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DETERMINATION OF URANIUM CONCENTRATIONS IN RICE SAMPLES AVAILABLE IN THE IRAQI MARKET USING THE CR-39 DETECTOR

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Abstract: In this study, uranium concentrations and specific activity in 10 rice samples were measured using a solid-state track detector (CR-39). Samples were collected from various local Iraqi markets with different origins (Iraq, India, USA, and Thailand). Our findings showed that the uranium concentrations in all studied samples ranged from 0.55 ± 0.28 to 1.74 ± 0.31 ppm, with a weighted average of 1.24 ± 0.99 ppm. In addition, the results demonstrated that the specific activity values of the studied samples were in the range 6.88 ± 3.52 and 21.49 ± 3.85 Bq/kg. The obtained results of the studied rice samples indicated that they are less than the acceptable limit established by many organizations such as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), International Atomic Energy Agency (IAEA), and World Health Organization.

Keywords: *Uranium, specific activity, track density, rice, CR-39*

1. Introduction

Understanding the distribution of radionuclides and their radiation percentages in the environment is crucial in evaluating the impact of radiation levels caused by natural and synthetic sources. Naturally occurring radiation comes from radioactive nuclides that exist in diverse contents in sediments, waters, and rocks. Almost all rocks contain naturally occurring radionuclides such as ^{238}U, ^{232}Th, and ^{40}K. Some of the radionuclides from these sources are ingested with food and water or are inhaled by humans. However, the health effects on humans mainly depend on the level of these radionuclides present in rocks and sediments (Al-Bayati, 2013; El-Arabi, Abbady, & Hussein, 2006).

Quantitative analysis of radioactive pollution in the atmosphere and in food products is crucial in controlling and minimizing its harmful effects on human health. In addition to natural radionuclides, reactor-made radionuclides are introduced to the atmosphere by nuclear weapon testing and numerous nuclear reactor accidents. Worldwide, consuming irradiated products from any area contaminated by nuclear radiation can affect people's health (Melquiades & Appoloni, 2002).

The effects of internal radiation exposure can be controlled by assessing several factors. The first factor relates to the slow development and the emergence of the radiation effect. The second factor is the relation between the absorbed radiation doses into the tissue and the required time for the radioactive material to decay, leading to the accumulation of radiation. The third factor highlights the levels of chemical toxicity of the radioactive nuclides combined with the harmful effects of radiation on organisms. Furthermore, congenital anomalies or genetic mutations occur as a consequence of exposure to high doses of radiation (Burgio, Piscitelli, & Migliore, 2018; Mettler, 2012).

Radioactivity in living organisms is ascribed to the amount of radioisotopes absorbed by the organs and/or tissues of the organisms, such as uranium, radium, and radon. It is well known that during severe exposure, radioisotopes could greatly damage the exposed organ or a living tissue. Inhaled radon gas is one of the key sources that cause lung cancer (La Verde et al., 2020; Vogiannis & Nikolopoulos, 2015).

Several studies have been conducted to study uranium concentrations and specific activities in food items, most notably rice. For example, a study by Najam et al. measured the radioactivity in different types of rice consumed in Nineveh Governorate (Iraq) using the NaI (Tl) detector. The results of this study showed that the specific activity of uranium-238 and its decay series ranged from 51.15 to 109.26 Bq/kg, with an average of 84.12 Bq/kg (Najam, Tawfiq, & Kitha, 2015). Also, Hameed et al. determined the specific activity and uranium concentrations of different types of rice and table salt consumed in Baghdad (Iraq) using the NaI (Tl) detector. They found that the specific activity of

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uranium-238 in rice samples ranged from 5.548 to 27.142 Bq/kg and that in salt samples ranged from Below Detection Limit (BDL) to 7.657 Bq/kg. The average in all samples was 5.548 Bq/kg (Hameed, Rejah, & Muter, 2016). In addition, Asmaa Ahmed Aziz studied and estimated the radioactivity in cereals (including rice) and legumes available in the Iraqi markets using the CN-85 nuclear trace detector. In the study, the concentrations of uranium-238 and radon-222 were calculated, and the results suggested that the maximum levels of uranium and radon were, respectively, 2.63 ppm and 137.17×10^2 Bq/m^3 (Aziz, 2018).

Soil contamination with radioactive nuclides could lead to an increase in radioactive concentrations in agricultural crops, including rice. Therefore, the present work aims to evaluate the level of uranium-238 in different types of rice available in the Iraqi market using the nuclear track detector CR-39.

2. Materials and Methods

2.1 Sample Preparation

In the current work, 10 types of widely used rice samples that are available in the Iraqi market from different origins (Iraq, India, USA, and Thailand) were analyzed. After sampling, the samples were dried, and then, they were grounded using an electric grinder, which is made of porcelain, and subsequently sifted using a standard sieve to attain a fine powder form with an equal size. A sensitive scale was used to weigh the rice samples and the sodium hydroxide crystals used in preparing the etching solution. Measured and standard samples weighing 0.5 g were pressed to form round tablets with a diameter of 2 cm and a thickness of 1 mm.

Five different standard concentrations of uranium were prepared with rice namely, 2,8,12,16,20 ppm using acetate powder chemical formula of $UO_2(CH_3COO)_2.2H_2O$ and its molecular weight of 424, which contains 56.13% uranium-238, where the required concentrations were prepared using the following equation (Al-Bayati, 2017):

$$C_1 \times W_1 = C_2 \times W_2, \ldots\ldots\ldots\ldots\ldots(1)$$

where C_1 and C_2 denote the concentrations of uranium of standard and studied rice samples, respectively, and W_1 and W_2 denote the weights of standard and studied rice samples, respectively.

2.2 Measurement Method

One of the most important techniques that can be employed to detect the levels of radioactive radium and uranium in rice samples is the use of solid-state nuclear track detectors (e.g., a CR-39 detector).

Solid-state nuclear track detectors (SSNTDs) are classified as insulating solid materials, which contain narrow trajectories to be occurring radiation damage when heavy ionizing particles pass through such as the proton, α-particle, heavy-ion, and fission fragments. The damaged region is called the radiation damage track or latent track (IAEA, U.S.A, 1987). On the basis of several parameters such as sensitivity, resolution, and variability of response, the most interesting SSNTD materials, and are optically clear amorphous, thermoset plastics (polymers) because of their good homogeneity and isotropy, excellent optical transparency, and uniformity. A plastic material that has all of the aforementioned properties was manufactured by Cartwright and his group. This new device was called CR-39 (Columbia Resin) (Pentreath, 1980; Sabbarese, Ambrosino, & Roca, 2020).

2.3 Irradiation and Chemical Etching

The irradiation of both the standard and studied samples was carried out simultaneously. The CR-39 detector was cut with an approximate area of 1×2 cm^2, and the detectors were placed on the samples of unknown concentration and the standard samples in a contiguous manner with the detector. Figure 1 shows the method of placing samples inside the irradiation system. An isotopic neutron source americium–beryllium (^{241}Am–Be) was used for irradiation with an activity of 5.92×10^{11} Bq and neutron flux of 5×10^3 n·cm^{-2}·s^{-1}.

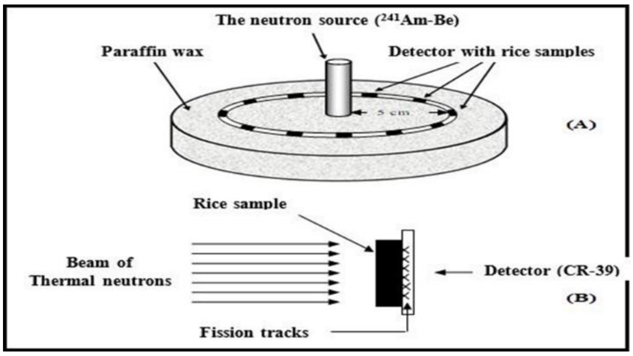

Figure 1. (A) The method of placing the studied and standard samples in paraffin wax in front of the neutron source. (B) The method of placing rice samples with the detector and recording the effects of fission tracks on the detector (Al-Bayati, 2019).

Chemical etching was performed after irradiation using a sodium hydroxide (NaOH) solution (6.25 N), which was prepared by dissolving 62.5 g of NaOH (with a molecular weight of 40 g/mole) in 250 mL of distilled water. After that, the abrasive solution was heated using a water bath at a temperature of 60°C for 5 h to show the effects in the standard and other samples. Then, the samples were washed and dried to move to the measurement process.

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Figure 2 displays the method of placing the detectors inside the chemical etching solution.

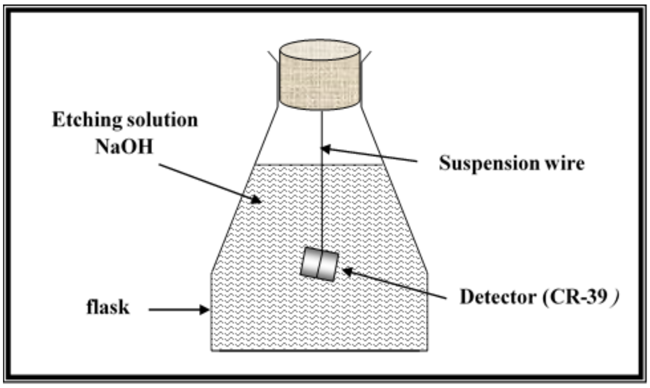

Figure 2. Chemical etching of the CR-39 track detector.

3. Results and Discussion

After the chemical etching phase ended, the stage of microscopic viewing began to detect tracks. This was conducted by selecting the suitable magnification and then by counting the tracks per unit area using a special lens divided into several squares. Ten readings were taken for each sample, and the area of the square was calculated and then divided by the average number of tracks (Nave) per unit area (A) to get the density of tracks (ρ_x) according to the following equation (Shahid, 2007):

$$\rho_x = \frac{N_{ave}}{A} \ldots\ldots\ldots\ldots\ldots\ (2)$$

Figure 3 shows the tracks of fission fragments recorded on the nuclear track detector of one of the samples.

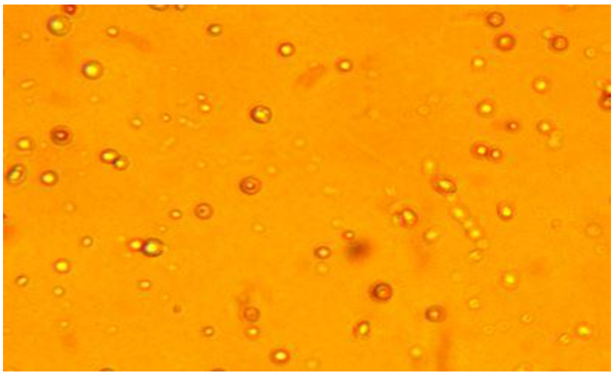

Figure 3. Tracks recorded on the CR-39 detector.

The calibration was carried out by irradiating standard samples containing known concentrations of uranium (C_s) with the samples to be studied using the neutron source (^{241}Am–Be). After irradiation, chemical etching of the detectors was carried out under the same conditions, and the track density (ρ_s) was calculated using a light microscope. The graphical relationship between uranium concentrations (C_s) and track density (ρ_s) was drawn for standard samples, and the relationship was linear, as shown in Figure 4.

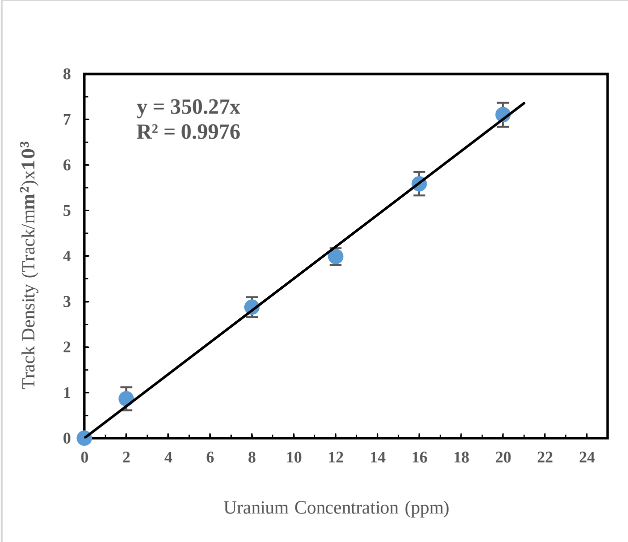

Figure 4. Calibration curves for standard samples.

The concentrations of uranium (C_x) in rice samples were calculated using the following equation (Al-Bayati, 2019);

$$\frac{\rho_x}{\rho_s} = \frac{C_x}{C_s} \rightarrow C_x = C_s \frac{\rho_x}{\rho_s} \rightarrow C_x = \frac{\rho_x}{slope}, \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where C_s is the concentration of uranium in the standard sample, ρ_s denotes the density of tracks in the standard sample, C_x corresponds to the concentration of uranium in the unknown sample, and ρ_x is the density of tracks in the unknown sample.

The specific activity of the rice samples was also computed using the following equation (Al-Bayati, 2017):

$$1 \text{ ppm} = 12.35 \text{ Bq/kg} \ldots\ldots\ldots\ldots\ldots (4)$$

Table (1) shows the track density, uranium concentrations, and specific activity in rice samples measured using the CR-39 detector. The results indicated that the highest concentration of uranium was 1.74 ± 0.31 ppm and the highest specific activity was 21.49 ± 3.85 Bq/kg in AL-Eman gold rice and the lowest concentration of uranium was 0.55 ± 0.28 ppm and lowest specific activity was 6.88 ± 3.52 Bq/kg in Abu Araba gold rice. The weighted average for the concentration of uranium and that for specific activity were 1.24 ± 0.99 ppm and 15.31 ± 12.22 Bq/kg respectively.

The levels of uranium concentration and specific activity of the studied rice samples are shown in Figures 5 and 6. In summary, our results are approximately located in the same range of specific activity, which has been reported in the literature (Hameed et al., 2016).

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Table 1. Track density, Concentration of uranium, and Specific activity of rice samples.

No.	Rice Type	Origin	Track Density (Track/mm^2)	Uranium Concentration (ppm)	Specific Activity (Bq/kg)
1	Eagle Star (Fakher)	Thailand	488.16 ± 159.97	1.39 ± 0.45	17.21 ± 5.64
2	Jasmine	Thailand	224.85 ± 76.40	0.64 ± 0.21	7.93 ± 2.69
3	Amber	Iraq	463.01 ± 57.41	1.32 ± 0.16	16.33 ± 2.02
4	ADM	USA	602.07 ± 101.48	1.72 ± 0.28	21.23 ± 3.57
5	Cihan	India	507.39 ± 78.83	1.45 ± 0.22	17.89 ± 2.77
6	King Crown	India	451.18 ± 92.51	1.29 ± 0.26	15.91 ± 3.26
7	Abu Araba gold	India	195.26 ± 99.85	0.55 ± 0.28	6.88 ± 3.52
8	AL-Eman gold	India	609.46 ± 109.38	1.74 ± 0.31	21.49 ± 3.85
9	Mahmoud	India	451.18 ± 111.79	1.29 ± 0.31	15.91 ± 3.94
10	Joker	India	544.38 ± 174.20	1.55 ± 0.49	19.19 ± 6.14
	Weighted average			1.24 ± 0.99	15.31 ± 12.22

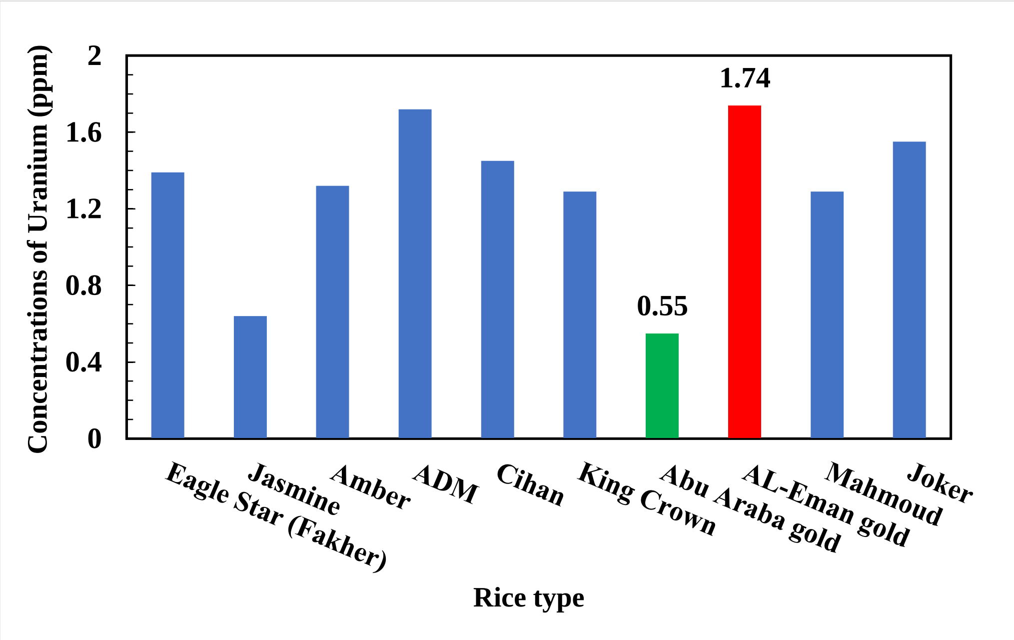

Figure 5. Concentrations of uranium in rice samples.

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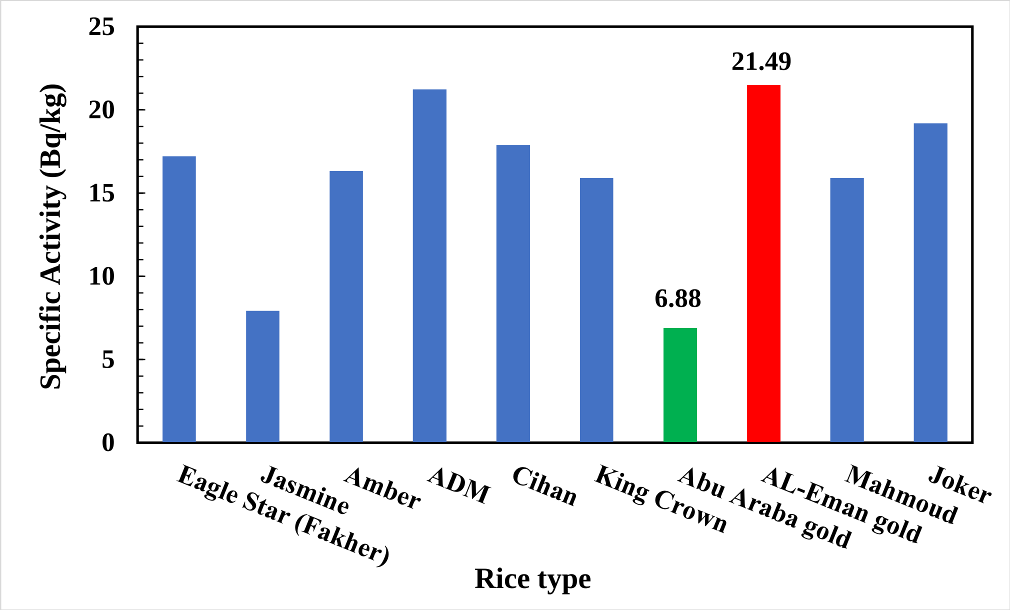

Figure 6. Specific activity in rice samples.

4. Conclusion

The current findings showed that the concentration of uranium-238 ranged from 0.55 ± 0.28 to 1.74 ± 0.31 ppm, with a weighted average of 1.24 ± 0.99 ppm. The highest concentration of uranium of 1.74 ± 0.31 ppm was reported for sample No. 8 (AL-Eman gold rice), and the second highest of 1.72 ± 0.28 ppm was recorded for sample No. 4 (ADM rice). The lowest concentration of uranium of 0.55 ± 0.28 ppm was observed in sample No. 7 (Abu Araba gold rice), and the second lowest of 0.64 ± 0.21 ppm was detected in sample No. 2 (Jasmine rice). On the basis of these concentrations, the specific activity was determined, and its value ranged from 6.88 ± 3.52 to 21.49 ± 3.85 Bq/kg, with an average of 15.31 ± 12.22 Bq/kg. The reason for the difference in values is the different agricultural soils and their geological nature. Moreover, the outcomes display that the concentrations of uranium-238 in the studied rice samples are less than the acceptable limit approved by the UNSCEAR, which amounts to 32 Bq/kg (S. A. Onjefu, 2019; UNSCEAR, 2000). Therefore, on the basis of our analysis, we found that rice consumption by humans would not bring any radioactive hazard.

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