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A Study of Natural Radioactivity and Gamma Radiation Hazard in Tobacco Leaves and Cigarettes in Oyo State, Nigeria

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ABSTRACT

A study of natural radioactivity on tobacco was studied in order to assess the natural radioactivity content and the gamma radiation hazard in locally produced tobacco leaves and cigarette product in Oyo State, Nigeria, using a well-calibrated Canberra NaI(Tl. The leaves were gotten from two farms known to be two of the major suppliers of the leaves to the dominant tobacco company in Nigeria, and the products were gotten from the market. The radionuclides detected and quantified in this study came from the naturally occurring ^{238}U and ^{232}Th decay series, as well as nonseries ^{40}K. The overall average values of the activity concentration due to ^{40}K, ^{238}U, and ^{232}Th were 57.51, 24.03, and 14.57 Bq kg^{-1} respectively, for tobacco leaves and 48.37, 17.52, and 12.39 Bq kg^{-1}, respectively, for cigarette products. Also, the mean external radiation hazard index (H_{ext}) was 0.13 and 0.11 for leaves and cigarette samples, respectively, while the mean internal radiation hazard index (H_{int}) was 0.20 and 0.15 for the two samples. The estimated values of these radiation indices were less than unity, and this implies that the health risk due to these radionuclides and their short-lived progenies are negligible.

Keywords: Radioactivity, Tobacco, Cigarette, Gamma Spectrometry, Radiation Hazard Indices

INTRODUCTION

Naturally occurring primordial radionuclides had long been associated with tobacco plants and its originating product (Martell, 1974). Radionuclides can come from the ground (terrestrial radioactivity) or produced as a result of the interaction of atmospheric gases with cosmic rays (cosmogenic radioactivity; UNSCEAR, 1993). Living organisms are continually exposed to ionizing radiations (background radiation) that are emitted as a result of the decay of these radionuclides present in tobacco. Tobacco is known to be an agricultural product processed from fresh leaves of plants in the genus *Nicotiana* and species *Tabacum* with high nicotine content, which makes the products to be addictive (Agba et al., 2012). It also contains minute quantities of radioactive isotopes that pose a radiation exposure hazard to those who intentionally or passively consume it (Naomi & Erik, 2010).

The main routes of the radionuclides in tobacco are due to root uptake from the soil and phosphate fertilizer that farmers use to increase the yield of tobacco farms (Jibiri & Bierre, 2011; Watters & Hansen, 1970). The other source of the radionuclides in tobacco is the trichomes of the leaves (Papastefanou, 2009). Trichomes are sticky, hair-like projections that thickly cover both sides of tobacco leaves. It absorbs tiny dust particles from the air that are loaded with small amounts of radioactive material (radon and its decay products), which could persist even when the leaves are dried and processed (Martell, 1974). Rain does not wash them away, and their existence in tobacco depends on the tobacco origin (how much fertilizers used and natural level of uranium and radium in the soil where the tobacco is grown). The properties and distribution of trichomes (hairs) on tobacco leaf surfaces suggest that they are effective collectors of small Aitken (nuclei) particles (<0.1-μm diameter) by means of diffusive deposition due to Brownian motion of the particles (Martell, 1974; Chakraborty & Weybrew, 1974; Barrera & Werusman, 1974).

The issue of radioactivity in tobacco smoke from cigarette (a product derived from tobacco leaves) has received much attention in the scientific press and medical press (Martell, 1982) as the exposure to excess level of background ionizing radiations can lead to several radiation injuries including cancers (Tchokossa et al., 2013). Biological effects of radiation are typically divided into two categories, namely, deterministic effects, which have a minimum (threshold) dose below which radiation injuries would not occur, and stochastic effects, in which low doses of radiation are extended over a period of time producing chronic or long-term effects (Tuner, 2007).

Cigarette smoke has been reported to be radioactive (Abd El-Aziz et al., 2005; Khater, 2004; Mennah, 2011; Madani et al., 2010; Agba et al., 2012; Papastefanou, 2009; Colangelo et al., 1992; Takizawa et al., 1994; Martell, 1982; among others). Activity concentration of ^{210}Po in Japan tobacco grands as reported by Takizawa et al. (1994) varied from 13.0 to 20.1 Bq kg^{-1} (mean 15.4 Bq kg^{-1}); 50 % of ^{210}Po present in tobacco was transferred into the smoke, and the other 50 % remained in the ash and butt. One pack-a-day smoker inhaled 24 mBq d^{-1} of ^{210}Po through smoking, and the annual inhalation was calculated to be 8.8 Bq. Colangelo et al. (1992) also reported that ^{210}Po in tobacco in Argentina ranged from 10 to 80 Bq kg^{-1} and the lung dose due to the use of tobacco varied from 75 to 600 μSv y^{-1}.

Furthermore, radiation dose from cigarette was evaluated from tobacco leaves in Greece before cigarette production by Papastefanou in 2009 using alpha and gamma spectrometry in which 75% of the radioactivity concentrations in the leaves was said to be present in cigarette smoke. It was concluded that the activities of

the radioisotopes of radium (^{226}Ra and ^{228}Ra) in the tobacco leaves reflected their origin from the soil by root uptake rather than fertilizers used in the cultivation of tobacco plants and Lead-210 was originated from the air and deposited onto the tobacco leaves and trapped by the trichomes. Potassium-40 in the tobacco leaves was said to be due to root uptake either from soil or from fertilizer. In the tobacco leaves, ^{226}Ra activity concentrations ranged from 1.80 to 7.57 Bq kg^{-1} (average = 3.38 Bq kg^{-1}), while ^{228}Ra activity concentrations ranged from 1.10 to 6.62 Bq kg^{-1} (average = 3.83 Bq kg^{-1}) and ^{210}Pb activity concentrations ranged from 6.34 to 18.2 Bq kg^{-1} (average = 14.12 Bq kg^{-1}; Papastefanou, 2009).

Studies have shown that other carcinogens contents in cigarette today had been reported to have been greatly reduced through the use of modern processing techniques and filter materials, only few studies have been carried out to investigate the reductions in radioactivity levels (Papastefanou, 2009). This work was then aimed to determine and relate the specific activity of ^{40}K, ^{238}U, and ^{232}Th found in tobacco leaves to that found in some locally produced cigarette products smoked by Nigerians. The gamma radiation hazards were also estimated to know the health risk posed by these radionuclides due to a large-scale consumption of tobacco in Nigeria at the present time.

MATERIAL AND METHODS

Sample Collection

The raw tobacco leaves that serve as the major raw material for the product come majorly from Oke Ogun area (Ilua, Igboho, Shaki, Iseyin, among others) in the northern part of Oyo State, Nigeria. Two tobacco-leaf-growing farmlands were chosen from Igbope in Igboho. The choice was based on the fact that they were the only assessable farms as at the time of conducting this research work. They are one of the major suppliers of tobacco leaves to the British-America Tobacco (BAT) Company in Oyo State, Nigeria, and have also been using special fertilizers in increasing the growing of their tobacco leaves. The use of this fertilizer may enhance natural radionuclide contents in the farm soils and through root uptake; it can be accumulated in the leaves. Cigarette products were obtained from the Agbeni Market in Ibadan, Oyo State, Nigeria. This market is a wholesalers market popularly known as the "mother of markets" in the city of Ibadan, Oyo State, Nigeria. At the point of collection of the samples, they were carefully labeled and placed in separate polythene bags to avoid cross contamination. A total of 22 samples comprising of 10 samples of fresh tobacco leaves and 12 samples of cigarette samples were analyzed. In order to ensure a good representative sampling at the two chosen tobacco-leaf-growing farmlands, the two farms were partitioned each into five blocks of sampling points. The leaves were collected across each block randomly and were thoroughly mixed together to represent a sample for that point. The sizes of the blocks were based on the size of the farms. Twelve cigarette samples of six different brands were bought from two different shops in the market. The descriptions of the various samples are shown in Table 1. Figure 1 also shows the map of Oyo State identifying the study area.

Table 1. Sample Information

S/N	Sample ID	Sample Names	Mass of Fresh Leaves (g)	Mass After Sieving of Dried Leaves (g)	Longitude	Latitude
Farm A						
1	FA1	Leaves at block 1	427.9	115.0	3°51☺☺57.11”E	8°49□2.78”N
2	FA2	Leaves at block 2	415.2	108.6	3°51□57.11”E	8°49□6.22”N
3	FA3	Leaves at block 3	458.4	119.9	3°51□57.12”E	8°49□9.69”N
4	FA4	Leaves at block 4	484.4	131.2	3°51□57.13”E	8°49□13.56”N
5	FA5	Leaves at block 5	425.0	111.8	3°51□57.15”E	8°49□16.71”N
Farm B						
6	FB1	Leaves at block 1	461.7	125.7	3°52□0.15”E	8°48□49.2”N
7	FB2	Leaves at block 2	455.3	122.4	3°52□2.82”E	8°48□49.1”N
8	FB3	Leaves at block 3	466.7	123.2	3°52□5.17”E	8°48□48.9”N
9	FB4	Leaves at block 4	429.1	113.6	3°52□7.23”E	8°48□48.8”N
10	FB5	Leaves at block 5	440.3	118.9	3°52□9.51”E	8°48□48.7”N
Tobacco Products (Cigarette)						
1	FD1	Pallmall red A	108.9	107.7	3°53□25.10”E	7°22□48.31”N
2	FD2	Pallmall red B	105.2	103.4	3°53□25.17”E	7°22□48.34”N
3	FE1	London Menthol A	97.7	94.8	3°53□25.10”E	7°22□48.31”N
4	FE2	London Menthol B	98.9	96.0	3°53□25.17”E	7°22□48.34”N
5	FF1	London King size A	111.4	110.8	3°53□25.10”E	7°22□48.31”N
6	FF2	London King size B	115.2	114.6	3°53□25.17”E	7°22□48.34”N
7	FG1	Royal standard A	93.1	91.2	3°53□25.10”E	7°22□48.31”N
8	FG2	Royal standard B	94.7	93.5	3°53□25.17”E	7°22□48.34”N
9	FH1	Aspen A	101.7	99.2	3°53□25.10”E	7°22□48.31”N
10	FH2	Aspen B	102.1	100.7	3°53□25.17”E	7°22□48.34”N
11	FI1	Pallmall green A	104.2	102.6	3°53□25.10”E	7°22□48.31”N
12	FI2	Pallmall green B	108.5	107.2	3°53□25.17”E	7°22□48.34”N

Note. Each cigarette sample contains one packet of cigarettes.

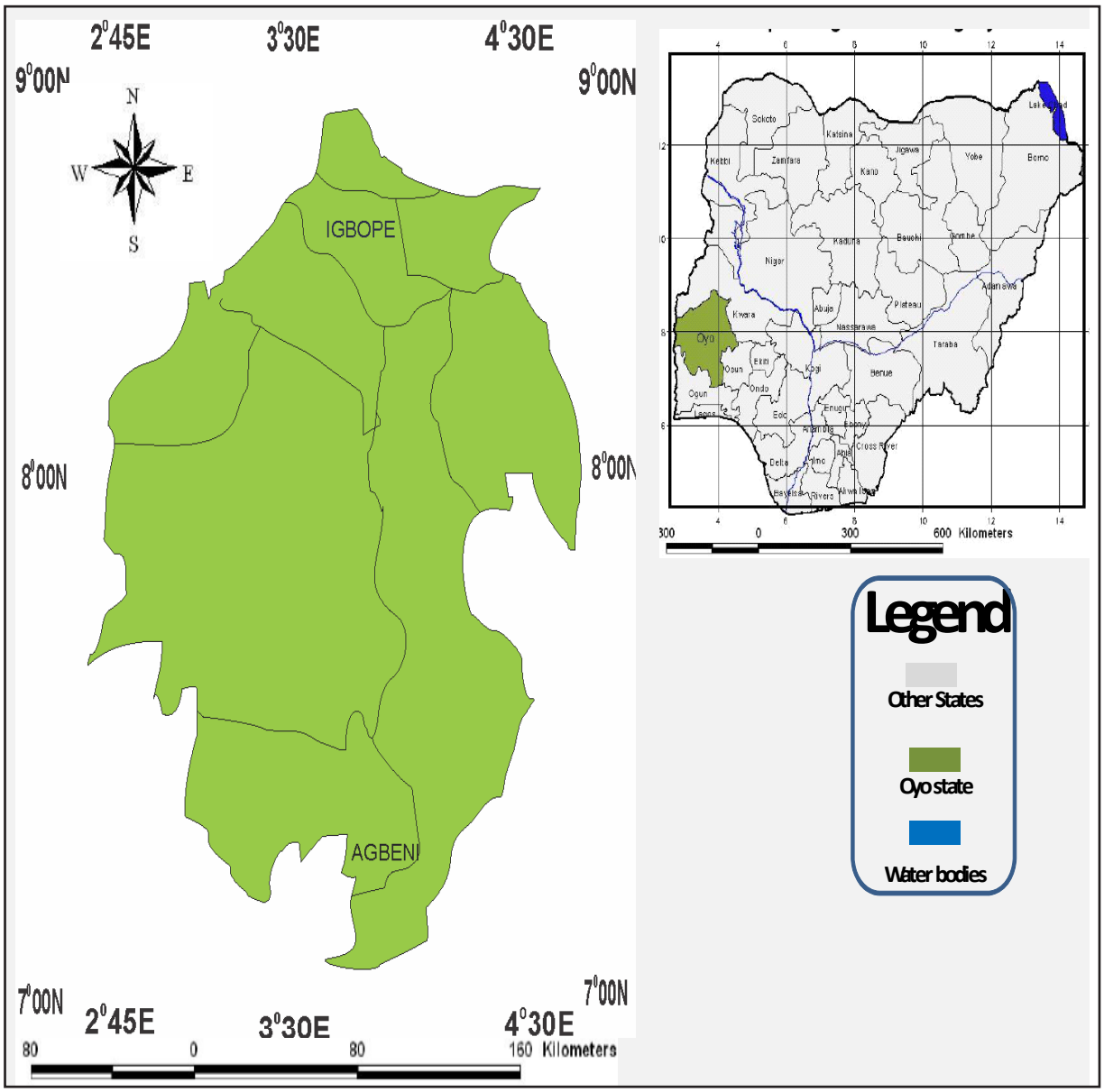

Figure 1. Geological map of Oyo State showing the study area.

Sample Preparation

All the 22 samples were oven dried at a temperature of 105°C to get a constant weight, then ground and passed through a mesh size of 2 mm. Each sample was weighed and sealed for at least 28 days in air-tight radon-impermeable plastic container washed with dilute HNO_3 and distilled water. This was done in order to allow for radon and its short-lived progenies to reach secular radioactive equilibrium prior to gamma spectroscopy.

Method of Measurement

The detector used for the radioactivity measurements was a lead-shielded 76-mm × 76-mm NaI(Tl) detector crystal (Model No. 802 series, Canberra Inc.) coupled to a Canberra Series 10 plus Multichannel Analyzer (MCA; Model No.1104) through a preamplifier. It has a resolution that is considered adequate to distinguish the gamma ray energies of interest in the present study. Each sealed sample was placed on the shielded NaI(Tl) detector and counted for 18,000 s. The sample containers have the same geometry as that of the IAEA reference sample used. The IAEA-375 soil reference material was used. An empty container of the same geometry and dimension was counted for the same counting time of 18,000 s to determine the background distribution spectrum. The choice of radionuclides to be detected was predicated on the fact that the NaI(Tl) detector used had a modest energy resolution. Hence, the photons emitted by them would only be sufficiently discriminated if their emission probability and their energy were high enough and the surrounding background continuum is low enough. Therefore, the activity concentration of ^{214}Bi (determined from its 1.120-MeV and 0.609-MeV γ-ray peaks) were chosen to provide an estimate of ^{226}Ra (^{238}U) in the samples, while that of the daughter radionuclide ^{228}Ac (determined from its 0.911-MeV γ-ray peak) was chosen as an indicator of ^{232}Th. ^{40}K was determined by measuring the 1.460 MeV γ-rays emitted during its decay. The net area under the corresponding peaks in the energy spectrum was computed by subtracting counts due to Compton scattering of higher peaks and other background sources from the total area of the peaks. From the net area, the activity concentrations in the samples were obtained using equation 1 (UNSCEAR, 2000; Beretka & Mathew, 1985).

$$C = \frac{A}{\varepsilon M_S P_\gamma t_c} \quad (1)$$

where C = the activity concentration of the sample I Bq kg^{-1},

A = the net area of the peak,
ε = efficiency of the detector for radionuclide *n*,
M_s = dried mass of ashed sample for measurement in kilograms,
P_γ = gamma emission probability (or branch ratio), and
t_c = counting time

Uncertainties

Uncertainties in gamma-ray spectrometry could result from the error in the determination of the nuclide specific counting efficiency and the statistical counting errors. These errors were put into consideration in the determination of radionuclide activity concentration.

The counting time was optimized to accommodate the operating conditions. A counting time of 18,000 s was used in order to minimize the statistical errors. This statistical error was from the full energy peaks (FEP).

RESULTS AND DISCUSSION

Radionuclide Concentrations

The activity concentrations of the tobacco leaves and cigarette samples were calculated using equation 1, and the results are presented in Tables 2 and 3, respectively. All the radionuclides detected and quantified came from the naturally occurring ^{238}U and ^{232}Th decay series, as well as nonseries ^{40}K. The specific activity concentration of ^{40}K, ^{238}U, and ^{232}Th in farm A ranged from 35.66 ± 8.91 to 93.23 ± 22.08 Bq kg^{-1} (with an average of

58.74 ± 15.86 Bq kg^{-1}), 10.65 ± 4.27 to 24.37 ± 9.87 Bq kg^{-1} (with an average of 19.13 ± 7.16 Bq kg^{-1}) and 8.92 ± 3.35 to 13.00 ± 4.54 Bq kg^{-1} (with an average of 11.39 ± 4.08 Bq kg^{-1}), respectively, while that of farm B ranged from 49.74 ± 13.48 to 70.63 ± 25.76 Bq kg^{-1} (with an average of 56.27 ± 17.43 Bq kg^{-1}), 25.20 ± 6.76 to 30.60 ± 12.06 Bq kg^{-1} (with an average of 28.92 ± 9.39 Bq kg^{-1}) and 16.20 ± 5.11 to 19.24 ± 6.08 Bq kg^{-1} (with an average of 17.74 ± 6.0 Bq kg^{-1}) for ^{40}K, ^{238}U, and ^{232}Th, respectively.

The overall average of the specific activity concentration due to ^{40}K, ^{238}U, and ^{232}Th in the two farms ranged from 57.51 ± 16.65 Bq kg^{-1}, 24.03 ± 8.28 Bq kg^{-1} and 14.57 ± 5.04 Bq kg^{-1}, respectively. Comparing the results with that done on phosphate fertilizers used on tobacco farms in Nigeria (Jibiri & Fasae, 2012) and with that of soils used for the production of tobacco leaves in Nigeria (Jibiri & Biere, 2011), ^{238}U and ^{232}Th concentrations seemed to be gotten from airborne deposits on the leaves apart from the ones gotten from soil and fertilizer. Radon gases (^{222}Rn and ^{220}Rn) from ^{238}U and ^{232}Th series respectively originating from the air might have been deposited onto the leaves of the tobacco plants and were trapped by the trichomes (Martel, 1974) while ^{40}K activity concentrations in the tobacco leaves may be due to root uptake from soil, fertilizers, or air deposition.

For cigarette products, the specific activity concentration of ^{40}K, ^{238}U, and ^{232}Th ranged from 40.13 ± 14.23 to 57.53 ± 20.13 Bq kg^{-1} (with an average of 48.37 ± 15.78 Bq kg^{-1}), 8.91 ± 3.41 to 28.56 ± 7.69 Bq kg^{-1} (with an average of 17.52 ± 5.73 Bq kg^{-1}), and 4.90 ± 1.49 to 19.39 ± 8.13 Bq kg^{-1} (with an average of 12.39 ± 4.50 Bq kg^{-1}), respectively.

It can be noticed that the radioactivity content varies within the same brands of cigarette and also between different brands. This may be attributed to the geographic region where the tobacco (raw material) is grown, the fineness of the tobacco cut, the size and composition of the filter, different manufacturing procedures, and age of the tobacco product (Watson, 1985, and Skwarzec et al., 2001).

From this result, it can be seen that the radioactivity contents were higher in the tobacco leaves when compared with the products. It is then evident from the result that the radioactivity contents of ^{40}K, ^{238}U, and ^{232}Th in the products were obtained from the tobacco leaves, which serve as the major ingredient of the products. This agrees with the work of Mennah (2011) that obtained ^{210}Po content in Sudan tobacco leaves greater than the content in Sudan cigarette products. This can be attributed to storage and manufacturing processes. Generally the activity concentrations of ^{238}U and ^{232}Th detected in the leaves and the products were found to be higher than other literatures reviewed outside the country. This was so because the activity concentrations of these radionuclides on soils where these tobacco are grown as reported by Jibiri and Biere (2011) were also higher.

Radiation Hazard Indices

These indices were used to estimate the level of gamma radiation hazard associated with the natural radionuclide in the analyzed samples. Equations 2 and 3 (Avwiri et al., 2014; Beretka & Mathew, 1985) were used to calculate the external (H_{ext}) and internal (H_{int}) radiation hazard, respectively.

$$H_{ext} = \left(\frac{C_{Ra}}{370}\right) + \left(\frac{C_{Th}}{259}\right) + \left(\frac{C_K}{4810}\right) \quad (2)$$

$$H_{int} = \left(\frac{C_{Ra}}{185}\right) + \left(\frac{C_{Th}}{259}\right) + \left(\frac{C_K}{4810}\right) \quad (3)$$

where C_{Ra}, C_{Th}, and C_K are the radioactivity concentration (Bq kg^{-1}) of ^{226}Ra (^{238}U), ^{232}Th, and ^{40}K, respectively, while H_{ext} is the external radiation hazard and H_{int} is the internal radiation hazard.

Internal exposure to radon is very hazardous. It can lead to respiratory diseases like asthma. Therefore, H_{int} should be less than unity for radiation hazard to be negligible (Avwiri et al., 2014). Natural radionuclide in soil, sediment, rocks, and vegetation and consumer products produce an external radiation field (H_{ext}) to which all humans are exposed, and therefore, H_{ext} must be less than unity for external radiation hazard to be negligible. When H_{ext} equals unity, there is a corresponding upper limit of radium equivalent dose (370 Bq/kg) (Avwiri et al., 2014; UNSCEAR, 2000).

The results are shown in Tables 2 and 3 for tobacco leaves and tobacco products, respectively. The external radiation hazard index (H_{ext}) for the leaves and cigarette samples ranged from 0.08 to 0.17 with an average of 0.13 and 0.06 to 0.15 with an average of 0.11, respectively. The internal radiation hazard index (H_{int}) ranged from 0.11 to 0.25 with an average of 0.20 and 0.09 to 0.23 with an average of 0.15 for the two samples, respectively. These values were both less than the recommended limit of 1 (unity), which is the threshold below which radiation hazard may not occur (UNSCEAR, 2000). Hence, the radionuclide contents in the leaves and products pose a negligible health risk.

Table 2. Activity Concentration of Radionuclides (Bq kg^{-1}) in Tobacco Leaves

S/N	Sample Codes	Radioactivity Content			Radiation Hazard	
		K-40	U-238 (Ra-226)	Th-232 (Ra-228)	H_{ext}	H_{int}
1	FA1	93.23 ± 22.08	24.37 ± 9.87	13.00 ± 4.54	0.14	0.20
2	FA2	58.71 ± 16.67	15.41 ± 8.09	11.87 ± 3.86	0.10	0.14
3	FA3	45.77 ± 11.78	23.08 ± 6.49	8.92 ± 3.35	0.11	0.17
4	FA4	35.66 ± 8.91	22.16 ± 7.06	12.95 ± 4.60	0.12	0.18
5	FA5	60.33 ± 19.86	10.65 ± 4.27	10.22 ± 4.07	0.08	0.11
	MEAN A	**58.74 ± 15.86**	**19.13 ± 7.16**	**11.39 ± 4.08**	**0.11**	**0.16**
6	FB1	70.63 ± 25.76	25.20 ± 6.76	16.20 ± 5.11	0.15	0.21
7	FB2	49.74 ± 13.48	28.87 ± 8.57	17.44 ± 8.02	0.16	0.23
8	FB3	54.63 ± 18.59	29.72 ± 9.49	18.10 ± 5.42	0.16	0.24
9	FB4	49.74 ± 13.48	30.21 ± 10.06	19.24 ± 6.08	0.17	0.25
10	FB5	56.63 ± 15.86	30.60 ± 12.06	17.74 ± 5.38	0.16	0.25
	MEAN B	**56.27 ± 17.43**	**28.92 ± 9.39**	**17.74 ± 6.00**	**0.16**	**0.24**
	OVERALL MEAN	**57.51 ± 16.65**	**24.03 ± 8.28**	**14.57 ± 5.04**	**0.13**	**0.20**

Table 3. Activity Concentration of Radionuclides (Bq kg^{-1}) in Tobacco Products

S/N	Sample Codes	Radioactivity Content			Radiation Hazard	
		K-40	U-238 (Ra-226)	Th-232 (Ra-228)	H_{ext}	H_{int}
1	FD1	49.81 ± 12.47	28.56 ± 7.69	9.49 ± 3.45	0.12	0.20
2	FD2	42.52 ± 15.69	14.43 ± 5.18	11.04 ± 3.61	0.09	0.13
	MEAN	**46.17 ± 14.08**	**21.50 ± 6.44**	**10.27 ± 3.53**	**0.11**	**0.17**
3	FE1	56.83 ± 19.95	19.04 ± 6.49	8.34 ± 3.42	0.10	0.15
4	FE2	46.01 ± 16.01	17.87 ± 5.98	7.18 ± 2.52	0.09	0.13
	MEAN	**51.42 ± 17.98**	**18.46 ± 6.24**	**7.76 ± 2.97**	**0.09**	**0.14**
5	FF1	40.13 ± 14.23	11.78 ± 4.68	4.90 ± 1.49	0.06	0.09
6	FF2	44.32 ± 13.12	13.85 ± 5.82	6.78 ± 2.76	0.07	0.11
	MEAN	**42.23 ± 13.69**	**12.82 ± 5.25**	**5.84 ± 2.13**	**0.07**	**0.10**
7	FG1	53.62 ± 19.84	12.77 ± 5.79	18.22 ± 6.81	0.12	0.15
8	FG2	57.53 ± 20.13	28.50 ± 6.88	15.34 ± 5.19	0.15	0.23
	MEAN	**55.58 ± 19.99**	**20.64 ± 6.34**	**16.78 ± 6.00**	**0.13**	**0.19**
19	FH1	44.14 ± 13.02	23.06 ± 7.31	12.57 ± 3.43	0.12	0.18
10	FH2	53.26 ± 17.13	8.91 ± 3.41	19.08 ± 7.87	0.11	0.13
	MEAN	**48.70 ± 15.08**	**15.99 ± 5.36**	**15.83 ± 5.65**	**0.11**	**0.16**
11	FI1	42.70 ± 12.31	16.49 ± 5.31	19.39 ± 8.13	0.13	0.17
12	FI2	49.57 ± 15.35	14.93 ± 4.13	16.28 ± 5.31	0.11	0.15
	MEAN	**46.14 ± 13.83**	**15.71 ± 4.72**	**17.84 ± 6.72**	**0.12**	**0.16**
	OVERALL CIGARETTE MEAN	**48.37 ± 15.78**	**17.52 ± 5.73**	**12.39 ± 4.50**	**0.11**	**0.15**

CONCLUSION

The radionuclides detected and quantified in this study came from the naturally occurring ^{238}U and ^{232}Th decay series, as well as nonseries ^{40}K. The activity concentrations of ^{238}U and ^{232}Th detected in the samples were found to be higher than other literatures reviewed outside the country. This was so because the activity concentrations of these radionuclides on soils where these tobaccos are grown as reported by Jibiri and Biere (2011) were also higher. The radioactivity contents were higher in the tobacco leaves when compared with the products. It is then evident from the result that the radioactivity contents of ^{40}K, ^{238}U, and ^{232}Th in the products were obtained from the tobacco leaves, which serve as the major ingredient of the products. This can be attributed to storage and manufacturing processes. The radioactivity content varies within the same brands of cigarette and also varies with different brands. The results obtained reflected the mean activity concentrations due to ^{238}U, ^{232}Th, and ^{40}K in the tobacco leaves to be the combination of root uptake from the soil, the fertilizers used for cultivation of tobacco plants in the farms and airborne radionuclides deposited on the tobacco leaves trapped by the trichomes. The estimated values of gamma radiation hazard were less than unity, which follows that health risk due to these radionuclides and their short-lived progenies are negligible.

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