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Radiation Risks of Daily Coffee Consumption: Analysis of Radioactive Nuclide Concentrations in Imported Coffee Beans (Case Study: Libya)

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ABSTRACT

This study examines the radiation risks linked to daily coffee consumption by analyzing the presence of natural and artificial radioactive contaminants in imported coffee beans in Libya. With coffee being a widely consumed beverage, this study addresses the often-overlooked issue of radioactive contamination in food products. Samples of roasted Arabica and Robusta coffee beans from India, Brazil, Colombia, and Ethiopia were collected and analyzed using a high-purity germanium (HPGe) detector. The results revealed no detectable levels of the artificial radionuclide; however, measurable concentrations of K^{40}, Ra^{226}, and Ra^{228} were identified. Notably, K^{40} concentration levels exceeded the UNSCEAR recommended limit in several samples, Ra^{226} and Ra^{228} concentrations remained within safe limits. The estimated annual effective dose from coffee consumption for adults ranged from 17.68 to 92.57 µSv.y^{-1}. The lowest effective dose that the consumer can receive comes from Colombian coffee, while the highest dose comes from Brazilian coffee. In general, all effective doses are below the global mean for internal radiation exposure. These findings suggest that while the radioactive content in the analyzed coffee poses minimal health risks, ongoing monitoring and regulation are crucial to ensure consumer safety.

المخاطر الإشعاعية للاستهلاك اليومي للقهوة: تحليل تراكيز النويدات المشعة في حبوب البن المستوردة (دراسة حالة: ليبيا)

خديجة العجيلي على ، يوسف محمود بيري ، سامية عبد الله الزوبيك ،
هناء رزق حفالش ، نادية محمد نجيب طريش

هدفت هذه الدراسة إلى تقييم المخاطر الإشعاعية المحتملة الناتجة عن الاستهلاك اليومي للقهوة، وذلك من خلال تحليل مستويات الملوثات الإشعاعية الطبيعية والاصطناعية في حبوب البن المستوردة إلى ليبيا. ونظراً لكون القهوة من أكثر المشروبات استهلاكاً على مستوى العالم، فإن هذه الورقة تسلط الضوء على قضية غالباً ما تُهمل في دراسات السلامة الغذائية، وهي التلوث الإشعاعي في المنتجات الغذائية. تم جمع عينات من حبوب البن المحمصة من نوعي "أرابيكا" و"روبوستا" والمستوردة من أربع دول رئيسية في إنتاج القهوة: الهند، البرازيل، كولومبيا، وأثيوبيا. وقد تم تحليل هذه العينات باستخدام منظومة مطيافية جاما عالية الدقة والمزودة بكاشف الجرمانيوم عالي النقاوة(HPGe) . أظهرت نتائج التحليل عدم وجود نشاط إشعاعي ناتج عن نويدات مشعة صناعية

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في المقابل، تم الكشف عن وجود تراكيز قابلة للقياس من النويدات المشعة الطبيعية: البوتاسيوم-40(K-40) ، والراديوم-226(Ra-226) ، والراديوم-228 (Ra228) . وقد تجاوز تركيز K-40 الحد المرجعي الذي أوصت به اللجنة العلمية التابعة للأمم المتحدة المعنية بآثار الإشعاع الذري(UNSCEAR) ، بينما ظلت تراكيز Ra-226 و Ra-228ضمن المستويات الآمنة. تراوحت الجرعة الفعالة السنوية المقدّرة الناتجة عن استهلاك القهوة لدى البالغين بين 17.68 ملي سيفرت/سنة و92.57 ملي سيفرت/سنة. وقد سجلت القهوة الكولومبية أقل قيمة للجرعة الفعالة، في حين كانت القهوة البرازيلية الأعلى من حيث الجرعة المقدّرة. ومع ذلك، تبيّن أن جميع القيم المسجلة للجرعة الفعالة السنوية كانت دون المتوسط العالمي للتعرض الإشعاعي الداخلي. تشير النتائج إلى أن مستويات النشاط الإشعاعي في حبوب القهوة التي تم تحليلها لا تمثل تهديداً صحياً كبيراً للمستهلكين في الوقت الراهن. ومع ذلك، فإن المراقبة المنتظمة والتنظيم الفعال يظلان ضروريين لضمان استمرار سلامة المنتجات الغذائية، والحفاظ على صحة وسلامة المستهلك على المدى الطويل.

INTRODUCTION

Radioactive elements contaminate drinks and food, and their ingestion through food intake accounts for a significant portion of the average radiation doses to various organs of the body. However, the possibility of contamination by radioactive elements has rarely been considered when determining the suitability of drink and food for human consumption. Drink and food consumption is an essential source of internal radiation dose. This point makes them crucial subjects for research on radiation protection among consumers. Moreover, research on internal radiation exposure due to contaminated food has been extensive, reflecting concerns over nuclear accidents, environmental contamination, and the effects of radioactive elements. UNSCEAR (2010) reported that radioactive elements like I^{131}, C^{137}, and Sr^{90} were detected in various types of food worldwide. These elements led to significant health risks, particularly an increase in thyroid cancer rates among those exposed. A study by Kanda (2013) assessed the contamination levels in various food items and found that while immediate contamination levels were high, effective food monitoring and safety measures reduced long-term exposure risks. Historical nuclear tests have also been a focus of study. The fallout from atmospheric nuclear tests during the Cold War introduced radioactive isotopes into the environment. It was examined the long-term impact of these isotopes on agricultural products and found persistent low-level contamination in soil and crops, which could contribute to internal radiation exposure over time (Geras et al., 2013). Research has also explored the impact of naturally occurring radioactive materials on food safety. In Libya, most foodstuffs for daily consumption are imported from several countries around the world with different radiation backgrounds. These materials may contain different concentrations of radioactive elements, both natural and artificial as well. Knowledge of radioactivity levels in the human diet is a particular concern for the estimation of possible radiological risks to human health. On the other hand, there are very few studies of radioactivity in foodstuffs that have been conducted in Libya, such as Elmasri & Algretli. (2023), Al-abrdi et al. (2023), and Ali et al. (2022); however, there are a few studies that focus on coffee, despite coffee being one of the most popular and widely consumed beverages locally and globally. Some naturally occurring radioisotopes and other elements present in soil and water are drawn into the roots of plants through ion channels or specific transporters (Jibiri *et al.*, 2016). In fact, the distribution of the radioactive elements and other elements throughout the plant tissues depends on their chemical characteristics and several parameters of the soil and the plants themselves (Awudu *et al.*, 2012). In addition, in the process of metal absorption from soil, the plant root system cannot differentiate between stable elements and radionuclides. The levels of radioactive materials in coffee consumed by the public must be carefully measured to assess any potential radiological risk. This study aims to determine the concentrations of natural and artificial radionuclides in roasted coffee bean samples purchased from various markets in Libya and to calculate the effective radiation doses resulting from coffee consumption. Based on these findings, the potential radiation risks associated with coffee intake can be evaluated.

MATERIALS AND METHODS

Collecting Coffee Samples and Preparation

The widespread consumption of coffee around the world requires many studies to determine the concentration of radioactive elements in it. The most common types of coffee in the world are (family *Rubiaceae*) Arabica coffee and Robusta coffee (Zaidi et al., 2005). Therefore, ten roasted coffee bean samples of both types were purchased from Libyan markets. The samples were imported from India, Brazil, Colombia, and Ethiopia. All samples were oven-dried for two hours at 80°C and sieved to obtain uniform particle size. At that point, the samples were transferred to Marinelli beakers and weighted. The weight of the samples ranged between 0.480 to 0.798 kg with an average of 0.619 kg. They were hermetically sealed with insulating tape to impede contact with air moisture as much as possible. The secular equilibrium is very important since it guarantees that the radioactivity of the radon parent and radon daughter is equivalen (Ramli *et al.*, 2009). Therefore, samples were kept for more than a month before measuring in order to achieve radioactive secular equilibrium. After that, measurements of all samples were carried out in the Environmental Measurements Laboratory in the Calibration Building at the Nuclear Research Center in Tajoura NRCT by using an HPGe detector.

Gamma spectrum analysis

A gamma spectrometry system was used to determine and measure the natural and artificial radioactive concentration in roasted coffee beans by the high-purity germanium (HPGe) detector. The experimental arrangement consisted of an HPGe detector with a relative efficiency of 25% and a resolution of 2.2 KeV at the 1332 KeV gamma line. First of all, the energy and efficiency calibrations of the detector were performed using different calibration sources. After that, background measurements were conducted under the same conditions as the sample measurements and were subtracted to obtain the net count rates for the samples. To evaluate the radioactivity concentration in roasted coffee bean samples, every sample was placed on the HPGe detector and counted for the same counting time (50000 s). Ra^{226} and Ra^{228} are not direct gamma-ray emitters, but it is possible to measure their activity through the gamma rays of their decay products; the gamma-ray line energies of 351.9 Kev from Pb^{214}, 609.3 Kev, 1120.2, Kev and 1764 Kev of Bi^{214} were used to represent the activity concentration of the Ra^{226} series. The activity of Ra^{228} has been calculated by using gamma ray line energies of 911 Kev for Ac^{228}, 583 Kev from Tl^{208}, and 238 Kev for Pb^{212}. Whereas the activity of K^{40} and Cs^{137} has been calculated from their gamma-ray lines of energies of 1460 Kev and 661 Kev, respectively (Sarap et al., 2014).

The activity concentrations

For the analyzed samples, the activity concentrations of a gamma-emitting radionuclide (Ac) in all coffee samples are calculated as follows:

$$Ac(Bq.\,kg^{-1}) = CPS/\,m.\,\varepsilon.\,\gamma \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (1)$$

Where;

CPS is the corrected net counts of the corresponding photo peak, *m* is the mass of the measured sample (kg), ε is the efficiency factor, and γ is the emission probability of gamma rays corresponding to a peak energy.

Committed Effective Dose

Direct measurement of the committed dose is impossible due to exposure to radionuclides and the accumulation of radiation dose. Effective dose computing is a convenient way to represent the radiation doses from different radionuclides. This term defines the risks of radiation-induced harm by utilizing the ICRP metabolic model. Radiation doses ingested (μSv. y^{-1}) are obtained by measuring radionuclide activities in coffee samples (Bq kg^{-1}) and multiplying these by the mean annual consumption of coffee per Libyan person which is 5.23 kg y^{-1} as reported by Helgi Analytics (2023). This is after multiplying the value of the concentration of each radionuclide by the value of its conversion factor. The values of 6.2×10^{-9} for K^{40}, 2.8×10^{-7} for Ra^{226}, and 6.9×10^{-7} for Ra^{228} were taken from ICRP publication 119 (ICRP, 2012). Total committed effective dose resulting from consumption of coffee is simply determined from the summation of the egestion dose due to all radionuclides.

RESULTS AND DISCUSSION

The measurements show that all study samples of coffee had no concentrations of the artificially produced radionuclide Cs^{137}. The provided table 1 summarizes the concentrations of K^{40}, Ra^{226}, and Ra^{228} in (Bq.kg^{-1}) for coffee samples originating from different countries to Libya.

Table 1: The concentrations of K^{40}, Ra^{226}, and Ra^{228} for the measured coffee samples

Sample code	Country of origin	K^{40} (Bq.kg^{-1})	Ra^{226}) Bq.kg^{-1}(	Ra^{228}) Bq.kg^{-1}(
SI1	India	546.02±27.30	10.91±0.54	MDA
SI2	India	918.77±45.93	14.71±0.73	MDA
SB3	Brazil	546.99±27.34	11.75±0.58	15.77±0.78
SB4	Brazil	572.19±28.60	6.28±0.31	8.27±0.41
SB5	Brazil	626.39±31.31	MDA	MDA
SC6	Colombia	674.74±33.73	5.48±0.27	MDA
SC7	Colombia	576.52±28.82	2.25±0.11	MDA
SC8	Colombia	546.11±27.30	MDA	MDA
SE9	Ethiopia	370.11±18.50	11.09±0.55	8.90±0.44
SE10	Ethiopia	778.56±38.92	MDA	MDA
Max		918.77±45.93	14.71±0.73	15.77±0.78
Min		370.11±18.50	MDA	MDA

MDA means below the minimum detectable activity.

Potassium [k^{40}] activity concentrations

All samples report potassium values above the MDA, indicating that potassium is consistently detectable in coffee samples, likely due to its natural abundance in biological materials. The concentration of K^{40} exhibits the highest variability among the measured elements, with concentrations ranging from 370.11 ± 18.50 Bq.kg^{-1} (Ethiopian coffee) to 918.77 ± 45.93 Bq.kg^{-1} (Indian coffee). From the table, it can be seen that Indian coffee has the highest concentration of K^{40}. The reason behind this may be the nature of the Indian soil, which is characterized by a high concentration of K^{40}, or due to the agricultural methods used there, including fertilization and the use of pesticides. In addition, Awudu et al. (2011) noted that the increased concentration of K^{40} might also be a consequence of a greater transfer of potassium element from the substrate to the plants. According to UNSCEAR recommendations, the concentration of K^{40} should not exceed 310 Bq.kg^{-1} in foodstuffs consumed by humans. In general, the K^{40} concentration is considered high in all samples except the Ethiopian coffee in sample code (SE9).

Radium [Ra^{226}] activity concentrations

The Ra^{226} concentrations in the coffee samples vary significantly across the different countries sampled, with values ranging from below detectable levels (MDA) to 14.71±0.73 Bq.kg^{-1}. The results of Table 1 show that the highest Ra^{226} concentration among the measured samples was observed in sample SI2, which was imported from India, with a concentration of 14.71±0.73 Bq.kg^{-1}. As for samples SB5, SC8, and SE10, which were imported from Brazil, Colombia, and Ethiopia, respectively, no Ra^{226} activity concentration appeared. In summary, the Ra^{226} concentrations in all coffee samples did not exceed the value recommended by the UNCEAR, which is less than 67 Bq.kg^{-1}. The variations in Ra^{226} levels could be attributed to several environmental factors, such as soil composition, mining activities, and agricultural practices. Regions with higher natural uranium deposits may reflect higher concentrations in agricultural products. The presence of Ra^{226} in food products, including coffee, raises health concerns, particularly regarding chronic exposure. While the concentrations observed in this study are relatively low, they can accumulate over time, necessitating monitoring and regulatory measures.

Radium [Ra^{228}] activity concentrations

Ra^{228} concentrations are mainly reported as MDA in a number of samples, as seen in Table 1, indicating that detectable quantities of Ra^{228} were not found in the samples under study. Sample SB3, imported from Brazil, has the highest content of Ra^{228} (15.77±0.78 Bq.kg^{-1}). Environmental elements, including the soil composition and geological features of the coffee-growing regions, may have an impact on the differences in Ra^{228} levels. Higher levels of Ra^{228} may be found in agricultural products in areas with higher natural deposits. The Ra^{228} concentrations in the coffee samples analyzed are predominantly below detectable levels, with a few exceptions showing low measurable amounts. The findings suggest that Ra^{228} is not a major concern in the sampled coffee from these countries. Continued monitoring and further research may be warranted to ensure that Ra^{228} and other radionuclides remain within safe consumption levels.

Comparing the results with previous studies provides deeper insight into the concentration of radioactive elements in coffee samples. Therefore, the obtained activity concentrations of K^{40}, Ra^{226}, and Ra^{228} in the investigated coffee samples have been compared with other published results around the world and are shown in Table 2.

Table 2: Comparison of the mean values of K^{40}, Ra^{226}, and Ra^{228} activities in the coffee samples with data from other studies

Country	The mean values of activity concentrations (Bq.kg^{-1})			References
	K^{40}	Ra^{226}	Ra^{228}	
Italy	907.4 ± 115.6	10.61 ± 4.02	13.73 ± 3.20	Roselli et al., 2013
Brazil	261 ± 18	17.9 ± 3.2	47.9 ± 10.6	Khandaker et al., 2020
Colombia	940.37±49.87	0.18±0.05	0.34±0.04	Abodunrin et al., 2024
India	666	12.3	0.685	Sangbok et al., 2021
Brazil	718	40.9	1.51	
Colombia	626	14.7	0.65	
Ethiopia	564	10	0,644	
India	732.4±36.61	12.81±0.64	MDA	Present Study
Brazil	581.8±29.10	9.02±0.45	8.01±0.40	Present Study
Colombia	599.12±29.95	3.87±0.19	MDA	Present Study
Ethiopia	574.34±28.71	5.54±0.27	4.45±0.22	Present Study
UNSCEAR	310	67	82	(UNSCEAR, 2000)

It is noted from Table 2 that the activity concentrations of radionuclides in all coffee samples in the current study, as well as in other studies, were below the recommended limit for Ra^{226} and Ra^{228}, which are 67 Bq.kg^{-1} and 82 Bq.kg^{-1}, respectively, while the concentration of K^{40} exceeded the values stipulated by UNSCEAR (2000). As UNSCEAR shows that most of the dose from such internal exposure is due to K^{40}.

Effective dose analysis

The total annual effective dose due to the measured radionuclides received by Libyan adults via consumption of coffee obtained from Libyan markets were ranged between 17.68 to 92.57 µSv.y⁻¹ (fig 1). When comparing the average values for each country of origin, it is found that the lowest effective dose that the consumer can receive comes from Colombian coffee, while the highest dose comes from Brazilian coffee. Concerning Indian and Ethiopian coffee, their consumption results approximately the same effective dose. In general, the total internal radiation exposure per consumer for all imported coffee samples is 41.28 µSv.y⁻¹, as a result of the ingestion of radionuclides, it is not exceeding the global mean value of 290 µSv.y⁻¹ for all studied samples (UNSCEAR, 2000).

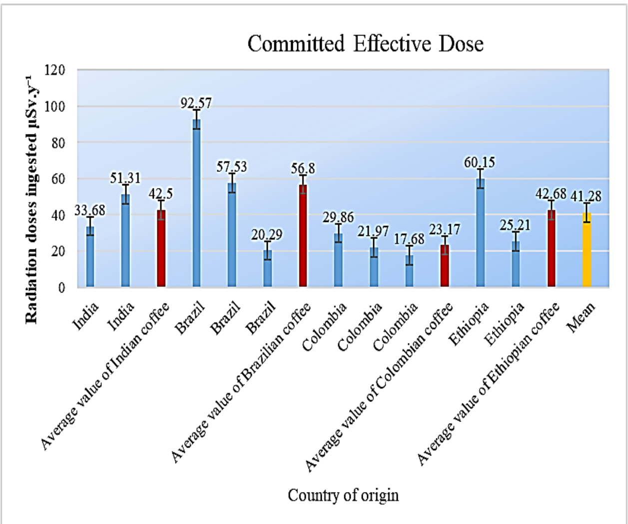

Fig. 1 shows the committed effective dose for studied samples

CONCLUSION

This study provides a comprehensive analysis of the radiation risks associated with daily coffee consumption in Libya by investigating the presence of natural and artificial radioactive contaminants in imported coffee beans. The results indicate that, while the analyzed coffee samples contained measurable levels of Ra^{226} and Ra^{228}, the concentrations of these radionuclides generally remained within safe limits as per UNSCEAR guidelines, except for the K^{40} concentration, which exceeded the permissible values. In addition, the estimated annual effective radiation doses from coffee consumption ranged from 17.68 to 92.57 µSv.y⁻¹, with Colombian coffee presenting the lowest effective dose and Brazilian coffee the highest. These values are significantly below the global mean for internal radiation exposure, suggesting that the current levels of radioactive contaminants in the sampled coffee do not pose a significant threat to public health. However, the findings underscore the importance of continued monitoring of radioactive contaminants in food products, particularly in imported goods, to safeguard consumer health. Given the potential for long-term exposure to accumulated radionuclides, it is crucial to establish and enhance food safety regulations and conduct further research on radioactive contamination in various food items. This proactive approach will help ensure that consumers are protected from any unforeseen health risks associated with radiation exposure through their diet.

RECOMMENDATION

The authors recommend strengthening food safety regulations and conducting more comprehensive studies on radioactive contamination in various food items, especially in regions with high levels of natural radioactivity.

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