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Uptake and distribution of natural radioactivity in rice from soil in north and west part of peninsular malaysia for the estimation of ingestion dose to man

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ABSTRACT

Paddy is the third most widely planted crop in Malaysia and most of the Malaysian people consume rice as their staple food. Hence, studies on the uptake of naturally occurring radionuclides by rice from soil of widely rice cultivated areas in Malaysia have been performed under normal field environments in order to evaluate various radiation hazards via rice consumption. The soil-to-rice grain transfer factors and the annual effective dose have been assessed for the natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K. The estimated transfer factors for ^{226}Ra and ^{232}Th were found far beyond compared to the IAEA reported value for rice. Among the detected radionuclides, ^{40}K shows the highest transfer factor in all study locations but close to the IAEA reported range. The total effective dose obtained due to an ingestion of radionuclides via rice consumption was within the range of world average value (290 μSv y^{-1}) compiled by the UNSCEAR (2000) in all study areas. On an average, the excess life time cancer risk (ELCR) values via rice consumption were found below the acceptable limit of 10^{-3} for radiological risk.

1. Introduction

Humans and their foodstuffs are exposed to various types of radiation that are originated from primordial, cosmogenic, terrestrial, natural decay series radionuclides (Dinh Chau et al., 2011). Every day, we ingest and inhale radionuclides via the consumption of food, water and air respectively. All types of food including rice contain detectable amount of radioactivity which successively relocate into the human body via the ingestion pathway. Potassium (^{40}K), thorium (^{232}Th), uranium (^{238}U) and their numerous progeny are the common radionuclides available in food and water (Yu and Mao, 1999; Natural Radioactivity – Idaho State University, http://www.physics.isu.edu/radinf/natural.htm). According to the UNSCEAR (1988, 2008) and Dinh Chau et al. (2011), an amount of 83% annual effective dose is experienced by individuals due to the natural decay series radionuclides whereas 16% is contributed by the primordial ^{40}K, and the remaining 1% is due to the anthropogenic radionuclides.

The well-known 16 elements (carbon, hydrogen, oxygen, nitrogen, phosphorus, sulfur, potassium, calcium, magnesium, iron, manganese, zinc, copper, molybdenum, boron and chlorine) are considered to be necessary for the growth and reproduction of plant (Karunakara et al., 2013). Besides these, a number of other natural radioactive elements such as U, Th and their progeny, ^{40}K, ^{7}Be, and artificial radioactive elements like ^{137}Cs, ^{90}Sr are present in plants in different concentrations (Karunakara et al., 2013). Some element may or may not be required for human metabolism. As an example, the element like radium and uranium are known to be present in plants although they are not identifying for the purpose of metabolic function. Radioactive elements ordinarily present in soil and normally not utilized in plant metabolism are absorbed in a manner independent of their radioactive properties.

Soil effluence by natural and fallout radionuclides has a nonstop radiological effect since it is freely transferred to human body via food chain like edible crops and drinking waters. Plant uptake is the main lane for the relocation of radionuclides from soil-to-human foodstuff. If these radionuclides conveyed to the edible portions of the plant, may cause a source of cumulative exposure to man (Shanthi et al., 2012). However, the uptake and distribution of radionuclides in plants depend on several factors such as soil pH, kind and amount of clays, exchangeable Ca and K and organic matter contents, physicochemical properties of the radionuclide, type of crop (crop species and variety, and cultural practices), fertilizer application, irrigation, plowing, liming and climate conditions etc. (Shanthi et al., 2012; Pulhani et al., 2005; Coughtrey and Thorne, 1983). Diet is the leading cause of human exposure to

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radioactive elements that guides to internal radiation doses (Saeed et al., 2012; Chen et al., 2005; Gaso et al., 2000).

Soil-to-plant and plant-to-human body is one of the foremost corridors for transmission of radionuclides to human organism (IAEA, 1982). After uptake by root, radionuclides are transferred to plant along with other nutrients or mineral necessary for their growth and reproduction of the plant (Joshy et al., 2011). These radionuclides translocate toward different parts of plant through the vascular system comprising the xylem and phloem; accumulate in several parts including the edible portions and would lead to endless radiation dose to man once consumed (Pulhani et al., 2005; Carini, 2001). Therefore, it is an important study to the spatial erraticism of natural radioactivity in soil and related radiation exposures through specific land produced food-stuffs.

The soil-to-plant transfer factor is one of the key parameters extensively used for the estimation of internal radiation dose from radionuclides through food consumption (Tsukada et al., 2002). Among the various kinds of food, rice is regularly consumed worldwide as well as countrywide like Malaysia. Consequently, human radiation exposure owing to the ingestion of radionuclide via rice consumption is a global concern (Alrefae and Nageswaran, 2013; Alrefae, 2012; IAEA, 1989; Yu and Mao, 1999). Rice (*Oryza Sativa L.*) is the major food crop and being the principal staple food for Malaysian in their basic daily diet, therefore the consumption of rice is treated as the most important pathways for the transfer of radionuclides into humans. It is consumed in the form of both boiled and white rice. Rice is also the dominant staple food crop in humid tropical and sub-tropical countries all over the world (Uchida et al., 2009). More than half of the world's population consumes rice as their main food. Paddy is the third most widely planted crop in Malaysia after oil palm and rubber. According to the department of agriculture (DOA, Malaysia), the estimated area of paddy planting in 2011 was about 687,940 hectares with potential yield of 2,578,519 metric tons in which rice production was 1,661,260 metric tons (DOA, 2012). The domestic consumption of rice per capita per year in Malaysia is at 95.9 kg in 2011/12 (GAIN Report MY3002, Malaysia, 2013).

Since the uptake of radionuclides from soil-to-plant and plant parts fluctuates with respect to the geological and geographical locations, it is suggested to use site-specific data (Joshy et al., 2011; IAEA, 1994) for an estimation of radiation hazards. As mentioned above, the transfer factor (TF) could differ by areas due to different climates, soil types and vegetations, therefore local TFs should be observed. Hence field studies under natural conditions in most of the rice grown areas of peninsular Malaysia were undertaken. Present study focuses on an estimation of radionuclide uptake through the measurement of activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in different rice samples and the associated soils collected from various places of peninsular Malaysia, and then determination of radiological impact causing from the consumption of rice grains. Recently, the IAEA-TECDOC-1616, (2009), IAEA, (2010) made an extensive review on the radionuclides concentration ratios (transfer factor) for various foods including rice. Uchida et al. (2009) have published a review paper on the radionuclide transfer factors for rice and mentioned that there are inadequate studies in this aspect. However, a general survey of literature reveals that Tsukada et al. (2002), Sasaki et al. (2002) and Uchida et al. (2007) from Japan; Choi et al. (2005, 2011a, 2011b, 1999) and Keum et al. (2007) from South Korea; Wang et al. (1998) from China; Quang et al. (2003) from Vietnam; and Saeed et al. (2012) from Malaysia conducted similar studies to obtain a radiological mapping on rice grown in south east Asian region. Since studies on the uptake of radionuclides via intake of it are still limited in the area under investigation, the present study would therefore make a valuable contribution to the establishment of a standard database of the natural radioactivity of rice in peninsular Malaysia. It can also serve as a reference for an assessment of radiological impact via rice consumption by the inhabitants of Malaysia and bordering regions.

2. Materials and Methods

2.1. Study area

Two areas in north Malaysia Kampung Sakan, Kedah and Kampung Permatang Tok Labu, Pulau Pinang) and one area in west Malaysia (Sungai Besar, Selangor) (Fig. 1) were chosen for this study because most of the rice in Peninsular Malaysia grown in these areas. Kedah (Latitude: 6° 23' N, Longitude: 100° 45' E) is tropical monsoon, with a uniform temperature between 21 °C to 32 °C throughout the year. It is generally dry and warm from January to April, and wet from May to December. Humidity is consistently high in the lowlands, averaging 82–86% per annum. Kedah's average annual rainfall lies between 2,032 mm to 2540 mm. Pulau Pinang (Latitude 5.5523' N, Longitude. 100.38' E) is not a tropical island like other parts of Malaysia with temperature between 23 °C to 32 °C and relative humidity 0–50% throughout the year. Pinang has little rain except during the Southwest Monsoon from April to September. An average annual rainfall of this region is 2670 mm. The climate is very much dictated by the surrounding sea and the wind system. Selangor (Latitude: 3°20′N, Longitude: 101°30′E) is tropical monsoon. Temperatures generally range from 27 °C to 35 °C during the day time throughout the year with relative humidity 76%–86%. Annual rainfall measures at 3,218 mm. Being located so close to the equator, the study areas do not have distinct seasons such as spring, summer, autumn or winter. The seasonal variation in solar radiation is low, resulting in an annual difference in day length of only 2 min along the equator and 49 min in northern regions. In consequence, there is a year round day length of 12.5 h (Nieuwolt, 1982). The region is distributed by steep hills with tropical forest of natural habitat and grows a variety of plants that play a vital role in the environmental transport of radionuclides. About 72 percent of Malaysian soils are Ultisols and Oxisols, which are acidic and highly weathered (IBSRAM, 1985). Phosphate fertilizers are suggested to use due to soil fixation. This problem is dealt with through the biennial addition of about 2 to 4 t/ha of limestone (Shamsuddin et al., 1992). The soil of the study areas mainly clayey-silty textured (45–60% clay, 25–35% silt and 15–20% sand) (Table 1).

2.2. Cultivation practices of rice by the farmers

Cultivation patterns play a vital role on the uptake of radionuclides from soil-to-plant (Uchida et al., 2009). Different varieties of rice are grown in the study regions and basic growing practices of them are more or less same in everywhere. There are two types of land used for rice cultivation in Malaysia namely, wet-land and dry-land. There have been several variations in the methods of rice plantation. It ranged from seed dibbling, mostly in upland conditions, to the conventional transplanting in the low land/wet rice cultivation (WRC) or double nursery plantation, wherein seeds were transferred from one nursery to another before being planted out in the main field. Direct seeding has been seasonally practiced over the years both in the main season (MS) and the off season (OS). The farmer does not practice the crop rotation and rice grown in the same field for years.

Farmers follow the traditional/mechanized practices of plowing the land, conditioning, planting, application of various inputs and harvesting. In Peninsular Malaysia, the uses of machines leading to the rice production are as follows: in land preparation (100%), in seed sowing (71.3%), in manuring (70.6%), in chemical