutron flux of $\Phi_{th} = 12 \times 10^{11}$ cm^{-2} s^{-1}. The samples were irradiated for 21600 s. After irradiation, the measurements were performed with a suitable cooling time (Tc), and result of the irradiated samples and the standard reference material obtained and counted with_high purity germanium (HPGe) detector supplied by ORTEC. A computer based analyzer ND6680 was used for data collection.

3. RESULTS AND DISCUSSION

The radioactivity of soil and onion was extensively studied at six locations of Johor and Perak, Malaysia.

The equation of transfer Factors (TFs) [12,15,16] from soil to leave and bulb of onion was calculated as follows:

$$\text{Transfer Factors (TFs)} = \frac{A_{crops}(\frac{Bq}{kg})}{A_{soil}(\frac{Bq}{kg})} \qquad (1)$$

Uncertainty of Transfer factor, *ΔTF* is given in the equation below;

$$\frac{\Delta TF^2}{TF} = (\frac{\Delta A_{crop}}{A_{crop}})^2 + (\frac{\Delta A_{soil}}{A_{soil}})^2 \qquad (2)$$

and,

$$\Delta TF = [\sqrt{(\frac{\Delta A_{crop}}{A_{crop}})^2 + (\frac{\Delta A_{soil}}{A_{soil}})^2}\,] \times TF \qquad (3)$$

where A_{soil} is the concentration of activity (Bq,Kg^{-1}) of the nuclide in soil, A_{crop} is the concentration of activity of the nuclide in crops Bq/kg. ΔA_{soil} is the uncertainty of concentration of activity of the nuclide in the soil while ΔA_{crop} is the uncertainty of concentration of activity of the nuclide in crops.

The dose rate of natural background radiation of the soil sample was measured 1m from the ground using a portable survey meter. The dose rates (nGy h^{-1}) and natural background (□Rh^{-1}) of six samples are shown in Table 1. The range of dose rates was recorded between 87 and 1218 nGy h^{-1} and natural background was recorded 10 -140□□Rh^{-1}. The highest dose rate was measured in the rubber estate at Kg Sungai Durian, Perak. The lowest dose rate was observed at Kg Rahmat, Kulai.

The activity concentrations of samples were measured for uranium, thorium and potassium by instrumental neutron activation analysis. The activity concentrations of these radionuclides were obtained for each sample (in units of Bqkg^{-1}) after correcting for background and Compton contributions. Table 2 shows the activity concentration of six selected soil samples. The sample S6 contains the highest activity (3778.1 ± 61.5 Bq/kg) of ^{232}Th followed by S2 (1932.7 ± 43.9 Bq/kg), S1 (988.5 ± 31.4 Bq/kg), S4 (175.6 ± 13.3 Bq/kg), S3 (119.6 ± 10.9 Bq/kg) and S5 (100.5 ± 9.1 Bq/kg). However, activity concentration of ^{238}U in soils differs from ^{232}Th where the highest activity occurs in S2 (1069.2 ± 32.7 Bq/kg), followed by S1 (574.9 ± 23.7 Bq/kg), S6 (536.0 ± 23.2 Bq/kg), S4 (208.2 ± 14.4 Bq/kg), S3 (107.9 ± 10.4 Bq/kg) and S5 (68.0 ± 8.2 Bq/kg). The activity concentration of ^{40}K in soils is as: S3 (679.4 ± 49.6 Bq/kg) > S1 (583.4 ± 42.6 Bq/kg) > S5 (225.9 ± 17.1 Bq/kg) > S2 (212.9 ± 15.7 Bq/kg) S4 (142.5 ± 10.6 Bq/kg) > S6 (37.1 ± 3.4). The activity concentration levels for ^{40}K were the smallest compare to the other two selected natural radionuclides ^{238}U and ^{232}Th. The highest activity was found to be 3778.1 ± 61.5 Bq/kg in ^{232}Th, 10682 ± 32.7 Bq kg-1 in ^{238}U and 679.4 ± 49.6 Bq kg-1 in ^{40}K of sample S6 at Kg.Sg Durian, S2 at Palong, Segamat and S3 Kg Tg Langsat Pasir Gudang respectively.

The activity of soils concentrations was studied to find out the correlation of the linearity with dose rate measurement. The natural background of soil and dose rate observed the tendency of samples as S5 < S4 < S3 < S1 < S2 < S6. The soil activity was calculated in BgKg^{-1}. The tendency of samples for soil concentration of ^{232}Th is as S5 < S3 < S4 < S1 < S2 < S6. Therefore, it affects the soil activity concentration of ^{232}Th as they also showed the trend such as S5 < S3 < S4 < S1 < S2 < S8. The linearity of the dose rate as well as activity concentration of the soils was observed. This study enabled the researcher to describe the transfer factor from the activity concentration of soil to the activity concentration of different parts of *Allium cepa*.

Table 3 lists the activity concentrations in bulb and leaves of onion measured for ^{232}Th, ^{238}U, and ^{40}K cultivated in six samples of soil. The concentration of activity for leave of onion was ^{238}U (1.2±0.4 to 12.1±3.4 Bq.kg^{-1}), ^{232}Th (2.2±1.5 to 9.8 ± 3.1 Bq/kg), and ^{40}K (695.2 ± 50.3 to 1024.7 ± 74.1 Bq/kg) respectively. The concentration of activity of bulbs of onion was ^{238}U (3.0±1.7 to 61.5±7.8 Bq/kg), ^{232}Th (2.0±1.4 to 101.3 ± 10.1 Bq/kg), and ^{40}K(480.7 ± 34.9 to 705.5 ± 50.1 Bq/kg). For ^{40}K, the maximum concentration 1024.7 ± 74.1 Bq/kg was absorbed in the soil samples S6 at Kg Sg Durian, Perak. For ^{232}Th, it was observed for leaves in all soil

Table 1. Measured gamma-ray natural background and dose rate of soil sample location

Samples	Area	Natural Background (μR h^{-1})	Dose Rate (nGyh^{-1})	Soil type
S1	Palong, Segamat (palm tree)	100	870	Orthic Ferralsols
S2	Palong, Segamat (rubber)	120	1044	Orthic Ferralsols
S3	Kg Tg Langsat, Pasir Gudang	17	147.9	Ultisols
S4	Kg Perigi Acheh, Pasir Gudang	14	121.8	Histosols
S5	Kg Rahmat, Kulai	10	87	Histosols
S6	Kg Sg Durian, Perak	140	1218	Granites

Table 2. Activity concentrations of ^{238}U, ^{232}Th and ^{40}K in soil samples

Part of onions	Label	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)
Leaves	S1	3.7 ± 1.9	9.8 ± 3.1	955.1 ± 69.4
	S2	12.1 ± 3.4	2.2 ± 1.5	893.9 ± 64.5
	S3	1.2 ± 0.4	2.8 ± 1.7	695.2 ± 50.3
	S4	5.6 ± 2.4	7.7 ± 2.8	856.2 ± 62.3
	S5	5.4 ± 2.3	6.1 ± 2.5	760.1 ± 55.3
	S6	3.2 ± 1.8	8.7 ± 2.9	1024.7 ± 74.1
Bulb	S1	61.5 ± 7.8	73.4 ± 8.6	480.7 ± 34.9
	S2	29.4 ± 5.4	52.7 ± 7.3	539.2 ± 39.1
	S3	3.0 ± 1.7	2.0 ± 1.4	560.7 ± 40.5
	S4	6.2 ± 2.5	5.3 ± 2.3	534.5 ± 38.8
	S5	22.7 ± 4.8	29.4 ± 5.4	652.3 ± 47.1
	S6	15.4 ± 3.9	101.3 ± 10.1	705.5 ± 50.1

Table 3. The activity of ^{238}U, ^{232}Th and ^{40}K in leaves and bulbs for onions

Label	Province	Activity concentration (Bq kg^{-1})		
		^{238}U	^{232}Th	^{40}K
S1	Palong, Segamat (palm tree)	574.9 ± 23.7	988.5 ± 31.4	583.4 ± 42.6
S2	Palong, Segamat (rubber)	1069.2 ± 32.7	1932.7 ± 43.9	212.9 ± 15.7
S3	Kg Tg Langsat, Pasir Gudang	107.9 ± 10.4	119.6 ± 10.9	679.4 ± 49.6
S4	Kg Perigi Acheh, Pasir Gudang	208.2 ± 14.4	175.6 ± 13.3	142.5 ± 10.6
S5	Kg Rahmat, Kulai	68.0 ± 8.2	100.5 ± 9.1	225.9 ± 17.1
S6	Kg Sg Durian, Perak	536.0 ± 23.2	3778.1 ± 61.5	37.1 ± 3.4

Table 4. Transfer factors from soil to onion

Part of onion	Site	TF(^{238}U)	TF(^{232}Th)	TF$^{(40}$Kr)
Leaves	S1	(6.13 ± 0.21) × 10^{-3}	(1.01 ± 0.01) × 10^{-2}	(1.280 ± 0.030) x10^{-1}
	S2	(2.31 ± 0.12) × 10^{-3}	(1.21 ± 0.01) × 10^{-3}	(2.049 ± 0.032) x10^{-1}
	S3	(1.10 ± 0.01) × 10^{-3}	(2.40 ± 0.03) × 10^{-2}	(1.012 ± 0.041) x10^{-1}
	S4	(2.74 ± 0.01) × 10^{-2}	(4.44 ± 0.02) × 10^{-2}	(2.452 ± 0.015) x10^{-1}
	S5	(7.92 ± 0.03) × 10^{-2}	(6.14 ± 0.02) × 10^{-2}	(1.834 ± 0.025) x10^{-1}
	S6	(6.01 ±0.01) × 10^{-3}	(2.32 ± 0.01) × 10^{-3}	(4.265 ± 0.021)x10^{-1}
	Range	(6.01 – 79.2) × 10^{-3}	(1.21 – 61.4) × 10^{-3}	(1.012 – 4.265) x 10^{-1}
Bulb	S1	0.107 ± 0.007	0.074 ± 0.001	(0.908 ± 0.021) x10^{-1}
	S2	0.028 ± 0.001	0.027 ± 0.002	(1.591 ± 0.022) x10^{-1}
	S3	0.028 ± 0.002	0.017 ± 0.001	(0.908 ± 0.014) x10^{-1}
	S4	0.030 ± 0.002	0.030 ± 0.001	(1.937 ± 0.012) x10^{-1}
	S5	0.334 ± 0.011	0.293 ± 0.012	(1.699 ± 0.012) x10^{-1}
	S6	0.029 ± 0.001	0.027 ± 0.002	(3.685 ± 0.043) x10^{-1}
	Range	0.028 – 0.334	0.017 – 0.293	(0.908 – 3.685) x10^{-1}

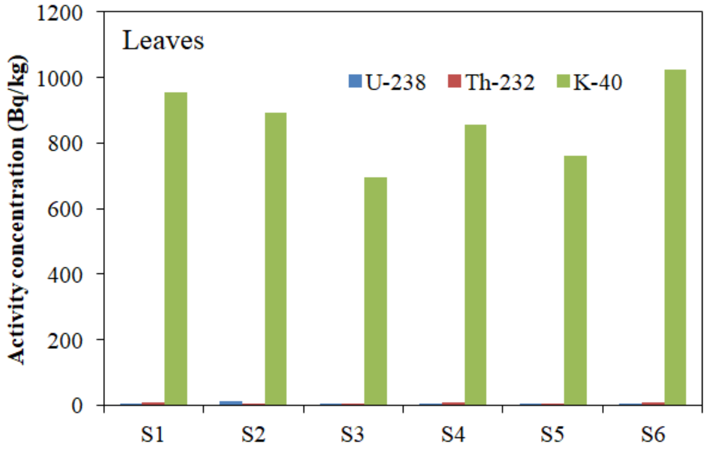

Fig. 1. Activity concentration of ^{238}U, ^{232}Th, and ^{40}K in leaves of onion

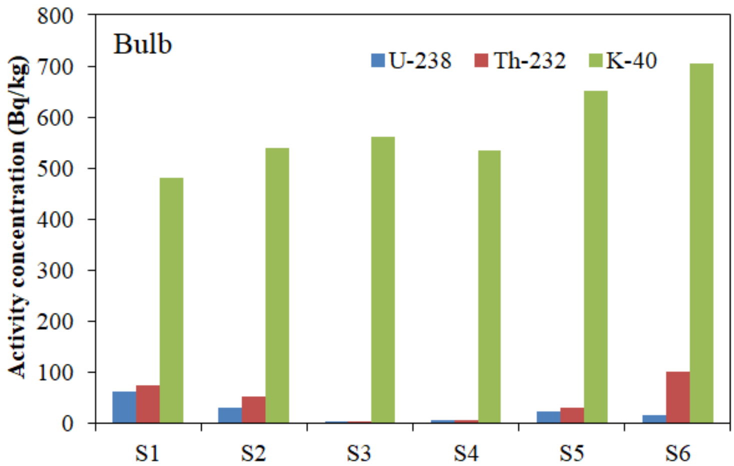

Fig. 2. Activity concentrations of 238U, 232Th and 40K in bulb of onion

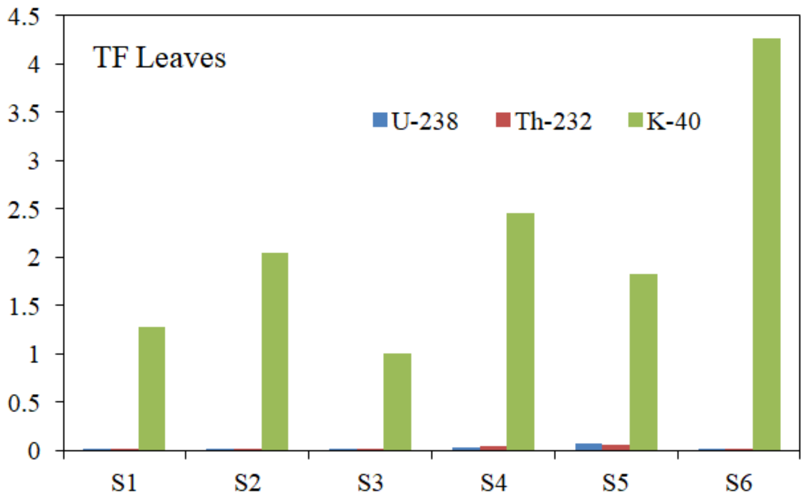

Fig. 3. Transfer factor in leaves of onion corresponding to the selected six soil samples

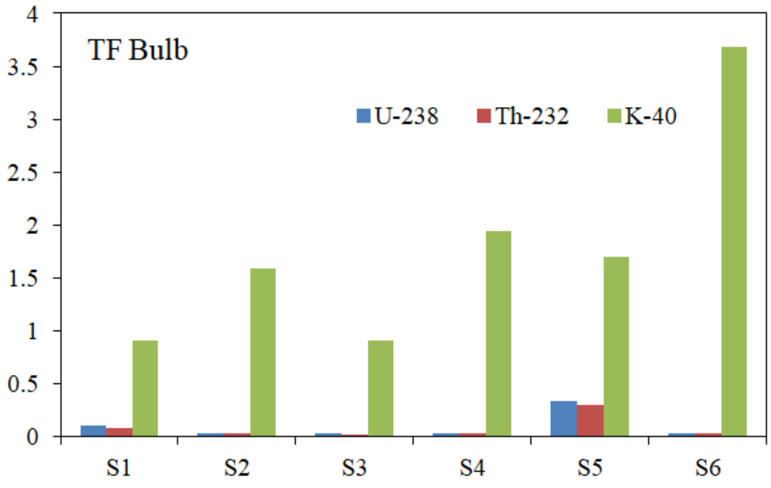

Fig. 4. Transfer factor in the bulb of onion corresponding to the selected six soil samples

samples, especially in S1 (9.8 ± 3.1 Bq/kg) and S6 (8.7 ± 2.9 Bq/kg). Furthermore, ^{238}U was observed with the highest concentration 12.1 ± 3.4 Bq/kg in sample S2 at Palong, Segamat. Fig. 1 and Fig. 2 show the activity concentrations in leaves and bulbs of onion corresponding to the selected six soil samples.

The activity of the bulb was in the ranges of (3.0 ± 1.7 – 61.5 ± 7.8), (2.0 ± 1.4 – 101.3 ± 10.1) and (480.7 ± 34.9 – 705.5 ± 50.1) Bq.kg^{-1} in the order of ^{238}U, ^{232}Th and ^{40}K nuclei. Considering the activity of the radionuclides, one can see that the highest concentration was observed for ^{40}K in the bulb of the onion. The activity concentrations for ^{238}U in the onion bulb is higher for bulb planted in S1 (61.5 ± 7.8 Bq/kg) while the lowest is from the bulb in S3 (3.0 ± 1.7 Bq/kg). For ^{232}Th, the comparison of the bulbs planted in six soil samples again reflects the correlation activity concentration, which S1 (73.4 ±8.6 Bq/kg), S2 (52.7 ± 7.3 Bq/kg) and S6 (101.3 ± 10.1 Bq/kg) dominate the highest values. We investigated the linearity of the dose rate as well as activity concentration of the soils.

The transfer factor for ^{238}U, ^{232}Th and ^{40}K of onion leaves and bulbs is shown in Table 4. and in Fig. 3 and Fig. 4. It is observed that the transfer factor of onion bulbs is generally higher than that in leaves. The transfer factor of ^{238}U is 0.028 – 0.334 and (6.01 – 79.2) × 10^{-3} for the bulbs and leaves, respectively. Among the onion parts, the highest transfer factor for ^{238}U found in sample S5 for both leave was (7.92 ± 0.03) × 10^{-2} and for the bulb, it was (0.334 ± 0.011). While in contrast, sample S3 leaves and bulb exhibit the lowest transfer factor; (1.10 ± 0.01) × 10^{-3} and 0.028 ± 0.002 respectively.

The TF for the plant leaves ranges from (1.21 – 61.4) × 10^{-3}, with S2 having the relatively lowest value (1.21 ± 0.01) × 10^{-3} while S5 (6.14 ± 0.02) × 10^{-2} exhibits the highest transfer factor value in leaves for ^{232}Th. We found that the TFs of onion leaves in the order of ^{40}Kr > ^{238}U > ^{232}Th. The TF of ^{40}Kr in the leaves of onion was found as (1.012 – 4.265) x10^{-1} that is at least three to four times greater than other radionuclides. This is also observed in the plant bulb transfer factor where the highest value is obtained from S6 (0.3685 ± 0.0043) and the lowest presented by bulb planted in S1 (0.0908 ± 0.0021). The TF show that uptake for potassium is higher than uranium (^{238}U) and thorium (^{232}Th). Leaves absorb a smaller amount of ^{238}U, while bulb absorbs smaller amounts of ^{232}Th and ^{40}K for onion. This research on the measurement of natural radioactivity in soil and onion and transfer factors reveals useful information for public concern in Malaysia.

4. CONCLUSION

We have investigated the dose rate of gamma in six different selected locations of soil samples in Malaysia using a portable survey meter. The dose range was 87 - 1218 nGyh^{-1}. The activity of ^{232}Th, ^{238}U and ^{40}K of 6 natural background soil and different parts (leave and bulbs) of onions was investigated by neutron activation analysis (NAA). The highest activity was detected to 3778.1 ± 61.5 Bq/kg in ^{232}Th, 10682 ± 32.7 Bq kg-1 in ^{238}U and 679.4 ± 49.6 Bq kg-1 in ^{40}K of sample S6, S2 and S3 respectively. The activity of leaves of onion was in the ranges of (1.2 ± 0.4 -12.1 ± 3.4), (2.2 ± 1.5 – 9.8 ± 3.1) and (695.2 ± 50.3 – 1024.7 ± 74.1) Bq/kg in the order of ^{238}U, ^{232}Th and ^{40}K nuclei. The corresponding concentrations of bulb were in the ranges of (3.0 ± 1.7 – 61.5 ± 7.8), (2.0 ± 1.4 – 101.3 ± 10.1) and (480.7 ± 34.9 – 705.5 ± 50.1) Bq/kg. We also observed that the linearity of activity concentration as well as dose rate of the soils. The transfer factors for onion leave are 0.006-0.079, 0.0012-0.0614 and 0.0101-0.4265 for ^{238}U, ^{232}Th, and ^{40}K respectively. The TFs values for onion bulbs are 0.028-0.334, 0.017-0.293 and 0.1908 -0.03685 of ^{238}U, ^{232}Th, and ^{40}K respectively. The transfer factor of onion bulbs is generally higher than in leaves. The TFs of activity for leave of onion decrease with the increase of concentration of activities of three radionuclides in the soil. There is no co-correlation in the transfer of elements from soil to the above-ground parts (leave) of the plants. Nevertheless, below the ground parts (bulb), there seems to correlate with the transfer of elements from soils to the onion. It can explain by the increase of transfer factor value with the increase of activity in the soil. The transfer factor of onion bulbs is generally higher than in leaves. Leaves absorb a smaller amount of ^{238}U, while bulbs absorb smaller amounts of ^{232}Th and ^{40}K for onion. This measurement of natural radionuclides in onion is useful for public concern in Malaysia.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Al-Masri MS, Al-Akel B, Nashawani A, Amin Y, Khalifa KH, Al-Ain F. J. Env. Rad. 2008;99:322-331.
2. Rodriguez PB, Tomè FV, Lozomo JC, Pèrez Fernāndez MA. App. Rad. and Iso. 2010;68:1154-1159.
3. Chen SB, Zhu YG, Hu QH. J. Env. Rad. 2005;82:223-236.
4. Adriano DC, Doswell AC, Ciravolo TG, Pinder JE, McLeod KW, Environ J. Radioactiv, 2000;49:307-317.
5. Changizi V, Jafarpoor Z, Naseri M. Iran. J. Radiat. Res. 2010;8;103-110.
6. Hasan MK, Ismail M, Khan K, Akhter P. Water Air Soil Pollut. 2011;219:129-142.
7. Kam E, Karahan G, Aslryukesk H, Bozkurt A. Int. J. Nutr. and Food Eng. 2016;10(6):389-394.
8. Aswood M, Jaafar MS, Bauk S. Appl. Phys. Res. 2013;5.
9. Ramli AT, Nursama HA, Husin W, Kholik W, Lee SK. Global J. Health Sci. 2009;1:140 -149.
10. Saeed MA, Yusof SS, Hossain I, Ahmed R, Abdullah HY, Shahid M, Ramli AT. Rom. J. Phys. 2012;57:1417-1424.
11. Saeed MA, Zainal NJ, Hossain I, Javed MA. J. Appl. Spect. 2014;81(N3):488(1-5).
12. Yussuf NM, Saeed MA, Wagiran H, Hossain I. Proc. Natl. Sci. India. Sect. A. Phys. Sci. 2020;90(3):383–387.
13. Available:https://www.healthline.com/nutrition/onion-benefits
14. International Atomic Energy Agency. Handbook of parameter values for the prediction of radionuclide transfer in temperate environments. IAEA. Vienna; 1994.
15. Uchida S, Tagami K, and Harai I, J. Nucl. Sci. & Tech. 2007;44:5.
16. Saeed MA, Yusuf SS, Hossain I. Romanian J. Phys. 2012;57(9):1417-1424.

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