Determination of the Potassium Content in Fruit Samples by Gamma Spectrometry to Emphasize its Health Implications

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***Abstract*—In this study, the activity concentration of ^{40}K and its' concentrations in 24 different types of fruits were determined using high purity germanium and sodium iodide scintillation (NaI) detectors. The results of the two measurements are consistent. The maximum and minimum activities of ^{40}K in dry samples were 750.61 ± 11.88 and 15.64 ± 0.86 Bq/kg in apricot and olive, respectively, while in fresh samples they were 152.27 ± 2.12 and 1.99 ± 0.11 Bq/kg in dates and olive, respectively. The highest and lowest potassium contents were 489.81 and 6.42 mg/100 g in fresh dates and olives, respectively. Drupe and tropical fruits, as a fruit family, typically had the highest level of ^{40}K activity and potassium concentration, whereas pome fruits showed the lowest levels. Many of these commonly consumed fresh fruits with rich potassium and water contents are lowering hypertension and improving the hydration status in people's nutrition. The rate of potassium-40 and total potassium concentration intake for a single unit or portion of the fruits was calculated.**

***Index Terms*—^{40}K, Health, HPGe, NaI, Fruits, Potassium**

I. Introduction

Potassium is a delicate, silver-white metal that is abundant in nature and found in every tissue of plants and animals. Three isotopes of the potassium element make up the element: ^{39}K (93.3%), ^{40}K (0.012%, 120 ppm), and ^{41}K (6.7%). While potassium-40 is radioactive with a half-life of 1.28×10^9 years (one of the few naturally occurring radioisotopes with an atomic number below 82), potassium-39 and potassium-41 are stable isotopes to radioactive decay (Peterson, 1996). One of the most prominent naturally occurring radionuclides is potassium-40 (Tolstykh, et al., 2016). Naturally occurring radioactive nuclides can be found in human habitats such as soil, water, food, and air, as well as in our bodies (Aswood, Jaafar, and Bauk, 2013). These radioactive nuclides can enter plants through their roots or leaves, where they are subsequently directly absorbed by humans as food (Alharbi and El-Taher, 2013).

While 89.3% of the ^{40}K decay through beta-emission to the ground state of calcium without gamma emission, the remaining 10.67% of the ^{40}K will decay by electron capture to an excited state of argon, resulting in a 1460.8 keV gamma decay to the ground state. The measurement of 1460.8 keV serves as a signature and verification for potassium-40 (Arena, 1969; Leutz, Schulz and Wenninger, 1965). Both internal and external health risks are present with ^{40}K. External exposure to this radioisotope raises concerns due to its intense gamma radiation (E = 1460.8 keV); While inside the body, ^{40}K poses a health risk due to the emission of beta particles (E_{max} = 1.35 MeV) and gamma rays, which are linked to cell damage and the potential to cause cancer in the future (Sarayegord, et al., 2009; Santos Jr., et al., 2005).

Numerous clinical and observational studies have demonstrated the risk of hypertension being reduced by consuming less sodium and more potassium. An increased potassium consumption lowers blood pressure in hypertensive populations (Perez and Chang, 2014). Hypertension (high blood pressure) increases a person's risk of cardiovascular disease (CVD) (Steddon, et al., 2014). Blood pressure ≥140 mm Hg systolic and 90 mm Hg diastolic (>140/90 mmHg) can be classified as hypertension. Aside from increasing the risk of CVD, hypertension has been linked to stroke and other chronic conditions such as cerebrovascular disease, ischemic heart disease, and renal failure (Pawloski, 2015). The World Health Organization (WHO) strongly recommends increasing potassium intake to at least 90 mmol/day (3.5 g/day) in adults to reduce blood pressure and the risk of cardiovascular disease (CVD), stroke, and coronary heart disease (CHD) (Burnier, 2019). Although most intervention studies have focused on high levels of potassium intake, observational studies show that increasing potassium intake by 750–1000 mg/day can reduce

ARO-The Scientific Journal of Koya University
Vol. X, No. 2 (2022), Article ID: ARO.11053. 11 pages
DOI: 10.14500/aro.11053
Received: 23 August 2022; Accepted: 02 October 2022
Regular research paper: Published: 20 October 2022
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blood pressure by 2–3 mm Hg. This reduction in blood pressure (BP) benefits the cardiovascular system by lowering the risk of cerebral vascular accidents (CVA) and other CVD events. Reduced sodium intake, increased calcium, potassium, and magnesium intake, a diet rich in fruits and vegetables, various antioxidants, and other "designer foods" and nutritional supplements are all known to the lower blood pressure (Houston, 2011).

In the literature, several techniques have been used by researchers to determine the potassium content in several types of food. One of these is the gamma measurements of ^{40}K which is a clean, accurate, and, low-cost method. Some used the high purity germanium (HPGe) detectors in food measurements (Abt, et al., 2016; Acquah and Pooko-Aikins, 2013), others used Sodium Iodide Based Detectors (Hoeling, Reed and Siegel, 1999; Escareño-Juárez and Vega-Carrillo, 2012). The Fluorimeters technique has been implemented to obtain potassium content in milk again, through the measurement of the ^{40}K (Emumejaye, 2012). Measurements of the potassium content of food samples also have been performed using atomic absorption spectrometers (Vaessen and van de Kamp, 1989).

The current study aims to estimate the ^{40}K activity concentration and total potassium contents in 24 sample fruits. These fruits are regularly consumed by residents of the Koya district. Knowing the potassium content of these fruits allows for making better recommendations for a better nutritional system that helps control blood pressure.

II. Materials and Methods

A. Samples collection and preparation

Twenty-four types of fruits were collected from local markets in Koya city. It is about 57.32 km far from Erbil. Erbil is the capital of Kurdistan Region-Iraq. Around 100 thousand inhabitants live in this area. As shown in Table 1, some of these fruits are grown locally, while others are from different countries. Except for date fruit, which was produced in the south of Iraq, other local fruits were grown nearby Koya city.

The edible portions of fruits are retained for analysis after being washed with tap water to remove soil and other unwanted material (Al-Masri, et al., 2004). The resulting fresh mass was then calculated by weighing and carefully distributed for initial drying after being cut into little pieces with a knife. Fruit samples were dried in an electric oven at about 80 °C until they reached a constant weight (Al-Absi, et al., 2015). Samples were crushed and processed into fine powder in the laboratory using an automatic grinder with an adjustable squeezer. The duration of the crushing process has been selected to guarantee homogeneous sample particle size. The components were crushed and then sieved through a sieve with a 35-mesh screen (the hole diameter is 0.5 mm). The same level from each sample was packed in a Marinelli beaker (one-liter size) for both gamma spectrometers. The net weights of samples were determined from the difference between the weights of sample-filled and empty beakers (Pourimani, Noori and Madadi, 2015; Al-Absi, et al., 2015). The codes for the samples were SF for fruits, each followed by a number ranging from SF1 for the date to SF24 for Olive fruit samples (Table I).

Table I presents fruit samples by common name, scientific name, family name, numbering codes, and their countries location. In addition, the dry to fresh weight percentage ratio (DFWR), and the water content percentage. The fresh weight of samples is the weight required to produce 1 kg of dried sample.

B. Gamma detection systems

Two gamma spectrometers were used to measure the activity concentration of ^{40}K in the fruits, the first using HPGe detector and the second using a thallium-activated sodium iodide scintillation (NaI) detector (Salih, Hussein and Sedeeq, 2019; Najam, Tawfiq and Kitha, 2015).

HPGe detector

The HPGe detector is a coaxial, p-type device manufactured by Princeton Gamma Tech (PGT). The diameter and length of the crystal are 70.6 and 70.7 mm, respectively. At the ^{60}Co gamma energy of 1332 keV, the detector resolution is approximately 1.96 keV. The detector's relative efficiency is 73% and has a peak-to-Compton ratio of 75/1. This performance is due to the crystal size, which has an active volume of 265 cm^3 (Ahmad, Almuhsin, and Hamad, 2021). The system is housed within a 10.1 cm high-performance copper/tin lined lead shield Kolga Model A340 cylindrical lead shield. This shield prevents background radioactivity. For about 10 h, the samples were placed over the detector. An empty sealed beaker was counted in the same way and with the same geometry as the samples to determine the background radiation in the surrounding environment around the detector. The counting time for each sample was 36000 s. During operation, the detector was cooled down by liquid nitrogen at 77 K to reduce leakage current and thermal noise prevention, and its warm-up sensor is coupled to the high voltage detector bias supply. The operating voltage was 4000V.

The spectra were analyzed with a Thermo Scientific System 8000 multi-channel analyzer and PGT's Quantum Gold 2001 computer software. The activity concentration of ^{40}K was directly determined using a 1460.5 keV (10.67%) gamma-ray line after measurements and correction of the net peak area of gamma rays of measured samples by background subtraction (Azeez, Ahmad, and Mansour, 2018).

Sodium iodide scintillation NaI(Tl) detector

The scintillator and the photomultiplier tube that make up the NaI (Tl) detector are optically connected. The sodium iodide crystal [NaI(Tl)] employed in the current work is a thallium-activated scintillator. With a 2 × 2-inch active area, the NaI(Tl) scintillation detector offers an energy resolution of 8% at the 662 keV Cs-137 line and 5.91% at the 1173 keV Co-60 line. This study made use of the MAC-CASSY

Table 1
Sample Identification and the Water Content Percentage for Samples

Samples	Family name	Location	Scientific name	Sample code	Fresh samples (kg)	DFWR %	Water %
Date	Drupe	Iraq	Phoenix dactylifera	SF1	1.28	78.1	21.9
Avocado	Tropical	Lebanon	Persea americana	SF2	4.48	22.3	77.7*
Banana	Tropical	Africa	Musa sepientum	SF3	3.97	25.1	74.9
Apricot	Drupe	Iraq	Prunus armeniaca	SF4	9.68	10.3	89.7
Pomegranate	Tropical	Iraq	Punica granatum	SF5	4.8	20.8	79.2*
Mulberry	Berries	Iraq	Morus alba	SF6	5.0	20.0	80.0
Fig	Tropical	Iraq	Ficus carica	SF7	3.99	25.0	75.0
Peach	Drupe	Iran	Prunus persica	SF8	8.2	12.2	87.8
Melon	Melons	Iraq	Cantalupensis	SF9	13.4	7.4	92.6
Kiwifruit	Tropical	Iran	Actinidia deliciosa	SF10	6.35	15.7	84.3
Strawberry	Berries	Iran	Fragaria ananassa	SF11	14.1	7.1	92.9
Grape	Berries	Iraq	Vitis vinifera	SF12	10.8	9.2	90.8
Mango	Drupe	Tanzania	Mangifera	SF13	6.9	14.4	85.6
Orange	Citrus	Turkey	Citrus sinensis	SF14	7.25	13.8	86.2
Plum	Drupe	Iran	Prunus domestica	SF15	9.6	10.4	89.6
Quince	Pome	Turkey	Cydonia oblonga	SF16	7.1	14.1	85.9
Lemon	Citrus	Turkey	Citrus limon	SF17	7.44	13.4	86.6
Grapefruit	Citrus	Turkey	Citrus paradisi	SF18	8.95	11.2	88.8
Pineapple	Tropical	Costa Rica	Ananas comosus	SF19	10.45	9.5	90.5
Pear	Pome	Iraq	Pyrus communis	SF20	7.8	12.8	87.2
Green apple	Pome	Iran	Malus domestica	SF21	8.4	11.9	88.1
Apple	Pome	Iraq	Malus pumila	SF22	7.5	13.3	86.7
Watermelon	Melons	Iraq	Citrus vulgaris	SF23	22.44	4.4	95.6
Olive	Drupe	Iraq	Olea europaea	SF24	7.84	12.7	87.3*

*Avocado and olive contain around 10% fat (oil), and Pomegranate contains about 1%, while the others contain<0.5%

computer-assisted science system. The background of the laboratory environment was measured by placing an empty Marinelli beaker on the detector with the same period and operating voltage used to determine the energy spectra of the samples. The operating voltage was 600V. The net sample spectra are calculated by subtracting the background from the sample measurements. A (1.5 cm) lead shield surrounds the detector to lessen the environmental background (Hussain and Hussain, 2011). Particularly at higher energy, NaI (Tl) is more efficient than solid-state detectors at detecting gamma radiation. Because it does not require cooling, the NaI (Tl) detector is easy to utilize in environmental research than a solid-state detector (Htwe and Lwin, 2010). The counting time of each sample was 18000 s.

III. Theory

A. Activity concentrations

The activity concentrations (A) of potassium ^{40}K, with an energy of 1.46 MeV, were measured in fruit and vegetable samples as follows (Azeez, Mansour, and Ahmad, 2019; Smail, Ahmad and Mansour, 2022).

$$A=\frac{N}{\varepsilon \times I_{\gamma} \times T \times M} \quad (1)$$

Where N is the net count, ε is the absolute gamma peak efficiency for the detector at a specific gamma-ray energy, and Iγ is the decay intensity of the 1.46 MeV of ^{40}K. T is the counting time of the measurement in seconds and M is the mass of the sample in kilograms. The relative combined standard deviation σ_A of the activity concentration is given by the formula [2]:

$$\frac{\sigma_A}{A}=\sqrt{\frac{\sigma_N^2}{N}+\frac{\sigma_\varepsilon^2}{\varepsilon}+\frac{\sigma_{I_\gamma}^2}{I_\gamma}+\frac{\sigma_M^2}{M}} \quad (2)$$

Where σ_N is the standard deviation of the N net count rate per second, σ^{ε}, σ_I^{γ}, and σ_M are the standard deviations of the ε, I^{γ}, and M, respectively (Smail, Ahmad and Mansour, 2022).

B. Energy calibration of the detection systems

The object of energy calibration is to derive a relationship between the peak position in the spectrum and the corresponding gamma-ray energy.

For the HPGe spectrometer, the standard point gamma-ray sources, such as ^{60}Co (peaks 1173.2 and 1332.5 keV), ^{137}Cs (peak 661.7 keV), and ^{226}Ra (peaks 295, 609, and 1120 and 1764 keV) were used to calibrate the energy of the gamma-ray.

Fig. 1 shows the plotted graph for the energy against channel number for the high pure germanium detector.

For the NaI spectrometer, the gamma-ray energy was calibrated by using the standard point gamma-ray sources, such as ^{60}Co (peaks 1173.2 and 1332.5keV), ^{137}Cs (peak 661.7 keV), and ^{22}Na (peaks 511, and 1275 keV).

Fig. 2 shows the plotted graph for the energy against channel number for the scintillation (NaI) detector.

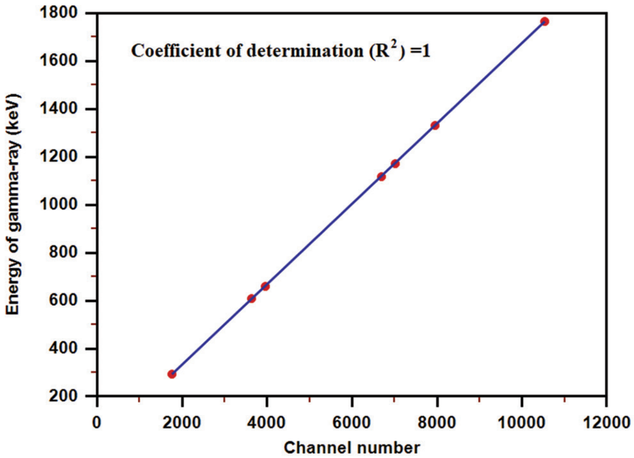

Fig. 1. Energy calibration graph for gamma-ray spectrometry system (HPGe).

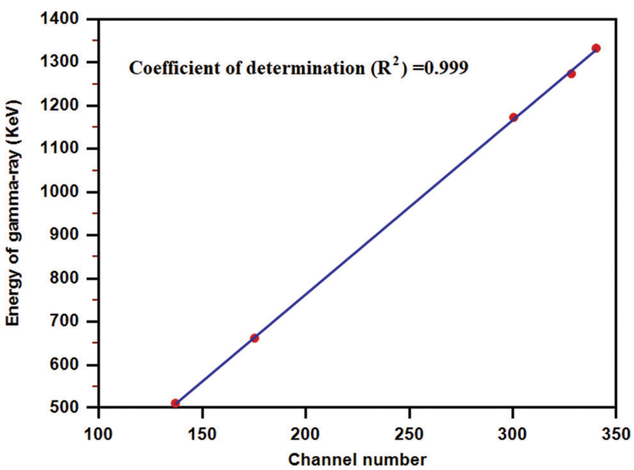

Fig. 2. Energy calibration graph for gamma-ray spectrometry system (NaI).

C. Efficiency calibration of the detection systems

Four gamma-ray sources, ^{226}Ra, ^{60}Co, ^{22}Na, and ^{137}Cs, were used to calibrate the efficiencies of the two systems. For at least 1 h, the spectra of these sources were counted by each detector. A sample of 713 g of potassium chloride (KCl) was employed as a ^{40}K radioactive source to determine the precise efficiency for the 1460 keV gamma photon of ^{40}K, For the HPGe detection system, the fitted data provide the following polynomial equation:

$$\varepsilon = 0.1158 - 3\times10^{-4} E_\gamma + 3\times10^{-7} E_\gamma^2 - 1\times10^{-10} E_\gamma^3 \quad (3)$$

Fig. 3 shows the plotted graph of the absolute full peak efficiency through the gamma-ray energy for the high pure germanium detector.

While the fitted data for the NaI(Tl) detection system gives the polynomial equation (4) and its plotted graph is shown in Fig. 4:

$$\varepsilon = 0.0291 - 5\times10^{-5} E_\gamma + 3\times10^{-8} E_\gamma^2 - 7\times10^{-12} E_\gamma^3 \quad (4)$$

Where ε is the absolute full peak efficiency of the detector, and E_γ is the energy of the gamma-ray in both equations.

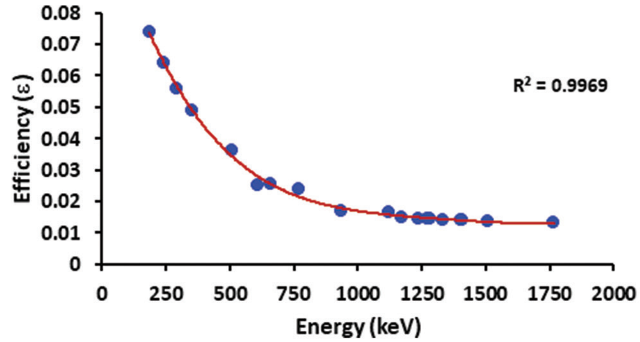

Fig. 3. The efficiency curve of the HPGe gamma spectrometer.

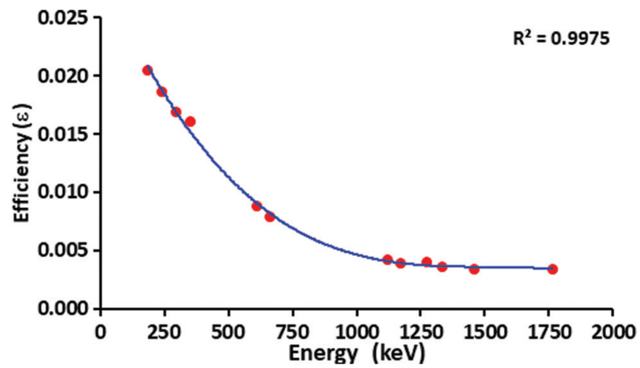

Fig. 4. The efficiency curve of the NaI(Tl) gamma spectrometer.

D. Minimum detectable activity

Currie's derivation is used to determine the minimum detectable activity (MDA) for any given nuclide at a 95% confidence level (L'Annunziata, 2012; Currie, 1968).

$$\varepsilon = 0.0291 - 5\times10^{-5} E_\gamma + 3\times10^{-8} E_\gamma^2 - 7\times10^{-12} E_\gamma^3 \quad (5)$$

Where σ is the standard deviation of the collected background over the energy range of interest during time T. T denotes the collection time (s), and ε is the system efficiency at the specific energy. I_γ is the decay intensity of the specified energy peak. M is the mass of the sample (kg). The MDA for a ^{40}K nuclide in the present work is around 3.6 Bq/kg.

E. Total potassium concentration (K)

Activity concentration of ^{40}K, calculated from its gamma emission in the photo peak of 1460 keV, can be used and converted into total potassium concentration in the sample, as follows (Tzortzis and Tsertos, 2004; Tin and Wai, 1993).

$$m = A \times \frac{t_{1/2}}{0.693} \times \frac{M_W}{N_A} x100\% \quad (6)$$

Where m is the percentage (%) fraction of potassium (^{40}K) in the sample, M_W, $t_{1/2}$, and A are the atomic mass (kg mole^{-1}), the half-life of ^{40}K (s), and the measured activity concentration (Bq/kg), respectively, ^{NA} is Avogadro's number (6.022 × 10^{23} atoms mole^{-1}). The total mass of the potassium in the sample can be determined from the ^{40}K

http://dx.doi.org/10.14500/aro.11053

mass, which is only about 0.012% of the total potassium mass.

F. Daily intakes of ^{40}K radioactivity

The radionuclide intakes can be calculated from the measured concentration of ^{40}K radionuclide in fresh fruit or vegetable (Bq/kg) and the daily consumption rate (kg/day) as follows.

$$Daily\,intake(mBq) = A \times DCR \times f \qquad (7)$$

Where A is the activity concentration of the sample in mBq/kg, *DCR* is the daily consumption rate in kg/day and *f* is the number of days the fruit is consumed in a week divided by 7 (days in a week) (Al-Absi, et al., 2015; Adedokun, et al., 2019).

IV. Results and Discussion

A. Potassium contents

One of the gained results of this study is the estimation of the percentage of water in studied fruits. Table I shows that the minimum water content is in the SF1 date fruit sample at 21.7%, and the maximum is in SF23 the fruit watermelon sample at 95.6%. Of twenty-four types, about 5 have a water content above 90%. The water content of fourteen types of fruits is between 80% and 90%. Four samples are in the range 70–80%, which leaves only one type with water content below 70%. Most of the fruits are grown locally or regional and are regularly consumed.

It is worth noting that there are some of these samples are oily fruits and include a negligible percentage of oil, olives and avocados containing approximately 10%, while pomegranates contain 1%. Some of the rest are as low as 0.5%.

This distribution of fruits regarding their percentage of water is a healthy sign for those who eat fruits regularly and in appropriate quantities, especially children. One of the studies conducted especially for this purpose confirms that regular intake of fruits may relevantly improve hydration status (HS) in children. Dietary interventions to increase fruit intake may be a promising strategy to achieve a positive water balance in this population (Montenegro-Bethancourt, Johner and Remer, 2013).

The activity concentration of potassium ^{40}K in (Bq/kg) for dried 24 fruit samples was studied using HPGe detector and thallium activated sodium iodide scintillation detector NaI(Tl). The results of the two systems are in good agreement, and the differences are within the limit of the statistical errors. In Fig. 5, the scatter diagram with the regression line of the two systems measurements is presented, with the determination coefficient being $R^2 = 0.9955$. Therefore, only the results of the HPGe spectrometer were discussed and treated here to avoid repetitions. However, Tables II and III contain both system's measurements for fruits.

Using gamma spectroscopy to measure the ^{40}K activity concentration in food is a perfect technique to estimate the radiological parameters and an efficient method to estimate the total potassium in food samples, especially those which contain a high ratio of light elements H, C, N, and O, such as the carbohydrates. These light elements are out of the lower limit of detection in the XRF technique. Therefore, the results of the XRF may lead to an overestimation of Potassium content.

The ^{40}K activity concentration in dried and fresh fruit samples is presented in Table II.

The activity concentrations in the fresh fruits can be obtained by considering the activity of 1 kg of the dried fruit sample as the activity of the total weight of the original quantity before drying.

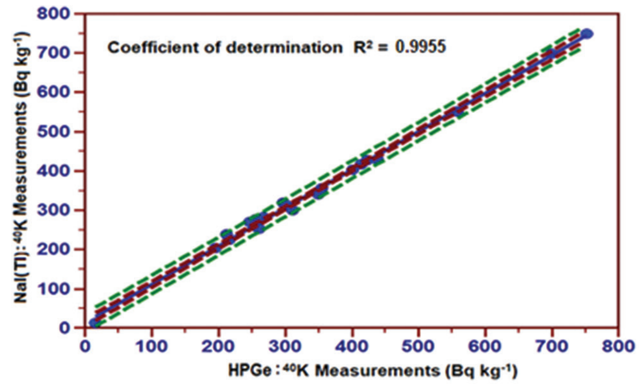

Fig. 5. The scatter diagram with the regression line of the two measurements.

Table II
Activity Concentration of ^{40}K (Bq/kg) in Dried and Fresh Fruits

Fruit samples	Dried fruits		Fresh fruits	
	HPGe	NaI (Tl)	HPGe	NaI (Tl)
Date	194.91±2.71	204.30±1.70	152.27±2.12	159.61±1.33
Avocado	400.85±4.66	402.83±3.29	89.47±1.04	89.91±0.73
Banana	349.45±3.46	340.50±2.73	88.02±0.87	85.77±0.69
Apricot	750.61±4.60	749.63±5.39	77.54±0.47	77.43±0.56
Pomegranate	296.06±3.56	320.48±2.62	61.68±0.74	66.76±0.55
Mulberry	300.76±3.19	313.76±2.53	60.15±0.64	62.75±0.51
Fig	215.39±2.65	225.12±1.86	54.98±0.66	56.42±0.47
Peach	437.85±4.45	429.68±3.46	53.39±0.54	52.40±0.42
Melon	698.11±5.25	698.97±5.31	52.09±0.39	52.16±0.39
Kiwi	255.67±3.15	277.27±2.30	40.26±0.49	43.66±0.36
Strawberry	557.73±5.47	551.49±4.42	39.55±0.38	39.11±0.31
Grape	422.25±4.26	428.30±3.44	39.09±0.39	39.63±0.32
Mango	255.67±3.42	268.38±2.21	37.05±0.49	38.89±0.32
Orange	267.34±3.50	282.28±2.34	36.87±0.48	38.93±0.32
Plum	353.88±3.60	356.19±2.86	36.86±0.37	37.10±0.29
Quince	252.76±3.02	260.26±2.13	35.60±0.42	36.65±0.30
Lemon	258.27±3.05	274.53±2.30	34.71±0.41	36.89±0.31
Grapefruit	310.50±3.36	300.09±2.44	34.69±0.37	33.53±0.27
pineapple	351.48±3.98	349.84±2.86	33.63±0.38	33.47±0.27
Pear	261.12±3.71	253.70±2.12	33.47±0.47	32.52±0.27
Green apple	246.56±3.45	270.37±2.25	29.35±0.41	32.18±0.26
Apple	212.12±3.07	238.85±1.99	28.28±0.41	31.84±0.26
Watermelon	413.28±4.07	417.71±3.34	18.41±0.18	18.61±0.15
Olive	15.64±0.86	13.22±0.11	1.99±0.11	1.68±0.02
Average	336.6±3.6	342.82±2.75	48.72±0.55	49.91±0.4

Table II shows that the dried apricot has a maximum activity concentration of ^{40}K, 750.61 ± 11.88 Bq/kg and the minimum is 15.64 ± 1.57 Bq/kg in dried olive. In the fresh fruits, the maximum activity concentration of ^{40}K is 152.75 ± 3.58 Bq/kg in fresh date and the minimum is 1.99 ± 0.20 Bq/kg in fresh olive. It is worth mentioning that the ^{40}K activity concentration in fresh apricot is 77.54 ± 0.47 Bq/kg, which is almost about 10th of its activity as a dry sample. This ratio is related directly to the dry to fresh weight ratio of the apricot sample, and this concept is valid for all samples.

Fig. 6 presents the activity concentration of ^{40}K for dried fruit samples by both detectors. Fig. 7 shows the activity concentration of ^{40}K in fresh fruit for these samples. Both figures emphasize that the two systems give very close results or equal.

Table III
Total Potassium Content (K) in (mg/100g) in Fresh Fruits

	Fresh fruits	
Sample	HPGe	NaI (Tl)
Date	489.81	513.41
Avocado	287.81	289.23
Banana	283.14	275.88
Apricot	249.42	249.09
Pomegranate	198.40	214.76
Mulberry	193.49	201.85
Fig	173.65	181.48
Peach	171.75	168.55
Melon	167.58	167.78
Kiwifruit	129.51	140.45
Strawberry	127.23	125.81
Grape	125.76	127.56
Mango	119.19	125.11
Orange	118.61	125.24
Plum	118.57	119.34
Quince	114.51	117.91
Lemon	111.66	118.69
grapefruit	111.59	107.85
pineapple	108.19	107.68
Pear	107.68	104.62
Green apple	94.41	103.53
Apple	90.97	102.44
Watermelon	59.24	59.87
Olive	6.42	5.42

The measure of the total potassium content (K) in these fruits is a key issue in this study since that concentration has a role in the medical concepts of using or encouraging people to consume food with high potassium. People, in general, consume fresh fruits. However, some of these fruits may present in a dried form in markets or as homemade food. Therefore, we are discussing the potassium concentration in fresh fruits.

Table III illustrates the total potassium content of fresh fruits. The maximum total potassium concentration values were obtained in the date fruit, which were 489.81 mg/100 g and 513.41 mg/100 g from HPGe and NaI spectrometers, respectively, while the minimum values were in olive (6.42 mg/100 g and 5.42 mg/100 g from HPGe and NaI spectrometers, respectively).

The data in Table III are presented in Fig. 8 for fresh fruits. Again, the total potassium concentration in fresh fruits reflects the water content in these types of fruits. From Fig. 8, it is clear that date fruit has the richest potassium content of any of the 24 studied samples of fruits with a clear margin of difference.

There was some difficulty in estimating the intake of total potassium and potassium-40. Since we are not testing an organized or designed food program, it is hard to calculate regular potassium intakes by population. Therefore, we assumed that the better solution to this problem is by calculating these intakes in a unit of consumption. The fruits can be counted and consumed in one meal, such as date, apple, and banana, we calculate the intake for the edible part of a single fruit. For those which cannot be counted or consumed by one person in one meal, such as watermelon and pineapple, we chose a proper served weight in one meal.

Table IV shows the intake of potassium ^{40}K (Bq) and the total potassium (K) (mg) in fruits by defining the mass and the frequency of their daily consumption based on the HPGe measurements. Accordingly, the consumed quantity of the preferable food should agree with established adequate intakes (AIs) by the National Academies of Sciences, Engineering, and Medicine (NASEM) for all ages based on the highest median potassium intakes in healthy children and adults (National Academies of Sciences, 2019).

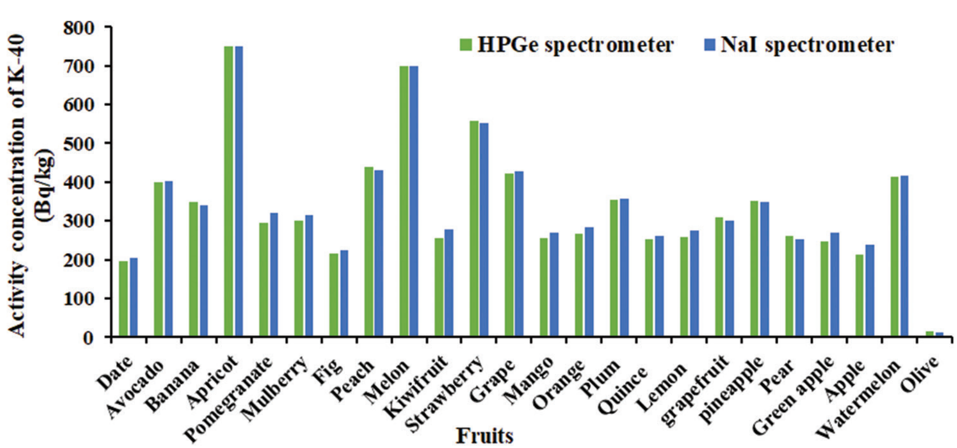

Fig. 6. Activity concentration of ^{40}K for dried fruits.

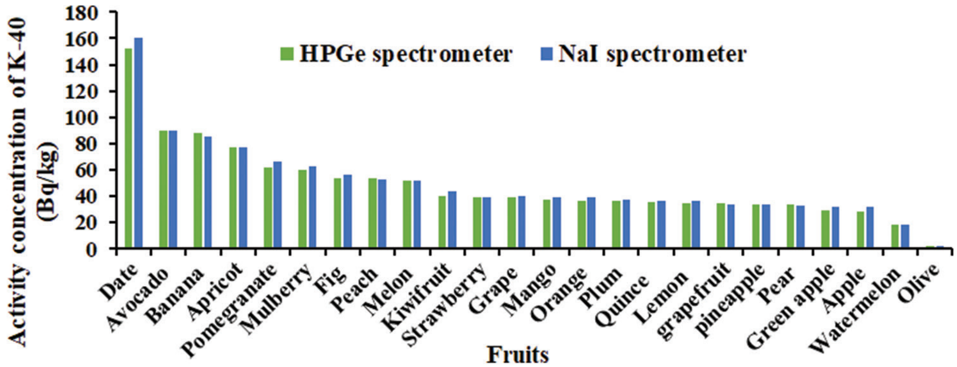

Fig. 7. Activity concentration of ^{40}K for fresh fruits.

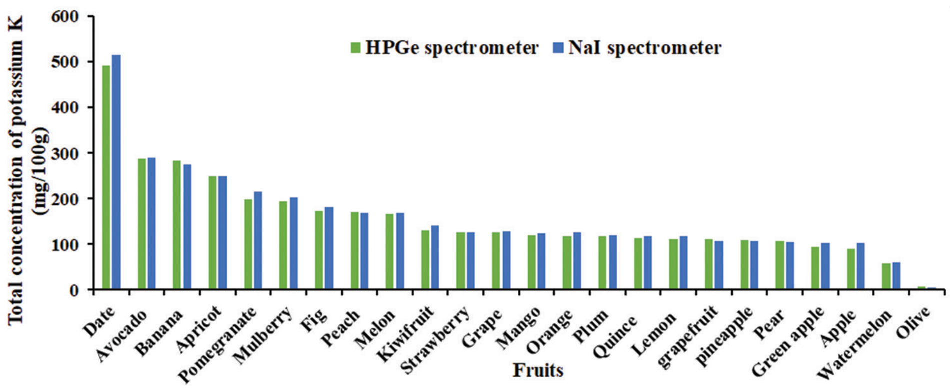

Fig. 8. Total potassium concentration in fresh fruits.

Table IV
Intakes of ^{40}K and Total (K) from Eating Specific Quantity Which Can Be Consumed as a Single Unit or Portion of the Fruits

Samples	Consumption unit	Mass (kg)	Intake of ^{40}K (Bq)	Intake of total (K) (mg)
Date	1	0.005	0.76	24.49
Avocado	1	0.12	10.74	345.38
Banana	1	0.11	9.68	311.45
Apricot	1	0.025	1.939	62.36
Pomegranate	1	0.2	12.34	396.80
Mulberry	1	0.013	0.78	25.15
Fig	1	0.03	1.62	52.10
Peach	1	0.1	5.34	171.76
Melon	Slice	0.3	15.63	502.74
Kiwifruit	1	0.06	2.42	77.71
Strawberry	1	0.015	0.59	19.09
Grape	1	0.004	0.16	5.03
Mango	1	0.3	11.12	357.57
Orange	1	0.18	6.64	213.50
Plum	1	0.02	0.74	23.71
Quince	1	0.21	7.48	240.48
Lemon	1	0.073	2.53	81.51
Grapefruit	1	0.215	7.46	239.93
Pineapple	Slice	0.3	10.09	324.59
Pear	1	0.14	4.69	150.76
Green apple	1	0.17	4.99	160.51
Apple	1	0.17	4.81	154.66
Watermelon	Slice	0.3	5.53	177.73
Olive	1	0.004	0.01	0.26

B. Comparison with other studies

In Table V, we compare the results of the ^{40}K activity concentration of the present work with some local, regional and international previous measurements and studies, each of these studies has mentioned a few dried or fresh types of the listed samples in the present study. In general, our results agree with some of the referenced data and are higher or lower in some of the other referenced data. Verities and fluctuations in the level of ^{40}K in fruits may neutrally occur due to their production environments regarding the place of growth and the use of fertilizers. Table VI shows the total potassium concentration of the present results compared to published data. Some of the referenced studies here used analytical methods instead of the radioactivity of ^{40}K to estimate the potassium contents.

C. The comparison of the activity levels of the ^{40}K and the potassium concentrations in subgroups of fruits

The activity levels of the ^{40}K and the potassium concentrations in six subgroups of fresh fruits (Fig. 9) were compared using the average values from groups of samples. These classes are classified according to the classification adopted in healthy nutrition systems.

The six classes of fruits were Citrus fruits, berries, drupe, pome, tropical, and melon fruits. Drupe and Tropical fruits generally had the highest level of activity for the ^{40}K and concentration of potassium, while pome fruits showed the

Table V
Comparison of Potassium Activity Concentration (^{40}K) (Bq/kg) in Fruit Samples for the Present Study with the Previously Published Literature

Types of samples		Activity concentration of ^{40}K		
		Present study	Other study	References
Dates	Fresh	152.27±2.12	50.29±2.02	Harb, 2015
Melon	Dry	698.1±12.59	880.28±71.67	Azeez, Mansour, and Ahmad, 2019
	Fresh	52.16±0.39	35.49±0.99	Canbazoğlu and Mahmut, 2013
Watermelon	Dry	413.3±8.13	300.27±20.07	Azeez, Mansour, and Ahmad, 2019
	Fresh	18.61±0.15	34.44±0.88	Canbazoğlu and Mahmut, 2013
Orange	Dry	267.3±6.21	279.74±7.70	Priharti and Samat, 2016
Apple	Dry	212.1±5.34	151.49±5.69	Priharti and Samat, 2016
	Fresh	28.28±0.41	26.25±1.24	Harb, 2015
Banana	Dry	349.4±6.76	401.59±5.85	Priharti and Samat, 2016
Mango	Dry	255.7±6.26	171.95±6.61	Priharti and Samat, 2016
Pear	Fresh	33.47±0.47	13.62±1.60	Canbazoğlu and Mahmut, 2013
Quince	Fresh	35.60±0.42	23.01±1.40	Canbazoğlu and Mahmut, 2013
Apricot	Fresh	77.54±0.47	114.90±4.52	Harb, 2015
Strawberry	Fresh	39.55±0.38	52.59±2.10	Harb, 2015
Fig	Fresh	54.98±0.66	37.25±1.56	Harb, 2015

Table VI
Comparison of Potassium Concentration (mg/100 g) in Fruits Samples for the Present Study With the Previously Published Literature

Fresh fruit samples	Potassium concentration (mg/100 g)		
	Present work	Other study	Reference
Date	489.81	486	Al-Farsi and Lee, 2008
Avocado	287.81	351	Vicente, et al., 2022
Banana	283.14	350	Vicente, et al., 2022
		357	Abt, et al., 2016
Apricot	249.42	259	Vicente, et al., 2022
Pomegranate	198.40	259	Vicente, et al., 2022
Mulberry	193.49	190.96	Liang, et al., 2012
Fig	173.65	232	Vicente, et al., 2022
Peach	171.75	190	Anavi, 2013
Kiwifruit	129.51	280	Cunningham, Milligan and Trevisan, 2001
Strawberry	127.23	170	Vicente, et al., 2022
Grape	125.76	170	Vicente, et al., 2022
Mango	119.19	160	Vicente, et al., 2022
Orange	118.61	150	Vicente, et al., 2022
Plum	118.57	157	Anavi, 2013
Quince	114.51	189	Hegedűs, Papp and Stefanovits-Bányai, 2013
Lemon	111.66	138	Vicente, et al., 2022
Grapefruit	111.59	127	Vicente, et al., 2022
Pineapple	108.19	130	Vicente, et al., 2022
Pear	107.68	119	Anavi, 2013
Apple	90.97	107	Anavi, 2013
Watermelon	59.24	87	Vicente, et al., 2022

lowest levels for ^{40}K and potassium. The major contributor to the potassium level in the drupe fruit is the Date fruit which has the highest level of potassium in fresh fruits in general. Avocados and bananas are the main contributors to potassium levels in fresh tropical fruits.

D. Statistical analysis

Histograms can show the symmetry of data distribution in statistical analysis. If the histogram shapes to the left and right of the vertical line are mirror images of each other, the distribution is symmetrical. The mean and median of a perfectly symmetrical distribution are the same for any data set. However, because each type of fruit is unique in its nature and composition, our data cannot follow such a distribution.

The histograms of the dry fruits data in both detection systems are not symmetrical, as shown in Fig. 10a and b. The distribution is referred to as skewed to the right because it is shifted to the right. In the HPGe detection system, the mean is 336.6 and the median is 298.4. The mean in the NaI(Tl) detection system is 342.8, and the median is 306.9. The Coefficient of Skewness in HPGe is 1.0396 and in NaI(Tl) is 1.006, with rejected normality in both cases.

E. Potassium's health impacts

Potassium is a mineral present in a variety of foods. It is an electrolyte that helps electrical impulses travel throughout the body and aids in several critical biological activities, including blood pressure, proper water balance, muscular

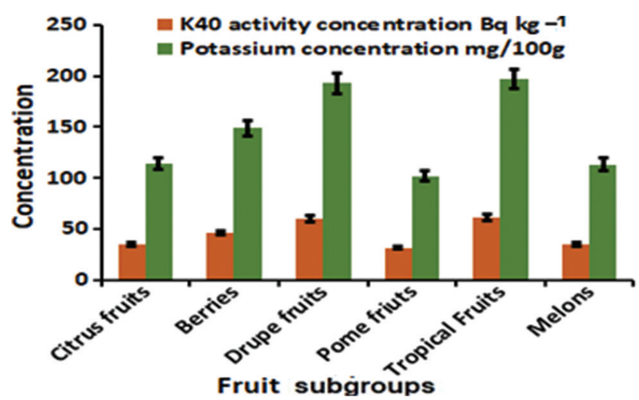

Fig. 9. The comparison of the average activities of ^{40}K and the average concentrations of potassium in six fruit subgroups, with the weighted average of errors of each region (Fresh samples).

contractions, nerve impulses, digestion, heart rhythm, and pH balance (acidity and alkalinity) (Shrimanker and Bhattarai, 2019). Hypokalemia and hyperkalemia are frequent electrolyte diseases induced by potassium intake variations, altered excretion, or transcellular shifts (Viera and Wouk, 2015).

Potassium deficiency can lead to major health concerns. A potassium deficit is characterized by excessive weariness, muscular spasms, weakness, or cramping, irregular heartbeat, constipation, nausea, or vomiting. Kidney illness, heavy diuretic usage, excessive sweating, diarrhea, vomiting, magnesium insufficiency, and antibiotic treatment, such as

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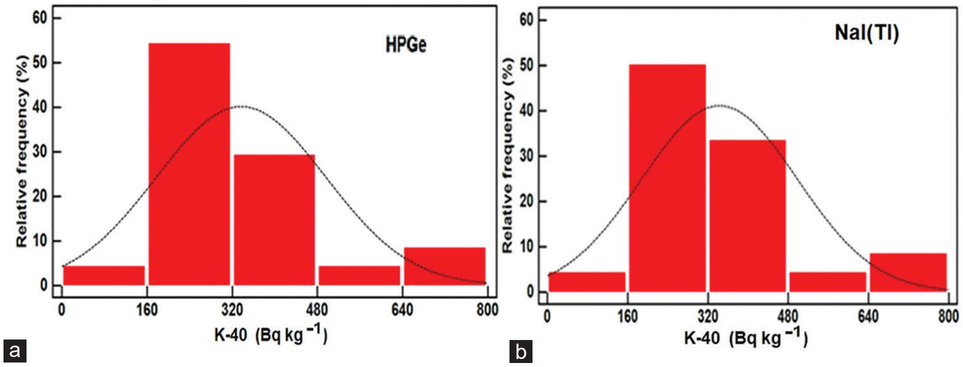

Fig. 10. The Histograms of the data distributions in the two detecting systems. (a) HPGe (b) NaI(Tl) in dry fruits.

carbenicillin and penicillin, can all cause potassium deficit or hypokalemia (low potassium) (Mujais and Katz, 1992; Kardalas, et al., 2018).

Potassium is not produced by the human body on its own. As a result, consuming a balanced diet of potassium-rich foods and drinks is crucial. The use of foods rather than supplements is advised by current efforts to increase potassium consumption. Potassium supplements are not often advised for patients, partly due to concerns about hyperkalemia (high potassium) (Weaver, 2013). An overabundance of potassium is unusual in those who follow a well-balanced diet. If you take too many potassium supplements, you may have overdoses include: renal illness, overtraining, cocaine use, potassium-saving diuretics, chemotherapy, and diabetes. The majority of people get enough potassium through a well-balanced diet. Potassium supplements may be prescribed by a doctor for those who have low potassium levels (Saxena, 1989: Maxwell, et al., 2013).

V. Conclusions

In this study, the activity concentrations of ^{40}K in samples for both detectors are linearly proportional and show the validity of both systems. The results reveal that most fruits contain a considerable amount of water, which makes them very beneficial as a part of the healthy food regime to indirectly preserve the hydration status of those who do not regularly drink enough fresh water and replace it with manufactured drinks and juice, such as children. Fruits contain varying amounts of potassium. Such variation can be used in medical prescriptions or advice for the partial replacement of sodium intake for establishing healthy nutrition or for those suffering from severe hypertension. Drupe and tropical fruits have the highest levels of ^{40}K and potassium in the fruits group, while Pome fruits have the lowest. The date fruit, a member of the drupe fruit family, has the highest level of potassium among fresh fruits in general. Avocados and bananas are the main contributors to potassium levels in fresh Tropical fruits.

Acknowledgment

The authors express their appreciation to the Department of Physics Faculty of Science and Health, Koya University, and the Nuclear Physics Laboratory for their cooperation and for providing and implementing the HPGe gamma spectrometer. Without their help, this work would not have been possible.

Conflict of Interest

The authors declare that they have no conflict of interest.

Data Availability

The datasets created and/or analyzed during the current work can be obtained from the corresponding author upon reasonable requests.

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